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# Surgical endodontics: quo vadis?

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Surgical endodontic intervention has emerged over the last 100 years as a significant treatment modality in the retention of sound teeth (1). While the evolution of this treatment modality and the refinement of its principles have had a long and tumultuous history, biologically based directives are emerging and are integrated with significant advances in clinical modalities. No longer does the endodontic literature support a litany of indications for surgical applications, but rather, well-thought, evidenced-based principles are guiding the selection of this treatment modality (2–7). Coupled with the introduction of magnification through the use of the surgical operating microscope, refined principles of soft and hard tissue management, use of tissue regenerative root-end fill materials, and enhanced principles of wound closure and postoperative management, surgical endodontics has emerged as a highly predictable and relatively painless procedure (8–13).

Ironically, the impetus for the evolution of contemporary surgical endodontic principles came from a better understanding of the challenges faced in the cleaning, shaping, disinfecting and obturating the complex and unpredictable anatomy of the root canal system. While technology in the non-surgical provision of treatment has advanced significantly (14), there still remains the challenge of eradicating microbial species and their biofilms from the root canal system, primarily in the apical third of the root (15–18). Even with this dictate, it is still imperative to consider the choice of non-surgical root canal treatment (19) or the revision of previous less-than-ideal treatment (20) before surgical intervention, as outcomes of non-surgical intervention would support this choice.

Surgical intervention is not a substitute for failure to manage properly the root canal system non-surgically, to assess thoroughly the periodontal status, and to ignore the shortcomings of the coronal restoration(s) (21, 22). Knowing when to choose surgical intervention is just as important as the expertise to be exercised in the surgical procedure and the judgment to be exercised in the assessment of what has been done (23). In essence treatment planning the choice of surgery may actually be more difficult and challenging than the surgical procedure itself (24). This is especially true with the massive and sometimes irrational movement to replace every endodontically treated tooth with or with symptoms with an intraosseous implant (25–30). Retention of the natural tooth structure is still the goal of quality dental care and many previously root-treated teeth that appear to be done quite well, yet exhibit adverse signs or symptoms, are viable candidates for non-surgical treatment revision or surgical revision of treatment (31–33).

With each patient that presents for treatment, the clinician is challenged to make choices that result in the best treatment possible for the patient. These choices are based on a number of factors that influence the clinician in the decision-making, problem-solving process (24, 34, 35). These factors include the following:

- Axioms that are commonly held in endodontics and supportive disciplines.
- Formative knowledge to support the choices.
- Clinical skill.
- Clinical experience.
- Problem solving skills.
- Patient preference after being informed fully of treatment options and their rationale.
- Economic factors.
- Evidence-based concepts.
- Integrity.

Failure to take all factors into account may lead to treatment plans that are ill advised or not in the best interest of the patient. While many teeth can be maintained with a surgical endodontic procedure, it may not be in the best interest of the patient to retain a tooth that has restorative or periodontal compromises

(24). Furthermore, if a tooth cannot be returned to symptom-free function following surgical intervention removal may be indicated. Moreover, while tooth retention is ideal for function and aesthetics, at times tooth resection or removal and replacement with a fixed partial prosthesis, a removable partial prosthesis, implant, or no replacement may be in the best interest of the patient (24).

This volume of endodontic topics focuses on multiple issues that deal with surgical endodontics, with a primary focus on apical surgery – a 'first' for this publication. Furthermore, other than textbook chapters, this is the first comprehensive literature-scientific, evidence-based publication on surgical endodontics in 15 years. This publication and its focus on the principles of apical surgery are supported by a multitude of general concepts that apply to treatment planning choices both prior to and following surgery, pain prevention and management, postsurgical management and outcomes. As the availability of true evidence-based information in surgical endodontics is sparse, there is in some topics presented by the author more of a best evidence approach to this treatment modality. The fact that this topic is presented by a cross section of clinicians, academicians and researchers, lends great credibility and reality to contemporary principles discussed. Hopefully this approach will encourage more evidence-based research and long-term outcomes studies to solidify or alter the concepts delineated herein.

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# Treatment choices for negative outcomes with non-surgical root canal treatment: non-surgical retreatment vs. surgical retreatment vs. implants

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The revision of negative treatment outcomes is a significant part of current endodontic practice. Both non-surgical and surgical retreatment procedures share the problem of a significant negative outcome in the presence of apical periodontitis. More positive results may be achieved in certain teeth with a combination of both procedures rather than either alone. However, there are pressures to replace these 'failed' endodontically treated teeth with implants. When comparable criteria are applied to outcomes, the survival rates of endodontic treatment and implant placement are the same. Time, cost, and more flexible clinical management indicate that endodontic retreatment procedures should always be performed first unless the tooth is judged to be untreatable. Endodontists should be trained in implantology to assist patients and referring colleagues in making informed treatment decisions.

## Introduction

The primary reason for a negative outcome with endodontic treatment is the persistence of bacteria within the intricacies of the root canal system (1, 2). Failure may also be attributed to the persistence of bacteria in the periapical tissues, foreign body reactions to overfilled root canals, and the presence of cysts (3–6). Historically, there is a great deal of literature dealing with non-surgical retreatment vs. surgical revision. This literature is being re-evaluated based on new standards of evidence.

Any current investigation of clinical treatment attempts to use evidence-based dentistry (EBD). The application of EBD has called into question past practices and current thinking. The American Dental Association has defined EBD as 'the systematic assessments of clinically relevant scientific evidence, relating to the patients oral and medical condition and history, together with the dentists clinical expertise and the patients needs and preferences' (7). In practical terms, this creates an 'evidence pyramid' with 5 levels of evidence. At the apex of the pyramid are prospective randomized-controlled trials (RCT) considered the highest level of evidence (LOE 1). Case reports and personal opinions are at the base of the pyramid and represent the least reliable data, LOE 5 (8). The criteria for evidence-based analysis include a large patient sample, a common point to commence the analysis, a long recall period, blind outcome criteria, and less than a 5% loss of the patient sample (9). This hierarchy of evidence, however, is still a matter of debate and is not universally accepted. Concato et al. (10) investigated the premise that observational studies are considered less reliable than RCT because they supposedly over-estimate treatment effects. Based on a literature review, the authors concluded that the average results of observational studies were very similar to those of RCT and do not magnify the effects of treatment. There are acknowledged difficulties in setting up prospective

studies. These include the numerous factors that affect treatment outcomes, defining the criteria for success and failure, and recalling a significant population of patients to assess results by statistical analysis (11–14). Guidelines for randomized clinical trials have been developed so that the quality of a study can be assessed (15), but the problem lies in the number of RCT that will be undertaken. Other levels of evidence, such as retrospective studies and case reports represent 'best-evidence dentistry' (BED). Best evidence currently provides the guidance for most clinical decision-making. The practicalities of mounting RCT are overwhelming, and this means that the reliance on BED is likely to continue. This is relevant because there are no papers dealing with non-surgical retreatment and surgical revision that reach the highest LOE, with most being at the lower levels of the scale (8, 16–20). The same is true in other areas of dentistry, including implant studies (21, 22).

## Endodontic alternatives: choosing non-surgical or surgical retreatment

Friedman (23) has suggested a rationale for non-surgical retreatment or surgery. For intracanal infection, non-surgical retreatment is generally most beneficial because it seeks to eliminate the bacteria from within the root canal system. Surgery for intracanal infections can isolate, but not eliminate, the bacteria from the root canal, and would be limited to those cases where non-surgical retreatment is not judged to be possible. When the etiology is independent of the root canal system (3–6), surgery is the most beneficial treatment. Non-surgical retreatment may still be indicated in these cases, especially when intracanal infection cannot be ruled out (23).

Many factors must be considered in determining a course of treatment. One is the dentist's experience and clinical skills. Another requirement is having the necessary equipment and resources (24). The primary consideration is the patient's values and expectations. Friedman (23) has discussed patient attitudes that must be considered when making treatment decisions. The most important is the patient's motivation to retain the tooth. Poor motivation indicates extraction and not clinical intervention, while high motivation would indicate non-surgical retreatment or surgery. If the patient desires the best long-term result, non-surgical retreatment would be the first choice in most cases. The premise that non-surgical retreatment improves the outcome of periapical surgery has been supported by both historical and current studies (25–29). However, when there are time constraints or financial pressures, surgery may be the first treatment choice (23). In cases where the prognosis appears similar, the degree of difficulty and patient preferences must be considered. Because the majority of dental treatment is elective, the wishes of the patient are the ultimate arbiter of treatment. Eckert (30) describes this as value-based dentistry, where the patients' perceived benefit from the treatment outweighs the clinical decision-making procedure, no matter what LOE was used to reach that decision. This is illustrated by outcome studies in endodontics. Many past studies have categorized teeth with caries, fractures, periodontal involvement, and poor coronal restorations as a negative endodontic outcome (31). Evidence-based or controlled best-evidence studies would conclude that these are non-endodontic causes of failure, and that the success of endodontic treatment itself is high and predictable. However, when value-based criteria are applied, the reasons for failure would be of little significance to the patient compared with the failure itself.

## Non-surgical retreatment

The decision to perform non-surgical or surgical retreatment is based on the premise that patients wish to retain their own teeth. Tooth loss affects confidence, daily living activities, and appearance (32). The emotional effects of tooth loss are similar in different cultural and ethnic groups (33), and are both significant and widespread (34). It is not surprising that the retreatment of failed cases is a significant part of endodontic practice (35). The incidence of periapical lesions following root canal procedures surveyed in many countries is 20–60% (23). In one study, over 20% of failed cases with apical periodontitis were extracted, but this finding was based on a small sample size (36). In a large epidemiological study of initial treatment outcomes, over 6 times as many teeth were extracted compared with teeth undergoing non-surgical retreatment (37). The reasons for this high rate of extractions are unclear, but may be due in part to perceived difficulties in performing non-surgical retreatment. A positive outcome following non-surgical retreatment is

influenced by many factors, and these have been comprehensively reviewed (18, 23, 38, 39).

## Apical periodontitis

The presence of apical periodontitis may or may not affect the outcome of initial endodontic treatment (23, 40). However, there is wide agreement that apical periodontitis is the most important variable influencing a positive outcome with non-surgical retreatment (23, 38, 41–43). According to Hepworth & Friedman (39), the retreatment of teeth without periapical lesions has a positive outcome of 95%, but in their study and others, this declines to 56–84% in the presence of a periapical lesion (38–40, 44). According to Friedman (38), some of these teeth may be undergoing healing, and the studies apply different assessment criteria. The true negative outcome rate may be only 10–16%. However, without long recall periods of a statistically significant number of patients as required by the levels of evidence criteria, this cannot be substantiated.

## Role of primary endodontic treatment

In those teeth with associated apical periodontitis, the technical quality of the primary root canal procedure directly influences both the need for and the extent of subsequent retreatment. Hoskinson et al. (41) reported that a 1 mm increase in the size of the preoperative periapical lesion resulted in an 18% increase in the risk of a negative outcome. In another study, a 1 mm loss of working length during initial treatment resulted in a 14% increase in the failure rate (43). Sjögren et al. (40) found that 94% of periapical lesions healed when the root filling was within 2 mm of the apex, a significant difference when compared with overfilled canals (76%) and those more than 2 mm short of the apex (68%).

## Bacterial and technical considerations

The presence of infection at the time a retreated case is completed has a highly significant effect on a positive outcome (45), with a 26% lower success rate found for teeth that were infected at the time of root filling (46). Paik et al. (8) identified one LOE 2 Cohort study dealing with technical deficiencies and retreatment outcomes (44). Gorni & Gagliani (44) reported an overall success rate of 69% of retreated cases. Teeth that were free of technical errors such as transportation, stripping, perforation, and internal resorption achieved a success rate of almost 87%, but those exhibiting one or more of the technical problems succeeded only 47% of the time. According to Gorni & Gagliani (44), the influence of prior procedural errors on retreatment outcomes had not been reported previously. Farzaneh et al. (18) found that a positive outcome was most influenced by the presence of a preoperative perforation. Other negative factors were the quality of the root filling, the lack of a final restoration, and preoperative apical periodontitis. The overall success (or 'healed') rate was 81%. This increased to 93% when asymptomatic and functional (i.e., surviving) teeth were included. Unlike primary root canal treatment, the level of the root filling was not a significant factor influencing a positive outcome for retreated teeth with periapical lesions (40).

## Occlusion

Does occlusal trauma affect the outcome of initial endodontic treatment and revision? Animal studies of excessive occlusal force on the pulp are limited, but they concluded that no significant pulpal changes result from occlusal trauma (47, 48). No animal studies of occlusal trauma on root filled teeth have been reported. Most clinical studies have investigated the relationship between occlusal adjustment and the incidence of post-visit pain with conflicting results (49, 50). One recent study has compared several factors associated with the periapical status of endodontically treated and restored teeth followed up for over 5 years. A direct relationship was found between occlusal forces and the presence of periapical lesions, the first time this has been reported (51). The role of the occlusion following endodontic treatment requires further investigation, and must be ruled out in cases with a negative outcome.

## Restoration

The quality of the restoration affects the outcome because of the possibility of leakage (38, 52). Contemporary literature supports the direct relationship

between a coronal restoration and the positive outcome of endodontic treatment (18, 37, 51, 53–55). Teeth not crowned following endodontic treatment were lost at 6 times the rate of those teeth that did receive crowns (37, 55). Iqbal et al. (51) identified poor crown margins as one factor significantly associated with the presence of post-treatment periapical lesions. Poor-fitting crowns may allow bacterial leakage and re-infection of the root canal system, and *in vitro* studies identify leakage as a possible cause of a negative outcome following root canal treatment (56–58). However, recent clinical studies suggest that coronal leakage may not be such a significant problem provided that the endodontic procedures are correctly carried out (59–61).

The relationship of cuspal coverage with tooth fracture in endodontically treated teeth has been investigated. Reeh et al. (62) concluded that endodontic procedures do not weaken teeth with intact marginal ridges. Fennis et al. (63) found a positive correlation between endodontic treatment and subgingival fractures, with the incidence in molars being 4 times that of premolars. Lagouvardos et al. (64) found that fractures in endodontically treated teeth occurred most frequently below the bony crest, contributing to a poor prognosis. Hansen et al. (65) reported on a 20-year retrospective study, concluding that amalgam restorations in endodontically treated teeth must have cuspal coverage for a favorable prognosis.

A positive outcome with root canal treatment depends on comprehensive treatment planning as much as technical expertise. Endodontists must be aware of the restorative requirements for a completed tooth, and must work closely with the referring dentist to achieve this end. Endodontic educational programs may need to expand their curricula to provide this knowledge.

## Surgical retreatment

Paik et al. (8), Mead et al. (19), and Friedman (23) identified two randomized-controlled studies (LOE 2) that compared non-surgical retreatment with surgical retreatment (66, 67). Friedman (23) concluded that based on these studies, there is no clear evidence of which approach is more beneficial. Paik et al. (8) also concluded that these studies (66, 67) were difficult to compare.

Danin et al. (66) assessed the outcome of retreatment or surgery evaluated clinically and radiographically after one year. Complete healing occurred in only 28% of the non-surgical cases and 58% of the surgery cases. Friedman (23) suggested that the low success rate for non-surgical retreatment compared with other studies might be due to technical difficulties such as blocked canals or perforations. Danin et al. (66) did not categorize the teeth to be retreated except by the size of the apical lesion, so this remains a speculation. While the positive outcome was higher for surgery, the difference was not statistically significant. However, this paper was written before the advent of more modern surgical techniques. There is no mention of enhanced magnification, but the roots were resected at a 45° angle. A 45° bevel increases apical leakage experimentally compared with a minimal bevel (68, 69). This may be a factor in the lower success rate recorded in this study. More recent reports using microsurgical techniques and a minimal bevel show a success rate of over 90% evaluated at one year and subsequently at 5–7 years (70, 71). Using a similar microsurgical technique, von Arx et al. (69) reported 88% healing in molars reviewed after 12 months. Rud et al. (72) reported 92% complete healing of mandibular molars using a dentine-bonded composite material. No apical cavity was prepared, and the material covered the entire apical preparation. The outcome was based on a radiographic assessment, and the patients were followed for over 12 years with a recall rate of 84%. Other studies using current improvements in materials and techniques have reported success rates in excess of 90% (25, 73). This higher success rate may in part be due to the ability of higher magnification to detect the presence of an isthmus in molar teeth. Isthmuses have been found in 83–90% of mesial roots in mandibular first molars, and in 36% of the distal roots. In maxillary first molars, an isthmus was present in 76% of the mesiobuccal roots (70, 74). von Arx (74) reported that no isthmuses were filled following root canal treatment. The untreated isthmus is a significant factor in the failure of root canal treatment and surgery (75). Modern microsurgical techniques allow the isthmus to be cleaned, prepared, and filled, which was rarely possible previously.

In the second study, Kvist & Reit (67) compared non-surgical and surgical retreatment at 1- and 4-year follow-up periods. Initially, surgical cases showed a higher healing rate than non-surgical retreatment, but

by 4 years there was no difference between the methods because of late 'failures' of some of the surgery cases. The retrograde seal consisted of vertically compacted gutta-percha softened in chloroform, or heat-softened gutta-percha used without a sealer. Chloroform and gutta-percha obturation techniques result in shrinkage and possibly compromise the integrity of the seal (76), as does the absence of a sealer when gutta-percha is used on its own. This may explain the increase in failed cases recorded at the 4-year follow-up.

Newer materials such as mineral trioxide aggregate (MTA) show great promise in providing a biocompatible retrograde filling material. In a recent study, the growth of new cementum over retrograde fillings occurred only with MTA when compared with amalgam and Super EBA (77). These recent advances in techniques and materials call into question the outcome levels for surgery reported in earlier studies. Further improvements are under investigation (78). Positive outcomes for surgical retreatment in excess of 90% can be achieved with careful case selection (25) and a skilled and experienced operator (53). This is equivalent to the survival rates of implants applying the same parameters of case selection and operator skills (see Implant outcomes).

## Outcome of periradicular surgery

Friedman (38) conducted a comprehensive analysis of the prognostic factors affecting surgical outcomes based on studies conducted from about 1960 to 1998. This analysis provides a basis for comparison with the current studies applying evidence-based and best-evidence criteria.

### Lesion size and characteristics

Historically, the literature has been inconsistent concerning the preoperative size of the lesion and surgical healing. There is no clear consensus that small (<5 mm) lesions heal more favorably than larger lesions (38). Lesions >10 mm do show a lower rate of complete healing and a greater incidence of incomplete healing by scar tissue formation (79).

Wang et al. (16) conducted a prospective study of endodontic surgery reviewed at 4 and 8 years. The overall healing rate was 74%. This study found that the healed rate was significantly higher for teeth with small (<5 mm) lesions. When the preoperative lesion was >5 mm, the risk of the persistence of the lesion increased almost fourfold. The other significant factor was the length of the root filling (see Quality of root filling). Intensive statistical analysis determined that other factors did not influence the outcome. These factors were the pre-operative categories of age, sex, tooth type and location, signs and symptoms, radiographic appearance of the borders of the lesion, type of root filling material and its technical quality, the periodontal condition, the presence of a perforation, a history of a root filling or retreatment, a history of prior surgery, how the tooth was restored, and whether a post was present. Intra-operative factors were the surgical procedure (apicoectomy, root-end filling, root-end non-surgical retreatment), use of a hemostatic agent, choice of root-end filling material, the root-end preparation depth, any complications during the procedure, whether antibiotics were prescribed, and the results of a biopsy. The post-operative categories included signs and symptoms, how the tooth was restored and whether a post was present, the incidence of root fracture, and the presence of apical periodontitis. The size of the apical lesion is a significant factor influencing a positive outcome following surgical retreatment.

### Tooth location

The actual tooth being treated appears to be less important than the access to it and the anatomy of the roots in determining a successful outcome (16, 38).

### Preoperative symptoms

Symptoms do not appear to affect the outcome of surgery (16, 38).

### Age and gender

Neither the age nor the sex of the patient appears to influence the outcome of surgery (16, 38).

### Quality of the root filling

Non-surgical retreatment of the root canals before surgery improves the prognosis for surgery (25-28, 53). However, there appears to be no correlation between the quality of the root filling and surgical success (38). Lustmann et al. (80) quoted one study that found that short root fillings had a better outcome

then roots filled to the apex or overfilled. The authors of that study speculated that the unfilled portion of the root canal harbored residual bacteria, and root resection removed this source of infection (80). Wang et al. (16) reached the same conclusion. They also found increased healing in overfilled teeth, the first time this has been reported. Wang believed that the improved healing of overfilled canals occurred because surgery eliminated the infection or other irritants to the periapical tissues, allowing healing to take place (4).

## Repeat surgery

A repeat of surgery is associated with a worse outcome than surgery performed the first time (38). Should periapical resurgery be considered for failed cases before extraction and replacement with a prosthesis or implant? Peterson & Gutmann (81) conducted a systematic review of the literature based on a standardized radiographic assessment of healing following primary surgery and resurgery followed up for at least 1 year. Eight studies fulfilled this and other statistical criteria. All papers but one were published before 1997. The success rate for the initial surgery was 64%. The resurgery success was approximately 36%, while 38% failed, and approximately 26% were categorized as uncertain healing. The success and failure rates were essentially the same. Despite this finding, the authors concluded that periapical surgery should be considered a viable treatment option because the 26% of the cases categorized as uncertain healing had the potential to heal over time based on the radiographic criteria used. This potential would yield a success rate equivalent to the initial surgery (81). The authors acknowledged the limited clinical application of these findings because the studies were carried out before the development of current microscopic techniques and new materials.

Gagliani et al. (82) compared periapical surgery and resurgery with a 5-year follow-up period. Using magnification and microsurgical root-end preparations, the positive outcome for primary surgery was 86% and 59% for resurgery. This seems to compare unfavorably with the results obtained by Rud et al. (72, 83) of 76–81% for resurgery. However, direct comparison between these investigations is difficult, in part because the apical preparation techniques and root-end filling materials differ. The dentine-bonded composite technique has not been widely reported by other authors, but it shows promise. Similar results have been achieved with a compomer material (84). While periapical resurgery requires further study, it appears to be a realistic alternative to tooth extraction (82) and is preferable to the loss of the tooth.

### Level of apical resection

Historically the level of root-end resection has received little attention. Altonen & Mattila (85) reported higher complete healing when the root was resected approximately half its length as opposed to one-third of its length. This probably reflects the surgical techniques available at the time, and contrasts markedly with current recommendations. Using microsurgical techniques, a resection of 3 mm is considered sufficient to eliminate apical pathology (86).

### Root-end filling and materials

The older literature generally supports the placement of a root-end filling. Many materials have been studied with inconsistent results (38). Attention has focused on IRM (87, 88), Super EBA (88, 89), dentine-bonded composite (72, 90, 91), and most recently mineral trioxide aggregate, MTA (77, 87, 92, 93). MTA appears to be very tissue tolerant, and promotes cementum regeneration (77).

## Non-surgical retreatment and surgery

Numerous studies support the conclusion that non-surgical retreatment of the tooth before surgery improves the prognosis (25–28, 53). Non-surgical retreatment in conjunction with surgery may have a better outcome than either procedure alone because all possible sites of infection are treated (79). However, the combination of the two procedures is not usually practiced. If the root canals are accessible, non-surgical retreatment prior to surgery is the treatment of choice (38).

## Root-end non-surgical retreatment of the root canal

When it is feasible to perform this procedure, non-surgical root-end retreatment of the root canal has a

higher success rate than root-end filling alone (38). A recent study of root-end retreatment prior to apical filling provides a basis of comparison with previous studies (16). Reit & Hirsch (94) reported a 71% success rate following root-end retreatment of 35 teeth. Another 23% showed a reduction in lesion size. The filling material was gutta-percha softened in chloroform. The recall period was from 1 to more than 4 years. Radiographic healing was assessed according to the criteria of Rud et al. (26). Wang et al. (16) reported a 100% success in 7 teeth using the same radiographic criteria (94). The root-filling materials were either gutta-percha with a sealer or Super EBA (16). The lower absolute success rate reported by Reit & Hirsch (94) may be due to the use of gutta-percha softened in chloroform that may leak over time (76). Root-end retreatment of the root canal, where anatomical constraints allow its use, may improve the prognosis of periapical surgery.

## Operator skill

There should be little difference among specialists performing endodontic surgery. However, the outcome could be influenced by experience and skill (38). Rahbaran et al. (53) compared the outcome of surgery performed in the oral surgery and endodontic units of a teaching hospital. The records were reviewed 4 years following surgery. The complete healing rate in the endodontic unit was approximately double that of the oral surgery department. The most important factor promoting a successful result was the technical quality of the surgery, reflecting the skill of the operator and thus agreeing with Friedman (38). However, if experience and skill are paramount, then the surgical outcome could be expected to differ considerably among specialists and not be similar as claimed by Friedman. Epidemiological studies suggest that the frequency of periapical surgery represents approximately 0.5–1.4% of treatment procedures (37, 54). In these studies, the incidence of surgery on anterior teeth was twice the rate of that for premolars and molars. This probably reflects the easier access, visibility, and familiarity with the anterior area. However, Lazarski et al. (54) found that over 87% of the cases treated in endodontic specialty practices were posterior teeth, represented by premolars (18.6%) and molars (69%). This implies that very few posterior teeth require, or are receiving, surgical treatment. While postgraduate endodontic programs may provide adequate training in periapical surgery, it is a skill that can erode without practice. This further implies that it may be difficult to sustain the necessary clinical skills and thereby the confidence to perform surgery on posterior teeth, particularly molars. Periapical surgery should be performed by endodontists, but not necessarily on all teeth by every endodontist. Referral to a more experienced colleague is in the best interest of the patient and should be actively encouraged when appropriate.

## Intentional replantation

Intentional replantation is a viable alternative to tooth extraction in selected cases. A Medline search under 'intentional replantation and endodontics' produced a total of 89 citations, 40 of these since 1993. The majority are case reports. These include treatment of root perforations (95, 96), vertical root fractures (97, 98), periodontal problems (99, 100), orthodontics (101), and trauma (102). Kratchman (103) has described a detailed protocol. This includes an extraction technique to minimize damage to the periodontal ligament and the use of a tissue culture medium during the extraoral period to maintain cellular viability. The use of tissue culture solutions is supported by other studies (104, 105), and may represent one of the advances that will make this treatment option more predictable. Emdogain, an enamel matrix-derived protein, shows promise in reducing the occurrence of replacement resorption following replantation (102, 106). Intentional replantation can serve as a provisional treatment during the adolescent growth phase when other restorative measures are not feasible.

## Transplantation

There are numerous studies dealing with the autotransplantation of teeth, usually third molars, to replace a missing first or second molar. The following studies are representative of the general conclusions. Endodontic treatment is indicated for teeth with closed apices, usually within a month after transplantation (107, 110). The prognosis for both closed and open apices is considered favorable (107, 108). Mejare et al. (110) reported a success rate of 81% of 50 replanted

third molars treated in an endodontic unit of a hospital. The cases were followed for 4 years. Periapical healing was evident in 96% of cases. Sobhi et al. (109) achieved an 88% positive outcome with mature third molars assessed at 6 months. In this study, endodontics was carried out before transplantation.

The studies show that there is no uniform protocol for the transplantation of teeth. Problems include low rates of focal replacement resorption and ankylosis (107, 110), infraocclusion and pulp necrosis (108), crestal bone loss and marginal periodontitis (107, 108, 110), and apical periodontitis (107, 108). However, all the studies concluded that transplantation offers a viable and economic alternative to implants in selected cases for orthodontic and restorative reasons. Failure would still leave the option of an implant procedure. Realistically, endodontists in private practice would rarely initiate this procedure. Instead, they would be part of a multidisciplinary team. The future may require a broader knowledge base for endodontists and closer cooperation with other specialties.

## Endodontics or implants?

The beginning of the 21st century should be a secure time for endodontics. A 100 years ago, the focal infection theory of Miller & Hunter discouraged endodontic treatment. Today, endodontics is universally accepted. Millions of teeth have been preserved, contributing to the health and well-being of patients around the world. Endodontics has reached a new level of understanding of the processes that are responsible for pulpal and periapical disease (1–6, 45, 111–113). Technical advances and the development of new materials promise greater efficiency and improved treatment outcomes. However, there is an air of concern as viable teeth, which could be treated or retreated endodontically, are being extracted in favor of dental implants.

Much of the current debate about 'endodontics or implants' has a familiar ring to it. This issue is reminiscent of the controversy in the 1970s concerning 'mummifying' paste root fillings (114) and more recently the revived and discredited focal infection theory of Huggins (115). Implant failures have been blamed on adjacent teeth that are asymptomatic, endodontically treated and free of any pathology (116). The implant companies are enjoying rapid growth on the stock market. Whilet they finance implant-training programs around the world, some dental schools are prohibiting endodontic graduate students from attending these courses (117). A survey by the American Association of Endodontists revealed that the 'inappropriate use of implants' varies in different regions of the United States (118). Simultaneously, with this focus on implants, there are threats to the future of endodontic education due to a decline in faculty numbers (119).

## Implants vs. endodontically treated teeth

Historically, there is a great deal of literature available dealing with implant studies. When the criteria of EBD are applied, there are no papers that reach the highest level of (21, 22). As discussed previously, the same is true in other areas of dentistry, including endodontic retreatment and apical and periradicular surgery (8, 16–20).

The rationale for extracting an endodontically treated tooth and replacing it with an implant is both emotive and controversial. This controversy is fully described in the recent article by Ruskin et al. (120), which is designed to be confronting. The authors make a case for the replacement of most endodontically treated teeth with implants. The issues raised and claims made will form the basis for the discussion of implants in this paper.

Ruskin et al. (120) state that an immediate implant has a more predictable outcome than an endodontically treated tooth as a basis for restorative dentistry. The authors cite variable success and failure studies for endodontic treatment, ranging from 64% to 95%, performed by both specialists and general practitioners (121, 122). They contrast this with implant survival rates that exceed 90% (123-126). Ruskin et al. (120) point out that the failure of an endodontically treated tooth is often non-endodontic in nature. These failures include recurrent caries, root fractures, and periodontal disease (31). They state that retreatment of endodontic cases is difficult, and may fail due to the persistence of infection and/or irritants both within the canal and in the surrounding tissues (2, 127, 128).

Ruskin et al. (120) also indicate that endodontically treated teeth usually have a history of prior restorations, and may be weakened by a loss of tooth structure (62).

Immediate implants, even in esthetic sites, are claimed to be predictable (129, 130). While restorative margins of restored teeth are positioned in the gingival sulcus, and may violate the principles of biologic width, an implant offers greater marginal integrity and plaque reduction. An implant is better able to retain a crown than a natural tooth, 'particularly one that is endodontically treated and supporting a post and core.' Ruskin et al. (120) maintain that the cost of orthodontic extrusion, surgery, endodontic re-treatment, and a post core and crown often exceeds that of a single tooth implant. They further state that the cost of a single tooth implant compares favorably with that of a crowned tooth because the crowned tooth has a reduced life span compared with the implant. According to these authors, the best candidate for endodontic treatment is a single rooted tooth with an intact crown that has become devitalized due to trauma, and that also fulfills an esthetic need. While each patient must be assessed individually, 'It is thus possible to consider early removal of teeth and placement of implants and implant-based restorations as a favorable treatment option compared with the majority of endodontically treated teeth'.

## Endodontics and implants: 'success' vs. 'survival'

Treatment outcomes in endodontics are usually measured by an absence of clinical symptoms and specific radiographic criteria. While clinical symptoms may be easier to measure, radiographic techniques and interpretation vary greatly, making comparisons among studies both difficult and, perhaps, meaningless (38). However, the strict guidelines traditionally used to evaluate the results of endodontic treatment are not uniformly applied to medicine or even other areas of dentistry, including implants. For example, the outcome for cancer patients is often expressed as a percentage of patients who have survived 5 years following their treatment. In dentistry, this concept of 'survival' is applied to implant studies. Implant survival has been defined as 'a retained non-mobile implant capable of supporting a crown'. However, some of these implants may have associated bone loss and periodontal defects (131). Such a broad definition makes a comparison with the strict criteria for a positive endodontic outcome not possible (23). Friedman (23) avoids the terms success and failure by suggesting that a treatment outcome be evaluated in terms of disease and healing. The absence of clinical symptoms and a normal radiograph are an indication of healing. The persistence of apical periodontitis is a sign of a continued disease state. If the radiolucency decreases over time, the tooth is considered to be healing. The recognition that pulpal and periradicular disease may be managed but not eliminated is an important departure from the traditional methods of evaluating outcomes based on clinical symptoms and radiographic findings.

This current thinking is reflected in a recent study of almost 1.5 million teeth from an insurance company database. The treatments were provided both by general dentists and endodontists, and a 97% retention rate followed up for 8 years was reported (37). An earlier study using the same parameters reported a retention rate of over 94% of 44,000 teeth reviewed for an average of 3.5 years (54). These results compare quite favorably with single tooth implant survival rates (132, 133). These studies also clearly show that any comparison between endodontic treatment and implant outcomes, such as made by Ruskin et al. (120), must be based on current and comparable literature sources. Furthermore, both of the above endodontic studies combine the results of general practitioners and specialists. This demonstrates that both general practitioners and specialists can achieve high levels of success with endodontic treatment. This may not be true for implant outcomes.

Endodontics and implants differ in their initial history. Endodontic treatment has always been a part of general dental practice. Recognition as a specialty in most parts of the world did not occur until the 1960s or later. An American Dental Association report in 1999 revealed that endodontists only treated approximately 25% of the total of cases surveyed (117). Implants, however, began at a specialist level involving large and often multicenter clinical trials. Only recently have general practitioners offered this service. According to Listgarten (14), the high success rates for implants may not be duplicated at the general practitioner level. Pure training courses, as opposed to educational curricula and academically based experiences, may be only of a few days' duration. The practitioner may lack the necessary diagnostic, surgical, and prosthetic skills. Patient selection may not be as strict as required for a clinical trial, and deviations from the recommended treatment are more likely when the dentist is

confronted with an unexpected clinical problem and has to improvise. Moreover, patients may not exercise the necessary home care to maintain the implant in an ideal environment (14).

Endodontics has a similar problem with training in new technologies. Short training courses, as opposed to educationally based curricula in rotary instrumentation, are very popular. Whether they supply sufficient knowledge and skills is questionable. Reducing the number of instruments to 'simplify' the technique may be detrimental to bacterial control and ultimate success, especially as it relates to the removal of bacterial species and tissue debris in the apical 1/3 of the canal (1, 134, 135). A lack of diagnostic and clinical skills in both areas may be reflected in malpractice claims. In Australia, for example, the incidence of claims is increasing, with implant claims four times the rate of those for endodontics (136). The average cost to one insurance company (136) of an implant claim was four times the average claim size for all events, while for endodontics it was slightly above the average claim size. Implant claims involve dentists with limited experience or insufficient training. The major causes of implant claims are diagnosis and case selection (24%), failure of restorations after osseointegration (18%), and unsatisfactory esthetics (14%). Endodontics claims are skewed toward new or inexperienced practitioners. In endodontics, the majority of claims relate to failed or inadequate root canal fillings (36%) and broken instruments (28%).

If the criteria for endodontic treatment outcomes are revised, certain issues must be addressed. In the two largest epidemiological studies on evidence-based outcomes (37, 54), the investigators could not assess the quality of the root canal fillings or the post-treatment incidence of clinical symptoms. The incidence of periapical lesions in endodontically treated teeth surveyed in many countries is 20–60% (23). A certain percentage of chronic periapical lesions will have a draining sinus tract. Other periapical lesions will transform into an acute apical abscess causing corresponding symptoms requiring remedial treatment. The question is whether the specialty of endodontics is prepared to adopt this 'laissez faire' approach to the post-treatment evaluation of treated cases. There is an important difference between the *epidemiological* evidence of the persistence of periapical lesions following endodontic treatment and the *acceptance* of this fact as a measure of positive or acceptable outcomes. There is a risk that this change in guidelines is partly a response to the challenge of implantology. A more realistic and biological comparison between endodontics and implants would be achieved by applying stricter criteria to implant outcomes (117).

## Indications for an implant

Becker (137) has outlined some of the reasons for extraction of a compromised tooth and replacement with an implant. These include an unfavorable crown to root ratio, insufficient root length, questionable periodontal status of the tooth, and the condition of the surrounding dentition. Lewis (138) goes further, advocating the removal of a healthy tooth if this benefits the overall treatment plan by meeting functional, esthetic, and financial requirements.

For endodontists, periradicular surgery includes root amputation and tooth sectioning. The literature is divided on the outcome of these procedures. In a frequently quoted study, Langer et al. (139) reported a 38% failure rate of 100 molar teeth that had undergone a root resection and were followed up for 10 years. Most teeth failed after 5 years. Mandibular molars failed at twice the rate of maxillary molars, usually due to root fractures, while maxillary molars were lost due to periodontal disease. Bühler (140) reported a similar result, with 32% of root resections failing after 10 years. Endodontic complications were the principal reason for the negative outcome. Other authors have concluded that teeth with a furcation lesion and needing a root amputation or hemisection have a guarded prognosis, and replacement with an implant should be considered (137, 141). Fugazzotto (142) found that both root-resected molars and molar implants placed in a terminal abutment position have a very poor prognosis.

In contrast, Erpenstein (143) reported that the prognosis for hemisected molars is favorable. They may be used as abutments for small span bridges if attention is paid to the occlusion. However, the follow-up period in this study was only 3 years. Bühler (144) concluded that with appropriate case selection, a hemisection has an outcome similar to an implant and is preferred to a molar extraction. Blömlof et al. (145) reported on a 10-year follow-up of root-resected molars compared with root-filled single rooted teeth. The survival rate was similar, provided the endodontic environment was stable and oral hygiene was optimal.

Carnevale et al. (146) published the results of another 10-year study of molar teeth. Soft tissue and osseous surgery was performed both on the experimental and control sites, and a root resection procedure was performed only on the experimental tooth. Plaque control was maintained throughout the observation period. The 10-year survival rate was 93% at the experimental site and 99% at the control site. The authors concluded that the favorable tissue and bone morphology allowed for the good oral hygiene that was carefully practiced by the patients. The requirement that patients be committed to maintaining a high standard of oral hygiene is stressed in all these studies, and thus is similar to achieving a positive outcome with implants. In a more recent paper, Langer (147) has reviewed his original findings, stating that there are so many variables in diagnosis and treatment of furcation lesions that no one treatment option is always correct.

Patient management may favor implant placement as opposed to periapical/periradicular surgery, particularly in older patients or those with a disability. Endodontic surgical intervention requires a high degree of patient cooperation, and this is not feasible in all cases. Extraction and the placement of an implant may provide more direct and easier access than treating the apices of some roots, particularly in molars, or damaged cervical areas due to perforations or resorptive defects. For some patients, no replacement of the missing tooth may be the best treatment plan, at least in the short term.

## Implant outcomes

A positive outcome with implant placement has been defined as '. . . an implant which is functional, symptom free, and with no obvious clinical pathology' (131). Smith & Zarb (148) proposed specific criteria for a positive outcome that are generally accepted in implantology. These criteria include no mobility, cervical bone loss that should not exceed 0.2 mm per year after the first year in function, no peri-implant radiolucency, and a design that allows an esthetic result. If these criteria are applied, the minimum success rates should be 85% at 5 years and 80% at 10 years. Vehemente et al. (149) conducted a literature review as part of a study of risk factors influencing implant survival. They examined 42 prospective studies with more than a one-year follow-up. The mean survival for implants at one year ranged from 73.8% to 100%. The 5-year survival figures were 85.6% to 100%. These studies represent clinical trials conducted under optimum conditions by experienced clinicians. In clinical practice, the surviving implants may include implants that are failing according to the criteria of Smith & Zarb (148). To confuse matters further, Listgarten (14) concluded that the criteria for positive outcomes have changed over time and that a consensus is lacking among practitioners.

El Askary et al. (150) have further classified implants as 'ailing, failing and failed'. 'Ailing' implants exhibit bone loss but no inflammation or mobility. The implants could fail if the bone loss progresses. 'Failing' implants show progressive bone loss and signs of inflammation, but still no mobility. These implants can be treated and the condition can be reversed once the etiology is established. 'Failed' implants are mobile and radiographically exhibit a peri-implant radiolucency. Mobile implants should be removed. Albrektsson (150) describes implant survival as implants that are still in function but untested against the positive outcome criteria. Surviving implants include the 'ailing and failing' implants. These implants may require further treatment, but their future is uncertain.

Negative outcomes can be grouped into early and late categories. Early failures (pre osseointegation) are due to surgical or postoperative complications. The majority of implants fail in the first 3–5 months of placement (14, 151, 152). These failures have been attributed to surgical trauma, iatrogenic factors, bone quality and quantity, bacterial contamination, and loading factors (151).

Late failures (post osseointegration) occur during and after the restorative phase (14). These failures are attributed to a non-infective retrograde peri-implantitis caused by occlusal overloading leading to bone loss (150–153); peri-implantitis due to infection may occur simultaneously. In patients with multiple implants, failures seem to cluster in a small subpopulation (154, 155). The reasons for this are not well understood, and may not be relevant for single tooth replacements. However, there is evidence that the pocket depth around implants increases over time (156). This could result in an increased loss of implants (152). As discussed previously, implants with peri-implantitis due to bacterial infection remain immobile until the last stages of the disease. In contrast, biomechanical failures result in increased mobility due to a loss of implant to bone contact (152).

## Management of negative outcomes

The failure of an implant is always clinically significant because extraction is the only alternative. The extraction may require surgery. Restorations must be removed, leading to altered function and possibly appearance. The bony defect must heal before further treatment can be undertaken.

Fortunately, a negative outcome following non-surgical root canal treatment can be managed with more flexibility, and in stages. Non-surgical retreatment, periapical surgery, periradicular surgery (hemisection and tooth sectioning), intentional replantation, or transplantation can prolong the life of the tooth. This can have psychological and economic benefits for the patient. Trope (157) has outlined such a scenario for 100 teeth requiring initial endodontic treatment. When the lowest reported positive outcome rates are applied to the initial treatment, retreatment, and then surgery, only three teeth will require extraction (157). Restorations are retained and function is unaltered.

## Periodontal factors

The periodontal health of the peri-implant tissue is critical in determining the outcomes of implant placement. Peri-implantitis due to infection appears to have many of the features of chronic adult periodontitis. Unlike a natural tooth, the collagen fibers are parallel to the implant and not attached to it. This may facilitate the accumulation of plaque and loss of bone (151). In patients with periodontal disease, there appears to be a strong association between periodontitis and implant failure. At least 10% of implant failures may be due to peri-implantitis (158). Cross infection from the teeth to the implant site is a possible mechanism (159). The elimination of periodontal disease is mandatory in prospective implant patients (153). The incidence of peri-implantitis reported in the literature depends on a predetermined probing depth threshold, and is somewhat subjective. In one study, reducing the probing depth by 1 mm reduced the incidence of peri-implantitis by almost 50% (160). Implants exposed to infection do not become mobile until the disease state is very advanced (151, 161). Ironically, lack of mobility alone does not mean that the implant is a success, but only that it has survived. In endodontics, periodontal disease is a negative factor, but it rarely precludes treatment (see Case selection).

## Occlusion

Implants lack a periodontal ligament and therefore the ability to buffer or dampen the forces of occlusal trauma (162). There is no agreed upon implant system that replicates the periodontal ligament (150); therefore, the occlusion must be assessed carefully. According to Meffert (163), implants can tolerate vertical but not lateral forces. Clenching exerts vertical force that may be excessive, and bruxism creates excessive lateral forces that will lead to bone loss. Bruxism is the primary cause of bone loss and implant mobility in the first year following implant insertion (153). Bruxism can also cause a bending overload of the implant. Bending leads to implant fracture (150). The loosening of abutment screws is a common finding, particularly with single crowns (131, 164). The incidence can be as high as 43% (131, 132). The loosening of a screw is a major sign of early-stage implant failure due to occlusal trauma and overloading (153).

While bruxism does not preclude implant placement, it must influence treatment planning (153). Recommendations include more implants and a wider implant diameter to share the occlusal load (165), eliminating cantilevers (160), narrowing the dimensions of the restoration, avoiding implants as pier abutments (150), eliminating contacts in lateral excursions, and using an occlusal guard (166).

Bruxism is detrimental to the survival of implant-supported fixed partial dentures (167). The literature is divided on the outcome of prostheses that are fixed to both natural teeth and implants. Some studies report a high incidence of intrusion of the natural tooth (150, 168), even resulting in separation of the natural tooth from the prosthesis (14). Other investigations show no difference in the survival of tooth/implant-supported fixed partial dentures (160). Molar implants placed in a terminal abutment position have a very poor prognosis (142). Occlusal trauma may cause a more rapid destruction of the bone supporting an implant compared with similar forces on a natural tooth (150).

Precise occlusal relationships are equally important for the success of single tooth implants (169, 14). Occlusal overloading is a major factor in the failure of implants after osseointegration, the other being peri-implantitis due to infection (151, 152). Single-tooth implants are subject to greater occlusal forces than bridged implants, and have a higher risk of failure (170).

## Single-tooth implants

### Case selection

The single-tooth implant is of most interest to endodontists. For a single-tooth implant, certain criteria described by Smith & Zarb (148) and Schmitt & Zarb (171) are generally accepted. There must be space for the implant. The adjacent teeth will have good restorations that cannot support the missing tooth without alteration or removal, and the patient will have declined to involve the adjacent teeth. Lastly, the patient will not accept a removable partial denture. According to Meffert (163), an implant may be precluded if the site impinges on vital anatomic structures, there is insufficient mouth opening to allow implant placement, and/or insufficient vertical dimension for the final restoration. The motivation to maintain good oral hygiene is an essential part of case selection (172). Patients who are unlikely to maintain a high level of oral hygiene should not be considered for an implant (151).

While excellent oral hygiene is always desirable, a less then optimum condition does not preclude endodontic treatment. The same is true, in most cases, for periodontal disease.

### Risk factors

A history of alcoholism, immune disorders, and other conditions that impair healing might be expected to preclude implant placement, but there is little evidence to support this assumption (151). Implants in patients with diabetes can be successful, at least in the short term (173). Medium to long-term follow-ups are lacking (152). Certain medications such as anti-osteoporosis drugs may be associated with implant failure, but this finding is only supported by case reports (152). However, there is a clear link to implant failure and smoking (149, 174). This finding is independent of patient populations and different implant systems (175). As discussed above, the periodontal health of the peri-implant tissue is critical in determining the success and the failure of an implant.

In endodontics, diabetes is associated with impaired healing of periapical lesions (161, 176, 177). However, in a recent study of factors affecting the outcome of endodontic treatment, smoking was not a significant variable (178). There are virtually no medical contraindications to endodontic treatment except for uncontrolled diabetes and possibly a recent coronary event (179).

### Treatment time

Implants are placed in either single or two stages. In the two-stage protocol, immediate single-tooth implants require a barrier to prevent infection of the extraction site during healing. Guided tissue regeneration does not always achieve this goal. A 4–6 week period may be recommended to allow for soft tissue healing over the extraction site before the implant is placed (180). Once the implant is placed, a 4–6 month period for the mandible and maxilla, respectively, is allowed before the implant can be restored. In practice, this may need to be extended to 6 and 8 months (163). According to Moiseiwitsch (181), while this is an ideal timeframe, a more realistic waiting period is 9–18 months, not allowing for any complications. For example, should an implant be placed immediately or delayed for 6 months following the extraction of an endodontically treated tooth with a periapical lesion because the socket is an 'infected' site? Clinical recommendations differ (163, 180), and accordingly can prolong the total treatment time. In a molar site, two implants rather than one may provide more support and distribution of occlusal stresses (169). Where bone quality is questionable or early loss of an implant is suspected, the placement of extra abutments ('sleepers') is suggested by some clinicians (182). Orthodontic extrusion of the failed tooth may be required for esthetic reasons. These measures will increase both the time and the expense of implant treatment.

Time can be saved if the single-stage protocol is followed. Single-stage placement has been associated with an increased risk of failure; the incidence may be almost twice that of the two-stage protocol (149, 150). However, other studies show that single-stage placement with immediate loading has a predictable outcome (120, 129, 130). This may in part be due to the characteristics of the implant surface (roughness, treatment with bioactive coatings, extent of contact with bone, etc.) and the use of a threaded implant surface (183). The time and expense saved may be illusory if esthetic considerations require other treatment such as orthodontic extrusion (see Esthetics).

### Cost

Implant treatment planning may involve separate examinations by the surgeon and restorative dentist.

A variety of radiographs, mounted study casts, and a surgical stent may be required (151). A cost–benefit analysis comparison between endodontic treatment and a single-tooth implant concluded that endodontics and a crown is less expensive, entails fewer office visits and is completed more quickly then the implant (184). Cost and time have been recognized as barriers to public acceptance and use of implants, with only 5% of patients having the treatment (185). This calls into question the claims of Ruskin et al. (120) and others concerning the time and cost of implants vs. endodontic treatment and coronal restoration.

## Regional anatomy and bone characteristics

The quality and quantity of bone for implant placement must be sufficient. Hutton et al. (154) studied implants supporting overdentures and concluded that the patients with both low density and quantity of bone were at the greatest risk of implant loss. The same risk exists for single-tooth implants (163). Type I bone is often found in the anterior mandible. However, single-tooth implants are infrequently performed in the anterior mandibular because of insufficient mesiodistal width (163). Type I bone will withstand more force than type IV bone. Type IV bone is frequently found in the anterior maxilla (163). Anatomic limitations in the anterior maxilla include the maxillary sinus, the nasal cavities, the reduced buccolingual dimension of the residual ridge and bony fossae and depressions (186). Anatomical limitations are a principal reason for not performing implants (187). The posterior maxilla generally has type III or IV bone. The quality of the bone, the maxillary sinus, and the more difficult access contribute to a lower success rate in the posterior maxilla (151). Numerous studies support a lower success rate for maxillary implants (14, 151, 164).

## Contraindications and precautions

In young people, implants are contraindicated until the growth phase is completed because the fixture will ankylose, resulting in infraocclusion (188). Infraocclusion may cause changes in the gingival architecture around the implant, with esthetic implications.

## Esthetics

The most frequent problem with implants is esthetics in the anterior maxilla (166). Patients often have unrealistic esthetic expectations (163). The response to a single-tooth implant will depend on the tissue biotype. Thin scalloped and thick flat biotypes respond differently to trauma. Thin scalloped tissue will tend to recede, while the thick flat tissue will respond by inflammation. Depending on the type of tissue and the height of the smile line, changes to the marginal tissue and interdental papilla may create esthetic problems. Correct diagnosis is critical (189, 190). Arnoux et al. (190) concluded that 'Nearly a decade of experience with the single maxillary anterior implant has led to the following conclusion: where esthetics is of prime concern, this technique probably has limited use, especially when the adjacent teeth are not to be restored with bonding, porcelain laminates, or crowns'. Furthermore, 'All practitioners who have used this kind of tooth replacement have, at times, wished they had done a classic fixed prosthesis instead'.

Approximately 1–2 mm of labial gingival tissue may recede following tooth extraction and immediate implant placement. Orthodontic extrusion of the tooth is recommended to position the free gingival margin more coronally prior to extraction (137, 191). Orthodontic extrusion takes time and creates its own esthetic challenges. Extrusion is more critical if the patient has a high smile line and a thin scalloped tissue biotype. Conte et al. (191) state that tooth extraction in the presence of this biotype is challenging and requires ' . . . flawless surgical execution'. In fact, it may be preferred to extract the tooth, perform grafting procedures, and place the implant 3–6 months later (191). Undoubtedly, the placement of implants in the anterior maxilla may be more complicated than stated by Ruskin et al. (120).

Given the above precautions, the immediate placement of an implant with an immediate provisional restoration preserves bone and tissue, while providing an interim esthetic result (120, 191). The provisional restoration must not be in function because premature occlusal loading may affect osseointegration. The patient must also avoid loading the tooth during mastication (191).

## Complications

Implant placement may result in overheating of the bone, perforation of the bony plate and leaving residual root fragments and foreign bodies in the site. Other complications include contamination of the implant

surface with saliva or bacterial plaque and placing the implant in an infected area (166, 192). Irreversible pulpal damage to teeth adjacent to recently placed implants has been reported (193, 194). However, an animal study concluded that the presence of teeth with existing periapical lesions does not affect adjacent implants (195). Balshi (166) listed the six major potential complications as esthetic, phonetic, functional, biological, mechanical, and ergonomic. The most frequent complication was esthetics in the anterior maxilla. Rose & Weisgold (162) listed some potential complications when implants are immediately placed into the extraction socket. These include thin, fractured, or non-existent facial bone, the angulation of the extraction socket, insufficient bone to stabilize the implant, a different diameter of the socket and the implant, and insufficient soft tissue to achieve wound closure. Goodacre et al. (164) conducted a comprehensive review of the literature and reported a wide range of clinical complications ranging from surgery through to mechanical, phonetic, and esthetic problems. However, the variations among the study designs precluded any systematic analysis of these complications. The choice of implant system itself may affect the success rate (153).

The loosening of abutment screws, necessitating additional office visits, is a common finding particularly with single crowns (131, 164). The incidence can be as high as 43% (131, 132). Screw loosening is the major sign of early failure and is due to occlusal trauma (153). Brägger et al. (160) found that up to 50% of implant-supported fixed partial dentures had technical problems requiring repairs and remakes. These include broken solder joints, fractured porcelain, and even fractured prostheses (162). The claims that implants are 'stronger' than natural teeth with 'bioactive' surfaces that 'bond' to bone are either incorrect or require further substantiation (196).

## Concluding remarks

Both non-surgical and surgical retreatment procedures share the problem of significant negative outcomes in the presence of apical periodontitis. Intracanal procedures to eliminate infection are technically difficult and perhaps impossible to achieve. There is no evidence that rotary instrumentation is an improvement over traditional methods in this regard. However, recent advances in endodontic microsurgery and bio-inductive materials show more promise in eliminating apical periodontitis. Traditionally, periapical surgery has been considered the 'junior partner' in the revision of a negative outcome. This may need to be reconsidered. Non-surgical retreatment in conjunction with surgery may have a better outcome than either procedure alone because all possible sites of infection are eliminated. This may be important given the pressures to replace 'failed' endodontically treated teeth with implants.

Implants represent a challenge to endodontics, created in part by the implant manufacturers. When comparable criteria are applied to outcomes, the survival rates of endodontic treatment and implant placement are the same. Time and cost favor an endodontic procedure. Implant treatment carries the risk of ongoing periodontal and occlusal complications, with particular problems in the esthetic zone. Implants have an 'all or nothing' outcome; that is, if an implant is lost, so is the attached prosthesis. Patients must be provided this information during the treatment planning phase. Accordingly, retreatment procedures should always be carried out first unless the tooth is judged to be untreatable. Endodontists should have some training in the theory and practice of implantology at least to help patients and referring colleagues to make an informed choice regarding all replacement options. Does that mean endodontists should place implants? This will remain an individual decision based on personal preference and the nature of the endodontist's practice.

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# Timeliness and effectiveness in the surgical management of persistent post-treatment periapical pathosis

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Common problems that cause persistent post-treatment periapical pathosis include infection remaining in the apical inaccessible areas, extraradicular infection including apically extruded dentine debris with bacteria present in dentinal tubules, radicular true cysts, foreign body reactions, inadequate non-surgical root canal treatment with or without iatrogenically altered root canal morphology, and vertical root fractures. Inadequate root canal treatment may be corrected non-surgically, while more complex problems may require surgical intervention. The important factors that warrant a successful surgery include good quality of the orthograde root canal treatment, deep retrograde preparation of the apical canal, and carefully cleaning and filling of the exposed isthmuses and accessory canals. Ideally, apical surgery and orthograde retreatment are performed simultaneously. In a recent study, 97% of the lesions including large ones of > 10 mm in diameter healed completely within 1 year after surgical intervention. Of the teeth that showed 'complete healing' at 4 years more than 85% already 'completely healed' at 2 years; thus, the endodontic post-treatment disease might be treated surgically or non-surgically within 2 years after the previous treatment.

## Introduction

According to Ørstavik & Pitt Ford (1), Friedman (2) and Trope (3), apical periodontitis (AP) is the unique endodontic disease treated by dentists and the task of dentists is to prevent and treat AP by minimizing root infection with effective treatment procedures. Following successful root canal treatment clinical symptoms originating from an endodontically induced apical periodontitis should neither persist nor develop and the contours of the periodontal ligament space around the root should radiographically be normal (4). AP can be present before and after root canal treatment. AP after previous root canal treatment is named as post-treatment disease, which is diagnosed up to 4 years after the previous treatment (4).

In cross-sectional studies performed in 15 countries or areas, radiographically verified periapical lesions occurred much more frequently in root-filled (RF) teeth than in non-RF teeth (5). AP was observed in 40% of RF teeth in a Belgian population (6), 44% in both Canadian (7) and Norwegian populations (8), 52% in both Scottish (9) and Danish populations (10), 61% in a German population (11) and 65% in a Spanish population (12). Clearly, the management of endodontic post-treatment diseases has become a significant part of endodontic practice.

The principle treatment modalities for the management of post-treatment periapical pathosis are orthograde retreatment and apical surgery. In a few studies (13–15), a success rate of 60–65% was recorded for surgical and non-surgical management of post-treatment disease. Many retreatments were performed on teeth that were free of post-treatment disease. These were done solely to correct radiographically or technically deficient root fillings, so called technical preventive retreatments. In studies where the sample included technical preventive retreatments, the success rate was relatively high, 75% recorded by Bergenholtz et al. (16). When technical preventive retreatments

were excluded, the success rate dropped to 48% (16) or 62% (17).

A significant advantage to surgical intervention is that it offers immediate access to the root apex. Furthermore, it includes curettage of the periradicular granulomatous tissues and the resection of the apical 3 mm of the root, which frequently contains infected canal ramifications (18, 19).

## Common problems that may cause post-treatment disease

According to the literature, at least seven problems may cause endodontic post-treatment disease, they are listed as follows:

1. Inadequate root canal treatment without iatrogenically altered root canal morphology (15, 20, 21).
2. Inadequate root canal treatment with iatrogenically altered root canal morphology (15, 20, 21).
3. Infection remaining in inaccessible areas in the apical portion of the root (18, 22).
4. Extraradicular infection (23–27), including extruded dentin debris with bacteria present in the dentinal tubules (28).
5. True radicular cysts and tumors (29, 30).
6. Foreign body reaction to cholesterol crystals (31) or extruded materials such as talc-contaminated guttapercha, particles of paper points, and particles of sealer (32–34).
7. Vertical root fractures (35, 36).

Problems 1–3 are intraradicular infection (37, 38). Problems 4–6 are extraradicular problems. Teeth with vertical root fracture are usually extracted (35, 36). The other problems are treated surgically or non-surgically (14).

## Problems difficult or impossible to solve without surgery

It is easy to understand why the extraradicular problems such as extraradicular infection, radicular true cysts, and foreign body reactions (problems 4–6) have to be solved surgically. Whilst the completion of non-surgical root canal treatment may shift the original balance between the infection and host defence so that the host defence can deal with the extra-radicular infection, there is no proof available for that assumption.

Based on the data of 1769 teeth, Yue & Wu (39) indicated that apical deltas and ramifications occurred in 7% of the teeth. In a study by Nair et al. (18), the apical 3 mm of the mesial roots of mandibular molars was removed surgically and examined histologically. Inter-canal isthmuses were present in 69% of the roots, and accessory canals appeared in 50%. According to Rubinstein & Kim (19), 81% of molars and 16% of premolars had isthmuses at the level 3 mm short of the apex. Rubach & Mitchell (40) demonstrated that lateral canals occurred in 45% of teeth and most lateral canals were located in the apical third (39). Therefore, in a larger number of teeth the apical 3 mm contains 'inaccessible areas'. Findings from recent studies have shown that infection in inaccessible areas in the apical portion of roots (problem 3) cannot be removed using non-surgically treatment modalities (18, 22).

In a histological study using correlative light and transmission electron microscopy (18), intracanal infection was confirmed in the apical 3 mm in 14 out of 16 root-filled teeth with preoperative periapical radiolucencies. Bacteria, mostly in biofilms, were found in inter-canal isthmuses and accessory canals (18). Because not all bacteria are encountered by histological methods, it is therefore impossible to determine the absence of bacteria using histological techniques. The authors concluded that the 2 specimens where bacteria were not detected were not necessarily bacteria free. 'It is very much likely that the 2 cases also contained residual microbes that were not encountered by the methods used' (18). These findings strongly suggest that in all teeth with a periapical radiolucent area, the apical, inaccessible portions of the canals contain large numbers of bacteria present in biofilms that cannot be removed by standard instrumentation and irrigation.

Bacterial biofilms are commonly found at the level of the apical foramen (22, 41) surrounded by large numbers of neutrophils (41). In inter-canal isthmuses, neutrophils were found in stages of disintegration, which coexisted with plenty of bacteria (18). These findings indicate the inability of the host defence. Calcium hydroxide was not used in the study by Nair et al. (18), where roots were filled in one visit. However, it is highly improbable or nearly impossible to place calcium hydroxide, which functions only when in direct contact with pathogens (42), into uniting isthmuses or apical ramifications. Therefore, even after using calcium hydroxide no better microbiological status might be expected in the apical 3 mm.

Traditionally, canals are prepared to the apical constriction, which lies 0.5–1.0 mm coronally from the foramen (43, 44). In this way a small portion of the main canal will remain uninstrumented, along with the many apical ramifications that are often present. If all these canal branches are considered, the total volume of unprepared canal space in any root may be substantial (39) and contain many microorganisms. Preparing root canals to the apical foramina (45–47) or using a patency file (48) may clean the most apical portion of the main canal, but bacteria are still likely to remain in lateral and accessory canals or in apical ramifications (18, 41) that remain uninstrumented or out of the reach of irrigants. Thus, preparing the canal to its terminus does not necessarily result in elimination of root infection.

In a study by Gorni & Gagliani (15), all teeth with post-treatment apical periodontitis were divided into two categories, with or without altered root canal morphology. In previous root canal treatments, canal blockage, apical transportation, ledging and perforation may occur in the apical portion and consequently an hourglass-shaped apical canal may be created that is difficult to clean and fill. In the study by Gorni & Gagliani (15), in approximately 50% of the retreated cases the root canal morphology had been altered by previous treatments. After performing non-surgical retreatment in such root canal morphology-altered teeth (problem 2), a mere 32.9% demonstrated healing (15), indicating difficulties in correcting root canal therapy in such root canal morphology-altered teeth. However, surgical removal of the apical 3 mm may easily solve these problems. For post-treatment disease associated with altered root canal morphology (problem 2), two options are present. The first is to perform non-surgical retreatment and wait, in which it is likely that two-thirds will fail (15). The second option is to perform apical surgery with or without a simultaneous orthograde retreatment (14, 19, 49). In conclusion, problems 2–7 that may cause post-treatment disease are difficult or impossible to solve without surgery.

## Problems that may be solved non-surgically

The only problem that can be solved non-surgically with a predictable amount of success is problem 1, inadequate root canal therapies without altered root canal morphology. In some cases, the periapical lesion is associated with a missed canal or a partly unfilled canal where a broken instrument is present. By a non-surgical retreatment the broken instrument is likely to be removed, and the missed canal may be located and treated properly (50). The success rate for cases with missed canals was reported to be 82% (13). However, the quality of non-surgical root canal treatments cannot be judged by two-dimensional radiographs. Thus, radiographically judged 'good root canal treatment' may actually be inadequate. In a study by Gorni & Gagliani (15), both 'good' and inadequate root canal treatments were categorized into either with or without altered root canal morphology and retreated non-surgically; provided the root canal morphology was not altered by the previous treatment. The non-surgical retreatment resulted into complete healing in 81.4% however, altered root canal morphology may not always be discernable on radiographs.

The success rate of non-surgical retreatment varies from 40% to 85% for cases with apical periodontitis (14, 15). Among others the percentage of each problem which caused the post-treatment disease accounted for the large variation. Theoretically, when a sample contains many cases with poor root canal therapies without altered root canal morphology (problem 1), the success rate of non-surgical retreatment may be high; when a sample contains many cases with problems 2–6, the success rate of non-surgical retreatment is expected to be low.

## Successful outcomes with surgical endodontics

When a decision is made to do surgery, one option is to perform orthograde root canal retreatment and apical surgery simultaneously (49). In a meta-analysis based on 9247 cases (14), weighted success rates for surgical and non-surgical treatments of endodontic failures were calculated. The success rate for apical surgery with simultaneous orthograde root canal treatment was 81%, noticeably higher than that for non-surgical retreatment or apical surgery without simultaneous orthograde root canal treatment. With this technique, the infected apical portion and any extraradicular infection are surgically removed. Because orthograde retreatment is performed simultaneously with the apical surgery, the coronal and middle portions of the root canal system are cleaned thoroughly (19, 51).

The root filling can be compacted also bi-directionally, both coronally and apically, with the intent on sealing the canal entombing any remaining bacteria. Furthermore, radicular cysts, foreign bodies, and any apically extruded infected dentine debris, which may induce persistent periapical inflammation (28), are surgically removed as well.

Using non-surgical procedures, it is difficult to compact the root filling tightly at the level of the apical foramen and thus entomb all remaining bacteria, while at the same time preventing apical extrusion of filling materials and dentine debris. Therefore, combinations of non-surgical root canal treatment and surgical apical resection has been used for research purposes (18, 34) and in treatments of post-treatment disease (14, 49).

At the time of root-end resection, the apical extent of the canals, exposed isthmuses and accessory canals (52, 53) should be carefully located and prepared with the help of a surgical operating microscope (SOM) and micro-mirror (19). Before filling the apically prepared cavity, it is irrigated ultrasonically to remove bacteria, debris and smear layer (54).

In cases where posts, cores or crowns are present, the access to the root canal may be obstructed. The removal of these restorations may be associated with a risk of tooth fracture. In addition, the fabrication of a new prosthetic restoration is frequently required. Both dentists and patients may prefer a strategy where apical surgery is performed without redoing the root canal treatment. However, voids are usually present in root-filled teeth allowing bacterial movement, either from the coronal to the apical or from the apical to the coronal (55). Because of defect in coronal restorations (20, 21) and persistence of infection in root canal inaccessible areas (18), the whole root canal may be coronally or reversibly re-contaminated during the long period between the root canal treatment (or retreatment) and surgery (56). While the infected apical 3 mm is removed during surgery, the infection remains in the middle and coronal portions. When patients whose lesion had healed clinically following surgery were recalled after 10 years or more, the number of successful cases had declined to 57.7% (57). The long-term failures after apical surgery (57, 58) indicate that the 3 mm retrograde filling did not confine all bacteria during the long period (59) and that endodontic surgery is not a long-term solution for inadequate orthograde root canal treatment. In cases where a simultaneous orthograde root canal treatment is not performed, it is suggested to perform a retrograde root canal preparation as far as possible in a direction toward coronal (19, 51, 60). In the study by Reit & Hirsh (51), this technique is named as retrograde root canal treatment that is performed to the level of the apical end of the post. In the *in vitro* experiment by Wu et al. (60), retrograde preparation and filling were 7 mm deep, significant less leakage was recorded as compared with the traditional root-end fillings. The success rate of current apical surgery was reported to be 97% at 1 year (19). In reality however, the success of apical surgery relies heavily on the quality of the non-surgical root canal treatment (19, 58).

## Timely management of persistent apical periodontitis surgically or non-surgically

It is clinically importance for practitioners to identify the presence of post-treatment apical periodontitis and advise further treatment correctly. If diagnosed too early however, teeth with healing periradicular tissues might receive unnecessary retreatment or surgery; in this case the presence of post-treatment apical periodontitis is overestimated. However, if it is diagnosed very late, many diseased teeth will remain untreated, and the burden of periapical infection cannot be eliminated in a timely manner.

According to the European Society of Endodontology (4), the initial root canal treatment should be followed for up to 4 years. During this period, many treated teeth are categorized as 'healing' (opposed to 'healed'), 'incomplete healing', 'healing tendency', or 'at hope' (61). These teeth are commonly associated with a decrease in size of the periapical radiolucency. On one hand, the periradicular tissues of these teeth are diseased at the moment; on the other hand, some of them may heal completely within a certain time. In this way many teeth with post-treatment disease have to wait for at least 4 years before receiving further treatment. If no signs of healing show after the initial treatment, non-surgical retreatment is performed and the retreatment should be followed for another 4 years. If still there are no signs of healing, apical surgery is indicated. If after 4 years this surgery is judged to leave the periradicular tissues in a diseased state, the patient may have had periapical inflammation/infection for 12 years before the decision to remove the tooth may be made.

This broadly accepted 4-year period of evaluation was originally suggested by Strindberg (62) a half century ago. Little was known regarding the kinetics of healing of chronic apical periodontitis at that time. In the absence of bacteria after tooth removal, complete healing can occur in the maxilla and the mandible of and animal model, the ferret, within one month (63, 64). After surgical endodontics in humans with the use of the SOM (19), 97% of the teeth treated healed completely radiographically within 1 year, with the average time for healing being 7 months. Large lesions of >10 mm diameter healed within 11 months, indicating a time frame required to allow the healing process and bone regeneration in human. Therefore, the persistent of periapical lesions after non-surgical treatment can be interpreted as existence of post-treatment infection. It therefore seems that the strategy of initial treatment, followed by a 4 year wait before retreatment and an additional 4 year wait before considering surgical intervention is not evidence based. The burden of periradicular infection should be minimized or eliminated in a timely manner (1–3).

Ørstavik (61) provided valuable information on the time-course of the healing of chronic apical periodontitis. Ninety-five roots with preoperative apical radiolucency 'completely healed' during a 4-year period following the root canal treatment, of which 81 (85%) 'completely healed' already at 2 years, whereas the other 14 (15%) healed later. The 14 roots that healed at 4 years might not all be available at the 2-year recall. Therefore, more than 85% of the roots that 'completely healed' at 4 years already healed at the 2-year time frame. In other words, the chance of late healing is rather low. This finding is in line with the finding of Byström et al. (65) who also found 85% of the healed cases healed at the end of 2 years. Thus, it seems reasonable to diagnose the presence of persistent apical periodontitis and advise further treatment at the end of 2 years, rather than the end of 4 years, providing a periapical radiolucency of any size is present. In the same study by Ørstavik (61), in 111 roots with pretreatment apical radiolucency the size of periapical radiolucency decreased 4 years following treatment. In 98 roots (88%), the periapical radiolucency already decreased within 1 year; and in the other 13 roots (12%) the radiolucency decreased later. Again, those 13 might not all be available at the 1-year recall. It seems reasonable, therefore, to categorize those teeth with unchanged radiolucent areas after 1 year as post-treatment disease and further treat them at the end of 1 year.

It seems that presence of post-treatment apical periodontitis can be diagnosed within 2 years after the previous treatment. At the end of 1 year, all treated teeth should be evaluated and divided into three categories: (1) without post-treatment disease: no symptoms or radiographic signs; (2) with post-treatment disease: with symptoms or an unchanged or enlarged periapical radiolucency; and (3) at hope (61), without symptoms but a decrease in the size of a radiolucency. Teeth 'at hope' should at the end of 2 years be further categorized into either (1) without post-treatment disease: no symptoms or radiographic signs; or (2) with post-treatment disease: with symptoms or a periapical radiolucency.

## Clinical implications

Based on the above analysis, the following suggestions are made for clinicians. Post-treatment disease should be diagnosed and treated either surgically or non-surgically within 2 years after the previous treatment. Root canal-treated teeth, where the radiolucency does not decrease in size within 1 year, should receive further treatment; treated teeth with periapical radiolucency at the end of a 2-year follow-up period should receive further treatment. At least seven problems may cause the post-treatment disease. When root canal morphology is not altered by the previous treatment, non-surgical retreatment is indicated. However, root fractures, infection remaining in the apical inaccessible areas, extraradicular problems such as extraradicular infection, radicular true cysts, and foreign body reaction, and inadequate treatment with altered root canal morphology can rarely be solved without surgery. The important factors that warrant a successful surgery include good quality non-surgical root canal treatment, deep retrograde preparation of the apical portion of the canal and carefully cleaning and filling the exposed isthmuses and accessory canals. Ideally, an orthograde retreatment and apical surgery are performed simultaneously.

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# Surgical preparation: anesthesia & hemostasis

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The intra-operative control of pain and hemorrhage represents significant factors that are required for modern, effective, and efficient endodontic surgical procedures. This review focuses on these important issues and emphasizes the level of clinical evidence of various studies reporting on interventions to alter pain or hemorrhage. To accomplish this goal, the review will provide an overview of the fundamental properties of local anesthetics and hemostasis and then build upon this foundation to provide evidence-based recommendations for treatment considerations.

## Anesthesia

Local anesthetics are widely used to provide regional analgesia for both surgical and non-surgical procedures. Although endodontic surgical procedures can be performed under general anesthesia and this regimen offers advantages for certain patient populations (such as patients who are very phobic about the treatment or those who have a mental disability), the additional cost, and increased morbidity and mortality rates compared with local anesthesia preclude its widespread use in endodontic surgery (1, 2). Local anesthetics are used to achieve three major goals in endodontic surgical procedures: (1) anesthesia during surgery; (2) hemostasis during surgery; and (3) prolonged post-surgical pain control. This latter property is due to a combined action of the drug on inhibiting peripheral neuronal discharges (min–hour duration), thereby reducing the subsequent development of central sensitization (hour–days duration).

### Mechanism of action of local anesthetics

Most local anesthetics exert their effect by diffusing across the plasma membrane and binding to the inner pore region of sodium channels. This prevents the inflow of sodium ions thus resulting in blockade of neuronal depolarization (3). As a result, the transfer of signals from the peripheral tissues to the central nervous system is blocked.

Local anesthetics differ in terms of their properties such as potency, duration of action, speed of onset, and differential neural block (Table 1). The potency of an anesthetic is inversely related to the concentration of the agent required to inhibit sodium channels (4). Any alterations that increase the lipid solubility of anesthetics such as alkalinization also increase their potency (5–8). The duration of action of an anesthetic also depends on its lipid solubility, protein binding, and rate of systemic absorption. Highly lipophilic agents such as bupivacaine, ropivacaine, and tetracaine have a long duration of action.

Several types of sodium channels have been identified in the last decade (9). An important group is the tetrodotoxin (TTX)-resistant channels. The activity of TTX-resistant channels has shown to be increased by prostaglandin E2 (PGE2), nerve growth factor, serotonin and other mediators (10–12). Because these channels are only 1/4 as sensitive to lidocaine as compared with other sodium channels, their increased activity during inflammation is thought to account, in part, for the failure of local anesthetics in inflamed tissues (Fig. 1) (11, 13). In addition, these data suggest that tissue inflammation may reduce the threshold for activation of these channels, possibly contributing to the peripheral mechanisms for reduced pain threshold

**Table 1. Selected properties of local anesthetics**

| | p$K_a$ | Speed of onset | Duration of action | Protein binding (%) |
|---|---|---|---|---|
| **Amides** | | | | |
| Lidocaine | 7.8 | Fast | 1.5–2.0 h | 64 |
| Mepivacaine | 7.8 | Slow | Up to 3 h | 77 |
| Bupivacaine | 8.1 | Slow | | 95 |
| Ropivacaine | 8.1 | Slow | Up to 6 h | 94 |
| Etidocaine | 7.9 | Fast | | 94 |
| Prilocaine | 7.9 | Fast | 2–3 h | 55 |
| Articaine | 7.8 | Fast | | 95 |
| **Esters** | | | | |
| Cocaine | | Slow | N/A | 98 |
| Procaine | | Slow | | 6 |
| 2-Chloroprocaine | 9.0 | Rapid | 45–65 min | |
| Tetracaine | | Slow | | 76 |
| Benzociane | 3.5 | Slow | N/A | |

Data taken from Clinical pharmacology of local anesthetics by John Tetazalff. Duration of action is based on data when the agent is used for infiltration.
N/A, not applicable.

(allodynia) or increased responsiveness to painful stimuli (hyperalgesia) observed in inflamed tissue such as post-surgical wounds. Based upon the key role of PGE2 in sensitizing this channel, it is possible that the non-steroidal anti-inflammatory drug (NSAID) class of drugs enhances the efficacy of local anesthetics by reducing PGE2-mediated channel phosphorylation (14).

A number of different surgical models have been used to evaluate local anesthetics. These include surgeries of the head and neck such as oral surgery (i.e. exodontia) and periodontal surgery. The oral surgery model utilizes patients undergoing surgical extraction of their impacted third molars and is generally recognized as a major test for evaluating new analgesic drugs. Other models that may be used to evaluate local anesthetics include minor surgical procedures such as bunionectomy, arthroscopic knee surgery, and tonsillectomy. Relatively few studies have evaluated anesthetics in patients undergoing surgical endodontic procedures. This review includes studies evaluating the efficacy of local anesthetics in normal volunteers as well as those conducted in patients undergoing surgery.

## Pain control during surgery

This section provides a review of the clinical trials evaluating the efficacy of various local anesthetics.

*Lidocaine*: Multiple randomized clinical trials have evaluated the efficacy of lidocaine as a local anesthetic (15–21). A randomized clinical trial evaluating the efficacy of 3.6 mL of 2% lidocaine with 1 : 100 000 epinephrine for inferior alveolar nerve block reported that although all of the subjects reported the presence of lip anesthesia, pulpal anesthesia (as determined by a lack of response to the electric pulp tester) was obtained in only 39% of central incisors, 50% of lateral incisors, and 68% of canines (15). While this study was not

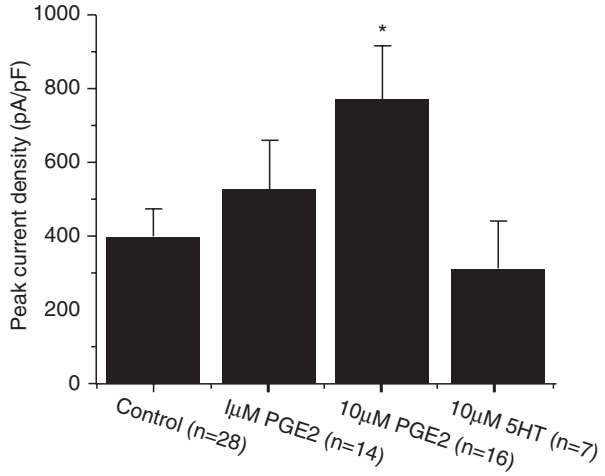


**Fig. 1. Effect of prostaglandin E2 (PGE2) or 5-hydroxytryptamine (5-HT) on peak current density in the tetrodotoxin-resistant sodium channel Nav1.9 in mouse DRG neurons. *$P<0.05$ From: Rush and Waxman (11). PGE2 increases tetrodotoxin-resistant Nav 1.9 sodium current in mouse DRG neurons via G-proteins. *Brain Res*: 2004: 1023: 264–271. Reproduced with permission from Elsevier.**

conducted in subjects undergoing endodontic surgery, it is possible to extrapolate from this and other similar studies as both soft tissue (e.g. lip anesthesia) and nociceptor (e.g. pulp anesthesia) are assessed.

The labial or lingual infiltration injection of 2% lidocaine with 1 : 100 000 epinephrine or 2% lidocaine with 1 : 50 000 epinephrine over the mandibular lateral incisors of healthy volunteers resulted in pulpal anesthesia in 43–50% of the subjects as evaluated by a randomized, double-blinded study (15). In another randomized study, 2% lidocaine with 1 : 100 000 epinephrine was administered by an inferior alveolar nerve block injection followed by a labial infiltration over the apex of the mandibular lateral incisor (16). This resulted in pulpal anesthesia in 62% of the tested lateral incisors. The administration of lidocaine for inferior alveolar nerve block resulted in pulpal anesthesia in 54–84% of the posterior teeth, as reported in a randomized clinical trial (22).

Other clinical trials have examined the effects of lidocaine with different concentrations of epinephrine. A randomized clinical study compared the effects of 3.6 mL of lidocaine with either 1 : 50 000, 1 : 80 000, or 1 : 100 000 for inferior alveolar nerve block (20). No significant differences were detected between the magnitude and duration of pulpal anesthesia obtained by the three different solutions during the 50 min post-injection period. Similar results were reported by a randomized clinical trial comparing the anesthetic efficacy of 1.8 mL of 2% lidocaine with 1 : 100 000 epinephrine, 3.6 mL of 2% lidocaine with 1 : 200 000 epinephrine, and 1.8 mL of 4% lidocaine with 1 : 100 000 epinephrine for inferior alveolar nerve block (23). This finding that the volume of lidocaine used for inferior alveolar nerve block does not result in a greater degree of success in achieving pulpal anesthesia was replicated in yet another clinical trial conducted on normal volunteers (21).

A double-blind study compared the efficacy of 2% lidocaine with 12.5 μg/mL epinephrine versus 2% lidocaine with clonidine15 μg/mL in subjects undergoing surgical removal of impacted or partially impacted lower third molars (24). The duration and intensity of anesthesia did not differ in the two groups of subjects. The onset of anesthesia as evaluated by subjects' report of lip numbness occurred earlier in the clonidine group. However, when the pin prick test was used to evaluate the onset of anesthesia, no significant difference was detected between the clonidine and epinephrine groups. This study also examined the number of patients who took ibuprofen (400 mg) during the 24 h post-operative period. While this information was not collected from a third of the subjects in the clonidine group, the available data indicated that the total number of patients who consumed analgesics in the 24 h post-operative period was significantly lower in the clonidine group as compared with the lidocaine group.

Taken together, data from these clinical trials demonstrate that lidocaine provides predictable success when used for maxillary infiltration, inferior alveolar nerve block, or for intraosseous injections. It is possible that a combination of lidocaine with clonidine results in less post-operative pain and is thus a better alternative than lidocaine with epinephrine for surgical procedures (25). However, this needs to be evaluated in prospective endodontic clinical trials.

*Articaine*: Although articaine has a reputation for providing improved local anesthetic effect, results from multiple clinical trials comparing articaine and lidocaine reveal that they are both equally effective (26–28). For example a recent randomized, double-blinded study conducted using a cross-over design and normal volunteers demonstrated that 4% articaine with 1 : 100 000 epinephrine did not differ from 2% lidocaine with 1 : 100 000 epinephrine when used to obtain inferior alveolar nerve blocks (29).

The efficacy of articaine in anesthetizing maxillary teeth was evaluated in a study in which normal volunteers were randomly assigned to receive 2% lidocaine with 1 : 100 000 epinephrine, 4% articaine with 1 : 200 000 epinephrine, and 4% articaine with 1 : 100 000 epinephrine by maxillary infiltration (30). While this study reported that the use of articaine resulted in a shorter onset and longer duration of action than lidocaine, this finding was not observed in two other similar studies (31, 32).

In conclusion, it is yet to be demonstrated that the use of articaine results in greater magnitude or duration of anesthesia as compared with lidocaine. Well-designed, randomized clinical trials are needed to evaluate and compare the effects of articaine with that of other anesthetics in endodontic surgical trials.

*Mepivacaine*: The efficacy of mepivacaine when administered for obtaining inferior alveolar nerve block was evaluated in a randomized, double-blinded, clinical study in which subjects were administered a masked cartridge of 3% mepivacaine, 4% prilocaine, or 2% lidocaine with 1 : 100 000 epinephrine (33). This study was conducted using the repeated measures design such that each subject received an inferior alveolar injection using masked cartridges of each solution at three successive appointments. No statistically significant differences were detected in the onset, success or failure, and duration of pulpal anesthesia among the three solutions. Thus, mepivacaine is a suitable anesthetic and is comparable to lidocaine.

*Bupivacaine*: The efficacy of bupivacaine when administered for inferior alveolar nerve block was evaluated in a randomized, double-blind study conducted using a cross-over design (22). The administration of lidocaine resulted in a faster onset of lip numbness while administration of bupivacaine resulted in a longer duration of lip numbness. The authors concluded that lidocaine was more effective than bupivacaine as determined by comparing the magnitude of pulpal anesthesia assessed with an electric pulp tester. While bupivacaine may not be as effective as lidocaine in achieving intra-operative anesthesia, it is very effective in reducing post-operative pain. This is discussed in detail later in this review.

*Ropivacaine*: This is the S-enantiomer of bupivacaine (34) and its efficacy was reported to be similar to that of bupivacaine in a double-blind, randomized study in normal volunteers (35). This was a double-blind repeated measures design where subjects received three maxillary anterior infiltrations at three separate appointments, consisting of 0.5% ropivacaine plain, 0.5% ropivacaine with 1 : 200 000 epinephrine, and 0.5% bupivacaine with 1 : 200 000 epinephrine. This study failed to detect any significant differences between the three solutions regarding anesthetic success and post-injection pain (Fig. 2). Administration of plain ropiva-

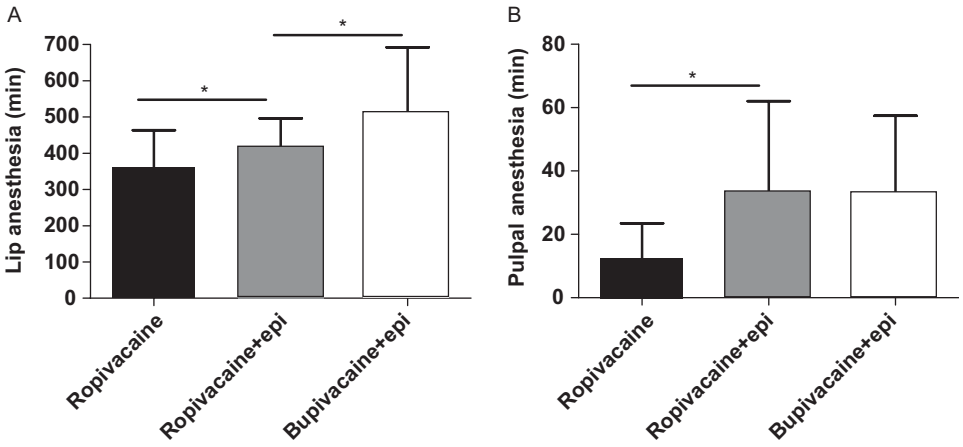


**Fig. 2. Duration of lip and pulpal anesthesia following administration of 0.5% ropivacaine plain, 0.5% ropivacaine+1 : 200 000 epinephrine, or 0.5% bupivacaine with 1 : 200 000 epinephrine. (A) Significant differences were detected between the duration of pulpal anesthesia following administration 0.5% ropivacaine plain and 0.5% ropivacaine+1 : 200 000 epinephrine and between 0.5% ropivacaine+1 : 200 000 and 0.5% bupivacaine with 1 : 200 000 epinephrine. (*$P<0.05$). (B) Significant differences were detected between 0.5% ropivacaine plain and 0.5% ropivacaine+1 : 200 000 epinephrine for pulpal anesthesia (*$P<0.05$). From: Kennedy M et al. (35). Anesthetic efficacy of ropivaccine in maxillary anterior infiltration.** *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*. **2001: 91: 406–412. Reproduced with permission from Elsevier.**

caine resulted in a shorter duration of pulpal anesthesia than the other treatments. No differences were detected between the duration of pulpal anesthesia with ropivacaine with epinephrine, and bupivacaine with epinephrine. However, the duration of lip anesthesia was significantly shorter following administration of 0.5% ropivacaine with 1 : 200 000 epinephrine, as compared with that of 0.5% bupivacaine with 1 : 200 000 epinephrine. Other clinical trials using much smaller sample sizes have also evaluated the effects of ropivacaine (36, 37). One of these studies failed to detect significant differences between ropivacaine and bupivacaine regarding the onset and duration of anesthesia, blood loss or post-operative pain experienced (37). Ropivacaine has the added benefit of having a lower potential for cardiovascular toxic effects (38, 39). The cardiotoxicity potency ratios for levobupivacaine, racemic bupivacaine, and ropivacaine, based on lethal dose is: 2.1 : 1.2 : 1, based on an animal study (39). Thus, ropivacaine has the advantage of being the least cardiotoxic among the currently available long-acting anesthetics.

*Levobupivacaine*: Like ropivacine, this is another S( – ) enantiomer of bupivacaine. The difference between the two is the length of the N-substituent, which is a butyl group for levobupivacaine and a propyl group for ropivacaine (40). Using the oral surgery model, a randomized, double-blind, clinical trial evaluating bupivacaine and levobupivacaine demonstrated that the two agents did not differ regarding the onset and duration of action and post-operative pain experienced (41). A randomized, double-blind, placebo-controlled clinical trial of subjects undergoing extraction of their impacted third molars demonstrated that administration of 0.75% levobupivacaine prior to surgery resulted in lower pain ratings and a longer time to request rescue medication than the administration of 2% lidocaine with 1 : 80 000 epinephrine (42). Another randomized double-blind study demonstrated that pre-incisional infiltration with levobupivacaine results in less post-operative pain as compared with ropivacaine (43). Thus, levobupivacaine is suitable for the control of post-surgical pain.

Multiple studies have evaluated the effects of warming the anesthetic solution on reducing the pain of injection. These randomized clinical trials were evaluated in normal volunteers, or patients undergoing dental procedures or minor surgical procedure such as eyelid surgery. While some of these studies have reported that warming the anesthetic to body temperature reduces injection pain as compared with anesthetic administered at room temperature (44–50), others have failed to detect any effect on injection pain (49, 51). *In vitro* studies have demonstrated that cooling lidocaine increases the duration of its effect, but this is yet to be evaluated clinically (8).

Buffering lidocaine with sodium bicarbonate is also reputed to reduce the pain experienced during injection. The results of many (52–54), but not all (55, 56), of these randomized clinical trials have reported that buffering of anesthetic solution results in significant reduction in pain during injection.

Hyaluronidase has been used as an adjunct to aid the onset of local anesthesia. It is an enzyme that cleaves hyaluronic acid, and thus is thought to facilitate the diffusion of the local anesthetic through the extracellular matrix. A randomized, double-blind study was conducted to determine the anesthetic efficacy of a buffered lidocaine with epinephrine solution compared with a combination of buffered lidocaine with epinephrine plus hyaluronidase solution in inferior alveolar nerve blocks (57). No differences were noted in the anesthetic effect of both the solutions. However, the combination lidocaine/hyaluronidase solution resulted in a significant increase in post-operative pain and trismus. Thus, it appears that the use of hyaluronidase should be avoided.

## Pain control in the postoperative period

Although local anesthetics are primarily used to reduce pain during surgery, they also play a role in post-operative pain control. This is achieved by two mechanisms. First, local anesthetics provide immediate (min–hrs) pain control via blockade of discharges from peripheral nerves. Second, the prolonged blockade of peripheral input acts to attenuate the component of post-operative pain that is due to central sensitization. Central sensitization refers to the amplification in responsiveness that occurs in the central nervous system in response to prolonged nociceptor stimulation (58, 59). Central sensitization is thought to mediate, at least in part, the central component of hyperalgesia and allodynia and is therefore an important mechanism for post-operative inflammatory pain conditions. The prolonged exposure to input from nociceptors (especially the unmyelinated C fiber nociceptors) results in allodynia and hyperalgesia. A key feature of central

sensitization is that it is due to a prolonged discharge of peripheral nociceptive neurons, in particular, the unmeylinated C fibers (60, 61). This property has an important clinical implication because it suggests that long-acting local anesthetics might produce profound post-operative analgesia even days after a single injection of the drug. The results from double-blind randomized clinical trials in post-surgical dental pain patients provide experimental support for this hypothesis. A randomized clinical trial conducted by Gordon et al. (62) elegantly demonstrated that administration of 0.5% bupivicaine immediately after extraction of impacted third molars resulted in decreased pain at later time periods (Fig. 3). In a subsequent study, minimizing the peripheral nociceptive barrage during the immediate post-operative period resulted in significantly less post-operative pain as compared with blocking the barrage during surgery. Thus, the prolonged nociceptor input from the first few hours *after* surgery appears to be a clinically significant factor in developing central sensitization. This finding supports the clinical recommendation that long-acting local anesthetics (e.g. bupivacaine) be injected at the completion of surgical procedures which may significantly reduce post-surgical pain for prolonged periods of time.

Similar results have been reported using other surgical models such as periodontal surgery and tonsillectomy (63–65). Although future randomized clinical trials using endodontic surgical patients are required, it is possible that the use of long-acting anesthetics such as bupivacaine in endodontic surgery will attenuate the development of central sensitization, resulting in decreased pain following endodontic surgical procedures.

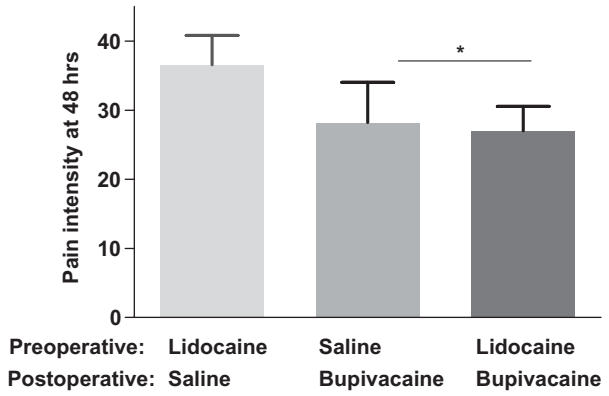


**Fig. 3. Pain intensity reported on a 100 mm visual analog scale 48 h after extraction of impacted third molars. Subjects in this study received either 2% lidocaine pre-operatively, 0.5% bupivacaine post-operatively, both, or placebo *$P<0.05$. Data from: Gordon SM et al. (62). Attenuation of pain in a randomized trial by supression of peripheral nociceptive activity in the immediate postoperative period. *Anest. Analg* 2002: 95(5):1351–1357. Reproduced with permission from Lippincott Williams & Wilkins.**

An important question to be addressed here is whether the administration of the anesthetic before or after surgery affects the attenuation of post-operative pain (66). A non-randomized clinical trial evaluated the effect of administration of 0.5% plain bupivacaine before and after extraction of impacted third molars. Subjects in this study had all their impacted third molars extracted at a single appointment under general anesthesia. The impacted third molars were extracted on one side 10 min after administration of bupivacaine. On the contralateral side, bupivacaine was administered after the molars were extracted. Pain intensity ratings from both sides were collected for up to 6 days after surgery. No significant differences were detected between the two sides. This study provides additional support to the conclusion that the nociceptive barrage induced by surgical manipulation (e.g. incision, tissue reflection, osteotomy, etc) is not as important as the post-operative barrage induced by tissue inflammation for the development of central sensitization.

A recent meta-analysis has evaluated whether NSAIDs, local anesthetics, systemic opioids, *N*-methyl D-aspartate (NMDA) antagonists, or epidural analgesics provide significant pre-emptive analgesia in post-surgical pain patients. This meta-analysis consisted of 66 randomized-controlled trials totalling 3261 patients and compared the same analgesic administered either in the pre-operative or post-operative periods (67). All the studies in this meta-analysis were randomized and double-blinded, and were published between January 1987 and October 2003. The exclusion criteria were studies in which pre-operative administration of the analgesic was compared with placebo or no treatment, comparison of different pre-operative and post-operative drug treatments, and comparison of pre-operative administration with a combination of pre-operative and post-operative administration. The primary outcome measures analyzed were pain intensity scores, consumption of supplemental analgesics, and time to first rescue analgesic. The mean difference in the outcome variables between the pre-operative and post-operative groups for each study was converted into an 'effect size'

and then an overall mean across all studies was calculated. An effect size of 0 indicates no difference between pre-operative and post-operative drug administration, a positive value indicates that pre-emptive analgesia is effective and a negative effect size indicates that pre-emptive analgesia is ineffective. The results of this meta-analysis indicate that pre-operative administration of NSAIDs improved time to first rescue analgesic request (effect size $+0.68$, $P<10^{-8}$) and reduced analgesic consumption (effect size $+0.48$, $P=0.00000003$) (Fig. 4). However the post-operative pain scores were not significantly reduced (effect size $+0.14$, $P=0.09$). The latter is likely because of the fact that the reduction in pain intensity is so great that differences between pre-operative and post-operative administration of NSAIDs could not be elucidated (the so-called 'floor effect'). When all three outcome measures were combined, the effect size for NSAIDs was $+0.39$ and the combined $P$-value was $<10^{-8}$, which is a highly significant difference favoring pre-emptive administration. Similarly, pre-operative local anesthetics had significant beneficial effects for reducing the need for supplemental analgesics and increased the time before the first analgesic was requested. In contrast, NMDA antagonists and systemic opioids were less robust in their effects.

A series of three randomized, cross-over studies using the oral surgery model evaluated the effect of pre-

| | Number of studies | Total number of subjects | P value |
|---|---|---|---|
| **Pain Scores** | | | |
| NSAIDs | 12 | 617 | .09 |
| Local anesthetics | 11 | 535 | .26 |
| Systemic Opioids | 7 | 324 | .04 |
| NMDA antagonists | 7 | 418 | .97 |
| Epidural analgesia | 13 | 653 | .00 |
| **Supplemental analgesics** | | | |
| NSAIDs | 12 | 582 | .00 |
| Local anesthetics | 8 | 360 | .00 |
| Systemic Opioids | 4 | 194 | .12 |
| NMDA antagonists | 7 | 418 | .09 |
| Epidural analgesia | 13 | 640 | .00 |
| **Time to first analgesic** | | | |
| NSAIDs | 6 | 307 | .00 |
| Local anesthetics | 7 | 306 | .00 |
| Systemic Opioids | 2 | 74 | .16 |
| NMDA antagonists | 4 | 258 | .34 |
| Epidural analgesia | 9 | 368 | .00 |

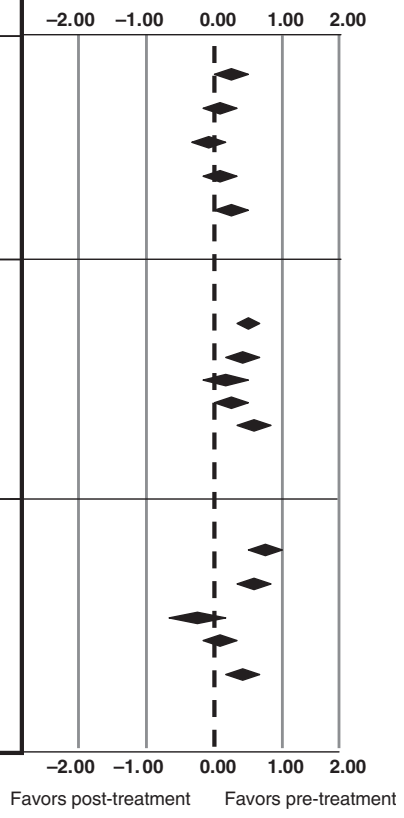


**Fig. 4. Results from a meta-analysis comparing the effects of various drugs for preemptive analgesia. Studies included in this analysis randomly administered the same drugs either pre-operatively or post-operatively and measured pain (visual analog scale), the need for supplemental ('rescue') analgesics, and the time before the first post-operative analgesic was requested. The results are displayed using a Forrest plot, also known as an odds ratio plot, which graphs the mean odds ratio (with 95% confidence intervals) calculated from two to 13 clinical studies. The table displays the number of studies, sample size, and *P* value for each outcome measure. The diamond in the plot displays the effect size obtained by pooling all the trials for each analgesic regimen. An effect size of 0 indicates no effect, a positive effect size indicates that pre-emptive analgesia is effective, and a negative effect size indicates that pre-emptive analgesia is ineffective. Data from: Ong CK et al. (67). The efficacy of preemptive analgesia for acute postoperative pain management: a meta-analysis. *Anesth Analg* 2005: 100 (3): 757–773. Reproduced with permission from Lippincott Williams & Wilkins.**

operative and post-operative administration of flurbiprofen as compared with acetaminophen in combination with oxycodone (68). The local anesthetics used in this study were either etidocaine or lidocaine. Factorial comparison of their data demonstrated that flurbiprofen suppresses post-operative pain independent of the local anesthetic used. Based on these as well other clinical trials, the pre-emptive use of NSAIDs is an effective method of reducing post-surgical pain.

Some studies have evaluated the use of topical anesthetics in the management of post-operative pain. A placebo-controlled, randomized, double-blind study on children who underwent tooth extractions demonstrated that the application of swabs soaked with 0.25% bupivacaine with 1 : 200 000 epinephrine after surgery for 5–10 min resulted in less post-operative pain than placebo (69).

## Adverse effects

Local anesthetics have been associated with both regional and systemic side-effects. Regional complications include paresthesia, hematoma formation and bleeding. Local nerve damage may be due to improper needle placement. A 21-year retrospective study on the incidence of paresthesia following administration of local anesthetics revealed a greater incidence of paresthesia associated with the administration of both articaine and prilocaine than predicted based upon usage (70). This study only includes non-surgical cases and thus ruled out surgical trauma as the causative factor for paresthesia. The study also evaluated the type of needles used, and the available data do not support any relationship between needle type and incidence of paresthesia.

Systemic effects of local anesthetics involve both the cardiovascular system and the central nervous system. A retrospective study documenting the incidence of morbidity and mortality in the practices of members of the Massachusetts Society of Oral and Maxillofacial Surgeons reported that in patients who were given local anesthetics alone the most common adverse event was syncope which occurred in one out of every 160 patients (71). Other adverse events included acute angina pectoris (1/29 775 patients), hypotension (1/35 729 patients), hypertension (1/44 662 patients), dysrhythmia (1/89 324 patients), and convulsions (1/10 509 patients).

A number of clinical trials have examined the hemodynamic effects of local anesthetics. The hemodynamic effects induced by maxillary infiltration of 3.6 mL of lidocaine with 1 : 80 000 epinephrine with those induced by ergometer exercise were compared in a clinical trial (72). The workload of the ergometer stress test was comparable to that of walking for 4.8 miles or doing light yard work. Echocardiography was performed to assess the hemodynamic changes induced. This study demonstrated that the hemodynamic effects induced by administration of the local anesthetic were less than those induced by the ergometer stress test.

Using a prospective randomized study with a crossover design, Wood et al. (73) examined the venous blood levels of lidocaine and change in heart rate after intraosseous and infiltration injections of 1.8 mL of 2% lidocaine with 1 : 100 000 epinephrine. The results of this study demonstrated that intraosseous administration of 2% lidocaine with 1 : 100 000 epinephrine (adrenalin) resulted in a transient tachycardia ($\sim$ 9 beats per minute, b.p.m.) that was greater than peak levels observed after maxillary infiltration even though the plasma lidocaine levels were similar following both routes of administration. Similar results were reported by a study examining changes in blood pressure in healthy volunteers who were administered a mandibular intraosseous injection of 2% lidocaine with 1 : 100 000 epinephrine (74). The administration of the anesthetic solution caused a transient elevation in heart rate but no change in systolic and diastolic blood pressure.

A randomized, double-blinded clinical trial compared the effect of intraosseous infiltration of 2% lidocaine with 1 : 100 000 epinephrine with those of 3% mepivacaine (75). No differences in blood pressure were reported between subjects receiving the two anesthetics. Intraosseous administration of mepivacaine had no effect on heart rate while administration of lidocaine with epinephrine resulted in an increase of heart rate in 67% of the subjects. A double-blind study examining the effect of 4% articaine with 1 : 200 000 epinephrine, 3% plain mepivacaine, and 3% prilocaine with felypressin 1 : 1 850 000 demonstrated that no significant hemodynamic changes occurred with respect to the basal values when administered in healthy patients subjected to surgical removal of a lower third molar (76). Multiple other studies of different local anesthetic agents in normal volunteers have reported similar results (77–79).

A double-blinded clinical study compared the effects of 2% lidocaine with clonidine or epinephrine in

subjects undergoing extraction of their mandibular third molars (24). No significant differences were detected in the systolic blood pressure, diastolic blood pressure and mean arterial pressure between groups. Heart rate was significantly increased in the epinephrine group 5 min after administration of anesthesia and during surgery compared with the clonidine group and with basal values. While the studies mentioned above were conducted in normal volunteers, others have examined the effect of local anesthetics with epinephrine in patients with significant cardiac problems. A double-blinded study examined the effect of local anesthetics in cardiac transplant patients with those in subjects without any cardiovascular disorders (80). The cardiac patients, who were more than 3 months post-transplant, received 2% lidocaine with 1 : 80 000 epinephrine or 3% prilocaine with 0.03 IU/mL felypressin as maxillary buccal and palatal infiltration anesthesia. The healthy volunteers were administered 2% lidocaine with 1 : 80 000 epinephrine. The change in systolic and diastolic blood pressure following administration of anesthetic as compared with their baseline values did not differ among the three groups. Tachycardia was noted in the cardiac transplant patients who received the epinephrine containing anesthetic. The mean increase in heart rate as compared with baseline was $23 \pm 7.1$ b.p.m. This sustained increase in heart rate was not observed in the other two experimental groups. The mean increase in transplant patients who received prilocaine was $-0.2 \pm 6.8$ b.p.m. and $4.8 \pm 7.9$ b.p.m. in the healthy patients who received epinephrine containing anesthetic.

From the above studies, it can be concluded that local anesthetics can be safely administered to subjects with certain cardiovascular problems and that it may be prudent to restrict the amount of epinephrine administered to about 4.4 mL of a 1 : 80 000 solution (80).

Methemoglobinemia is a rare complication of prilocaine and articaine (81–84). Risk factors include anemia and cardiopulmonary disorder. The early symptoms of methemoglobinemia are headache, lethargy, tachycardia, weakness, cyanosis, and dizziness. As the condition worsens, dyspnea, acidosis, cardiac dysrhythmias, heart failure, seizures, and coma may occur (85). Methemoglobinemia is not detected by pulse oximeters and may give a misleading impression of patient oxygenation (86). It is spontaneously reversible and may be treated by intravenous administration of methylene blue.

The toxic effects of local anesthetic on the central nervous system (CNS) include excitation followed by depression. CNS toxicity may first cause some symptoms such as lightheadedness, dizziness, and visual and auditory disturbances including tinnitus (87). These are followed by signs of CNS excitation such as muscular tremors of the face and extremities and generalized tonic–clonic convulsions. These symptoms may then be followed by CNS depression resulting in drowsiness, unconsciousness, coma, respiratory depression, and arrest. In certain cases, the CNS depression may occur very rapidly without the preceding excitation. These include cases where the drug administration has been very rapid, such as in intravascular injections, or in patients who are under the effect of CNS depressants.

*Prevention and management of systemic toxicity*: The systemic toxicity of local anesthetics can be prevented by avoiding the use of excessive doses and by using aspiration to detect the intravascular location of the needle. The management of toxic effect includes the use of oxygen when the early signs of toxicity are first detected. Anticonvulsants (such as intravenous benzodiazepines or barbiturates) must be administered if the patient has a systemic seizure. Cardiovascular toxicity, especially owing to bupivacaine, can be resistant to therapy and may require the use of large doses of ionotropic drugs.

## Future directions

Recent advances include the use of peripherally acting opioid antagonists. A number of animal studies have demonstrated that the local administration of opioids has an analgesic effect when administered into inflamed tissues. These effects are not seen when the opioids are applied to normal tissues and instead, the rapid development of competence of the peripheral opioid receptors is triggered by the release of inflammatory mediators such as bradykinin (88). The presence of peripheral opiate analgesia in humans was demonstrated in a series of double-blind, placebo-controlled, clinical trials (89). These trials were conducted using the endodontic model of hyperalgesia and the oral surgery model in order to evaluate both chronic and acute inflammation. In the first part of the study equal volumes of sterile saline placebo, local anesthetic (2% mepivacaine with 1 : 20 000 levonordefrin), or morphine sulfate (0.4, 1.2, or 3.6 mg) were injected into

the intraligamentary space in subjects with a diagnosis of pulpal necrosis and acute exacerbation of a chronic apical periodontitis. Using both a 100 mm visual analog scale and a 4-point category scale, a time-related analgesic effect of morphine was detected, which peaked at the 15–20 min time interval. When the effects of systemically (subcutaneous administration into the volar forearm) and locally (intraligamentary) administered morphine sulfate (1.2 mg) were compared using the same model, it was seen that local administration of morphine had a significant analgesic effect, while the effect of systemically administered morphine did not differ from placebo. A randomized clinical trial found that the administration of articaine plus 1 mg morphine into inflamed resulted in significant and prolonged analgesia in the post-operative period following tooth extraction as compared with injection of the same solution into normal tissue (90).

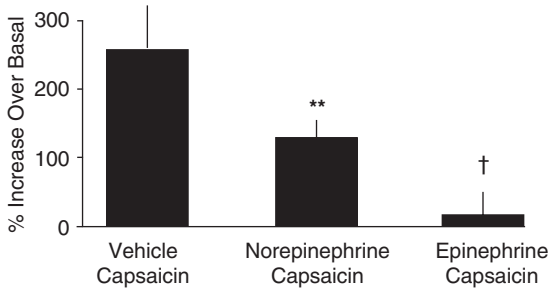


**Fig. 5. Effect of pre-treatment with vehicle, norepinephrine (10 nM), or epinephrine (10 nM) capsaicin-evoked release of immunoreactive calcitonin gene-related peptide from *in vitro*-superfused dental pulp. **$P<0.01$ vs. vehicle. †$P<0.01$ vs. vehicle and norepinephrine. Reproduced with permission from Bowles et al. (94).**

Another randomized clinical trial compared the effects of subcutaneous administration of tramadol (2 mg/kg) with that of 1 mg/kg lidocaine (1 mg/kg) in subjects undergoing minor surgery (lipoma excision and scar revision) (91). In subjects who received tramadol, the time for first analgesic use was longer and the total number of analgesics consumed in the 24 h post-operative period was lower than in those who received lidocaine.

Yet another effective strategy to reduce peri- and post-operative pain is by using adrenergics. Small-diameter sensory neurons are known to express both α- and β-adrenergic receptors (92, 93). A recent study on bovine dental pulp demonstrated that adrenergic agonists such as epinephrine and clonidine inhibit capsaicin-evoked neuropeptide release (Fig. 5) (94). Capsaicin is known to selectively activate a ligand-gated ion channel known as TRPV1, which is expressed on a major class of nociceptors. The use of adrenergics in high concentrations for better hemostasis during surgery offers an additional advantage of preventing nociceptor activation. Thus, adrenergics may be used in the future as peripheral analgesics, possibly combined with local anesthetics.

Anecdotal evidence suggests that red heads require more local anesthetic than others to achieve profound analgesia. A recent study by Liem et al. (95) compared the effect of 1% lidocaine in red-haired and dark-haired women. Subjects in this study were exposed to noxious electrical stimulation after subcutaneous injections of 1% lidocaine. The results indicated that red-haired women were more resistant to the anesthetic effects of subcutaneous lidocaine than dark-haired women,

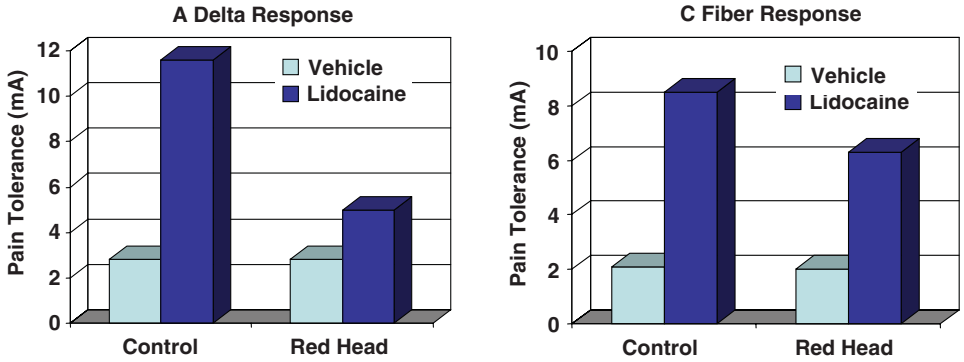


**Fig. 6. Pain tolerance threshold in women with red or dark hair ($n = 60$). Electrical stimuli were applied on the forearms of subjects 5 min after administration of 2 mL of 1% lidocaine. Controls had uninjected areas on the same forearms. Subcutaneous lidocaine was less effective in women with red hair as compared with women with dark hair, $P = 0.005$. Data from: Liem EB et al. (95). Increased sensitivity to thermal pain and reduced subcutaneous lidocaine efficacy in redheads. *Anesthesiology* 2005: 102(3): 509–514. Reproduced with permission from Lippincott Williamson & Wilkins.**

particularly when evaluating stimuli sufficient to activate A-delta nociceptors (Fig. 6). More studies are required to replicate these findings in endodontic pain patients and to elucidate whether red-heads simply require higher dosages of lidocaine to obtain adequate anesthesia.

## Mechanisms of hemostasis

Well-controlled hemostasis is a critical factor for surgical procedures and the post-operative course of healing (96, 97). In one study of 60 patients undergoing endodontic surgery, the amount of intra-operative hemorrhage ranged from 1 to 48 mL, with the duration of surgery being a major predictor of bleeding (98). Although this comparatively small magnitude of bleeding implies that endodontic surgical procedures are generally well tolerated in healthy patients, case reports indicate that patients with coagulopathies may have substantial blood loss during comparatively atraumatic endodontic procedures (99). In addition to the potential medical risk, the delivery of modern endodontic surgical procedures requires superb visualization of the surgical field. Thus, knowledge of the mechanisms and management of hemostasis is an essential skill for endodontic surgery.

A simplified overview of mechanisms of hemostasis (Fig. 7) provides a foundation for assessing the pre-operative patient and managing hemostasis in the intra- and post-operative periods. The induction of vascular injury triggers four major phases of hemostasis (100–103).

The first phase of hemostasis involves vasoconstriction at the site of injury and is elicited by the release of serotonin and thromboxane A2 (TXA2). The immediate vasoconstrictive period reduces blood flow through the injured tissue and provides some initial protection to loss of circulating volume in the vascular compartment. The vasoconstrictive phase may last up to several hours after trauma.

The second component of hemostasis involves platelet adhesion and degranulation. Activated thrombin promotes the adherence of platelets to exposed collagen fibers, leading to the development of a soft plug of platelets. The 'clumping' of platelets is promoted by activated fibrinogen. Two classes of hemostatic agents, collagen and adrenergic agonists (e.g. epinephrine), promote activation of platelets and this contributes to their mechanism of action (103).

The third phase of hemostasis involves clot formation that occurs due to the release of factors from platelets and injured tissue that trigger the clotting cascade and the development of a fibrin/platelet plug at the site of injury (100–103). Activated platelets release ADP, TXA2, serotonin, Factor V, and other substances such as phospholipids and lipoproteins. The formation of fibrin polymers entraps platelets and erythrocytes, leading to a stable plug formation. Although it should be recognized that both the intrinsic and extrinsic pathways mediate clot formation (Fig. 8), more recent studies emphasize the rapid temporal integration of both pathways in clinical settings (100, 102, 103), rather than a simplistic division into either intrinsic or

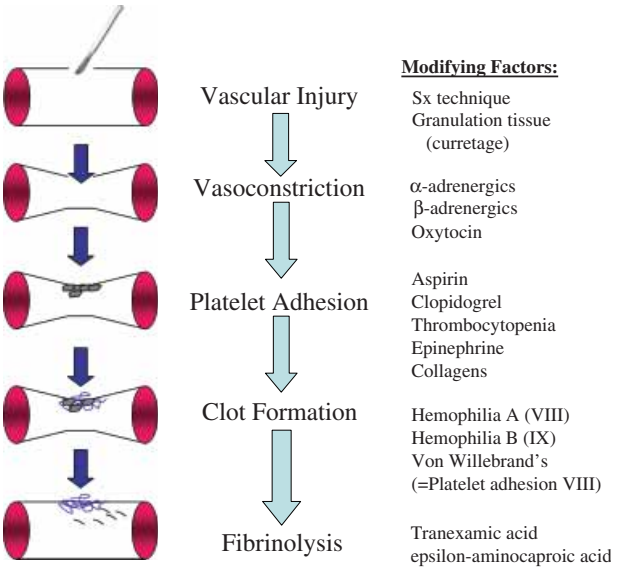


**Fig. 7. Schematic illustration of the hemostatic pathways illustrating the impact of selected drugs or disorders on hemostasis.**

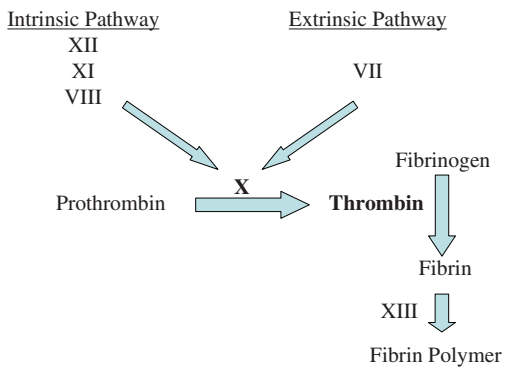


**Fig. 8. Intrinsic and extrinsic pathways of the clotting cascade.**

extrinsic pathways of clotting. It should be readily appreciated that enzymatic activation of multiple levels of downstream enzymes is a highly efficient mechanism for amplification. In general, the intrinsic pathway occurs when blood contacts the negative charges of proteins embedded in the basement membrane of connective tissues or RNA released from injured cells (100). The intrinsic pathway involves factors XII (Hageman factor), XI, VIII, prekallikrein, and high-molecular-weight kininogen; this pathway is so named because all of these factors are 'intrinsic' to the vascular compartment. In contrast, the extrinsic pathway, occurs extremely rapidly, augments the activity of the intrinsic pathway and is activated by tissue injury. The extrinsic pathway involves factor III (tissue factor) and factor VII; this pathway is 'extrinsic' as it involves a tissue factor (factor III) found outside of the vascular compartment. From a surgical perspective, the extrinsic pathway is critically important, and indeed, the tissue factor-induced initiation of this pathway is thought to contribute to most clinical situations involving the coagulation pathway (103). The two pathways merge with the activation of factor X leading to the common coagulation pathway (100). The mechanical product of this cascade, fibrin, forms the structural elements of the clot. However, it should be appreciated that the enzymes activated in this pathway contribute to other functions (e.g. chemotaxis, etc), resulting in a coordinated response to tissue injury.

Finally, the fibrinolytic pathway mediates the dissolution of the fibrin/platelet plug in the post-operative period (Fig. 7). The enzyme plasmin is responsible for fibrinolysis and two forms of the inactive precursor circulate in blood. Plasmin rapidly cuts fibrin at a minimum of 50 amino-acid sites, leading to efficient depolymerization (104). Dental surgical procedures impact fibrinolysis activity in saliva, and in turn, oral hemostasis is altered by acquired (e.g. tranexamic acid, epsilon-aminocaproic acid) or developmental abnormalities of the fibrinolytic system (105).

## Pre-operative assessment

Although a certain level of intra-operative bleeding is expected with surgical trauma, the clinician should suspect an acquired or inherited bleeding disorder when bleeding is evident from many sites even after initial good hemostasis. Although this may be easily correctable in certain cases (i.e. curettage of granulation tissue), it emphasizes the need for appropriate pre-operative assessment. In contrast, consistent bleeding from a single site is usually associated with surgical trauma to a larger vessel or a highly vascular structure (e.g. sinus) (100). Given the complexity of the clotting cascade, it is not surprising that many diseases and drugs can alter hemostasis (Table 2). Accordingly, the pre-operative evaluation of the patient's medical history represents a critical time for assessing the presence and magnitude of a risk for altered hemostasis and for planning modifications to the surgical plan (106, 107).

Several diseases are well recognized to interfere with the clotting cascade, leading to poor hemostasis. von Willebrand's disease is the most common heritable bleeding disorder and the three major subtypes of this disease are due to a deficiency of Factor VIII levels or activity. A case series of 63 patients with von Willebrand's disease undergoing dental extractions concluded that local treatment with tranexamic acid and fibrin glue with desmopressin (0.3 μg/kg) minimizes bleeding problems in the majority of cases (108). Other case series provide similar conclusions (109). In one series of three female patients with von Willebrand's disease, the pre-operative treatment with estrogen (as either oral contraceptives or HRT) was reported to reduce surgical bleeding as compared with their prior experiences (110). In one case series of 16 patients with Hemophilia A or B undergoing extractions, the combined use of local treatments (e.g. fibrin glue, gelatin packing, and post-operative application of tranexamic acid) and systemic treatments (e.g. dihydro-D-arginine vasopressin) produced good hemostasis in the majority of cases. Hemophilia B (Factor IX deficiency) comprises about 15% of all hemophilia cases and case reports describe the successful management of nine hemophilia B patients for dental surgery by combined administration of antifibrinolytc agents (e.g. ε-aminocaproic acid or tranexamic acid) with monoclonal antibody purified factor IX (MAb factor IX) (111). Recombinant-activated factor VII (rFVIIa, NovoSeven™; Novo Nordisk, Princeton, NJ, USA) has been used to promote hemostasis in patients with hemophilia A or B, liver disease, thrombocytopenia, or thrombocytopathia and has been characterized as a 'universal' hemostatic agent because of its ability to activate thrombin directly (112–115). Moderate-to-severe factor XI deficiency because of several genetic

**Table 2. Common disorders of hemostasis**

| Class | Example |
|---|---|
| Hypocoagulability | |
| Impaired platelet function | Drugs (e.g., aspirin) |
| | Radiation |
| | Splenomegaly |
| | Autoimmune |
| Impaired clotting activity | Impaired protein synthesis (e.g., vitamin K) |
| | Classic hemophilia (Factor VIII; ~ 80% of all hemophilias) |
| | Hemophilia B (Factor IX; ~ 15% of all hemophilias) |
| | Hemophilia C (Factor XI; ~ 5% of all hemophilias) |
| Hypercoagulability | |
| Increased platelet function | Atherosclerosis |
| | Diabetes |
| | Smoking |
| Increased clotting activity | Pregnancy |
| | Oral contraceptives |
| | DIC (disseminated intravascular coagulation) |

Table adapted from: http://www.pathoplus.com/blood.htm.

polymorphisms has been reported in Ashkenazi Jews and is associated with risks in hemostasis during dental surgical procedures (116, 117). Platelet disorders can be categorized by a lack of sufficient concentration of platelets (thrombocytopenia) or lack of adequate function (thrombasthenia), and case reports are available describing dental surgical procedures for both conditions (118, 119).

Other diseases or conditions promote the clotting cascade leading to extensive clot formation. Examples include disseminated intravascular coagulation (DIC), antithrombin III deficiency, Protein C deficiency, protein S deficiency, and oral contraceptive use. Type II diabetics have reduced fibrinolytic activity, and these patients may present for treatment with fibrinolytic agents (120).

Many drugs are well recognized to alter hemostasis. For example, patients often take oral anticoagulant therapy for several indications including reduction of risk for stroke or myocardial infarction (121, 122). In one randomized study, patients were administered aspirin (100 mg/day) and either continued aspirin to the day of tooth extractions or stopped taking aspirin 7 days before surgery. Although the continuous aspirin-treated patients had significantly greater values as evaluated by standard laboratory bleeding tests, both groups were in the normal range for bleeding time (1–3 min), and there was no clinical difference in the amount of surgical bleeding (123). The authors concluded that local hemostatic control was sufficient for surgical treatment of patients on low-dose aspirin and that drug cessation was not indicated. However, in one case report of a patient with immunosuppressants secondary to organ transplant, treatment with a low-dose aspirin therapy was associated with substantial intraoral hemorrhage following a dental surgical procedure; a platelet transfusion was required for hemostasis (124). Patients take warfarin as anticoagulant therapy for many indications. A randomized clinical trial on 109 patients (international normalized ratio (INR) $< 4.1$) indicated that cessation of warfarin for 2 days prior to the procedure had no effects on clinically important post-operative bleeding after extractions as compared with patients who continued warfarin therapy (125). A randomized-controlled trial evaluated 31 patients taking coumarin for changes in INR after acetaminophen treatment (1500 or 3000 mg/day $\times$ 14 days); the use of this analgesic did not produce clinically significant changes in INR values (126). Antibiotics have been reported to interfere with vitamin K metabolism (presumably by interference with gastrointestinal bacterial populations) in certain patients (127), and a case report has attributed post-operative bleeding to amoxicillin-induced vitamin K deficiency in a patient treated with oral irrigation with a tranexamic acid (4.8%) mouth rinse (128).

The pre-operative assessment should include questions specifically pertaining to the use of herbal or alternative medications. Systematic reviews of the literature indicate that problems related to hemostasis (e.g. garlic, ginkgo, and ginseng), cardiac rhythmicity

(e.g. ephedra), or drug interactions (e.g. ginseng, kava, St John's wort, and valerian) can occur with many commonly used herbal medicines (129, 130). A case report suggests that chronic abuse of cocaine may be associated with post-extraction hemorrhage (131), possibly due to alterations in adrenergic receptor activity.

Pre-operative assessment should include collection of a thorough medical history and possible consideration of laboratory testing to provide an objective measure of some component of the clotting cascade. The relative value of these tests and recommended clinical management have been discussed in recent reviews (100, 103, 132). The partial thromboplastin time test (PTT) assesses the intrinsic coagulation system and uses a negatively charged surface to activate this pathway. The prothrombin time (PT) evaluates the critical extrinsic coagulation pathway and assesses for deficiencies in fibrinogen and Factors II, V, VII, and X. The INR provides a standardized value for the PT test and is often used to assess the coagulation status of patients with congenital or acquired coagulation disorders. Patients on anticoagulation therapy have been recommended to have INR values of 1.5–2.5 prior to dental surgery as a compromise between minimizing the potential for thrombosis while attempting to attain reasonable hemostasis (133). More recently, several clinical studies, case series, and reviews have recommended maintenance of oral anticoagulation therapy, in an attempt to avoid thrombotic events, and have instead focused on local hemostatic interventions to maintain hemostasis in dental surgical procedures (123, 125, 134–140). For example, in one prospective, randomized-controlled clinical trial, 250 patients on oral anticoagulant therapy were compared with 250 control patients, and the incidence of post-operative bleeding after tooth extraction was compared. The oral anticoagulant group had local hemostatic treatment (e.g. fibrin sponge, silk sutures, and post-operative compression with a gauze saturated with tranexamic acid) and there was no difference in the incidence of post-operative bleeding complications (1.6% vs. 1.2%, respectively) between the two groups (141). An extensive discussion of these risk : benefit issues of this approach is available (100, 142, 143), and medical consultation may be indicated in these situations (144). In addition, the INR does not appear to predict post-operative bleeding. In one case series of 249 patients undergoing 543 extractions, patients with INR values of 1.00–1.99 (5% bleeding), 2.00–2.49 (12.8% bleeding), 2.50–2.99 (15.2% bleeding), 3.00–3.49 (16.6% bleeding), and INR > 3.50 (13% bleeding) all had similar incidences of bleeding (134). The authors concluded that local surgical treatment (gelatin sponge and sutures) without cessation of anticoagulant therapy was sufficient for hemostasis, and that INR levels within these ranges do not appear predictive for post-operative bleeding. Similar results have been reported for 66 patients with abnormal laboratory test values associated with factor XII deficiency, dysfibrinogenemia, the lupus-like anticoagulant, and pseudothrombocytopenia (145); in general, local treatment conditions are sufficient for surgical hemostasis in many cases. Normal platelet counts range from 150 000 to 400 000/μL, and a platelet count of at least 50 000/μL is preferred in many surgical procedures (100, 118). Interestingly, cutaneous bleeding time does not correlate with post-operative bleeding, although the duration of the surgical procedure and the presence of immediate post-operative oral bleeding time after surgery do correlate with post-operative bleeding (146).

One extensive review has recently concluded that one of the best predictors for poor surgical hemostasis is the collection of a thorough medical history that discloses a prior history of bleeding occurrences (100). Specific questions should focus on gathering information about: (1) prior history of bruising, frequency of bruising (e.g. 'Do you easily bruise?), size of bruises, etc; (2) prior history of surgeries (including tooth extractions such as third molars) and any post-operative bleeding; (3) drug use (e.g. aspirin, etc); (4) transfusions; and (5) relevant medical history (e.g. anemia, malignancies, connective tissue diseases, immune status) (147).

## Pharmacological management of hemostasis

The experienced surgeon controls hemostasis using a variety of both pharmacological and non-pharmacological methods. Although these topics are divided in this review for purposes of logical presentation, it should be appreciated that both approaches are generally used simultaneously to achieve the desired control of the surgical field.

Adrenergic agonists ('vasoconstrictors') are widely used to promote surgical hemostasis. Clearly infiltration injection of even one 1.8 mL cartridge of 2%

lidocaine with 1 : 100 000 epinephrine produces about a threefold elevation in blood levels of epinephrine, although there are little to no detectable systemic cardiovascular effects at this dose, and the local hemostasis is of course much greater than that observed with injection of plain lidocaine (148). A randomized, double-blind, controlled clinical trial reported that hemostasis was judged to be significantly better in dental surgeries with 1 : 100 000 epinephrine containing local anesthetics as compared with 1 : 200 000 containing local anesthetics (149). Moreover, the use of lidocaine containing 1 : 50 000 epinephrine produced more than a 50% improvement in hemostasis as compared with 2% lidocaine containing 1 : 100 000 epinephrine in patients undergoing periodontal surgery (150). Thus, the use of a local anesthetic containing 1 : 50 000 epinephrine has been advocated for local infiltration around the surgical field. Clinical trials indicate that injection of local anesthetics containing 1 : 50 000 produces a transient tachycardia that returns to normal within 4 min of injection (151). In addition, it has been suggested that a slow rate of injection (e.g. 1–2 mL/min) provides time for lateral diffusion of the drug across the surgical field, leading to improved constriction of vessels throughout the surgical area.

Epinephrine is also available in a racemic solution for local placement into the surgical crypt. It has been recommended that packing the surgical crypt with several epinephrine-impregnated cotton pellets, applying pressure for 2–3 min, and then removing all except the first pellet will lead to effective hemostasis (152). This process can be repeated if necessary. A recent randomized-controlled clinical trial compared 33 patients undergoing endodontic surgery with local hemostasis consisting of either racemic epinephrine-containing cotton pellets (Racellet™ #3, Pascal Co. Inc., Bellevue, WA, USA) or installation of a ferric sulfate solution (Vicostat™, Ultradent Inc., South Jordan, UT, USA). Adequate hemostasis was judged to occur in 100% (17 of 17) in the epinephrine pellet group and in 94% (15 of 16) of the ferric sulfate group (153). There was no change in systemic blood pressure or pulse with either treatment group. Of course, care must be taken when removing the last cotton pellet to avoid a potential foreign body reaction due to cotton fibers left in the surgical crypt. The use of a resorbable material containing epinephrine has the potential advantage of avoiding this issue. This was addressed in a recent randomized-controlled clinical trial comparing 48 patients undergoing endodontic surgery with local hemostasis consisting of a resorbable collagen sponge (Colla-Cote™, Integra Lifesciences Corp., Plainsboro, NJ, USA) treated with either saline or with epinephrine (10 drops of 2.25% racemic epinephrine from a 0.5 mL vial; Nephron Pharmaceutical Corp, Orlando, FL, USA). The Colla-Cote sponge (1 × 2 cm) was impregnated with saline or epinephrine, packed into the surgical crypt and then additional pads were added, pressure was maintained for 3–4 min, and then all except the first pad was removed. The intra-operative hemostasis was judged to be effective in 17% (1 of 6) of the saline-treated sponges and in 93% (39 of 42) of the epinephrine-treated sponges (154). There were no detectable systemic cardiovascular events as measured by blood pressure or pulse rate.

Tranexamic acid acts to inhibit fibrinolysis and thereby maintains clot integrity. In one randomized study, 49 patients on warfarin were maintained on the anticoagulant therapy and were given oral irrigation with tranexamic acid (10 mL of 4.8% solution as an oral rinse four times per day × 7 days) or an intra-operative fibrin sealant for dental extractions with local application of oxidized cellulose mesh and sutures. Both groups had similar and successful management of hemostasis, with the tranexamic acid irrigation being more cost effective (155). These findings have been replicated in other placebo-controlled randomized clinical trials (156). In another randomized study, 85 patients on warfarin were maintained on the anticoagulant therapy and were given either a 2-day or a 5-day presurgical regimen of oral irrigation with tranexamic acid (10 mL of 4.8% solution as oral rinse four times per day × 7 days) for dental extractions with local application of oxidized cellulose mesh and sutures. Both groups had similar and successful management of hemostasis, suggesting that the 2-day pretreatment with tranexamic acid irrigation was more cost effective (135). Other case reports have described systemic treatment with tranexamic acid to lead to post-operative hemostasis in patients with congenital coagulopathies undergoing dental surgery (157).

Desmopressin (1-desamino-8-D-arginine vasopressin; DDAVP; Ferring Pharmaceuticals, Sufferin, NY, USA) is a synthetic analog of vasopressin that increases Factor VIII levels. Case reports and case series indicate that DDAVP and local treatment (e.g. fibrin glue, gelatin packings, and tranexamic acid) promote hemostasis in many patients with von Willebrand's disease

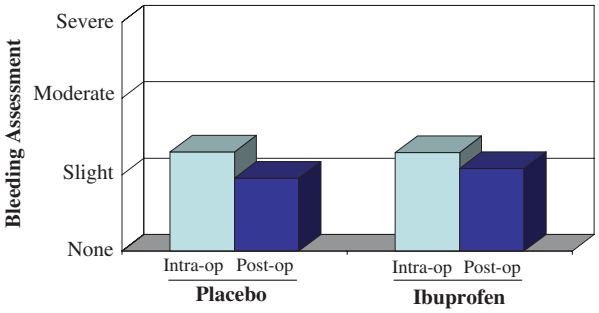


**Fig. 9. Effect of ibuprofen (400 mg tid starting 24 h before surgery and continuing for 4 days post-operatively) vs. placebo on assessment of clinical bleeding after extraction of impacted third molars. Reproduced from: Lokken P et al. (164). Bilateral surgical removal of impacted lower third molar teeth as a model for drug evaluation: a test with ibuprofen. *Eur J Clin Pharmacol* 1975: 4(8): 209–216. With kind permission of Springer Science and Business Media.**

or Factor XI deficiency undergoing surgical procedures (109, 158–161).

Thrombin is available in a power form (e.g. Thrombin-JMI; Jones Pharma Inc. St Louis, MO, USA) and, as expected, promotes hemostasis upon local administration into the surgical wound. Case series and reviews report the production of good hemostasis with local application of thrombin powder on dental surgical wounds in patients with oral anticoagulant therapy (133, 162).

Many NSAIDs are recommended for post-operative pain control. As NSAIDs (including aspirin) might influence post-operative bleeding via inhibition of cyclooxygenase, it is reasonable to consider whether NSAIDs alter post-operative hemorrhage. Although data for endodontic surgical procedures are not available, a systematic review of the effect of NSAIDs on post-operative bleeding after tonsillectomy concluded that non-aspirin NSAIDs have no significant effects on clinical bleeding, whereas aspirin does significantly increase post-operative bleeding (163). Figure 9 illustrates the effects of ibuprofen 400 mg vs. placebo on intra- and post-operative bleeding in patients undergoing extraction of impacted third molars (164).

## Non-pharmacological management of hemostasis

Surgical techniques can be considered as an integrated collection of methods and instruments designed to minimize intra-operative bleeding. The judicious design of flaps, placement of instruments, and handling of tissues provide several benefits including improved access, visibility, hemostasis, pain control, and healing (97, 152, 165–167). Although the harmonic scalpel has not yet been reported in endodontic surgical clinical trials, a randomized study on 28 patients undergoing tonsillectomy reported an 80% reduction in intra-operative bleeding after harmonic scalpel removal of one tonsil as compared with conventional scalpel dissection tonsillectomy with electrocautery on the contralateral side (168). A similar benefit for reduced bleeding was observed on comparing the harmonic scalpel with conventional procedures in 60 patients undergoing thyroidectomy (169), and reviews of this device are available in the oral surgery literature (170).

Several forms of absorbable sponges have been advocated for hemostasis. Collagen-based materials are highly purified forms of animal collagen that are available in various preparations including CollaCote™ (Integra Life Sciences Corp.), CollaStat™ (American Medical Products Inc, Freehole, NJ, USA), Instat™ (Ethicon, Piscataway, NJ, USA), and Hemocollagene™ (Septodent Inc., Kent, UK). Although these materials can be difficult to manipulate in a wet surgical field, they appear effective for promoting hemostasis without a significant delay in healing. In one study of 53 patients undergoing tumor resection, manual pressure combined with the application of a collagen sponge was compared with a novel collagen-based composite material (CoStasis™, Orthovita, Malvern, PA, USA), with a reported 70% and 100% control of hemorrhage, respectively (171). Another example of absorbable sponges is based on oxidation of alpha collagen fibers and includes Surgicel™ (Johnson & Johnson Inc., Piscataway, NJ, USA). In a case series of 26 patients on oral anticoagulants (INR = 2.1–4), the use Surgicel™ in the extraction socket was no different from fibrin glue (Beriplast P™, Centeon LTD, West Sussex, UK) for post-operative hemorrhage control (172). Studies have demonstrated slow absorption of Surgicel™ over a 120-day observation period and thus this material might have an impact on healing. A third example of absorbable sponges is based on gelatin proteins and includes Gelfoam™ (Pharmacia, Peapack, NJ, USA). Although Gelfoam™ promotes platelet activation, it has been reported to produce delayed healing.

Medical-grade calcium sulfate is used as a resorbable matrix for healing and can be placed into a surgical crypt and then carved to improve hemostasis and

visibility (152). In one randomized clinical study on 6-month healing of three-wall periodontal pockets, there was no significant difference in healing of lesions treated with calcium sulfate plus autogenous bone vs. bioresorbable membranes plus autogenous bone (173). However, a randomized-controlled study on 20 patients undergoing endodontic surgery demonstrated significantly greater healing at 1 year in the calcium sulfate (Surgiplaster™, Class Implant, Rome, Italy)-treated group (seven of 10 patients) as compared with the control group (three of nine patients) (174). These authors also reported that application of calcium sulfate tended to improve hemostasis.

Ferric sulfate (e.g. Cut-Trol™, Ichthys Inc, Mobile, AL, USA; Vicostat™, Ultradent Inc.) is a low pH (0.8–1.6) necrotizing agent that produces a chemical coagulation similar to an electrical cautery (175). The application of ferric sulfate to a bleeding surgical crypt leads to rapid hemostasis. However, the continued presence of the agent and the coagulum delays post-operative healing in animal studies (176). This emphasizes the need for curettage and irrigation at the completion of surgery, and this removal technique has been shown to result in normal healing in ferric sulfate-treated animals (175). As described previously, a recent randomized-controlled clinical trial compared patients undergoing endodontic surgery with local hemostasis consisting of either ferric sulfate treatment or placement of racemic epinephrine-containing pellets (Racellet™ #3, Pascal Co. Inc.). Both treatments produced equivalent intra-operative hemostasis (153).

Electocautery is a traditional means of producing hemostasis via coagulation and vesicular clumping (174, 177). A randomized study on tonsillectomy patients compared post-operative hemostasis where electrocautery was performed in one tonsillar crypt vs. electrocautery plus argon beam coagulation in the contralateral crypt. The results indicated that 81% of elecrocautery surgical fields and 92% of argon beam surgical sites had complete post-operative hemostasis (178). One concern raised with electrocautery techniques is the delayed bone healing that is known to occur after local production of high temperatures.

Bone wax is a mixture of purified beeswax and isopropyl palmitate. Although this is a traditionally used hemostatic agent, a concern has been raised that residual bone wax may interfere with postsurgical healing (179), and it has been demonstrated that residual bone wax allows persistent bacterial colonization in the surgical field (180). Therefore, it is not generally recommended for surgical hemostasis (96). To address this concern, a case report described the addition of calcium alginate fibers (Coalgen™, Brothier, France) to bone wax (bone wax, Ethicon, Sommerville, NJ, USA) prior to placement in an endodontic surgical crypt. This mixture led to good hemostasis and improved removal of the material (181).

An important non-surgical method of maximizing hemostasis is the removal of granulation tissue. Chronically inflamed tissue has a high density of blood vessels and is a potential source for intra-operative bleeding at the periradiacular area (98). Curettage of granulomas reduces this source of bleeding.

Lasers have been advocated for many dental indications including hemostatic control (182–184). However, in one randomized clinical trial on 50 dental implant sites, the Erbium : yttrium aluminum garnet (YAG) (Er : YAG) laser was not found to differ from conventional second-stage surgical exposure of implants for the control of hemorrhage (185).

The local application of autologous platelets or platelet-rich plasma has been reported to promote hemostasis and post-operative healing (186, 187). A recent case report using platelet-rich plasma for endodontic surgery has been described (188). However, no randomized clinical trials in endodontic surgical patients have been reported. A Cochrane Systematic Review on platelet-rich plasma for surgical hemostasis concluded that evidence supported a beneficial effect of this treatment, although many of the cited studies had a small sample size or were uncontrolled designs (189). Similarly, a Cochrane Systematic Review on fibrin sealants concluded that they were effective in promoting hemostasis, with, again, concern raised about underpowered or poorly designed studies (190).

The post-operative application of local pressure and good tissue approximation serve as common non-pharmacological techniques for the maintenance of hemostasis (191). In one randomized control study, patients on warfarin treatment underwent multiple tooth extractions in which local treatment consisted of placing gelatin sponges in the extraction sites with closure by interrupted resorbable sutures with or without external application of the adhesive *n*-butyl-2-cyanoacrylate (Histoacryl™; B. Braun, Melsungen, Germany; Glustitch™; Glustitch Inc, Delta, BC, Canada). The results indicate that the group having

adhesive tissue approximation experienced significantly less bleeding without resorting to changes in warfarin treatment (136). A case series of 130 patients undergoing root end surgery, extractions, and periodontal surgery reported that application of *n*-butyl-2-cyanoacrylate improved hemostasis and pain control (192). A second adhesive, octyl-2-cyanoacrylate, has been approved by the Food and Drug Administration for closure of incisions and lacerations, and has been shown to reduce bleeding form cutaneous lacerations (193).

## Summary

The generation of effective intra-operative anesthesia and hemostasis are critical pillars supporting the foundation of effective endodontic surgical procedures. While the use of anesthetics in endodontic surgery has not been examined extensively, we have extrapolated from other studies and it appears that anesthetics can be safely used to reduce both peri- and post-operative pain. Anesthetics including lidocaine and articaine can be used to obtain effective anesthesia of the soft and hard tissues. Post-operative pain can be effectively reduced for up to 48 h after surgery by the administration of long-acting anesthetics.

The control of hemostasis begins with the pre-operative assessment of the patient's medical history and current medication usage. Effective intra-operative hemostasis often requires the slow infiltration injection of one to two cartridges of local anesthetic containing 2% lidocaine with 1 : 50 000 epinephrine and waiting for tissue blanching as a sign of effective vasoconstriction. Excellent surgical skills including careful design of flaps, handling of tissues, positioning of retractors, etc, to reduce trauma to the tissue. Hemostasis in the surgical crypt can be managed by any of several techniques, including resorbable sponges containing epinephrine or direct application of ferric sulfate. Although additional clinical trials comparing various methods are indicated, treatment with epinephrine appears to have minimal systemic effects and avoids the potential delayed wound healing that might occur if not all of the ferric sulfate is removed. A reasonable alternative, particularly for patients at cardiovascular risk, might be the local application of a calcium sulfate paste on the surgical crypt. Good tissue approximation with appropriate suturing techniques combined with 5–10 min of wound compression is effective for promoting post-operative hemostasis in otherwise healthy patients.

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# Magnification and illumination in apical surgery

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Non-surgical root canal therapy has proven to be a highly successful procedure when the case is properly diagnosed, treated, and restored. If non-surgically treated tooth fails to demonstrate healing and the reason for failure is endodontic in origin and not periodontal, traumatic, or restorative in nature, apical surgery is often the treatment of choice. Significant advances in the use of magnification and illumination and supportive armamentarium in recent years have benefited treatment protocols in apical surgery such that teeth, which might otherwise have been extracted, now have a predictable chance for retention. The purpose of this article is to review the development and application of these advances and their implications in apical surgery.

## Introduction – several paths cross

The separate pursuits of intention, knowledge, and technology on occasion entwine and over time the resultant effect serendipitously benefits mankind. The development of apical microsurgery is such an example. The desire to eliminate disease at the root end, the need to obtain a clearer understanding of the complexities of pulpal anatomy, and the use of enhanced magnification and illumination have fathered contemporary apical surgery, more accurately described as apical microsurgery.

## Elimination of disease at the root end

While the origins of apical surgery can be traced to pre-Colombian times (1, 2), contemporary surgical endodontics began its journey in the early 1960s, along with the recognition of endodontics as a specialty in the United States in 1964. Emphasis was placed on root-end filling materials and their sealing ability. As apical surgical procedures evolved, much controversy existed and personal choices evolved with little biologic basis. Surgery at this time, and until recently was often performed with inadequate lighting, no magnification, and a limited armamentarium. Frank et al. (3) reported that success rate in apical surgeries sealed with amalgam, which had been considered successful, dropped to 57.7% after 10 years (3). Gutmann & Harrison (4) identified the task of modern-day endodontics to 'eliminate the art and craft otherwise inherent in surgical endodontics – the heuristic – and encourage a relentless, honest pursuit of the contemporary challenges of endodontic surgery.' Shabahang (5) recently described apical surgery as endodontic therapy through a surgical flap. The main purpose of apical surgery is to remove a portion of a root with anatomical complexities laden with tissue debris and microorganisms or to seal the canal when a complete seal cannot be accomplished through non-surgical means (5). The complexity of these root canal spaces has only recently been appreciated.

## Anatomical complexities

Walter Hess (6), a Swiss dentist, first published his landmark anatomical studies in the early 1920s. When his work was first published, many clinicians felt that the anatomical complexities reported were artifacts created by injecting vulcanite rubber under too much pressure (Figs 1 and 2). However, more progressive thinkers of that time believed that the results had merit and sought more effective ways to clean, shape, and obturate root canal systems. More recently, Takahashi and Kishi (7), using a dye infusion process, also studied anatomical complexities. These models clearly show the majesty and grace of the human dental pulp (Figs

**Fig. 1. Hess model of a mandibular molar showing anatomical complexities throughout the root canal system.**

**Fig. 3. Takahashi model of the mesial view of the mesial root of a mandibular molar. Note the mid-root isthmus and the apical bifidity of the buccal canal. Also note the multiple apical termini.**

**Fig. 2. Hess model of a mandibular premolar showing anatomical complexities in the apical terminus.**

**Fig. 4. Takahashi model of a mandibular second premolar. Note how the single canal bifurcates, rejoins, and then splits once more at the canal terminus.**

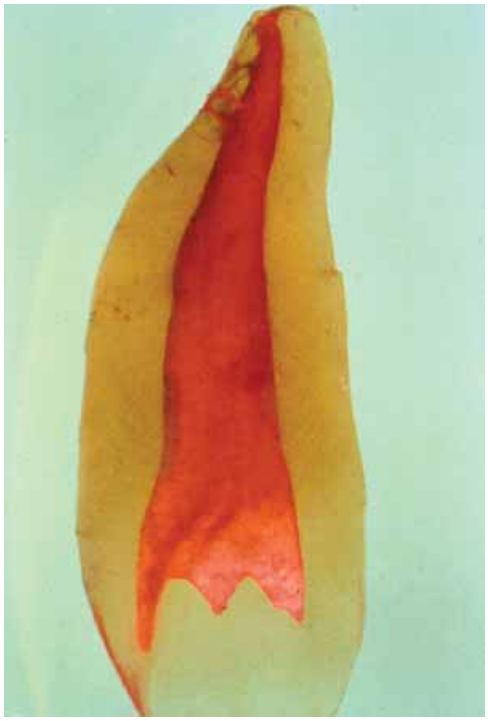

**Fig. 5. Takahashi model of a maxillary central incisor. Note the multiple portals of exit in the apical third of the root.**

**Fig. 6. Takahashi model of a mandibular molar. Note the anatomical complexities present in both roots.**

3–6). Weller et al. (8) studied the incidence and location of the isthmus in the mesial buccal root of the maxillary first molar and found a partial or complete isthmus 100% of the time at the 4 mm level of resection. West (9) looked at the relationship between failed root canal treatment and unfilled or underfilled portals of exit (POEs). Using a centrifuged dye, he identified that 100% of the failed specimens studied had at least one underfilled or unfilled POE. As 93% of the canal ramifications occur in the apical 3 mm (10), logically, the clinician should attempt to treat the root canal system to the full extent of the anatomy. Failure to address these anatomical concerns will leave the etiology of failure unremoved and re-infection, even after the removal of a periapical lesion, may reoccur. Clearly, root canal systems are more complex than thought previously. Significant pulpal anatomy such as accessory canals and isthmuses has to be considered when performing both non-surgical and surgical endodontic treatment. The acceptance of the significance of these anatomic complexities and the need to eliminate them may in fact have been the genesis of modern apical surgery, which could further be appreciated with the introduction of magnification.

## A brief history of magnification

Although the first accurate lenses were not made until about the year 1300, credit for the first microscope is usually given to Hans and Zacharias Jansen, a father and son who operated a Dutch lens-grinding business, around 1595 (11). They produced both simple (single lens) and compound (two lenses) microscopes.

Using a compound microscope, in 1665, Robert Hooke coined the word cell while describing features of plant tissue (11). Another pioneer of microscopy Anton van Leeuwenhoek produced single lenses powerful enough to enable him to observe bacteria 2–3 μm in diameter in 1674 (11).

Little was done to improve the microscope until the middle of the 19th century when Carl Zeiss, Ernst Abbe, and Otto Schott devoted significant time to develop the microscope, as we know it today. While Zeiss concentrated on the manufacturing process, Abbe and Schoot devoted their time to the theoretical study of optical principles and conducting research on glass (12). Their product was the genesis of the surgical operating microscope (SOM) that ultimately found its way into the practice of medicine.

## Evolution of magnification and illumination in medicine

In 1921, Dr Carl Nylen (13) of Germany reported the use of a monocular microscope for operations to correct chronic otitis of the ear. The unit had two magnifications of × 10 and × 15 and a 10 mm diameter view of the field. This microscope had no illumination.

In 1922, the Zeiss Company (Germany) working with Dr Gunnar Holmgren of Sweden, introduced a binocular microscope for treating otosclerosis of the middle ear. This unit had magnifications of × 8– × 25 with field-of-view diameters of 6–12 mm (14).

In the United States ophthalmologists were using the slit lamp for examination of the anterior structures of the eye before World War II, but it was the otologists who introduced the SOM to the medical community. In the late 1940s, Dr Jules Lempert, a leading mastoid surgeon from New York, had been using loupes to perform his surgery. Dr Lempert realized the limitations of loupes. He needed more magnification and illumination and was in search of a microscope. While attending a show of industrial equipment in Germany, he found a microscope that he felt he could adapt. This was the Zeiss epi-teknoscope. Zeiss sold three of these units to the Storz Instrument Company in St Louis, Missouri, one of which went to the Lempert Institute of Otology (15). The epi-teknoscope was based on Galilean optics. Galilean optics are those optics that focus at infinity. This is markedly different from Greenough optics (convergent optics), which are found in dissecting or laboratory microscopes. Greenough-type microscopes necessitate observation with convergent eyes, resulting in accommodation of the observer and eye fatigue. The advantage of Galilean optics is that the light beams going to each eye are parallel. With parallel light instead of converging light, the operator's eyes are at rest as if he were looking off into the distance. Therefore, operations that use the SOM and take several hours can be performed without eye fatigue.

Dr Samuel Rosen, an otologist from Philadelphia, learned of the microscope that Dr Lempert had obtained. He also purchased one and developed a procedure to replace the stapes mobilization technique with one that could restore permanent hearing after the tiny bones of the middle ear had ossified (15).

The formal introduction of the binocular operating microscope took place in 1953 when Zeiss introduced the Opton ear microscope. This was the forerunner of the OPMI 1 (the first modern microscope). The Opton had a 5-step magnification changer, which could produce magnifications in five steps from × 1.2 to × 40 and field-of-view diameters from 4.8 to 154 mm. Working distances were a remarkable 200–400 mm. The Opton had built-in coaxial illumination, which added immensely to visual acuity (14).

The use of the SOM in ophthalmology developed at a much slower rate. Many ophthalmic procedures could be performed without the microscope. Initially, loupes seemed adequate, and emphasis was placed on developing better loupes. Light amplification was not a particular problem because side illumination was available. The need for a co-axial illumination light source (found in an SOM) did not become important to ophthalmologists until they started performing extra capsular cataract extraction. In order to see the posterior capsule, a red reflex from the retina was needed. This reflex is produced by co-axial illumination (15). Many ophthalmologists during the early 1970s felt that the SOM made simple and highly successful operations complicated and drawn out. However, a few clinicians began to use the 'ear scope,' as it was called, to perform cataract removal. They soon recognized the advantage of the wide field, better depth of focus, better illumination, and the advantage of variable magnification when using the SOM instead of loupes.

The development of the SOM in neurosurgery was similar to that in ophthalmology. In 1966, while performing cranial nerve dissections at UCLA on a closed-circuit television for dental students, Dr Peter Jannetta, a neurosurgeon, made an anatomical discovery. The trigeminal nerve is generally described as emerging in the cerebellopointine angle in two bundles: sensory (portio major) and motor (portio minor). Jannetta noted a portio intermedius, which he theorized needed to be preserved when cutting the portio major in order to preserve light touch perception after surgery for trigeminal neuralgia. Using the SOM, he further developed a microvascular decompression procedure to visualize and free up small blood vessels wrapped around the trigeminal nerve root, thereby relieving compression on the nerve and eliminating the symptoms of trigeminal neuralgia (16).

In the mid 1970s, Contraves AG of Zurich, in conjunction with Dr M Gazi Yasargil (Switzerland) and Dr Leonard Malis (USA), introduced a neurosurgical floor stand, which combined a perfectly balanced

suspension of the microscope with electromagnetic locking of each primary axis of the various floor stand elements (14). Advancements of this nature made the SOM a mainstay in the modern hospital operating room for all medical disciplines.

## Evolution of magnification and illumination in dentistry

The use of magnification to enhance visualization in dentistry dates back over a century. In 1876, Dr Edwin Saemisch, a German ophthalmologist, introduced simple binocular loupes to surgery (17). Soon after, dentists began experimenting with loupes to assist in the performance of precision dentistry and this continued to be the practice until the late 1970s.

In 1962, Dr Geza Jako, an otolaryngologist, used the SOM in oral surgical procedures (18). Dr Robert Baumann, an otolaryngologist and practicing dentist, described the use of the otologic microscope in dentistry in 1977 (19). He predicted that the SOM would find a place in the armamentarium of the modern dentist as it did in otorhinolaryngology, neurosurgery, vascular medicine, and gynecology.

In 1978, Dr Harvey Apotheker, a dentist from Massachusetts, and Dr Jako began the development of a microscope specifically designed for dentistry. In 1980, Dr Apotheker coined the term 'microdentistry' (20, 21). The 'DentiScope' (Fig. 7) was manufactured by Chayes-Virginia Inc., USA, and marketed by the Johnson and Johnson Company. The Dentiscope had a single magnification of × 8 and dual fiberoptic lights, which were directed toward the surgical field. The unit could be mounted on a mobile stand or could be permanently mounted to a wall. Unfortunately, because of lack of initial interest in the product, the Dentiscope was dropped from production. Despite this setback, there was still interest in using the SOM in dentistry.

In July of 1982, the First International Congress in Microsurgical Dentistry was held in Bordeaux, France. Drs Jean Boussens and Ducamin-Boussens chaired the meeting. In attendance were many of the early pioneers including Drs Baumann, Jako, and Apotheker (22). Dr Apotheker continued to work with and research on the operating microscope. In 1984, along with Dr Howard Reuben, they reported its use for the first time in apical surgery (23). Two years later, Dr Howard Selden reported his experience with the SOM (24).

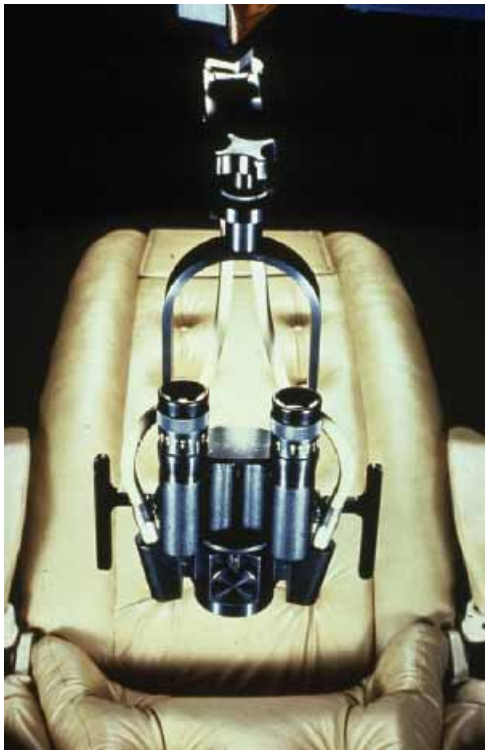

**Fig. 7. The original Dentiscope (courtesy of Dr Noah Chivian).**

Interest surged again among endodontists in 1989 when Drs Noah Chivian and Sandy Baer formed a company called Microdontics and sold the remaining DentiScopes. All of these microscopes found their way into endodontic offices throughout the United States by the end of the decade.

Dr Gabriele Pecora gave the first presentation on the use of the SOM in surgical endodontics at the 1990 annual session of the American Association of Endodontists in Las Vegas, Nevada. He used the Zeiss OPMI I SOM. Dr Richard Rubinstein and Dr Gary Carr began using medical-grade microscopes for apical surgery in 1990 and reported on their experience (25–28). Shortly thereafter, Dr Carr founded the Pacific Endodontic Research Foundation, which was dedicated to teaching micro-endodontics.

In March of 1993, 11 years after the introduction of the DentiScope, the first symposium on microscopic endodontic surgery was held at the University of Pennsylvania School of Dental Medicine. The first university-based training program was founded at the University of Pennsylvania, School of Dental Medicine shortly thereafter.

By 1995, there was considerable increase in the use of the SOM. Microscope companies such as Zeiss, Global, and JEDMED offered microscopes with a variety of features that could accommodate virtually any practitioner and office environment. Improved lighting systems, variable adjustable binoculars, and improved ergonomics created opportunities for visual acuity that were far superior to what was available just a decade earlier.

In the summer of 1995, a workshop was held for endodontic department chairmen and program directors to address the need for enhanced magnification and its role in advanced specialty education programs. The American Association of Endodontics sponsored the workshop. Drs Carr, Rubinstein, Ruddle, West, Kim, Arens, and Chivian, all early pioneers in endodontic microscopy, taught the course that was both lecture and hands-on. At the end of the 2-day workshop, there was a unanimous decision among the teachers to recommend that proficiency in the use of the microscope in both surgical and non-surgical treatment be included in postgraduate endodontic education programs to the Commission on Dental Accreditation of the American Dental Association. The Commission met in January 1996, and the mandatory teaching of microscopy was passed and included in the new Accreditation Standards for Advanced Specialty Education Programs in Endodontics. The new standards went into effect in January 1997. As in medicine, the incorporation of the SOM moved slowly but it has ultimately changed the fields of both surgical and non-surgical endodontics and the way they are practiced.

In 1999, Mines et al. (29) reported the frequency of use of the microscope as a function of years since completing advanced endodontic education as follows: $<5$ year, 71%; 6–10 years, 51%; and $>10$ years, 44%. The most frequent use of the microscope in apical surgery was in root-end preparations and in placing root-end fillings. Since this study was reported, more endodontic residents have completed programs and are now in practice and more non-users have retired. One can assume that the frequency of use has increased and will continue to increase in time.

As an alternative to the SOM, some practitioners use loupes, loupes in conjunction with headlamps, and the recently introduced endoscope for apical surgery. A review of each of these choices of magnification and illumination will point out their benefits and limitations as surgical adjuncts.

## Loupes

Historically, dental loupes have been the most common form of magnification used in apical surgery (Fig. 8). Loupes are essentially two monocular microscopes with lenses mounted side by side and angled inward (convergent optics) to focus on an object. The disadvantage of this arrangement is that the eyes must converge to view an image. This convergence over time will create eyestrain and fatigue and, as such, loupes were never intended for lengthy procedures. Most dental loupes used today are compound in design and contain multiple lenses with intervening air spaces. This is a significant improvement over simple magnification eyeglasses but falls short of the more expensive prism loupe design.

Prism loupes are the most optically advanced type of loupe magnification available today. They are actually low-power telescopes that use refractive prisms. Prism loupes produce better magnification, larger fields of view, wider depths of field, and longer working distances than other types of loupes. Only the SOM provides better magnification and optical characteristics than prism loupes.

The disadvantage of loupes is that $\times 3.5$– $\times 4.5$ is the maximum practical magnification limit. Loupes with higher magnification are available but they are quite heavy and if worn for a long period of time can produce significant head, neck, and back strain. In addition, as magnification is increased, both the field of view and depth of field decrease, which limits visual opportunity.

**Fig. 8. $\times 2.5$ and $\times 3.5$ dental loupes (Designs for Vision, Ronkonkoma, NY, USA).**

**Fig. 9. Surgeon with a surgical headlamp and × 2.5 loupes (Designs for Vision).**

Visual acuity is heavily influenced by illumination. An improvement to using dental loupes is obtained when a fiberoptic headlamp system is added to the visual armamentarium (Fig. 9). Surgical headlamps can increase light levels as much as four times that of traditional dental operatory lights. Another advantage of the surgical headlamp is that since the fiberoptic light is mounted in the center of the forehead, the light path is always in the center of the visual field.

## Endoscopy

Endoscopy is a surgical procedure whereby a long tube is inserted into the body usually through a small incision. It is used for diagnostic, examination, and surgical procedures in many medical fields. Goss and Bosanquet (30) reported that Ohnishi first used the endoscope in dentistry to perform an arthroscopic procedure of the temporomandibular joint in 1975. Detsch et al. (31) first used the endoscope in endodontics to diagnosis dental fractures in 1979. Held et al. (32) and Shulman & Leung (33) reported the first use of the endoscope in surgical and non-surgical endodontics in 1996. Bahcall et al. (34) presented an endoscopic technique for endodontic surgery in 1999.

The endoscopic system consists of a telescope with a camera head, a light source, and a monitor for viewing. The traditional endoscope used in medical procedures consists of rigid glass rods and can be used in apical surgery and non-surgical endodontics. A 2.7 mm lens diameter, a 70° angulation, and a 3 cm long rod-lens are recommended for surgical endodontic visualization and a 4 mm lens diameter, a 30° angulation, a 4 cm long rod-lens are recommended for non-surgical visualization through an occlusal access opening (35). The recently introduced flexible fiberoptic orascope is recommended for intracanal visualization, has a .8 mm tip diameter, 0° lens, and a working portion that is 15 mm in length.

The term orascopy describes the use of either the rigid rod-lens endoscope or the flexible orascope in the oral cavity. The recently introduced Endodontic Visualization System (EVS) (JEDMED Instrument Company, St Louis, MO, USA) incorporates both endoscopy and orascopy into one unit (Fig. 10). The EVS system allows for two methods of documentation. The camera head used in the EVS system is an S-video camera and, as such, documentation is usually accomplished by recording streaming video onto tape or digitized to DVD. Digital stills can be obtained by using the JEDMED Medicapture system, which can work with any existing video system. Images are captured on a USB flash drive in either JPEG or BMP format with a resolution of up to 1024 × 768 pixels and transferred to a computer for editing and placement into case reports or presentations.

Clinicians who use orascopic technology appreciate the fact that it has a non-fixed field of focus, which allows visualization of the treatment field at various angles and distances without losing focus and depth of field (36). Unlike the treatment fields when loupes or a microscope is used, the endoscope and orascope are in much closer proximity to the field of treatment. Moving the lens closer to the point of observation creates various levels of magnification. This equates to greater clarity at higher magnification, often in the range of × 30– × 40. Because of this close proximity to the point of observation, factors like condensation and blood can affect the clarity of the image and the use of anti-fog solutions are recommended. Furthermore, endoscopes and orascopes will not provide a discernible image when placed in blood, dictating the need for excellent hemostasis in the operating field. Observation of the surgical field for both the operator and the assistant is through a monitor (Fig. 10). Critics of this form of magnification point out that the images viewed are two-dimensional and too restrictive to be useful when compared with the stereoscopic images provided with loupes or microscopes.

Orascopy was never intended to replace loupes or the microscope but rather to complement these other

**Fig. 10. Endodontic visualization system utilizing a fixed rod lens for apical surgery (courtesy of Dr James Bahcall).**

forms of magnification when specific magnification is needed (37). Bahcall & Barss (35) recommend using × 2 to × 2.5 loupes for visualization in conjunction with the use of the endoscope in apical surgery to reflect gingival tissue, remove cortical and medullary bone, and isolate the root end. They further recommend that the endodontist hold the endoscope with a comfortable pen grasp while the assistant retracts the gingival tissue and suctions during surgical treatment.

## SOM

One of the most important developments in surgical endodontics in recent years has been the introduction of the SOM. Most microscopes can be configured to magnifications up to × 40 and beyond (Figs 11–13) but limitations in depth of field and field of view make it impractical. The lower-range magnifications (× 2.5 – × 8) are used for orientation to the surgical field and allow for a wide field of view. Mid-range magnifications (× 10 – × 16) are used for operating. Higher-range magnifications (× 20 – × 30) are used for observing fine detail. The most significant advantages of using the SOM are in visualizing the surgical field and in evaluating surgical technique (Fig. 14). Clearly, if a task can be seen better it can be performed better. Fractures, POEs, and canal isthmuses can be readily seen and dealt with accordingly.

### Magnification

The magnification possibilities of a microscope are determined by the power of the eyepiece, the focal

**Fig. 11. JEDMED V-Series SOM with assistant binoculars, a three-chip video camera, and counter balanced arms.**


**Fig. 12. Global G-6 SOM (Global Surgical™ Corporation, St Louis, MO, USA) with an enhanced metal halide illumination system.**

length of the binoculars, the magnification changer factor, and the focal length of the objective lens. Diopter settings on the eyepieces adjust for accommodation and refractive error of the operator. As in a typical pair of field binoculars, adjusting the distance between the two binocular tubes sets the interpupillary distance. Binoculars are now available with variable inclinable tubes from 0° to 220° to accommodate virtually any head position.

Magnification changers are available in 3-, 5-, or 6-step manual changers, manual zoom, or power zoom

**Fig. 13. Zeiss OPMI PROergo (Carl Zeiss Surgical Inc., Thornwood, NY, USA) with magnetic clutches, power zoom, and power focus on the handgrips.**

**Fig. 14. Micro-mirror view of SuperEBA™ retrofill at × 16.**

changers. Manual step changers consist of lenses that are mounted on a turret (Fig. 15). The turret is connected to a dial, which is located on the side of the microscope housing (Fig. 16). The dial positions one lens in front of the other within the changer to produce a fixed magnification factor. Rotating the dial reverses the lens positions and produces a second magnification factor. A typical 5-step changer has two sets of lenses and a blank space on the turret without a lens. When you factor in the power of the eyepiece, the focal lengths of the binoculars, and the objective lens with the magnification changer lenses, five fixed powers of magnification are obtained: two from each lens combination and one from the blank space. A manual

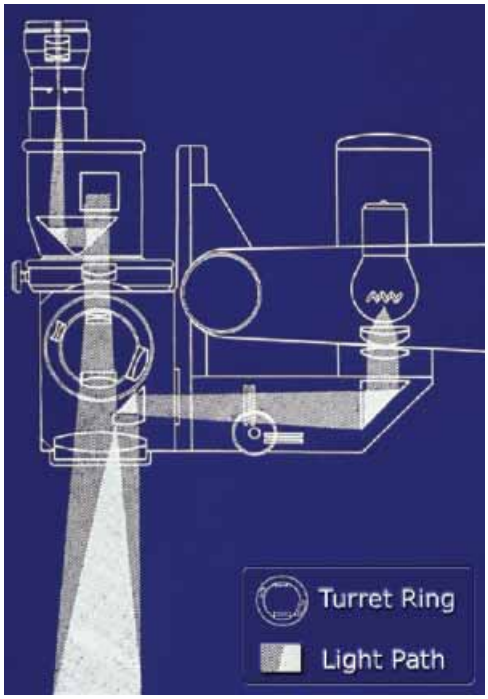


**Fig. 15. Cross-sectional diagram of a typical 5-step SOM head showing the turret ring in the body of the microscope.**


**Fig. 16. Turning the dial rotates the turret ring inside the body of the SOM and creates five magnification factors.**

zoom changer is merely a series of lenses that move back and forth on a focusing ring to give a wide range of magnification factors. A power zoom changer is a

mechanized version of the manual zoom changer. Power and manual zoom changers avoid the momentary visual disruption or jump that is observed with manual step changers as you rotate the turret and progress up or down in magnification. Power zoom changer microscopes have foot controls, which allow the surgical field to be focused and magnified hands-free.

The SOM is focused much like a laboratory microscope. The manual focusing control knob is located on the side of the microscope housing and changes the distance between the microscope and the surgical field. As the control knob is turned, the microscope is brought into focus. Some microscopes are fine focused by turning a focusing ring mounted on the objective lens housing.

The focal length of the objective lens determines the operating distance between the lens and the surgical field. With the objective lens removed, the microscope focuses at infinity. Many endodontic surgeons use a 200 mm lens, which focuses at about 8 in. With a 200 mm lens there is adequate room to place surgical instruments and still be close to the patient.

As mentioned earlier, as you increase the magnification, you decrease the depth of field and field of view. While this is a limitation for fixed magnification loupes, it is not a limiting factor with the SOM because of the variable ranges of magnification. If the depth of field or field of view is too narrow, the operator merely needs to back off on the magnification as necessary to view the desired field.

## Illumination

The light provided in an SOM is two to three times more powerful than surgical headlamps and, in many endodontists offices, has replaced standard overhead operatory lighting.

As can be seen in Fig. 15, the light enters the microscope and is reflected through a condensing lens to a series of prisms and then through the objective lens to the surgical field. After the light reaches the surgical field, it is then reflected back through the objective lens, through the magnification changer lenses, through the binoculars, and then exits to the eyes as two separate beams of light. The separation of the light beams is what produces the stereoscope effect that allows us to see depth.

Illumination with the SOM is coaxial with the line of sight. This means that light is focused between the eyes in such a fashion that you can look into the surgical site without seeing any shadows. Elimination of shadows is made possible because the SOM uses Galilean optics. As stated earlier, Galilean optics focus at infinity and send parallel beams of light to each eye. With parallel light, the operator's eyes are at rest and therefore lengthy operations can be performed without eye fatigue.

## Accessories

A beam splitter can be inserted into the pathway of light as it returns to the operator's eyes. The function of the beam splitter is to supply light to an accessory such as a video camera or digital still camera. In addition, an assistant articulating binocular can be added to the microscope array.

The advantages of adding assistant articulating binoculars are numerous. The assistant becomes optically important to the surgical team and develops a keener understanding not only of what is expected in the surgery but why it is expected (Fig. 17). She/he sees stereoscopically exactly what the operator sees. Placement of a surgical suction becomes accurate and the assistant can visually anticipate the surgeon's next step in the procedure. Most clinicians have found that bringing the assistant into the visual sphere increases job satisfaction significantly.

## Documentation

Historically, there have been a number of ways to incorporate documentation while using the micro-

**Fig. 17. Doctor and assistant at the surgical operating microscope.**

scope. Among them have been 35 mm photography, sublimation dye prints, and videotaping. With the introduction of digital radiography systems, clinical images can now be captured on a video capture card installed on the operatory computer. The video camera mounted on the microscope's beam splitter sends a real-time video signal and an unlimited number of images can be captured or recorded during the procedure. These images can then be saved along with radiographic images and reviewed with the patient after the surgery (Fig. 18).

As stated previously, digital recording systems like the JEDMED Medicapture System provide another alternative for recording digital images. The unit can be placed in line with any video signal and images can be recorded on a USB flash drive and transferred to a computer for use at a later time. Digitally created clinical and radiographic images, regardless of the source, can then be exported to a Microsoft Word document for case reporting or placed into PowerPoint presentations for teaching purposes.

Using the microscope and digital radiographic systems in this way provides opportunities for unsurpassed doctor and patient communication. Furthermore, communication with referring dentists and teaching possibilities are also enhanced.

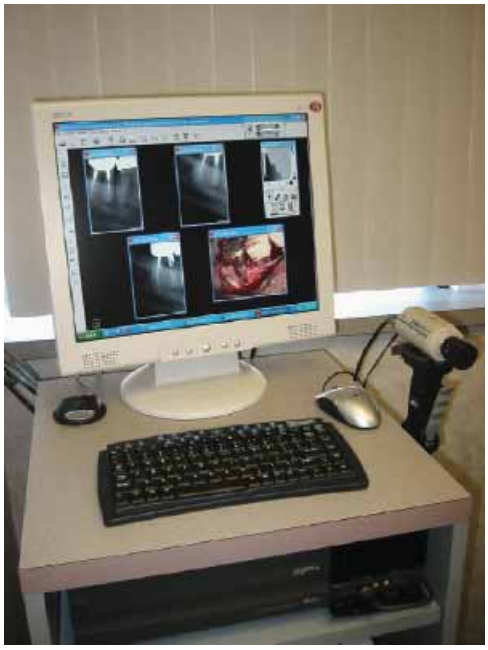

**Fig. 18. Digital radiographs and clinical images on 19′ flat panel LCD screen.**

## Ergonomics

As stated earlier, the binoculars on many SOMs have variable inclination. This means that the operator's head can develop and maintain a comfortable position. All stooping and bending is eliminated, thereby forcing the operator to sit up straight tilting the pelvis forward and aligning the spine in proper position. This positioning should create a double s-curvature of the spine, with lordosis in the neck, kyphosis in the mid-back, and lordosis again in the lower spine. Such posturing is not possible when the clinician is wearing a headlamp and loupes or using an endoscope. With these devices, there is still the tendency to bend over the patient, creating poor ergonomics and developing head, neck, and shoulder strain. Constant bending over the patient collapses the diaphragm and may inhibit oxygen exchange causing fatigue later in the workday. This is eliminated with the upright positioning achieved while using the SOM.

While performing apical surgery, the clinician uses two assistants (Fig. 19). The primary assistant or suctioning assistant is seated so that she/he can observe the doctor's perspective through the assistant articulating microscope. The secondary assistant stands to the doctor's dominant side and is responsible for placing instruments into the doctor's hand. If desired, the secondary assistant can view the surgery in real time on either of two monitors placed in the operatory, which display digital radiographs and real-time video. Positioned this way, the doctor should never have to take his eyes from the SOM and the surgical field and should be able to maintain an appropriate and beneficial posture throughout the entire procedure.

**Fig. 19. Doctor using two assistants during apical surgery.**

## Misconceptions about surgical microscopes

### Magnification

A frequently asked question is 'how powerful is your microscope'? The question really addresses the issue of useable power. Useable power is the maximum object magnification that can be used in a given clinical situation relative to depth of field and field of view. The question then becomes 'how useable is the maximum power'? While magnification in excess of $\times 30$ is attainable, it is of little value while performing apical surgery. Working at a higher magnification is extremely difficult because slight movements by the patient continually throw the field out of view and out of focus. The operator is then constantly re-centering and refocusing the microscope. This wastes a considerable amount of time and creates unnecessary eye fatigue. Those clinicians who use the endoscope for apical surgery would also agree that higher magnifications are for critical evaluation only and not for operating.

### Illumination

There is a limit to the amount of illumination that an SOM can provide. As you increase the magnification, you decrease the effective aperture of the microscope and therefore limit the amount of light that can reach the surgeon's eyes. This means that as higher magnifications are selected, the surgical field will appear darker. In addition, if a beam splitter is attached to the microscope, less light will be available for the photo adapters and auxiliary assistant binoculars. This decrease in illumination at a higher magnification is not a problem while using the endoscope because the light source of the endoscope is at the tip of the endoscope and the camera compensates for any light loss. Furthermore, depth of field concerns while using the endoscope are not an issue because the aperture of the endoscope is quite small and, as in photography, as you decrease the aperture or the f-stop, you increase the depth of field.

### Depth Perception

Before apical surgery can be performed with an SOM, the clinician must feel comfortable receiving an instrument from his assistant and placing it between the microscope and the surgical field. Learning depth perception and orientation to the microscope takes time and patience. There is a learning curve and it will vary among operators. As a general rule, it is suggested that each clinician reorient himself to the SOM prior to beginning each surgery and practice various surgical scenarios with his assistants prior to each case. If the clinician is not a recent graduate of an advanced specialty training program in endodontics, it is strongly suggested that he enroll in a university-based microsurgical training program prior to purchasing a microscope to avoid making costly mistakes.

### Access

One of the problems encountered in apical surgery is gaining physical access to the sight of infection. The SOM will not improve access to the surgical field. If access is limited for traditional surgical approaches, it will be even more limited when the microscope is placed between the surgeon and the surgical field. Use of the SOM, however, will create a much better view of the surgical field. This is particularly true in diagnosing craze lines and cracks along the bevelled surface of a root or when the surgeon is preparing a tiny isthmus between two canals ultrasonically. Because vision is enhanced so dramatically, apical surgery can now be performed with a higher degree of confidence and accuracy. Repeated use of the microscope and concurrent stereoscopic visualization will help the clinician develop visual imagery of the various stages of apical surgery, which is necessary in learning sophisticated surgical skills.

### Flap Design and Suturing

Incising and reflecting soft-tissue flaps are not high-magnification procedures. In many cases, they can be performed with the naked eye or with low-power loupes. Basic single interrupted stitch suturing can also be performed with little to no magnification. While the microscope could be used at low magnification, little is gained from its use in these applications. However, with the introduction of the delicate papilla base incision, which requires the use of 7-0 sutures and a minimum of two sutures per papilla microscopic magnification, with a minimum of $\times 4.3$, is suggested (38). The SOM is used at its best advantage for osteotomy, apicoectomy (apicectomy), apical preparation, retrofilling, and documentation.

## Apical microsurgery

As stated previously, one of the most important advantages of using the operating microscope is in evaluating the surgical technique. It has been said that necessity is the mother of invention. This is also true when it comes to the design and application of surgical instruments. Those pioneers who began using the microscope some two decades ago observed early on that most traditional surgical instruments were too large to be placed accurately in small places, or that they were too traumatic when used to manage soft and hard tissue. This led to the development of a microsurgical armamentarium and the true practice of apical microsurgery.

Apical microsurgery can be divided into 20 stages or sections. These are flap design, flap reflection, flap retraction, osteotomy, periapical curettage, biopsy, hemostasis, apical resection, resected apex evaluation, apical preparation, apical preparation evaluation, drying the apical preparation, selecting retrofilling materials, mixing retrofilling materials, placing retrofilling materials, compacting retrofilling materials, carving retrofilling materials, finishing retrofilling materials, documenting the completed retrofill, and tissue flap closure.

While it is beyond the scope of this paper to discuss all of the instruments that could be used in the various stages, it is appropriate to discuss those that are of particular import to the microscopic component of apical surgery, many of which have been recently introduced.

After anesthesia is obtained, micro-scalpels (Fig. 20) (SybronEndo, Orange, CA, USA) are used in the design of the tissue flap to incise delicately the interdental papillae when full-thickness flaps are required. Vertical incisions are made $1\frac{1}{2}$ to two times longer than in traditional apical surgery to assure that the tissue can be easily reflected out of the light path of the microscope.

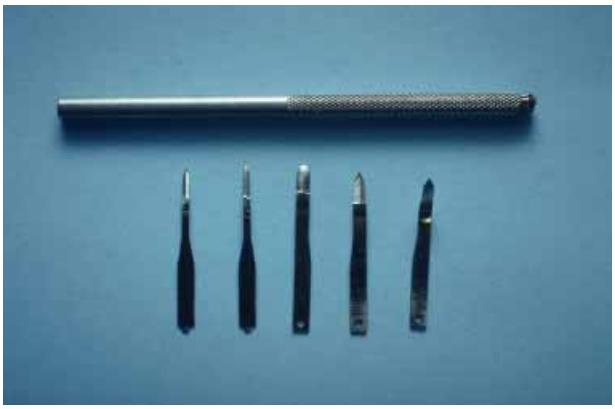

**Fig. 20. A variety of micro scalpels sized 1-5 used for precise incision.**

**Fig. 21. Comparison of the small ends of two mini-Molts and a standard Molt 2-4 curette.**

Historically, tissues have been reflected with a Molt 2-4 curette or a variation of the Molt 2-4. This instrument is double ended and the cross-sectional diameters of the working ends are 3.5 and 7 mm. Under low-range magnification, it can readily be seen that even the smallest end of this instrument is too large to place beneath the interdental papilla without causing significant tearing and trauma to the delicate tissues. Rubinstein Mini-Molts (Fig. 21) (JEDMED Instrument Company) are now available in two configurations whose working ends are 2 and 3.5 mm and 2 and 7 mm. The smaller ends of these instruments provide for atraumatic elevation of the interdental papilla making flap reflection more predictable and gentle to the tissues.

Once the tissue has been reflected, instruments such as the Minnesota retractor have been used to retract the tissue away from the surgical field while assuring visual access. Maintaining pressure on this instrument for even a short period of time often causes restriction of blood flow to the fingers of the operator and its use can be quite uncomfortable. A series of six retractors (JEDMED Instrument Company) (Fig. 22) offering a variety of serrated contact surfaces that are flat, notched, and recessed have been introduced to allow the operator several options for secure placement in areas of anatomical concern. Among these are placements over the nasal spine, canine eminence, and mental nerve. The blades of the retractors are designed

**Fig. 22. Blade and contact surfaces of the Rubinstein Retractors 1-6.**

**Fig. 23. Impact Air 45™ and surgical length bur in close proximity to the mental nerve × 8.**

to retract both the flap and the lip and are bent at 110° to keep the retractor and operators hand out of the light path of the microscope. The handles are ergonomically designed to decrease cramping and fatigue and can be held in a variety of grips. A seventh retractor offering universal positioning has recently been introduced.

Because the SOM enhances vision, bone removal can be more conservative. Handpieces such as the Impact Air 45™ (SybronEndo), introduced by oral surgeons to facilitate sectioning mandibular third molars, are also suggested for apical surgery to gain better access to the apices of maxillary and mandibular molars. When using the handpiece, the water spray is aimed directly into the surgical field but the air stream is ejected out through the back of the handpiece, thus eliminating much of the splatter that occurs with conventional high-speed handpieces. Because there is no pressurized air or water, the chances of producing pyemia and emphysema are significantly reduced.

Burs such as Lindemann bone cutters (Brasseler USA, Savannah, GA, USA) are extremely efficient and are recommended for hard-tissue removal. They are 9 mm in length and have only four flutes, which result in less clogging. With the use of an SOM, the Impact Air 45™ and high-speed surgical burs can be placed even in areas of anatomical jeopardy with a high degree of confidence and accuracy (Fig. 23).

With the SOM, periapical curettage is facilitated because bony margins can be scrutinized for completeness of tissue removal. A Columbia 13-14 curette is recommended in small crypts because it is curved and can reach the lingual aspect of a root. After the Columbia 13-14 is used, the Jacquette 34/35 scaler is recommended to remove the remainder of the granulomatous tissue. Because of its sharp edge, the Jacquette 34/35 is an excellent instrument for removing granulomatous tissue from the junction of the cemental root surface and the bony crypt. The more the tissue that can be removed the less the work for the body to do relative to wound healing.

There is agreement that the main cause of failure in conventional endodontic treatment is the clinician's inability to adequately clean, shape, and obturate the entire root canal system (39). As stated previously, the majority of this uncleaned anatomy is located in the apical 3 mm (8, 9, 10) and for this reason a 3 mm resection is recommended. With the introduction of ultrasonics for creating root-end preparations, a second reason for a 3 mm resection has emerged. Layton et al. (40), Beling et al. (41), Min et al. (42), Morgan & Marshall (43), and Rainwater et al. (44) have studied the incidence of craze line, cracks and fractures in the root and cemental surfaces after ultrasonic root-end preparations. While all of these studies showed a statistically significant increase, none has shown any clinical significance as a result of their findings. Inasmuch as the greatest cross-sectional diameter of a root in the apical 6 mm is typically at the 3 mm level, this should be the location of the resection in order to create an adequate buffer or cushion to absorb the potential deleterious effects of ultrasonic energy.

Traditionally, a long bevel was created in order to provide access for a microhead handpiece. With the introduction of periapical ultrasonics, little to no bevel is needed. This results in fewer cut dentinal tubules and less chance of leakage.

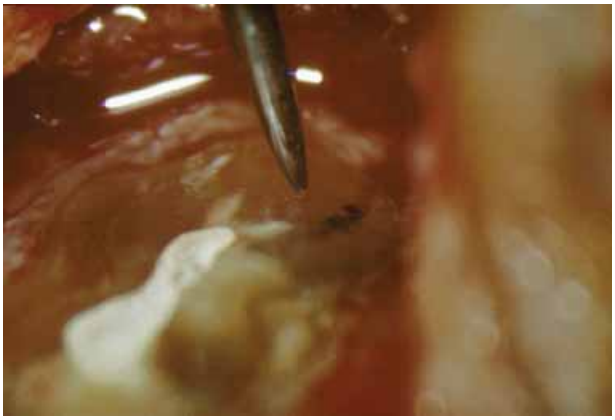

**Fig. 24. CX-1 explorer locating an untreated portal of exit on the bevelled surface of a previously retrofilled root at × 20.**

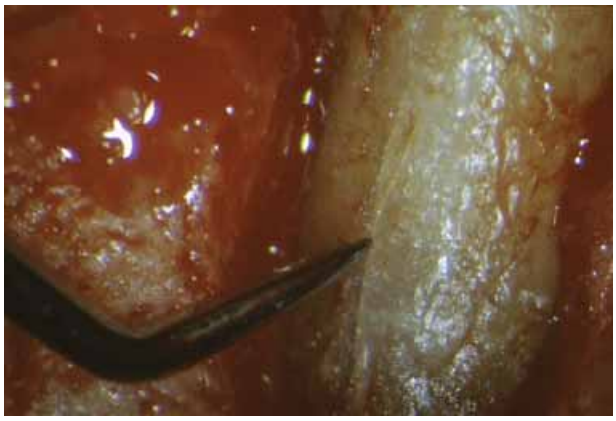

**Fig. 25. CX-1 explorer locating a crack on the facial surface of a root at × 20.**

**Fig. 26. Thermoplasticized gutta-percha spinning around a stainless-steel tip at × 16.**

After the root-end resection has been completed, the bevelled surface of the root can be examined under mid-range magnification. Using a small CX-1 micro explorer (SybronEndo), small micro fractures, isthmuses, and POEs can readily be seen (Figs 24 and 25).

Since the introduction of ultrasonic technology in the early 1990s by Carr (27), apical preparations have been made with ultrasonic tips. These tips are driven by a variety of commercially available ultrasonic units, which are self-tuning regardless of changes in tip or load, for maximum stability during operation. A piezoelectric crystal made of quartz or ceramic located in the handpiece is vibrated at 28 000–40 000 cycles per second and the energy is transferred to the ultrasonic tip in a single plane. Dentin is then abraded microscopically and gutta-percha is thermoplasticized. Continuous irrigation along the tip cools the cutting surface while maximizing debridement and cleaning.

Since their initial introduction, a variety of tips and tip configurations have been introduced to accommodate virtually any access situation. Most ultrasonic tips are 0.25 mm in diameter and approximately 3 mm in length. When used, they are placed in the long axis of the root so that the walls of the preparation will be parallel and encompass about 3 mm of the apical morphology. As the piezoelectric crystal in the handpiece is activated, the energy is transferred to the ultrasonic tip, which then moves forward and backward and dentin is 'brush cut' away in gentle strokes. The combination of the SOM and ultrasonic tips makes previously challenging cases routine. By combining magnification and ultrasonic technology, apical preparation can be visualized and executed with a high level of confidence that was previously unattainable.

Brent et al. (45) studied the incidence of intradentin and canal cracks in apical preparations made with stainless-steel and diamond-coated ultrasonic tips. They found that diamond-coated tips do not result in significant root-end cracking and can remove cracks caused by prior instruments. For this reason, diamond-coated tips are suggested as the last ultrasonic tip to be used in root-end preparation. Furthermore, clinical use of diamond tips has shown that they are more efficient at removing gutta-percha when compared with stainless-steel tips. The irregular surface of the diamond coating appears to grab and hold the gutta-percha facilitating removal. When using smooth-surfaced ultrasonic tips, the gutta-percha just spins on the smooth surface making removal difficult (Figs 26 and 27).

When using ultrasonic tips, the clinician should use gentle brush strokes with the smallest tip possible to

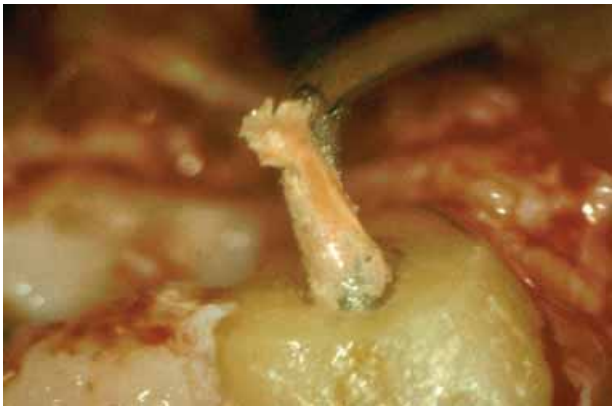

**Fig. 27. Thermoplasticized gutta-percha 'walking' out of the preparation at × 16.**

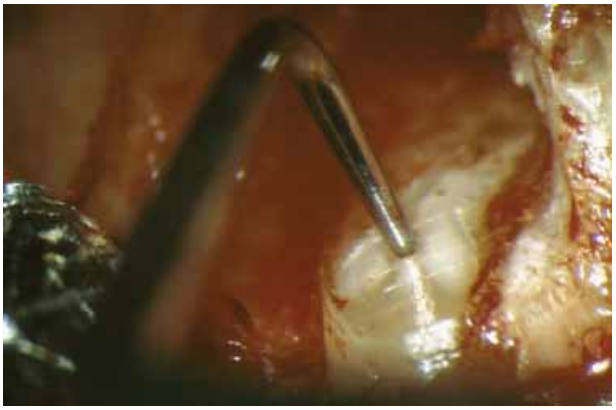

**Fig. 28. Off-axis angulation with an ultrasonic tip at × 16.**

conserve root dentin. This procedure should be observed while using mid-range magnification of the SOM. Pressure on the tip should be gentle. If resistance is met, it is assumed that the tip is lingually verted. The operator should then back off to low-range magnification to verify whether the tip is in the long axis of the root. If this step is not taken and a lingually verted path is continued, a perforation of the root might occur (Fig. 28).

There have been no clear guidelines on how to make the apical preparation until recently. Gilheany et al. (46) studied the angle of the bevel and the depth of the preparation from the facial wall necessary to affect an adequate apical seal. They reported that a 1 mm preparation was necessary with a 0° bevel, a 2.1 mm preparation was necessary with a 30° bevel, and a 2.5 mm preparation was necessary with a 45° bevel. They further recommended a 3.5 mm deep preparation when measured radiographically to account for errors

**Fig. 29. Zinni ENT micromirrors.**

in vertical angulation. This study raised the question as to whether preparation of an isthmus, which is so common (8, 9, 10), should be treated differently than the preparation of the main canals. Clearly, to satisfy the criteria set forth by Gilheany et al. (46), a 3 mm circumferential preparation in the long axis of the root, which includes all the anatomical ramifications of the pulp space including the isthmus, must be prepared and cleaned.

Another development in apical microsurgery has been the introduction of the surgical micro-mirror. Among the early pioneers of micro-mirrors was Dr Carlo Zinni, an otorhinolaryngologist from Parma, Italy (47). Being an early user of the microscope, Zinni recognized the need to view the pharynx and larynx indirectly for proper diagnosis. Zinni crafted the first polished stainless steel mirrors from which the early endodontic micro-mirrors were developed (Fig. 29).

Micro-mirrors come in a variety of shapes and sizes, and have diameters ranging from 1 to 5 mm. There have been many surfaces used on micro-mirrors. Among them have been polished stainless-steel, polished tungsten carbide, and diamond-like coating. Recently introduced micro-mirrors have a rhodium coating. Rhodium is extremely hard and durable and is unsurpassed in reflectivity, clarity, and brightness. They are front surface, scratch resistant, and autoclavable (JEDMED Instrument Company) (Fig. 30). Using the SOM, it is now possible to look up into the apical preparation to check for completeness of tissue removal. Before using micro-mirrors, it was impossible to assess the thoroughness of apical preparation. Failure to completely remove old root canal-filling material and debris from the facial wall of the apical preparation (Fig.

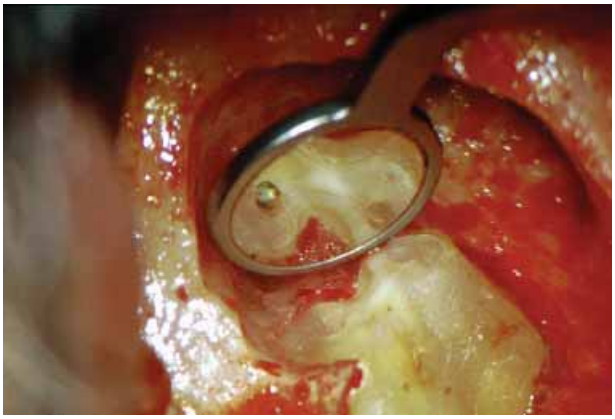

**Fig. 30. Rhodium micro-mirror view of the bevelled surface of the root at × 13.**

**Fig. 31. Micro-mirror view of gutta-percha and debris on the facial wall of the apical preparation at × 16.**

31) may amount to facial wall leakage and eventual failure if not cleaned before placement of an apical restoration.

Debris can be removed from the facial wall by capturing the maximum cushion of thermoplasticized gutta-percha with a small plugger (Fig. 32) and compacting it coronally. A variety of small pluggers ranging in diameters from .25 mm to .75 mm are available for this purpose. Facial wall debris can further be addressed by removal with a back action ultrasonic tip. Virtually all modern-day ultrasonic tips have some degree of back action in their design. This angle can vary between 70° and 80°.

Once the apical preparation has been examined, it should be rinsed and dried. Traditionally, apical preparations were dried with paper points before placing retrofilling materials. This allowed for thorough adaptation of retrofilling materials against the walls of the cavity preparation and decreased the

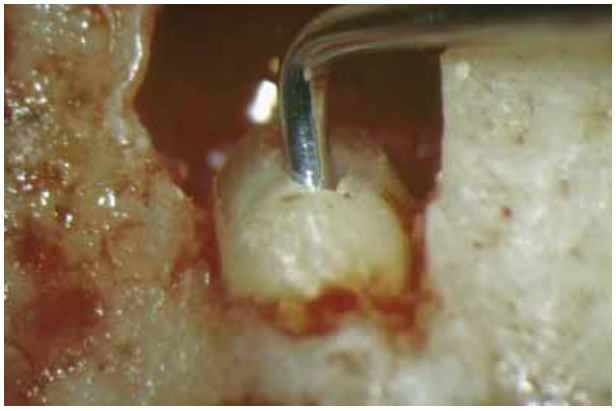

**Fig. 32. Compacting thermoplasticized gutta-percha away from the facial and compressing it coronally at × 16.**

chances of creating material voids. Microcontrol of air and water is now accomplished by using a small blunt irrigating needle (Ultradent Products Inc, South Jordan, UT, USA) mounted on a Stropko Irrigator (SybronEndo). The irrigator fits over a triflow syringe and allows for the directional microcontrol of air and water (Fig. 33). Air pressure can be regulated down to 4 psi. Now the bevelled root surface and the apical preparation can be completely rinsed and dried before inspection with micro-surgical mirrors. Anatomical complexities, isthmuses, and tissue remnants are more easily seen when the cut surfaces are thoroughly rinsed and desiccated (Fig. 34).

After the apical preparation is rinsed and dried, retrofilling materials such as SuperEBA™ (Harry J. Bosworth Co, Skokie, IL, USA) and ProRoot™ MTA (Dentsply Tulsa Dental, Tulsa, OK, USA) are placed into the apical preparation. The clinician should select instruments and carriers that allow for direct observation of placement to observe the material's performance as it is placed into the apical preparation. Cement consistency retrofilling materials, such as SuperEBA™, are mixed to a putty consistency and carried to the apical preparation in small truncated cones 1–2 mm in size on a #12 spoon excavator (Fig. 35). The cross-sectional diameter of this instrument is 1 mm and, therefore, does not block the visual access to the apical preparation. The tip of the cone reaches the base of the preparation as the sides of the cone contact the walls. Between each aliquot of material, a small plugger (JEDMED Instrument Company) that will fit inside the apical preparation is used to compact the SuperEBA™ (Fig. 36). Additional aliquots of material

**Fig. 33. Stropko Irrigator with an attached blunt irrigating needle.**

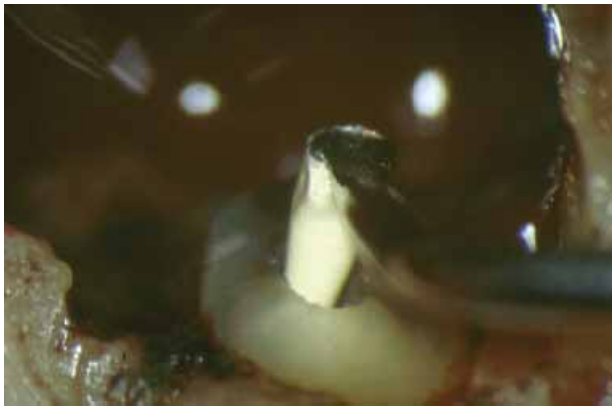

**Fig. 35. Placing SuperEBA™ into the apical preparation with a #12 spoon excavator at × 16.**

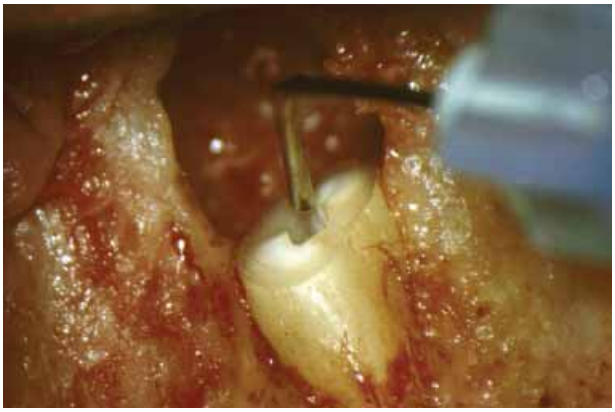

**Fig. 34. Blue Micro Tip™ drying the apical preparation at × 13. Note the chalky dry bevelled surface.**

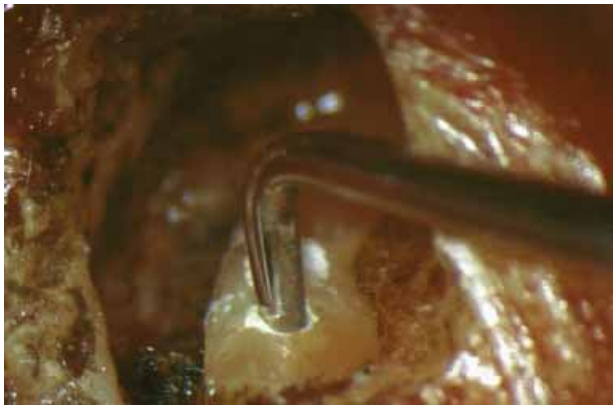

**Fig. 36. Plugging SuperEBA™ into the apical preparation with a small plugger at × 16.**

are added and condensed until there is a slight excess mound of material on the bevelled surface of the root. Final compaction is accomplished with a ball burnisher. When the cement has set, a finishing bur or smooth diamond is used to finish the retrofilling. After the SuperEBA™ has been finished, a CX-1 explorer is used under high magnification to check for marginal integrity and adaptation. Final examination of the retrofilling is performed after the surface has been dried with a Stropko Irrigator, because it is more accurate to check the margins of the preparation when the bevelled surface of the root is dry (Fig. 37).

Materials such as ProRoot™ MTA are best delivered to the apical preparation with a carrier-based system. The problems with carriers in the past were that the diameters were too large to fit into the apical preparation, bends were inadequate, and they plugged easily. The recently introduced Micro Apical Placement System (MAP) (Roydent, Johnson City, TN, USA) (Fig. 38) addressed these problems. This system consists of several delivery tips with cross-sectional diameters ranging from 0.9 mm for small preparations to 1.5 mm for use in immature roots. The plungers are made of a PEEK material, which has a coating similar to Teflon™ and therefore retrofilling materials will not stick to the surface. The PEEK plunger can easily navigate a triple-bended carrier. When in use, the carriers should not be packed too tightly and gentle pressure should be used to express the material. The carriers should be disassembled and cleaned immediately after use.

When placing ProRoot™ MTA select a carrier that will fit into the apical preparation (Fig. 39). This will avoid spilling material into the bony crypt. ProRoot™ MTA is then compacted with small pluggers that will fit into the apical preparation to assure thorough compaction and less chance of leakage. As ProRoot™ MTA is cohesive to itself but only slightly adhesive to the walls

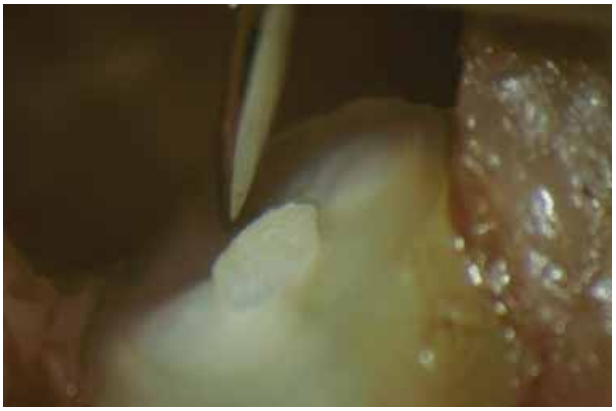

**Fig. 37. Checking for marginal integrity with a CX-1 explorer at × 20.**

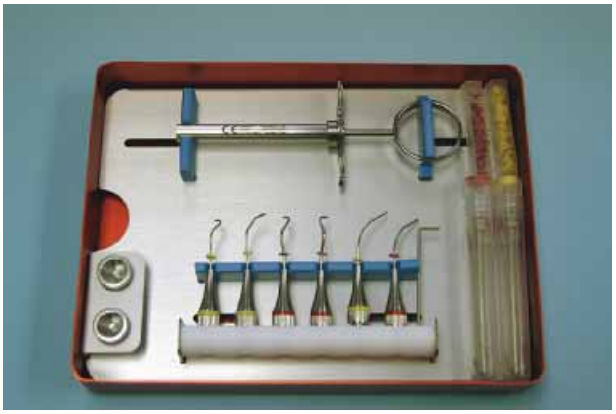

**Fig. 38. Micro apical placement system.**

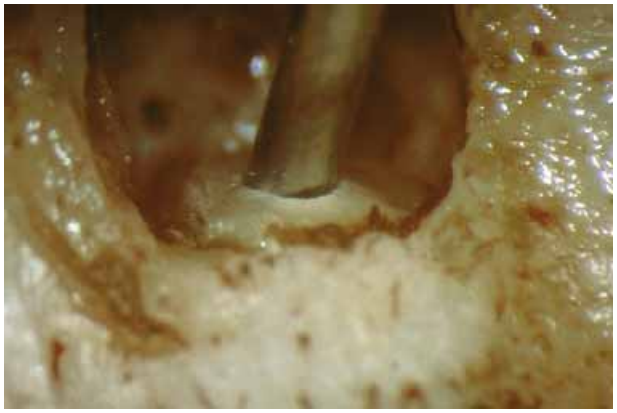

**Fig. 39. Micro apical placement carrier placed inside the apical preparation at × 16.**

**Fig. 40. ProRoot™ MTA being pulled out of the apical preparation at × 16.**

of the preparation, care must be taken to avoid pulling the material out of the preparation (Fig. 40). Gentle teasing and wiping of the material along the walls of the preparation will assure its complete placement.

The ProRoot™ MTA retrofilling is finished by wiping the bevelled surface with a moist cotton pellet. Visual inspection at mid-range magnification is used to check for any remaining cotton fibrils and also to check for marginal integrity.

Emphasis has been placed on using small pluggers. However, when apical surgery involves immature roots using small-diameter pluggers to condense retrofilling materials can be inefficient and may waste considerable time. JEDMED recently introduced three new pluggers. These pluggers incorporate 60° and 90° angles and cross-sectional diameters of 1.5, 2.0, and a 1 mm ball that address these needs (Fig. 41). The combination of using a large 1.5 mm diameter MAP carrier and a large-diameter plugger provides efficient retrofilling of apical preparations made in immature roots.

After the bony crypt has been examined under mid-range magnification to assure it is free from debris, the completed case is documented with digital radiographs and clinical images. These images are saved along with any images that were captured during the surgical procedure, and are used for reporting and review with the patient.

The final stage of apical surgery is tissue repositioning and suturing. As stated previously, basic single interrupted stitch suturing can be performed with little to no magnification. Interproximal suturing and navigating around tight embrasures and alveolar bone can be very difficult and cumbersome especially when one tries to use the SOM and indirect vision with mouth mirrors. Conversely, more advanced suturing techniques such as the papilla-base incision require multiple small sutures per papillae and make visualization with the SOM mandatory.

**Fig. 41. Comparison between micro and macro pluggers.**

The key to suture removal is in the healing of the epithelium. Harrison & Jurosky (48) reported that a thin epithelial seal was established in the horizontal wound at 24 h and a multilayered epithelial seal was established in the vertical incisional wound between 24 and 48 h. The SOM can be used to facilitate suture removal at low-range magnification. Microsurgical scissors and tweezers should be used to cut and remove the sutures. Care should be exercised during removal so as not to damage the suture site.

## Does apical microsurgery really make a difference?

The SOM was originally introduced as a surgical tool. Almost immediately after its introduction many clinicians realized its benefit in conventional treatment and non-surgical retreatment. Consequently, many instruments and devices were developed for use in disassembly, post removal, and removal of separated instruments.

Gorni & Gagliani (49) reported the outcome of 452 non-surgical retreatment cases 2 years after treatment. The range of magnification used during treatment of the cases was × 3.5– × 5.5. They reported a success rate of 47% when the root canal morphology had been altered, and a success rate of 86.8% when the root canal morphology was respected. The overall success rate reported was 69%. A difficult question to answer when considering a non-surgical versus a surgical approach is whether the clinician can readdress the original biology of the case. This question may be impossible to answer without actually re-entering the case and possibly rendering the tooth non-restorable after disassembly. Considering this possible outcome, apical microsurgery may have been a better approach.

As mentioned previously, Frank et al. (3) reported that a success rate in apical surgeries sealed with amalgam, which had been considered successful, dropped to 57.7% after 10 years. Friedman et al. (50) reported successful treatment results as 44.1% in 136 premolar and molar roots that were observed over a period of 6 months to 8 years. In a randomized study, Kvist & Reit (51) compared the results of surgically and non-surgically treated cases. They could find no systematic difference in the outcome of treatment, which ranged in success from 56% to 60%. These studies all used a traditional surgical protocol without the benefit of an SOM and microsurgical armamentarium.

Rubinstein & Kim (52, 53) reported the short-term and long-term success rate for apical surgery using the SOM and SuperEBA™ as retrofilling material as 96.8% and 91.5%, respectively. The rate of heal independent of lesion size was 7.2 months. Unlike most early surgical studies (54–59), which reported the pooled results of multiple clinicians, and consisted mostly of anterior teeth, 60% of the cases reported consisted of premolar and molar teeth.

Several recent studies (60–65) have demonstrated a favorable outcome of apical surgery performed with ultrasonic technology similar to that used by Rubinstein & Kim (52, 53). However, none of these studies used the SOM. Furthermore, the follow-up periods in these studies were considerably shorter. However, because of variations in treatment and evaluation methods, direct comparisons with the cited studies cannot be made.

Although it is impossible to state whether the unusually high success rate reported (52, 53) resulted from the microsurgical technique and use of the SOM or the SuperEBA™ material, it is the clinical impression of the author that it is both the technique and the material with the emphasis on the technique. What is clear is that clinicians who use the SOM and microsurgical armamentarium now possess the necessary magnification, illumination, armamentarium, and subsequent precision to perform apical surgery at the highest level of care.

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# Soft tissue management: flap design, incision, tissue elevation, and tissue retraction

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The ultimate goal in surgical endodontics is not only the eradication of periapical pathosis but also preservation of periodontal conditions using suitable surgical techniques. Acceptable treatment outcomes are no longer possible without consideration of esthetic consequences for all involved dentoalveolar structures. During surgical endodontics the cortical bone is exposed by incising, elevating, and reflecting a full-thickness tissue flap. Certain basic principles must be considered before deciding on the type of incision and flap design. Thorough knowledge of regional anatomical structures in conjunction, as well as prevailing periodontal conditions affect and must be considered when making the proper decision on how and where to reflect the mucoperiosteal tissues. Various modes of incision can be selected, including horizontal, sulcular, submarginal, and vertical releasing incisions. The variety of flaps reflects the number of variables to be considered before choosing an appropriate flap design. While many flap designs have been suggested over the years, some have become obsolete and new techniques have emerged. It is critical that incisions and tissue elevations and reflections are performed in a way that facilitates healing by primary intention. This can be obtained by complete and sharp incision avoiding severing or traumatizing the tissues during elevation; it is equally important to prevent drying of tissue remnants on the root surface and drying of the flap during the procedure. The introduction of microsurgery to surgical endodontics attempts to minimize trauma and to enhance surgical results. Because of the combination of magnification and more delicate instruments, improved and careful tissue handling has become possible. Additional improvements in flap design and soft tissue manipulation are considered key elements in enhanced biological and esthetic outcomes of marginal soft tissues.

## Introduction

Endodontic pathosis not responding to non-surgical re-treatment may be eliminated with surgical intervention (1, 2). The goal of surgical therapy is to provide conditions that are such that healing and repair can take place. Treatment involves removal of necrotic material, tissue break-down products, reduction, and/or elimination of infection from the root canal system, followed by a fluid-tight seal of the apical portion of the root canal with a biocompatible material (3). Although the prognosis in the literature varies widely (4), the success rate for surgical endodontics has reached fairly high levels in recent years (5, 6). This is partly because of improved fulfillment of treatment principles and surgical techniques (7, 8).

The assessment of treatment outcomes is mostly based on evaluation of clinical and radiographic criteria of healing of the periradicular tissues. Periodontal conditions, as a contributing factor in relation to postoperative success, have not been addressed extensively. Jansson et al. (9) studied the relationship between apical and marginal healing after periradicular surgery. They found persisting endodontic infection as a contributing risk factor for progressing marginal attachment loss following periradicular surgery. Ehnevid et al. (10) also reported impaired periodontal healing in teeth with periapical lesions.

The ultimate goal in modern dentistry is not only the eradication of any pathological process associated with a specific tooth and repair of the involved components but also regeneration of lost tissues because of pathosis

as well as conservation and achievement of 'white' and 'pink' esthetics, in particular, in the more visible anterior jaw (11). 'White esthetics' refers to natural crown structures, or tooth-colored restorations of teeth with suitable materials. With restorative modalities, it is possible to obtain results, that come very close to the natural look of teeth (12). Likewise, 'pink esthetics' refers to soft tissues and underlying bone, which are equally important for an optimal esthetic result.

Management of the periodontium with suitable surgical and reconstructive techniques followed by long-term maintenance of the results are a great challenge in modern dentistry. The objective of preserving the dentition is no longer acceptable without consideration of esthetic consequences for all involved dento-alveolar structures (13).

The present article will address the tissue flap design and the manipulation used to gain access to the underlining bone covering the roots, which are to be treated surgically. Emphasis will be placed on the considerations of classical and modern soft tissue treatment modalities in order to fulfill the current functional and esthetic requirements.


**Fig. 1. Anatomy of a healthy gingival situation. IP, interdental papilla; CMG, cervical marginal gingiva with free marginal gingiva; AG, attached gingiva; MGJ, mucogingival junction; AM, alveolar mucosa.**

## Biology of the gingiva

The gingiva is one of four components of the periodontium, which further comprises of periodontal ligament, alveolar bone, and cementum. Each of these structures is distinct in its location and tissue architecture, but they function together as a single unit. One component in a certain periodontal compartment can influence the status of the adjacent structures. Consequently, pathological changes and injuries in one area of the periodontium will have a marked effect on the repair or regeneration of the adjacent periodontal structures.

Anatomically, the extension of the gingiva reaches from the papilla to the mucogingival junction, where it joins the alveolar mucosa. It attaches to the cementum of the teeth and to the alveolar process (11, 14). The gingiva is divided into three areas, namely free marginal gingiva, papilla, and attached gingiva (Fig. 1). Histologically, gingiva consists of superficial epithelial structures covering underlining connective tissue. The attachment of the gingival tissues to the tooth comprises of junctional epithelium attachment, averaging 0.97 mm, and a connective tissue attachment of 1.07 mm or in sum approximately 2 mm; this dimension is called the biologic width.

The papilla displays two peaks connected with a concave depression termed col. A papilla contains both non-keratinized sulcular and col epithelium as well as keratinized oral epithelium (14–16). The col area consists of a squamous stratified non-keratinized epithelium.

### Gingival epithelium

The gingival epithelium can be divided into three different types based on their location and composition (14) (Fig. 2). The oral epithelium extends from the mucogingival junction to the tip of the gingival crest. The sulcular epithelium is located between the gingival crest and the most coronal portion of the junctional epithelium. The junctional epithelium extends from the base of the gingival sulcus to a level approximately 2 mm coronal from the alveolar bony crest. In a healthy situation without attachment loss, the junctional epithelium reaches the cemento-enamel junction. The junctional epithelium is closely adapted to the tooth surface to fulfill sealing and attachment functions.

### Oral gingival epithelium

The oral epithelium is a stratified squamous keratinized epithelium, and four different cell layers can be identified (Fig. 3). The cells of the stratum basale lie in close contact with the basement membrane, which

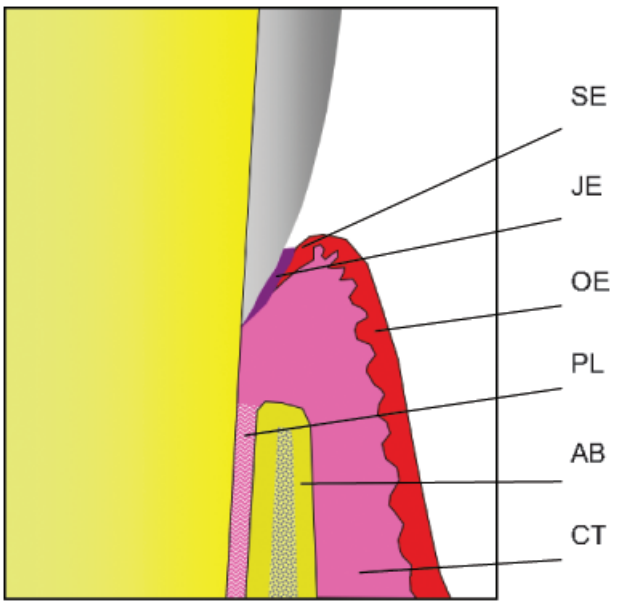


**Fig. 2. Schematic drawing of gingival histology; SE, sulcular epithelium; JE, junctional epithelium; OE, oral epithelium; PL, periodontal ligament; AB, alveolar bone; CT, connective tissue.**

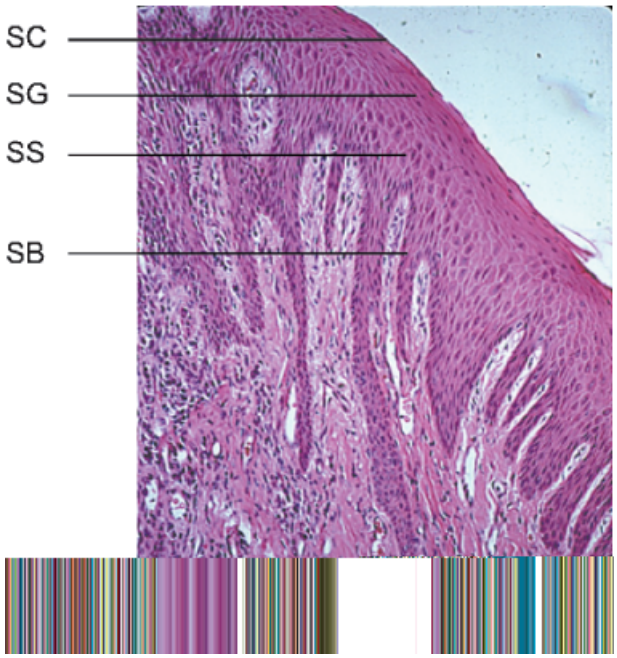


**Fig. 3. Histology of the gingival epithelium/connective tissue interface. SB, stratum basale; SS stratum spinosum, SG, stratum granulosum; SC, stratum corneum. Note the marked extensions and depressions forming the rete ridges (courtesy Dr J. Gutmann).**

separates the epithelium from the subjacent connective tissue. These rather small cells multiply continuously and as they mature into keratinizing cells, they form the stratum spinosum. The cells of the spinous layer are largest in size and form the thickest layer of all epithelial cells. Closer to the surface, the cells become flattened (stratum granulosum), whereas in the most superficial layer (stratum corneum) the cells are flat and closely aligned, often without nuclei.

The oral epithelium also contains Langerhans cells, also known as dendritic cells; they are mostly located in the stratum spinosum. These cells play an important role during the inflammation process as they bind and process antigens to the local lymph nodes and present them to macrophages and lymphocytes (17). Generally speaking, the oral epithelium, which is between 0.2 and 0.3 mm in thickness, has a largely protective function (18).

## Oral sulcular epithelium

The sulcular epithelium makes up the lining of a gingival sulcus. A healthy sulcus extends to a depth of 0.5 mm. The sulcular epithelium is structurally similar to the oral epithelium. The epithelial/connective tissue interface in the sulcus area forms rete pegs, which become elongated when inflammation is present. In contrast to the junctional epithelium, the sulcular epithelium is less permeable and not extensively infiltrated by polymorphonuclear leukocytes. It has mostly protective functions.

## Junctional epithelium

The junctional epithelium is distinctly different from sulcular and oral epithelium in both its origin and structure. In its most apical portion, the junctional epithelium forms but few cell layers. The thickness of the junctional epithelium increases gradually to 15–30 layers at the border to the sulcular epithelium. The cells of the stratum basale multiply rapidly and the reproduced cells tend to align themselves parallel to the long axis of the tooth and exfoliate into the gingival sulcus. The interface between the junctional epithelium and connective tissue is almost straight. Migrating polymorphonuclear leukocytes are present throughout the junctional epithelium. This migration process increases considerably during the development of an inflammatory process. In addition to polymorphonuclear leukocytes, T lymphocytes are then present (19).

In contrast to other oral epithelia, where cells are in close apposition to each other and little extracellular space exists, the junctional epithelium displays gaps between cells. These gaps are presumably responsible for the permeability of the junctional epithelium. The intercellular matrix not only functions as an adhesive between cells but also aids adhesion to tooth surfaces and to the basement membrane separating the epithelium and the connective tissue. Moreover, the intercellular matrix plays an important role in regulating diffusion of water, nutrients, and toxic materials through the epithelium (20, 21).

The junctional epithelium is responsible for the formation of the epithelial attachment to the tooth surface. Likewise, it provides a barrier and communicates aspects of host defense against bacterial infection (22). Epithelial cells have been recognized as metabolically active and capable of reacting to external stimuli by synthesizing a number of cytokines, growth factors, and enzymes (14, 23, 24).

## Gingival connective tissue

Fibroblasts, another major cellular component of connective tissue, are of mesenchymal origin; they rarely form cell-to-cell contacts but rather attach to the surrounding matrix of collagens and other glycoproteins. Fibroblasts synthesize the extracellular matrix of connective tissue and take part in the regulatory process; they may respond to a variety of stimulants through production of cytokines, enzymes, enzyme inhibitors, or matrix macromolecules. These enzymes allow the regulation of matrix degradation for remodeling or turnover purposes (25). Accordingly, fibroblasts are sensitive to changes in the matrix, growth factors, or cytokines. In case of an injury they are able to chemotactically migrate and attach to various substrates. Once at the site of the trauma, fibroblasts commence matrix synthesis.

The major component of the matrix are collagenous proteins. The collagen fibers are organized in a distinct architectural pattern. They have been classified according to their location, origin and insertion, such as dentoalveolar, transgingival, interseptal, circular fibers, etc. Connective tissue consists of 55–60% supragingival fibers, which attach gingiva to teeth and provide the basis for its firmness and biomechanical resistance during mastication (14).

## Gingival changes during inflammation

Although bacteria are the most common cause of disease induction, a critical part of early inflammation is the manner in which the gingival epithelium not only act as a barrier, but also initiates the first critical signals of a bacterial assault to the underlying connective tissues. The junctional epithelium is particularly involved in the initial phase of the inflammatory process. When dental plaque has accumulated, epithelial permeability is important in initiating cellular signaling events. Epithelial cells are also capable of producing a number of substances, which have the potential to attract neutrophils to help battle buildup of bacteria. At the same time, the intercellular spaces begin to widen and serve as a primary pathway for inflammatory exudates to the gingival sulcus. Likewise, molecules from the external surface can penetrate toward the connective tissue. This response is restricted to the junctional epithelium only.

Once this high level of infiltration persists because of continuous plaque accumulation, the rapid turnover of junctional epithelium cells is insufficient to retain health and a process of ongoing tissue damage is established. Following neutrophil migration and activation of macrophages and lymphocytes within the connective tissue, cells of the basal layer are capable of producing collagenases, which can degrade the underlying collagen. The junctional epithelium then starts to migrate in an apical direction, resulting in the formation of a periodontal pocket (26).

Connective tissue destruction can be observed as early as 3–4 days after plaque accumulation (27). Within the foci of inflammation, polymorphonuclear lymphocytes and macrophages are the cells mainly responsible for collagen fiber destruction. In many cases, the inflammatory response remains contained within the gingival tissues; in this sense, the gingiva has a protective role. The vascular response to the inflammatory process is a marked increase in the number and the size of capillary loops in the connective tissue just adjacent to the junctional epithelium. A specific feature of the endothelial-lined venules is their facilitation of polymorphonuclear leukocyte migration rather than lymphocyte migration. A variety of additional factors present in the local environment determine the activity of fibroblasts, affecting migration, adhesion, proliferation, and the matrix synthesis (28). A high level of interaction exists between neutrophils,

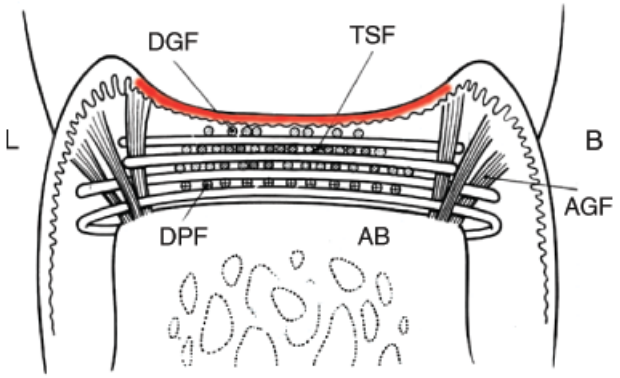


**Fig. 4. Schematic diagram of a cross-section of the interdental papilla. L, lingual; B, buccal, red area junctional epithelium; AB, alveolar bone; DGF, dentogingival fibers; TSF, transseptal fibers; DPF, dentoperiosteal fibers; AGF, alveolargingival fibers (courtesy Dr J. Gutmann).**

**Fig. 5. Schematic drawing of gingival blood vessels. Reprinted with permission from (77).**

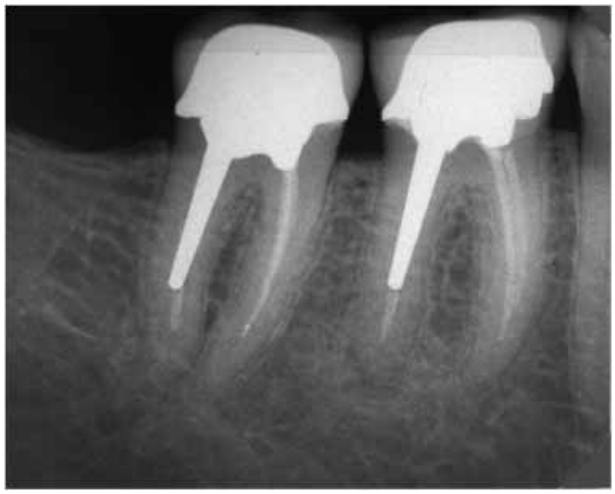

**Fig. 6. Dental radiograph of a first mandibular molar with a radiolucent lesion on the distal root. The mental foramen is not visible.**

lymphocytes, and fibroblasts. Numerous studies indicate that lymphocytes exert a significant cytotoxic effect on gingival fibroblasts either through the release of soluble mediators or via direct cell-to-cell contact (29). However, should the balance between bacteria and host defense shift unfavorably, uncontrolled tissue destruction can take place and the inflammation may expand deeper into the periodontal ligament and alveolar bone, resulting in attachment loss in conjunction with apical migration of the junctional epithelium.

## Anatomy

The gingival tissue reaches from the papilla to the mucogingival junction, where it joins the alveolar mucosa (11, 14). The height of the gingiva from the mucogingival junction to the gingival margin is highest on the labial aspect of the maxillary incisors and decreases in height in distal areas (30). The papilla, an esthetically and functionally an important structure, is the tissue between two adjacent teeth. It is considered to be roughly pyramidal and triangular in shape (31). The embrasure contor and the specific anatomy of adjacent crowns determine the shape of the papilla (14–16, 32). Depending on the width of neighboring crowns and contact point areas, the papilla has one, or for most teeth, two peaks – lingually and buccally, joined by a concave col (Fig. 4) (11, 15, 16, 33). In a mesio-distal direction, the midsection of the col slopes toward each tooth. On these slopes, the epithelium gradually changes its appearance toward the characteristics of the epithelial cuff (epithelial attachment). The width of the col between the buccal and lingual papilla and the depth of concavity in the col area increase gradually from anterior to posterior teeth (16).

The papilla usually fills the entire interproximal space between neighboring teeth. Tarnow and Magner (32) studied the factors influencing papilla height and found that the presence or absence of the interdental papilla depends upon the distance between the contact point and the crest of the bone. When the distance from the contact point to the bone measured 5 mm or less, the papilla was present almost 100% of the time. With a distance of 6 mm, the papilla was present 56% of the time, and when the distance measured 7 mm or more, the papilla was present 27% of the time or less.

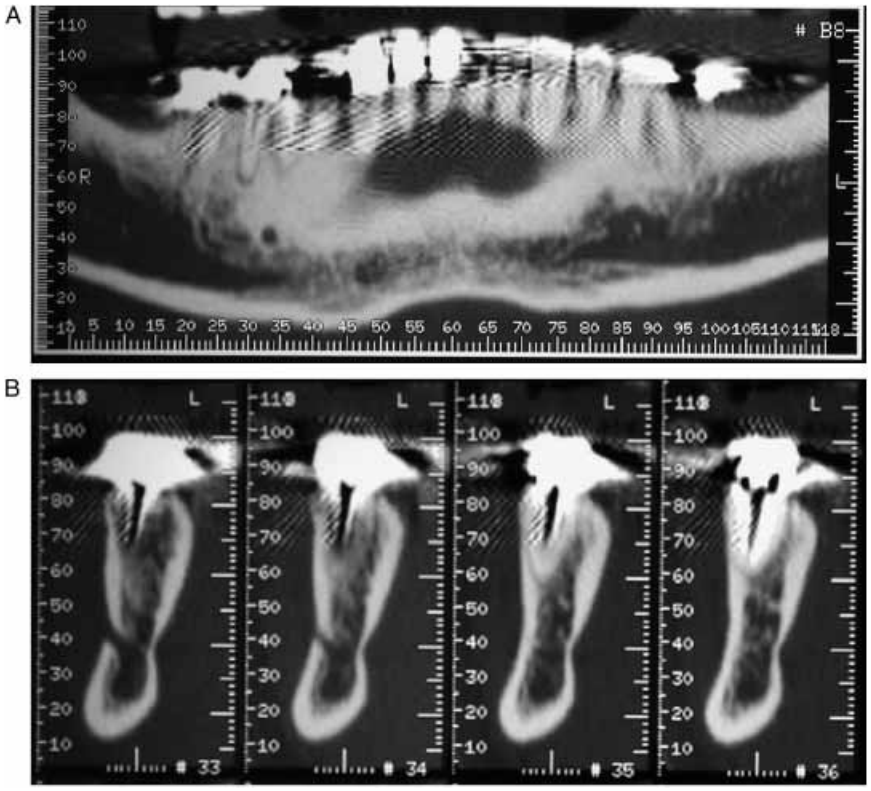


**Fig. 7. Computed tomography (CT) of the mandibular molar in Fig. 6. Overview (A) of the CT image, with numbers corresponding to the sections seen in B. note the unusual position of the mental foramen on the section #33, which is located between the mesial and distal root of the first molar.**

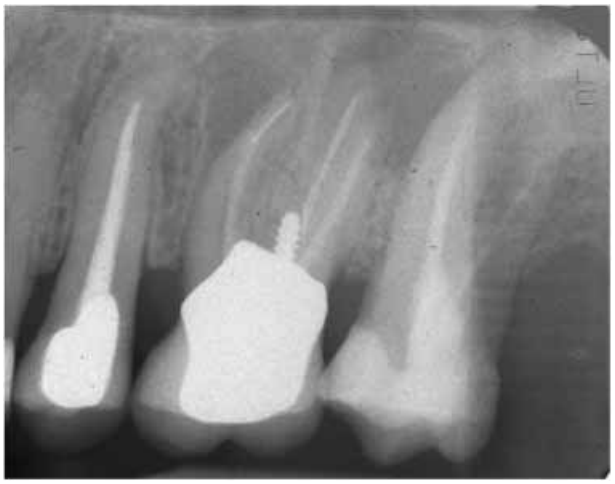

**Fig. 8. Radiograph of an extensive radiolucency involving the left maxillary molars. Note no signs of sinus extending to the roots or the lesion.**

**Fig. 9. Panoramic radiograph of the same patient as in Fig. 8. Note also no apparent interaction of the maxillary sinus with the apical pathosis.**

Another important anatomical consideration is the supply of blood vessels to alveolar mucosa and gingiva. There are four interconnected pathways of blood supply: the subepithelial capillaries of the gingiva and alveolar mucosa, the vascular network within the periosteum, the intraseptal arteries in the bone marrow, and the plexus of the periodontium. The periosteal and the periodontal plexus communicate directly through Volkmann's canals without participation of the vessels of the bone marrow; thus, unified histological responses to surgical wounding are observed (34) (Fig. 5). The gingiva and periosteum are blood supplied mainly through supraperiosteal vessels, which run roughly parallel to the teeth's long axis, branch, and

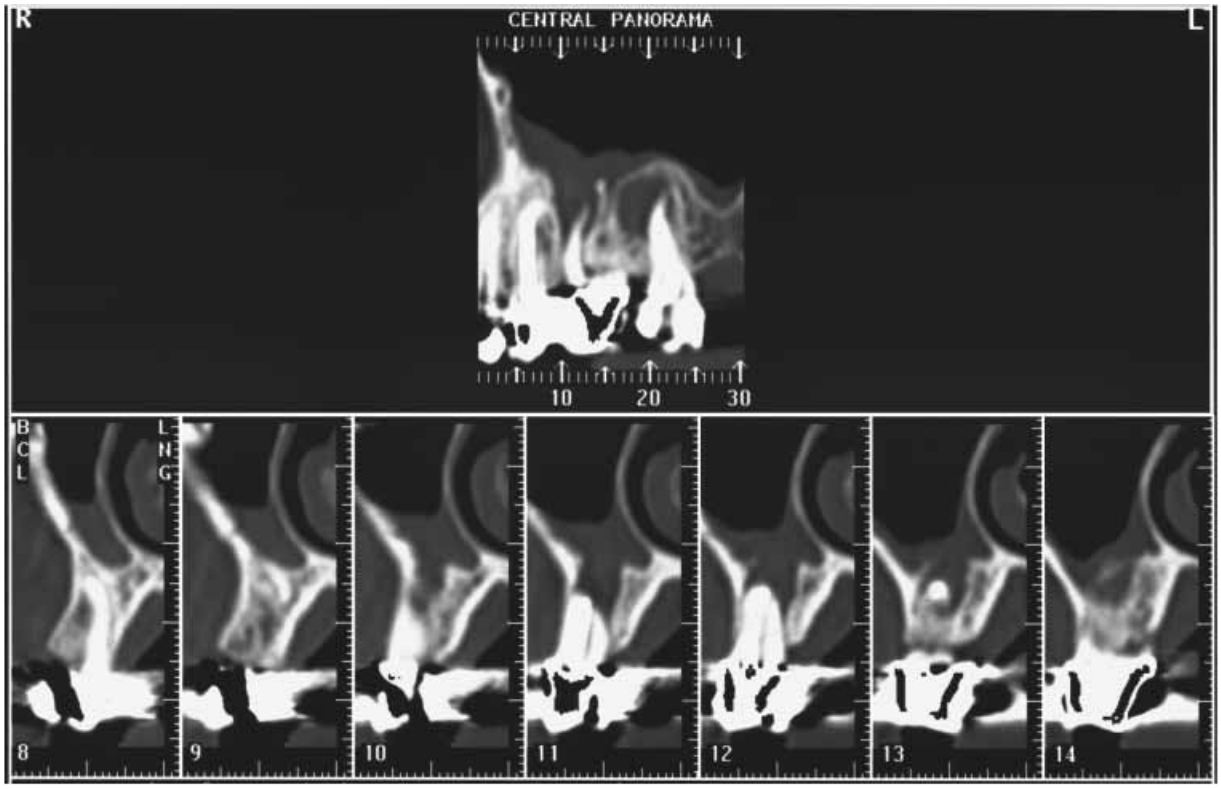


**Fig. 10. Computed tomography image from molars in Figs 8 and 9. Upper image represents the central panorama, with markers corresponding to specific sections below. Sections 10–13 show the mesiobuccal root of the left first molar. Open communication between the apical lesion and the sinus. The sinus membrane is considerably thicker in the basal portion.**

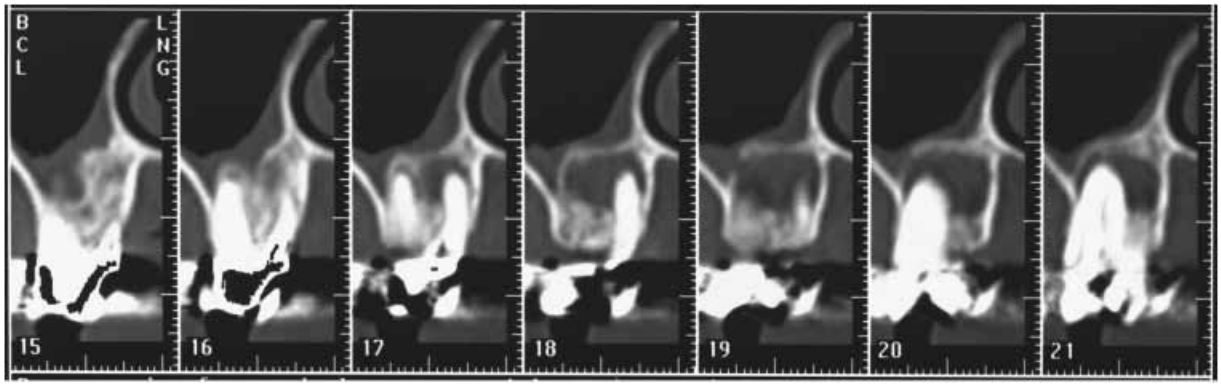


**Fig. 11. Computed tomography of the section imaging the distal and palatal root of the first molar from Figs 8 and 9. Sections 16 and 17 show a thin cortical bone layer and a recessus of sinus cavity interposing over the buccal root. The distal root is located further palatally behind this small sinus recessus and is covered with a thin layer of bone. The apical pathology over the distal root is completely surrounded by bone without direct contact to the sinus. Note the extensive palatal lesion.**

subdivide in the lamina propria of the gingiva and form the vascular network on the periosteum (34–36). To a lesser degree, rami perforantes of the intraseptal arteries penetrating the interdental bone and the periodontal ligament vessels supply the gingiva with blood, the vessels finally ending in loops termed the gingival plexus in the tips of connective tissue papillae (11, 14, 37–40). The multiple interconnections between different plexus through numerous anastomoses and collateral pathways of circulation establish adequate

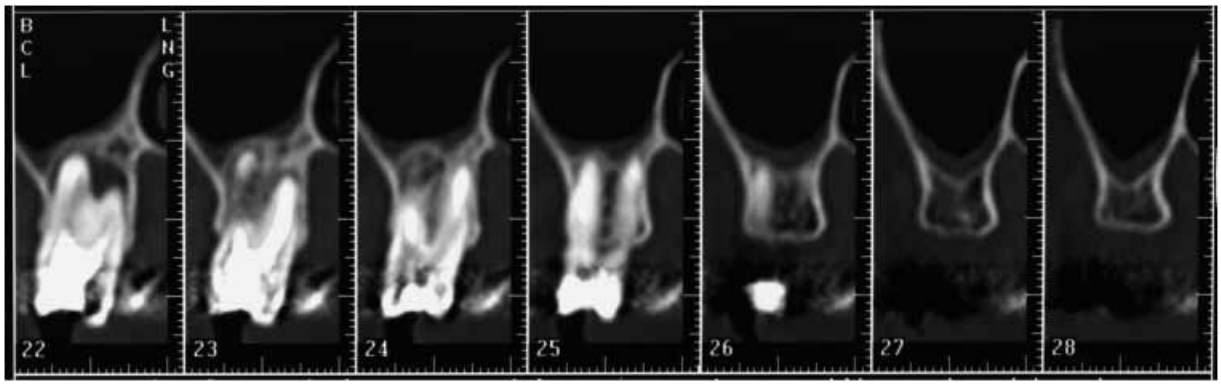


**Fig. 12. Computed tomography images for the second molar from Figs 8 and 9. Although the lesion is visible over the roots in sections 20–22 (Figs 11 and 12), the apical area of the second molar has no bony resorption and is intact (sections 23, 24). The lesion visible in the mentioned section is the extension of the apical lesion of the palatal process from the first molar.**

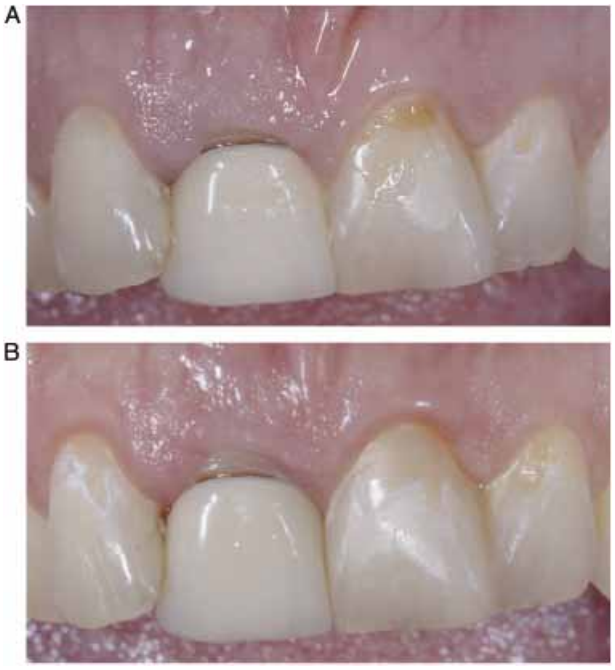


**Fig. 13. Recession following surgical procedure on an upper central incisor. (A) Preoperative situation. (B) Recall at 1 year. Note the retraction of the gingival margin and exposure of the root surface.**

blood supply, if single vessels are severed surgically (34–36, 39, 40).

## Access to the apical pathosis

Proper access to the pathological process is one of the prerequisites of any surgical procedure. Lesions of endodontic origin are generally located within bone surrounding the root(s). Consequently, during surgical endodontic treatment, bone is exposed by elevating and reflecting a full-thickness tissue flap, which consists of periosteum, gingival, and mucosal tissues. Certain basic principles must be considered before deciding on the type of incision and the flap design.

### Regional anatomical structures in relation to the pathological process

The location and path of the blood vessels and nerves should be evaluated, protected, and preserved during the surgical procedure. Besides the general knowledge of these structures, acknowledging their precise location is crucial in specific areas. When mandibular premolars or molars are involved in the surgical procedure, the protection of the neurovascular bundle in the mandible and mental foramen is of great importance. The mental foramen is generally located apically to the roots of mandibular premolars, but its location can vary. Dental radiographs do not show the mental foramen and the mandibular canal predictably (41). Klinge et al. (42) also assessed the detection of the mandibular canal in panoramic radiographs and tomography compared with the periapical radiographs. The incidence of the mandibular canal being 'not visible' was higher for tomography and panoramic radiographs, which leads to the conclusion that these imaging techniques are no substitute for periapical radiographs when trying to localize the mandibular canal. Computed tomography (CT), on the other hand, predictably detects neurovascular structures that would be important to protect during surgery (41). CT

images not only show the real transversal and vertical relation between the lesion, root, and mandibular canal, but also allow actual metric measurements. When measurements in CT images were compared with actual vivo distances, 70% were exact and 94% of the values were within ± 1 mm of real distances. Figure 6 shows a preoperative radiograph of a mandibular molar with an apical lesion on the distal root. In the image, there were no signs of a closeby mental foramen or mandibular canal. A CT scan of the same area revealed an unusual distal position of the mental foramen between the mesial and distal roots of the molar to be treated (Fig. 7). The position of the mental foramen is relevant for proper placement of the vertical incision and for protecting its integrity during the mobilization and retraction of the flap.

A CT is also valuable in determining the full extent of an apical pathosis in relation to other neighboring elements such as the maxillary sinus. When sinus involvement is anticipated, the flap has to be extended in such a way that wound closure can take place over sound bone, maintaing a safe distance from the surgical access. Figure 8 demonstrates a clinical radiograph of maxillary molars with a periapical lesion that involves the roots of the first molar and partially extends to the second molar. The panoramic radiograph as well as the dental radiograph did not give any information about sinus interrelations or eminent difficulties (Figs 8 and 9).

Surprisingly, a CT scan can reveal complex sinus involvement with treatment consequences. Figures 10–12 demonstrate that there is a close proximity of the sinus. Figure 10 shows the area of the mesial root of the first molar. Sections 11, 12, and 13 show the relevant images for endodontic surgery in this case. There is a direct communication between the apical lesion and the maxillary sinus. The sinus membrane appears to be considerably elevated and thickened. Section 12 shows an additional, untreated second root canal in the mesiobuccal root. Figure 11 displays the buccal and palatal roots. Usually, buccal roots of upper molars are just located superficially under buccal bone and are relatively easy to access surgically. Based on the radiograph in Fig. 8, one would expect soft granulomatous tissue representing the apical lesion, as soon as the buccal bone has been penetrated. However, sections 16 and 17 in Fig. 11 reveal a thin bony plate covering the sinus cavity in this area. The sinus forms a small recessus around the distobuccal root. This root is covered by an additional thin layer of bone that surrounds a small lesion over the distobuccal root. Consequently, during surgical entry, after initial bone removal, the sinus membrane has to be mobilized and elevated to expose a second layer of bone covering the distal root. This second bone layer needs to be removed to expose a small apical lesion on the distobuccal root. The large lesion on the radiograph (Fig. 9) points most likely to pathosis involving the palatal root. The sections with images of the palatal root are nos. 17–20. There is a small communication visible between the lesion and the sinus cavity, as can be detected on the buccal aspect of the lesion. The close proximity of the palatal root to the palate makes the palatal approach the preferable way of treating this particular situation. Finally, possible involvement of the second molar has to be considered. Sections 20–24 in Figs 11 and 12 show the mesiobuccal root of the second molar. Although sections 20–22 show a lesion surrounding the mesial root, sections 23 and 24 display a healthy periapical area around the mesiobuccal root. The root tip is completely surrounded by bone, demonstrating that the lesion is not caused by the second molar, but is solely an extension of the palatal lesion from the first molar, superimposed over the root of the second molar.

## Periodontal conditions

The decision-making process in surgical endodontics is, to a great extent, impacted by prevailing periodontal conditions. Probing depth should be measured stepping around the tooth with a periodontal probe and noting any furcation involvement in multi-rooted teeth. A distinction should be made between the histological and the clinical pocket depth in order to differentiate between the depth of the actual anatomic defect and the measurement recorded by the probe. Gingival inflammation will increase probing depth readings because of collagen fiber resorption in the connective tissue (see the section on the Biology of the gingiva). Periodontal probing in acute gingivitis or periodontitis will represent clinically the distance between the gingival margin and the crestal bone or the level of collagen fibers still intact in the connective tissue above the crestal bone. Thus, measured probing depths in these cases are generally larger than the actual histological attachment level or pocket depth (43). The probe penetrates the epithelial layer and

connective tissue without meeting resistance to a level where a stop is encountered, which can be either bone or deeper collagen fibers in the connective tissue. This results in an overestimation of the 'true' depth of pocket. Another reason for potential overestimation of pocket depth is the presence of tissue swelling. Therefore, bleeding on probing has to be assessed in the evaluation process. The degree of inflammation is correlated to the amount of bleeding. As the inflammatory process is mainly plaque induced, attempts should be made to reduce the inflammatory process presurgically. This can be achieved through increased and improved plaque control prior to the surgery. Plaque reduction includes professional measures by a dental hygienist and meticulous oral hygiene by the patient. In general, it may be advisable to prescribe a 0.2% chlorhexidine rinse twice daily 1 week before and 2 weeks after the surgery. Chlorhexidine reduces plaque growth significantly (44, 45), reduces postoperative discomfort, and promotes healing (46, 47). Moreover, rinsing with chlorhexidine markedly reduces the bacterial load and contamination of the operative area, operator and staff (48).

The presence, type, and quality of restorations with special reference to the position of the restoration margin to the gingiva must be determined and are critical to the esthetic outcome of the surgical procedure. Manipulations on soft tissues in areas with restoration margins placed subgingivally for esthetic reasons can lead to exposure of these margins because of recession following the surgery (Fig. 13). How to address this problem will be discussed extensively at a later point in this article.

The determination of the attached gingival width is another important aspect in making the proper treatment plan with regard to the flap design. When a submarginal incision is considered, a minimum of 2 mm of attached gingiva is necessary to maintain a stable position of the gingival margin (49). When a submarginal incision has been made, the marginal gingiva in the cervical area is supplied with blood from crestal vessels and to a minor extent from the periodontal ligament (34). Insufficient blood supply compromises the survival of the unreflected tissue and can lead to necrosis and the potential for a deleterious esthetic result. Clinically, the width of attached gingiva can be determined by subtracting the probing depth from the distance between the gingival margin and the mucogingival junction (Fig. 14).

## Flap design

When designing a tissue flap, various modes of incision can be selected, including horizontal, sulcular, submarginal, and vertical releasing incisions. The tissue flap in its entirety can be a full-thickness or a combination of a full- and a split-thickness flap. Consequently, a number of flap designs exist and are discussed in the literature, including specific rules and recommendations (3, 50–53). The variety of flap designs reflects a number of variables to be considered. While many designs have been suggested over the

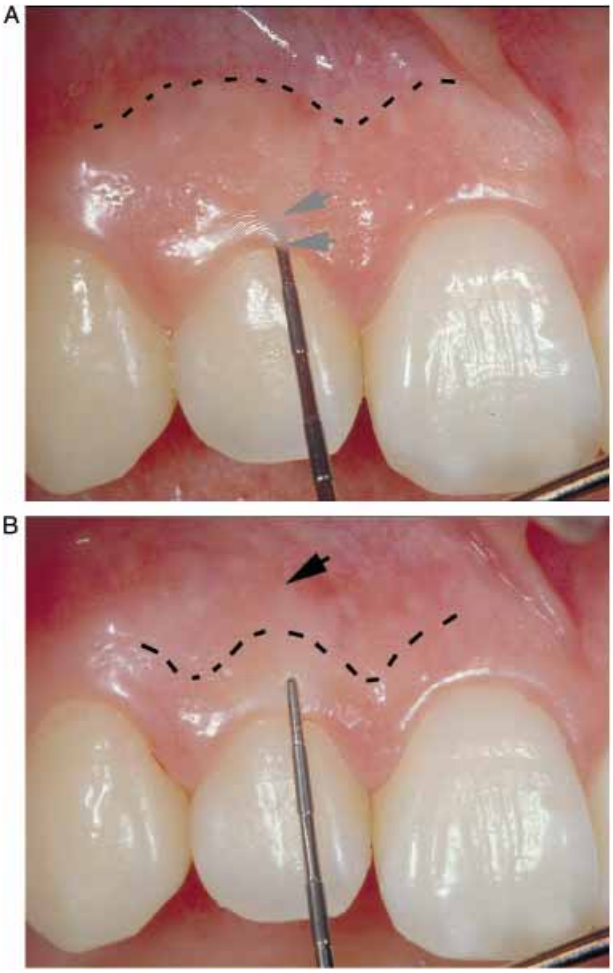


**Fig. 14. Determination of the width of the attached gingiva. (A) Measurement of the probing depth. The gingival tissue over the probe represents the free gingiva. Probing depth is designated by arrows. (B) Arrows mark the mucogingival line. The distance between the tip of the probe (representing the probing depth) and the mucogingival junction is the width of the attached gingiva. The dashed line represents the location for a proper placement of a submarginal incision.**

years, some have become obsolete and new techniques have emerged (54).

It is critical that tissue incisions, elevations, and reflections are performed in a way that facilitates healing by primary intention. This goal can be obtained, firstly, by using a complete and sharp incision of the tissues, secondly, by avoiding severing and trauma of the tissue during elevation, and, finally, by preventing drying of tissue remnants on the root surface and drying of the reflected tissues during the procedure (3).

## Semilunar flap

A semilunar flap consists of a straight or curved horizontal incision in the alveolar mucosa of the apical area, placed all the way to the bone. A multitude of disadvantages have made this flap design obsolete. The semilunar flap will only provide limited access to the apical area. It will sever a maximum of blood vessels by cutting horizontally. Placing the line of incision over the bony defect means that the wound cannot be closed over sound bone. Oral tissue at the apical level consists of many elastic fibers and muscle attachments, both of which exert pulling forces on re-approximated surgical wound margins. This retractive force will not only make suturing difficult, but will result in a constant tension on the flap, poor alignment of wound edges, gap formation, and impaired healing (53).

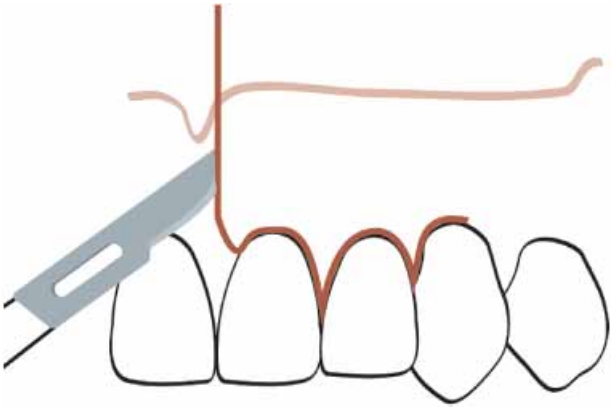

**Fig. 15. A triangular flap is performed by placing a sulcular incision extending to at least two teeth distal from the releasing vertical incision. Reprinted with permission from (3).**

**Fig. 16. Surgical exposure of a cervical resorption using a triangular flap.**

## Triangular flap

The triangular flap design comprises a horizontal incision extending to several teeth mesial and distal of the involved tooth and one vertical-releasing incision, usually placed at the mesial end of the prospective flap (Fig. 15). A triangular flap exposes marginal and midsections of the root. Apical areas are generally difficult to reach without pulling extensively on the flap. If the access is too limited, the triangular flap can easily be converted into a rectangular flap by placing an additional releasing incision at the distal end of the horizontal incision. The triangular flap is mainly indicated for treatment of cervical resorptions (Fig. 16), perforations, and resections of short roots. The main advantages for this flap design are the minimal disruption of the vascular blood supply to the reflected tissues and easy repositioning at wound closure. The drawback is a risk of recession due to the marginal line of incision.

## Rectangular and trapezoidal flap

Rectangular and trapezoidal flaps are a continuation of a triangular design by adding a second vertical incision on the distal end of the flap (Fig. 17). The difference between the rectangular and trapezoidal version is the degree of divergence of the vertical incisions. Blood vessels run roughly parallel to the long axis of the teeth. In order to disrupt the vascular supply least, the vertical incision should be placed parallel to the root. This favors the rectangular flap (39, 55). On the other hand, the blood supply and survival of the mobilized tissue

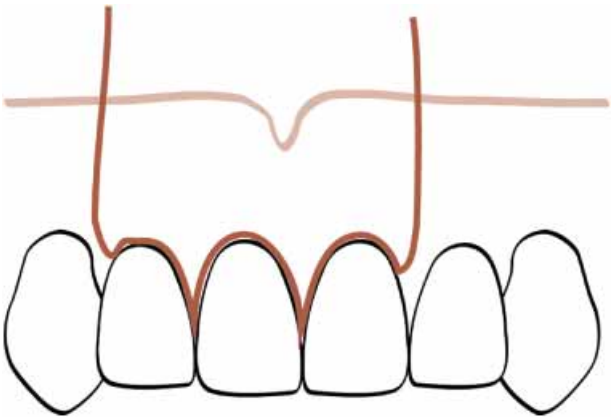

**Fig. 17. Rectangular flap comprising of two vertical releasing incisions, connected by a horizontal marginal incision. Reprinted with permission from (3).**

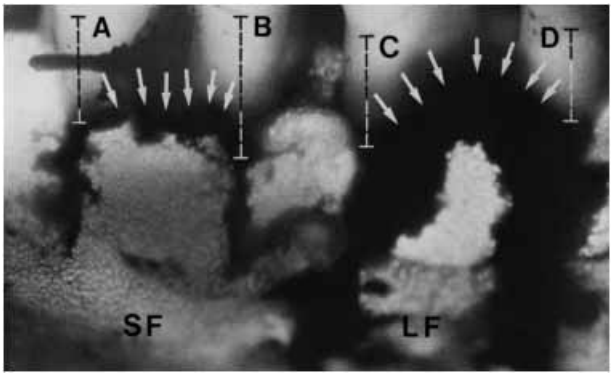


**Fig. 18. Fluorescein angiography following placement of a short (SF) vs. long (LF) full-thickness flap. Lines A to D indicate the distances from the cemento-enamel junction. Reprinted with permission from (56).**

appeared to be the best when the basis was broader than the proximal end of the flap (56). However, the unreflected tissue loses the greater part of its blood supply in broad-based flaps. For this reason, the vertical incisions should never be placed converging; rather, the flap width should be extended one or two teeth mesially or distally to the tooth involved. Figure 18 shows the difference in circulation disturbance in a short full-thickness flap vs. a long full-thickness flap of comparable flap width by means of fluorescein angiography. Mörmann & Ciancio (56) studied the effect of various types of surgical procedures on the gingival capillary blood circulation. The circulation changes observed suggested that flaps receive their major blood supply from their apical aspect, but not exclusively. However, the horizontal marginal incision severed the anastomoses between the gingival and periodontal vasculature. Flap blood perfusion was maintained up to the point where the ratio of length to width of the parallel pedicle flap equaled 2 : 1. Several authors have confirmed this finding (57, 58). The length/width ratio requirement usually favors a slight trapezoidal shape of the flap, with strong a preference of extending the horizontal dimension of the flap over several teeth.

**Fig. 19. Rectangular sulcular full-thickness flap involving a tooth with a discolored root, covered with a metalloceramic crown.**

Repositioning the tissue and wound closure in the rectangular and trapezoidal flaps are easy because of the definite position of the papillae during re-approximation of the tissue. In esthetically critical areas with prosthetic restorations involving subgingivally placed crown margins (Fig. 19), a postoperative sequel can result in recession, leading to an esthetically compromising exposure of the crown margins (Fig. 13).

## Submarginal flap

The submarginal flap design also referred to as an Ochsenbein–Luebke flap (59) is similar to the rectangular flap, with the difference that the horizontal incision is placed within the attached gingiva. The two vertical incisions are connected by a scalloped horizontal incision, performed roughly parallel to the marginal contour of the gingiva (Fig. 20). The submarginal incision should only be used when there is a broad zone of attached gingiva with a minimum of 2 mm (49) (Fig. 14B). Leaving a sufficient amount of marginal attached gingiva in place is important to avoid deprivation of blood supply to this unreflected tissue and risk its necrosis. Such a tissue breakdown will lead to a major recession with devastating esthetic result.

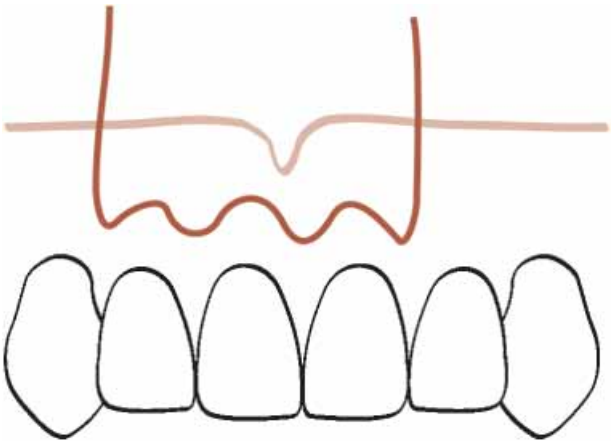

**Fig. 20. Submarginal incision consisting of two vertical incisions connected by a scalloped horizontal incision within the attached gingiva. Reprinted with permission from (3).**

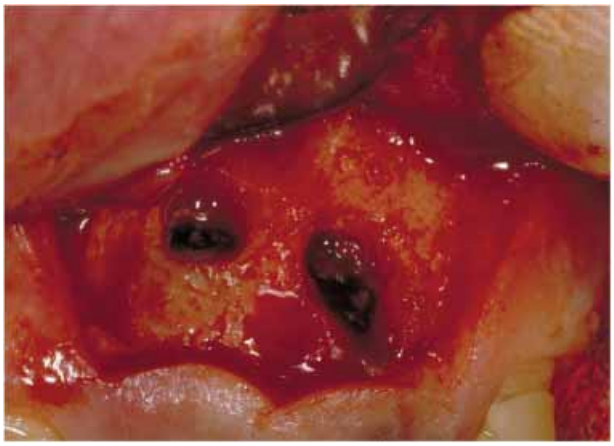

**Fig. 21. Drawback of the submarginal flap. The incision margin ended up being just underneath the bony defect seen on the right; this represents an undesirable situation.**

Nevertheless, the fear of even small recessions is the driving force for considering the submarginal flap. When properly planned and performed, the submarginal flap will leave the marginal gingiva untouched and does not expose restoration margins.

The crestal bone is not denuded, preventing potential attachment loss observed with marginal flaps. Pihlstrom et al. (60) studied healing results when a sulcular full-thickness flap was elevated in an area with shallow pockets (1–3 mm). They observed loss of attachment, which was still present 6.5 years postoperatively .

Incised tissue margins should not be placed over the underlying apical lesion or surgical bony access, as this scenario carries a higher risk of postoperative infection. In Fig. 21, the incision line turned out to be in close proximity to the bony cavity, which should be regarded as a drawback for the submarginal flap in similar cases. Possible scar tissue formation is another disadvantage (see the article on wound healing in this issue).

## Papilla-base flap

The papilla-base flap was suggested to prevent recession of the papilla. This flap consists of two releasing vertical incisions, connected by the papilla-base incision and intrasulcular incision in the cervical area of the tooth. The name is derived from the preparation of the papilla base using a microsurgical blade. The size of the blade should not exceed 2.5 mm in width. Controlled and minute movement of the surgical blade within the small dimensions of the interproximal space is crucial.

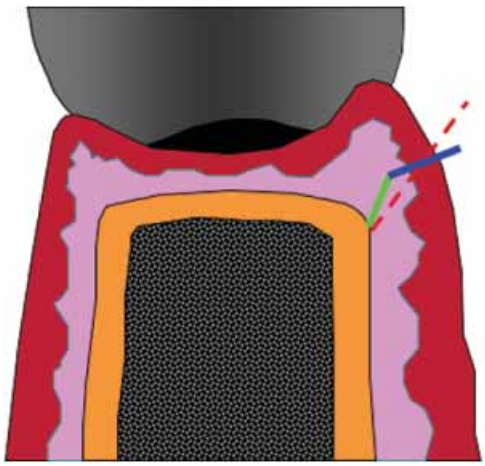

**Fig. 22. Schematic drawing of incision types. The red line represents a single straight incision directed to the crestal bone margin as used for the papilla preservation technique in periodontal application. The green and blue lines delineate the two incisions needed for the papilla base incision. The first shallow incision placed at the lower end of the papilla in a slight curved line, perpendicular to the gingival margin (blue line). A second incision, directed to the crestal bone margin from the base of the previously created incision, is placed (green line). The result is a split-thickness flap on the base of the papilla.**

The papilla-base incision requires two different incisions at the base of the papilla. A first shallow incision severs the epithelium and connective tissue to the depth of 1.5 mm from the surface of the gingiva (Fig. 22, blue line). The path is a curved line, connecting one side of the papilla to the other. The incision begins and ends perpendicular to the gingival

**Fig. 23. Elevated split-thickness flap showing the papilla-base incision and major part of the papilla unaltered and apical to the crestal bone level of a full-thickness flap. Reprinted with permission from (64).**

**Fig. 24. Result of successful elimination of periodontal disease, but great loss on attachment level. Note the unsatisfactory esthetic result with wide open interproximal spaces.**

margin (Fig. 29). In the second step, the scalpel retraces the base of the previously created incision while inclined vertically, toward the crestal bone margin. The second incision results in a split-thickness flap in the apical third of the base of the papilla (Figs 22 and 23). From this point on apically, a full-thickness mucoperiosteal flap is elevated. Although the papilla-base flap achieved very predictable healing results, this technique is challenging to perform. Atraumatic handling of the soft tissues is of utmost importance in order to obtain rapid healing through primary intention. The epithelium of the partial-thickness flap has to be supported by underlying connective tissue; otherwise, it will necrose and lead to scar formation. On the other hand, excessive thickness of the connective tissue layer of the split flap portion could compromise the survival of the buccal papilla left in place.

The ideal thickness of the partial-thickness flap has not been studied. Epithelium thickness varies between 111 and 619 μm with a mean of 364 μm (61). The recommended thickness of free gingival grafts was reported to be 1–2 mm (62, 63). Based on the gingival graft studies, a thickness of 1.5 mm was chosen for the split-thickness flap in the papilla-base incision. The selected thickness resulted in excellent healing results (64).

## Strategies and procedures

The treatment of soft tissues with adequate surgical techniques and maintenance of a healthy appearance are a challenge in modern esthetic dentistry. The primary goal of preservation of the dentition is no longer acceptable without consideration of esthetic consequences (13). For many years, periodontal therapy has focused on elimination of periodontal disease. Periodontal pathosis can be disfiguring and great care must be exercised during surgery to minimize a negative esthetic impact of the therapy. Patients no longer accept healed periodontal tissues accompanied by impaired esthetic results. An example is shown in Fig. 24. As a consequence of this problem, 'periodontal plastic surgery' was defined in a consensus report as surgical procedures performed to prevent or correct anatomical, development, traumatic, or plaque disease-induced defects of gingiva, alveolar mucosa, or bone (65–67). Later, periodontal microsurgery was suggested as refinement in existing basic and new surgical techniques. This was made possible by the use of a magnified vision through an operating microscope and microsurgical instruments. Improvements in flap design and soft tissue manipulation are considered key elements in improved biological and esthetic outcomes of regenerative periodontal procedures (68). There is a

general agreement that the same basic principles apply to endodontic surgical interventions (37, 69).

The choice of flap designs should allow the maintenance of optimal and sufficient blood supply to all parts of the mobilized and nonmobilized portions of the soft tissues (37, 39, 55, 56, 69). This implies specifically that vertical releasing incisions should run vertical, parallel to the long axis of the teeth and supraperiosteal blood vessels in the gingiva and mucosa. Paramedian releasing incisions are recommended to minimize the risk of recession (39). The initial portion of the vertical incision should be placed perpendicular to the marginal course of the gingiva toward the mid section of the papilla and gradually turning the incision parallel to the tooth axis (Fig. 25). Adequate micro-configuration of the gingival margins will minimize any potential recession of the tissues.

Postoperative results are also influenced by the amount of tissue shrinkage. With prolonged duration of the surgical procedure, there is a risk of drying out of the tissues, especially when a high degree of hemostasis has been achieved. The tissues must be kept moist at all time to help avoid shrinkage and dehydration (70). This can be particularly problematic in submarginal flap design, resulting in difficult flap re-approximation, with more tension on the tissues. Minimal tension during re-approximation and after suturing is important to avoid impairment of the circulation in the wound margins (56). Shrinkage of the reflected tissue with wound dehiscence will ultimately lead to increased scar formation.

Tissue trauma such as stretching, tearing, or distortion should be avoided through appropriate magnification and careful manipulation with microsurgical instruments (71, 72). The elevation process following the incision is aimed at undermined elevation of the periosteum. In order to enhance regeneration of the bone and periodontal ligament over the resected root surface, certain cells have to be prevented from repopulating the bony defect (73). When the integrity of the periosteum has been maintained, it will serve as a barrier against the connective tissue cells, so that these cells cannot invade the bone cavity during the healing process and prevent a complete bone fill. Scaling of root attached tissue and tissue tags on the cortical bone should be avoided to allow rapid reattachment and protection against bone resorption (37, 55, 74). After reflecting the mucogingival tissues, a retractor must be placed securely on sound bone to prevent compression

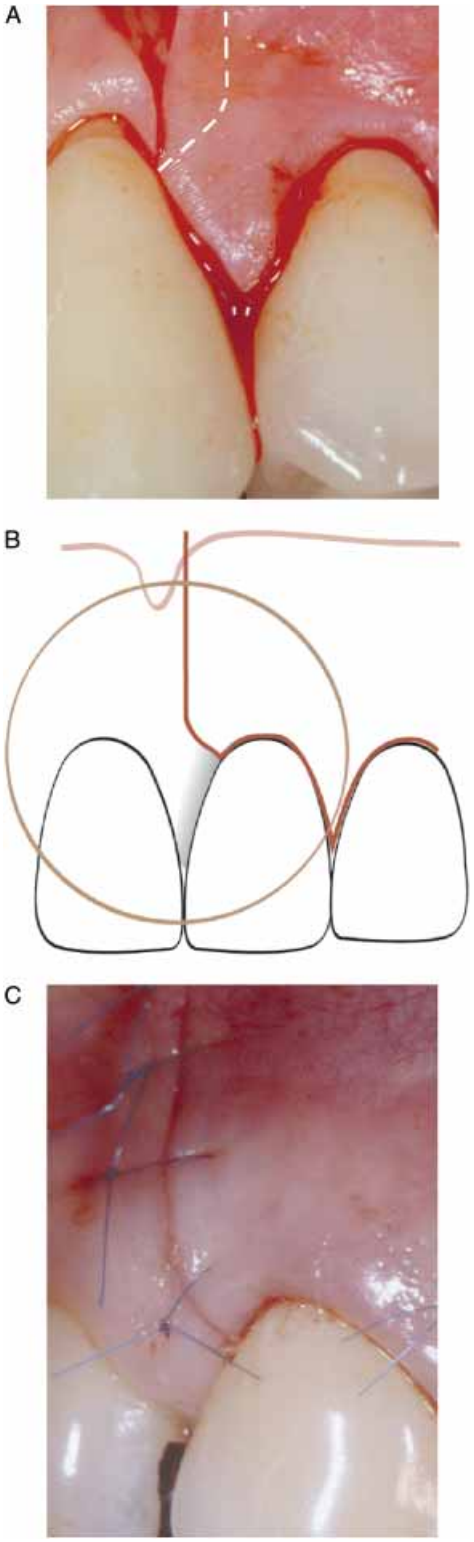


**Fig. 25. Vertical releasing incisions. (A) Incorrect straight vertical incision creates compromised tissue area with insufficient blood supply, which will eventually necrose. (A) dashed line indicates the desired incision course. Reprinted with permission from (7). (B) Correct placement of the releasing incision perpendicular to the marginal contour of the gingiva shown in a schematic diagram (B), reprinted with permission from (3). (C) Clinical example of a correctly placed incision.**

or crushing of the soft tissue (Fig. 26). Excessive trauma from retraction may cause increased swelling and delayed healing. As a practical measure to avoid tissue slipping under the retractor, a fine groove is made with a small round bur in which the retractor can be positioned (3).

## Papilla preservation and protection

The interdental papilla is the portion of the gingiva between two adjacent teeth. It was long considered to have the sole function of deflecting food debris. In reality, the role of the papilla is more complex: it is a biological barrier that protects periodontal ligament, cementum, and alveolar bone from the oral environment (75). Another important reason to respect the integrity of the papilla during dental treatment is that it is critical for aesthetic, functional, and phonetic reasons. Complete and predictable restoration of lost interdental papillae is one of the greatest challenges in periodontal reconstructive surgery (11).

The most frequently used flap in periradicular surgery is a full-thickness marginal flap. In this flap design, the papilla is mobilized and becomes part of the flap (76). Ideally, a sulcular incision should dissect the buccal from the lingual papilla in the area of the col (Fig. 27). In narrow interproximal areas, complete dissection of the buccal papilla is often difficult and may lead to tissue loss.

Studies have highlighted the healing of the papilla following microsurgical treatment in endodontic surgeries (64, 77–80). Specific emphasis was placed on the outcome in healthy periodontal tissues – a most challenging situation – with the goal of preventing a recession of the gingiva. Preliminarily, shrinkage of the papillae after sulcular flaps with complete mobilization of the papilla was investigated (81). The reduction in papillary height increased gradually in the initial healing phase. None of the 17 sites remained at the preoperative levels at any time. Subsequently, a quantitative study analyzed the recession of the interdental papilla in again periodontally healthy situations. All experimental sites exhibited a significant loss of the papilla height at 1 and 3 months. Major loss of the papilla height occurred between baseline and the 1-month recall ($1.1 \pm 0.8$ mm). At 3 months retractions increased in 10 sites, while in three sites the loss had diminished compared with the 1-month value ($0.2 \pm 0.3$ mm). These results indicate that the traditional sulcular flap results in considerable retraction of the papilla height after 1 and 3 months and more importantly in spite of the microsurgical techniques used.

Holmes (33) excised interdental papillae in 16 dental students: one from the anterior and one from the posterior area of each student. From 32 specimens, 22 papillae did not regenerate to their original shape and height. The regenerated papillae appeared flatter, did not fill the embrasure as completely as before excision, and the cols were less concave.

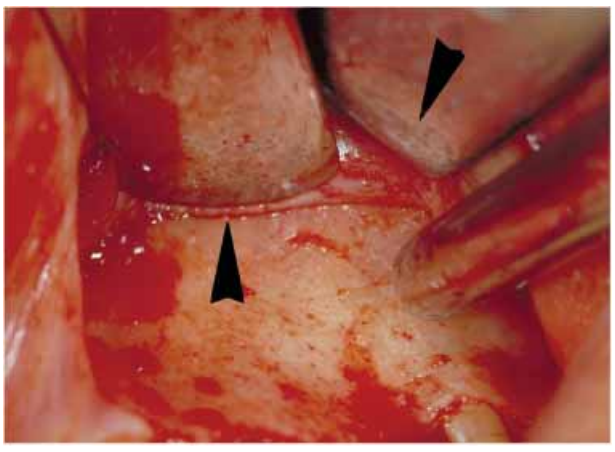

**Fig. 26. Traumatic placement of tissue retractors (arrow). Note the tissue squeezed under the instrument causing distinct damage.**

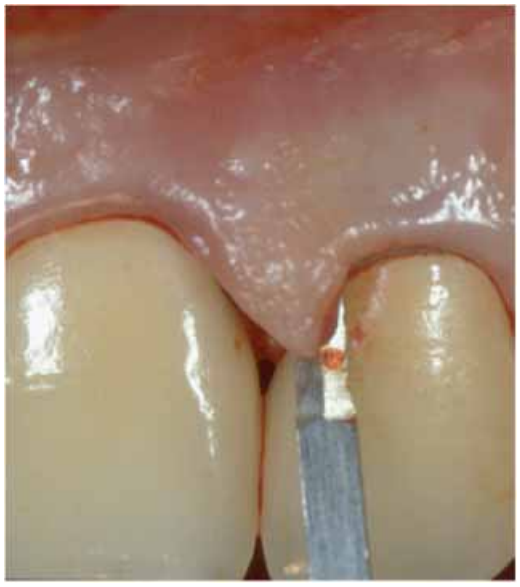

**Fig. 27. Dissection of the papilla using a microsurgical blade. Reprinted with permission from (3).**

The issue of papilla preservation has been widely addressed in the periodontal literature. In anterior periodontal surgery, for aesthetic reasons, papillary retention procedures have been advocated (82, 83). Modified papilla preservation techniques allowed primary closure of the interproximal space over a bioabsorbable membrane (84, 85). This technique used a horizontal incision at the base of the papilla on the lingual aspect of the interproximal space (Fig. 22, red line). The buccal and lingual papillae were mobilized to the buccal. Following debridement and defect coverage with a membrane, the flap was repositioned coronally and the interproximal space was covered with the papilla attached to the buccal flap. Complete and immediate closure over the membrane, a crucial point for successful outcome, was obtained in all treated sites. Preservation of the papilla in periodontal therapy is an accepted procedure, as described by several authors (68, 83, 86).

When this incision technique was used for a buccal flap during endodontic surgery, leaving the entire papilla in place, a marked indentation line resulted during the healing process (Fig. 28). Lubow et al. (52) suggested a similar type of incision, claming excellent healing results. Healing images from this article were comparable with the result shown in Fig. 28, which cannot be considered acceptable in today's critical and magnification-enhanced judgment. In periodontal applications, this healing modality is of no relevance as the incision is invisible because of its lingual position. The indentation is a result of localized tissue necrosis as a consequence of a sharp, pointed flap margin that is not adequately vascularized. The connective tissue in this area will not be able to survive, which may lead to a small tissue defect followed by scar formation, as can be seen clearly in Fig. 28.

**Fig. 28. A single straight horizontal incision results in a marked indentation line, which is esthetically unacceptable.**

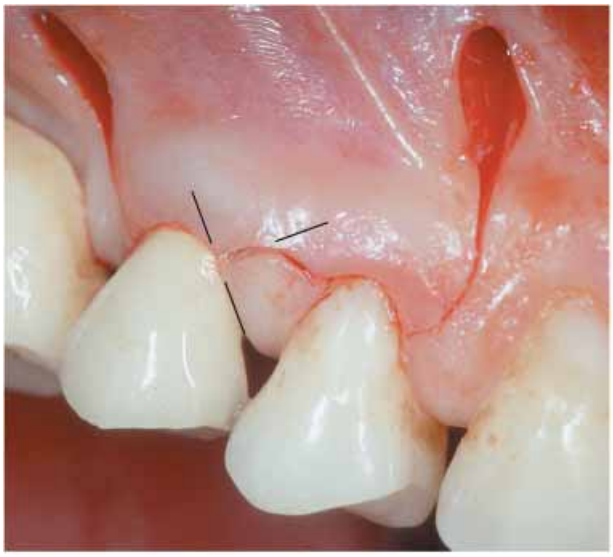

**Fig. 29. Curved incision line placed perpendicular to the gingival margin (see lines). Reprinted with permission from (64).**

Avoiding thinning of the entire flap will prevent tissue breakdown by creating sufficient thickness of the split flap. The recently suggested papilla-base flap addresses these issues (7). The suggested thickness of the split-thickness flap was based on recommendations for free gingival grafts, which advocate a tissue thickness of 1–2 mm (62, 63). The selected thickness resulted in no tissue defects (64). While the papilla-base incision requires a learning curve, its use leads to predictable and satisfying long-term results (79).

Atraumatic tissue handling is mandatory to obtain scar-free healing. Key points of the papilla-base incision are prevention of thinning of the split flap and avoidance of pointed tissue margins (Figs 22, 28, 29). The tissue will then remain vital in its entire extent without leaving a defect and consequently scar formation. When full mobilization of the papilla was used to elevate a flap, considerable and significant recession resulted after 1 and 3 months (80, 81). In contrast to the classical marginal flap with inclusion of the papillae,

the papilla-base flap showed no loss of papilla height during the observation period (64). Two comparative studies with short-term and long-term observation periods found significant differences in loss of papilla after 1, 3, and 12 months when the papilla-base flap was compared with full mobilization of the papilla (78, 79). These studies confirmed considerable recession at all recall appointments for full marginal flaps while flaps after papilla-base incision showed no loss of height.

## Conclusion

The introduction of microsurgery to surgical endodontics attempted to minimize trauma and enhance surgical results. Because of the combination of magnification and more delicate instruments, improved and careful tissue handling has become possible. This in turn allows for more predictable healing and less aesthetically compromising tissue defects and recessions (see also chapter on wound healing). To achieve these goals, several measures are necessary, including accurate preoperative treatment planning in reference to the condition and the quality of the tissue to be manipulated. Minimal trauma should be inflicted during incision, elevation, and reflection of a tissue flap. Both reflected and unreflected tissue should be kept moist during the entire procedure, especially when a high degree of hemostasis has been achieved. Flap design plays an important role as to how much recession will occur after the surgery.

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# Hard tissue management: osseous access, curettage, biopsy and root isolation

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Following adequate tissue incision, reflection and retraction to expose the surgical site, the next stages of periradicular surgery consist of osseous access through the cortical bone, if still intact, and subsequent removal of any soft tissue lesion surrounding the apical and/or lateral aspects of the associated root to provide unimpeded access to these sites. The soft tissue lesion may on occasions encapsulate foreign material that may perpetuate the lesion if left *in situ*. Any excised lesion should be sent for histopathologic examination to confirm the clinical diagnosis and exclude other pathoses.

## Osseous entry

Osseous entry or osteotomy involves removal of cortical and cancellous bone to gain direct access to the apical portion, and the lateral aspects if necessary, of the root or roots of a tooth where periradicular periodontitis is present. There may be fenestration of the root tip through the buccal cortical plate, thus providing instant access. The operator may encounter a periradicular soft tissue lesion that has perforated the cortical plate, in which case curettage of the lesion permits access to the root either without bone removal or minimal extension of the borders of the defect for improved access. Frequently, however, there will be an intact cortical plate that requires removal to expose the surgical site. This is achieved routinely by using rotary instruments.

The main consideration with cutting through bone tissue is the trauma and injury inflicted on the tissue mechanically and particularly by the generation of heat. The tissue may also be more vulnerable to trauma as studies have demonstrated a significant reduction in blood flow to teeth and gingival tissue following the administration of local anesthetic solutions containing the vasoconstrictor adrenaline (1, 2). It is therefore reasonable to postulate that the blood supply to the periosteum and the cortical bone will be similarly affected, with likely changes in its response to trauma and subsequent healing potential. Furthermore, bone may be more heat sensitive in an ischemic state (3).

### Effect of heat

Several studies confirmed that irreversible damage to bone occurred when it was heated to above 56°C and that this temperature was easily exceeded during bone cutting. One study reported a temperature rise to 100°C (4), although this was caused by the use of an oscillating bone saw rather than a small dental bur. Weakening of collagen to hydroxyapatite bonds, denaturation of enzymes such as alkaline phosphatase, osteocyte necrosis and blood flow stasis have all been reported (3, 5–7).

However, it was Eriksson and co-workers' (8–10) in a series of elegant studies that showed the previous underestimation of the temperature at which irreversible damage occurs in bone tissue. In the first study (8), a titanium implant, modified to act as a thermal chamber, was inserted into the tibia of rabbits. Bone was allowed to regrow through a small side hole in the implant and could be viewed through a microscope.

The chamber was then heated for a period of time and the effect on bone, both immediately and over a period of up to 8 weeks, was examined. They initially established that, following a temperature rise to 53°C for 1 min, the blood flow either stopped in some vessels or became sluggish. After 2 days there was complete vascular stasis and subsequently these vessels were slowly replaced with fewer larger vessels. Fat cells were resorbed and bone remodelling only began 3–5 weeks following the injury. They repeated this experiment (9) with different temperatures and time periods. At 50°C for 1 min, or 47°C for 5 min, similar damage occurred, with fat cells gradually replacing the bone tissue present prior to the injury. At 47°C for 1 min, there was still the usual initial vascular response, but little or no gradual replacement of bone with fat cells was seen. They concluded that the threshold for irreversible damage to bone is at the level of 47°C and that injury through heat had to be carefully controlled to avoid impaired bone healing.

In a further study (10), they examined bone regeneration 4 weeks after applying varying temperatures, 50°C, 47°C and 44°C for 1 min. They recorded that the threshold temperature for impaired bone regeneration was between 44°C and 47°C at an exposure time of 1 min. These landmark studies were particularly relevant in the field of implants, where osseointegration is central to the success of these fixtures, but also provided the endodontic surgeon with a clear warning of the risks of overheating the tissues.

There has been a considerable resurgence of interest in the field of heat generation, relating to osseointegrated implant fixture site preparation. The situation is rather different as burs are required to cut a hole into the bony site of some 3–6 mm in diameter and from 8 mm to perhaps 15 mm or more in length. However, the principle of assessing the damage to the cortical plate of bone is the same, and some of the research, therefore, is relevant to surgical endodontics.

## Cutting speed

Several histological studies carried out in the 1960s compared the effect of cutting bone (usually the mandibles of dogs) with burs driven by conventional low-speed and the recently introduced high-speed air rotor handpieces, with and without coolant (11–16). They concluded that, overall, high-speed handpieces were responsible for less or no worse than similar injury. Healing was reported to be more rapid. Moss (11) and Costich et al. (12) also commented on the light pressure needed when using high-speed handpieces to cut bone, the reduced time involved in the procedure and, anecdotally, improved patient acceptance clinically. Recent research in the implant field is generally not so applicable in this area as very low cutting speeds in the region of 2000 r.p.m. are routinely used (17), however, one study (18) did compare the heat generated when preparing implant sites in rabbit tibias with coolant using slow, intermediate and high-speed handpieces. The high-speed range significantly reduced heat production. Abouzgia & Symington (19) however, indicated in an *in vitro* study that drilling at higher speeds and with greater force was responsible for less temperature rise, while Davidson & James (20) recently reported that drill speed, feed rates and drill diameter had the most significant impact on thermal changes.

The main drawback to the use of high-speed handpieces in oral surgery and surgical endodontics is the risk of surgical emphysema from the air/water spray directed at the cutting site. The Impact-Air 45 handpiece was introduced to prevent such an occurrence by providing a coolant only stream directed at the bur tip and exhausting air away from the cutting site (Fig. 1). Subsequently, other handpiece manufacturers have followed suit. The handpiece head was angled at 45° to the shaft of the instrument originally to facilitate access to impacted third molars. This has proven to be a great advantage in surgical endodontics performed with the use of a microscope, as the head can be angled in such a way that the entire cutting portion of the bur is visible to the operator.

**Fig. 1. Impact-Air handpiece with 45° angled head.**

## Coolant

Clearly, water or saline coolants applied directly to the cutting surface of a bur in contact with bone will reduce the temperature rise considerably and limit or prevent permanent damage (6, 11, 14, 15, 21). Bur temperatures, in particular, are significantly lower when water cooled. Recent implant research has indicated that the bur temperature rises rapidly and is higher than the surrounding bone tissue (22). If irrigation is not used, temperatures far in excess of 47°C were noted in seconds in this *in vitro* study.

There is general agreement in the older oral surgery literature and the recent implant literature that liquid coolants are necessary to offset the heat generated by cutting, regardless of speed of cut or pressure exercised. Kerawala et al. (23) expressed concern with temperature rises during use of burs to prepare for osteosynthesis self-tapping screws. They reported that irrigation had the greatest effect on the temperature recorded, with the absence of irrigant resulting in temperatures in excess of 70°C.

Drills used for cutting sites for implant placement use either internal or external irrigation systems, or both (24), but burs used in periradicular surgery may be cooled adequately with a simple external coolant stream. There is no high-speed handpiece and friction grip surgical bur available that uses internal irrigation. Furthermore, the coolant stream must be directed accurately to the cutting surface of the bur and the surgical assistant must position the suction tip in such a way as to remove excess coolant without allowing the coolant stream to be diverted from its path onto the rotating bur. The other advantage of this constant coolant stream is that it assists in removing bone chippings and coagulated blood and debris from the flutes of the bur, thus maintaining an efficient cutting surface and less frictional heat (25).

Ideally the coolant should be sterile water or saline (26), but this has been difficult if not impossible to achieve if the fluid travels through dental unit waterlines. Several workers have reported on the very high colony-forming unit (CFU) count of coolant expressed from water/air syringes and high-speed handpieces, although there appears to be no evidence in the literature of significant infection of the operating site from such coolants (27–29). The site itself, of course, is not sterile, but contaminated with oral bacteria present in the saliva. The recommended alternative involves the assistant directing sterile coolant from a syringe onto the contact area of bur and bone, but this is difficult to achieve if the operating site is in the posterior portion of the arch.

Recent research has shown, fortunately, that there is now the opportunity to lower the CFU count in dental unit waterlines very significantly, notably by the use of electrochemically activated (30), or super-oxidized, water (31). Other chemical systems have also been advocated to achieve the same goal of removing the bacteria present in the biofilm present on the inner walls of dental unit tubing (32).

## Bur design

Moss (11) compared different bur types, as well as investigating the effect of bur speed. He reported that round burs, in particular the No. 6 round bur, caused smaller zones of aseptic necrosis than fissure burs, which Calderwood et al. (13) found cut efficiently along their length, but very poorly on the bur's end surface. However, they obtained the poorest results from diamond burs, where cutting was inefficient and healing delayed. The diamond grit is likely to trap more bone particles and thus increase frictional heat – no author of current texts recommends the use of diamond burs for cutting through the cortical plate during periradicular surgery.

Bur design for surgical use subsequently concentrated on round, steel burs with widely spaced flutes that minimize clogging with bone chips and coagulated debris and reduce vibration. They are recommended for use by various authors (33–35).

A round bur is, however, an unsatisfactory design to resect a root tip and provide a uniplanar surface. Diamond-coated and crosscut fissure burs also produce rougher surfaces than a straight fissure bur (36) and, more recently, a multi-purpose bur (37). An alternative to a round bur is the Lindemann H151 (Brasseler USA, Savannah, GA, USA), a tapered steel surgical bur recommended by several authors (34, 38–40). It has a widely spaced flute design similar to a surgical round bur (Fig. 2), but will produce an acceptable surface of the root tip during resection of the apex, and thus may be used conveniently for both functions. Should a smoother surface be considered necessary, the subsequent use of a tungsten carbide finishing bur has been recommended – a sub-micron diamond-coated finishing bur will actually roughen the surface even more

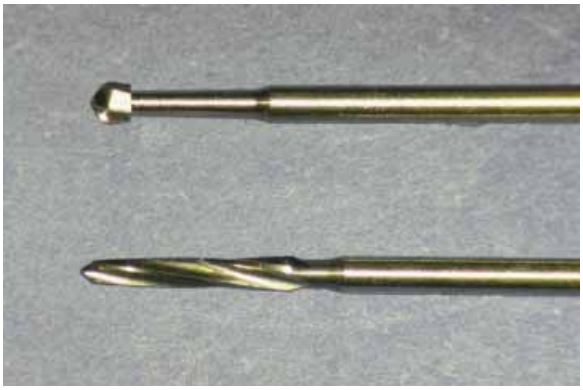

**Fig. 2. A surgical round bur and the Lindemann H151 tapered bur. Note the widely spaced flutes to minimize clogging and reduce vibration. Both burs have friction-grip shanks.**

(37). It is imperative that this bur, or indeed a round bur, is used with a light brushing or stroking action, running almost parallel to the surface of the cortical plate to maximize the effect of water cooling and reduce friction (41) (Fig. 3). At this angle, the rounded cutting tip is similar in outline to a round bur. Once the cortical bone is cut away and the osteotomy is deepened, the opening should be large enough for the coolant to reach the bur tip when it is angled progressively from the long axis of the cortical plate (Fig. 3).

Although there is no evidence of the effect of used or blunted burs on cutting efficiency and therefore temperature elevation in periradicular surgery, Allan et al. (42) reported recently on the effects of repeated drill use on bone temperature when preparing holes for osteosynthesis self-tapping screws, cut into a cortical plate. There were significant differences in the temperatures generated; the temperature rise when a new drill was used was 7.5°C, compared with a drill used in theatre for an unknown time where the increase was 25°C. As drill cost was low, they recommended single use burs. It would be prudent to follow the same advice for surgical burs in periradicular surgery.

## Anatomical structures

The other area of possible trauma relates to damage to the maxillary sinus and the various neurovascular bundles. The structures mainly at risk are the inferior alveolar and mental nerve bundles, although the operator needs to have a good anatomic understanding of the positions of the greater palatine neurovascular bundle, the floor of the nose and the inferior orbital

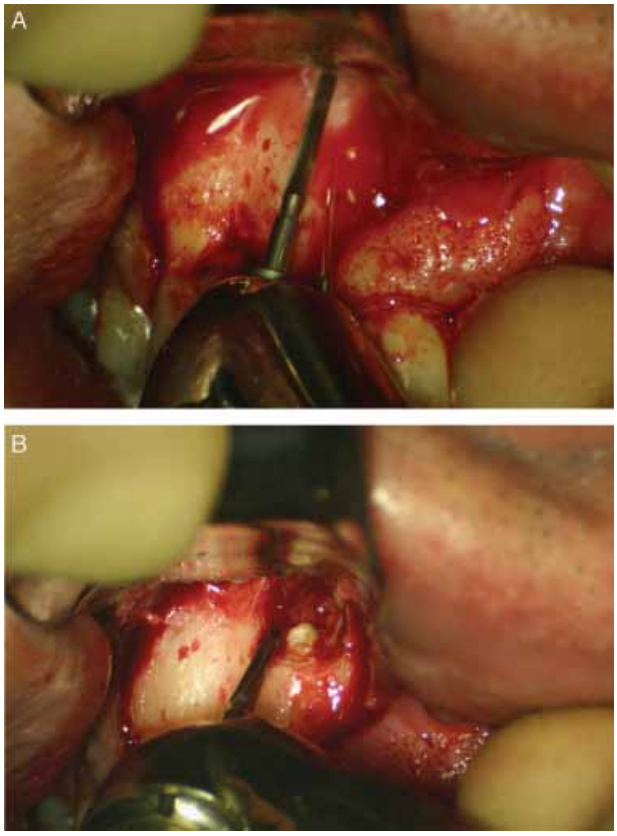


**Fig. 3. (A) Lindemann bur almost parallel to buccal alveolar plate – note liquid coolant steam directed at bur tip. (B) Bur now angled in toward right angles to buccal alveolar plate to remove sufficient bone to expose 3–4 mm of root tip.**

region. More detailed information can then be gained from relevant radiographs of the site.

Pre-operative periapical radiographs are a pre-requisite to any surgical procedure – a paralleling technique with optimal film or sensor placement must be employed. The tooth length may then be measured on the radiograph and will give a good approximation within a couple of millimeters of the total tooth length. A hand instrument of known length, such as an appropriately long pocket measuring probe, may then be placed over the tooth and the likely position of the root apex estimated. Where the tooth to be treated is multirooted, or the operator suspects there may be a single root with more than one canal present, additional views from an altered horizontal angulation of the tube-head to the mesial or distal, should be exposed. One additional angled view would be the minimum, but for maxillary posterior teeth, both mesial and distal views are considered necessary to gain the maximum information (39).

The surgeon should study closely the preoperative periapical radiographic views, and a dental panoral tomograph if available, to determine the position of the mandibular and mental canals and the mental foramen. Additional intraoral views with altered vertical alignment will aid in assessing the relationship of the mandibular canal to the root apices in the mandibular posterior region (33).

Provided the surgeon has a good understanding of the anatomy of the surgical site and additional information gleaned from the available radiographs, osseous entry is a safe and predictable procedure. Working with magnification and co-axial lighting will improve visibility significantly and allow accurate and delicate movements and control of high-speed handpiece and bur to cut precisely.

## Technique of bone removal

### Site of entry

There may be a perforation of the soft tissue lesion through the buccal plate that facilitates osseous entry and is the optimal starting point (Fig. 4). This is frequently the case where a resurgery procedure is being performed, as persisting disease is present following the initial periradicular surgery procedure. The original osteotomy may never heal and the crypt is filled with granulomatous tissue (Fig. 5). There may be a fenestration whereby the root tip is positioned outside the buccal plate (Fig. 6), or a bony dehiscence that exposes a significant length of the root.

When an intact cortical plate is present, however, locating the root tip may be far more difficult, especially if the surgeon is relatively inexperienced (Fig. 7). If there a thin layer of the cortex over the buccal aspect of the root, as is often the case with maxillary anterior teeth, the cortical topography may be viewed and palpated and the position of the root accurately ascertained – this necessitates a full muco-periosteal tissue flap or a limited flap design such as the Luebke-Oschenbein where the buccal cortical plate is fully exposed. Several authors have proposed a technique whereby an initial osteotomy access cavity or depression is made and then a small piece of lead sheet from an intraoral radiograph film packet is cut and placed into the site. A periapical radiograph is exposed – it is then usually possible to orientate the position of the root apex with the radiopaque marker and extend the osteotomy in the appropriate direction (33, 38–40).

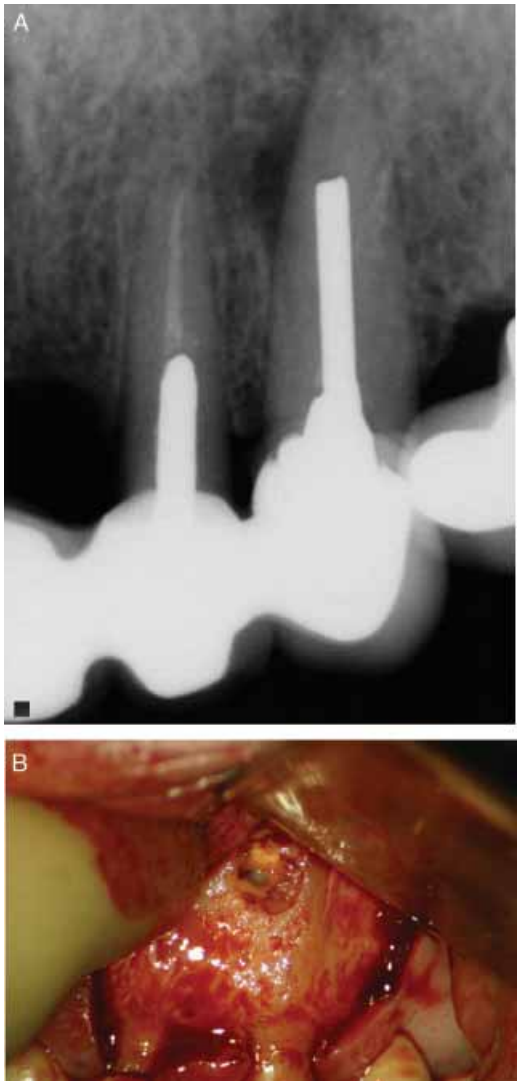


**Fig. 4. (A) A lateral lesion, in addition to an apical one, is apparent at the upper left maxillary canine. (B) The soft-tissue lesion has perforated through the buccal cortical plate, aiding location.**

Root tissue is commonly more yellow and darker than adjacent bone. Unlike bone, it is not possible to indent it with a probe, nor does it bleed; it is also surrounded by a periodontal ligament (43). If location and visualization is still a problem, a small amount of 1% methylene blue dye may be placed into the bony crypt on a micro-applicator or brush tip. This material will preferentially stain the periodontal ligament (Fig. 8), thus displaying the root outline more clearly (38–40). The particular aspects of osseous access to different areas of the oral cavity are as discussed below.

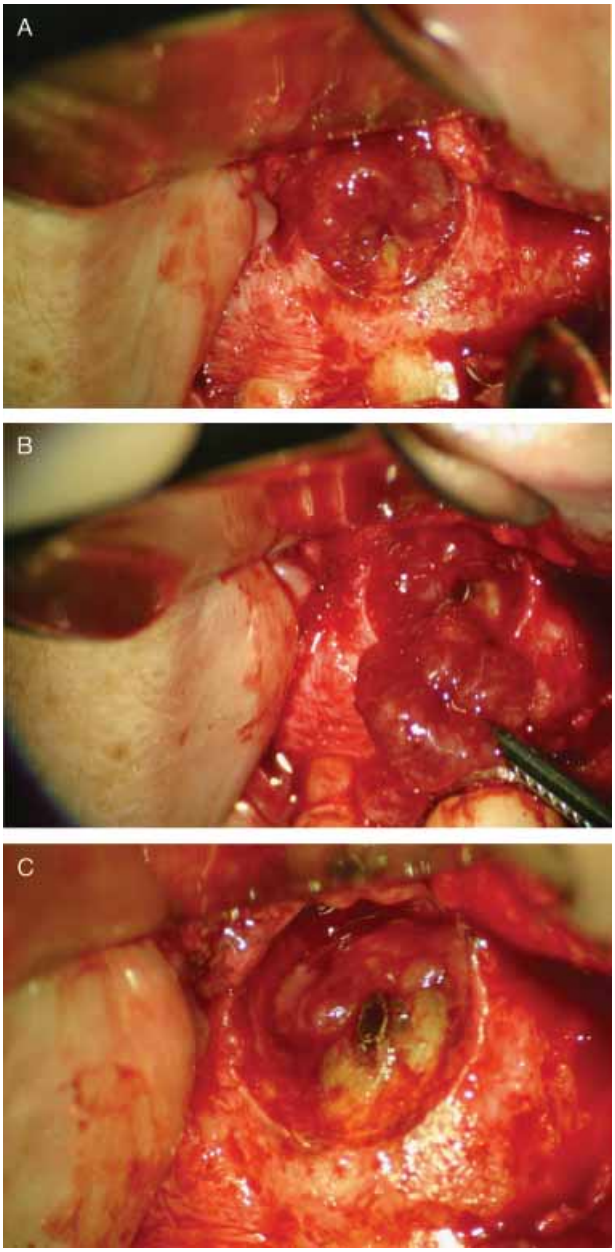


**Fig. 5. (A) Large granulomatous lesion associated with failing previous periradicular surgery. (B) Following curettage, lesion being removed from the bony crypt. (C) Exposed root tip – no cutting of bone has been necessary.**

**Fig. 6. Mesiobuccal root of tooth #26 fenestrated through buccal plate – there is also granulation tissue around the root.**

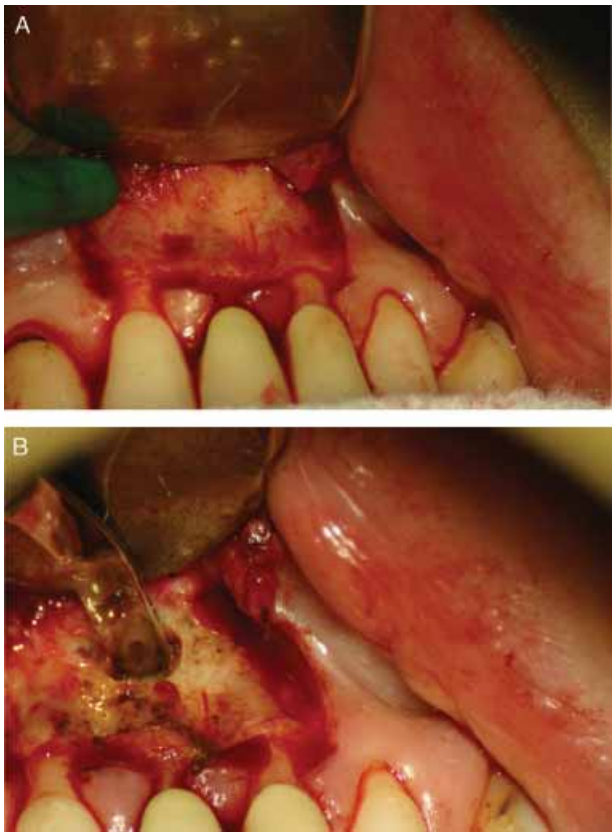


**Fig. 7. (A) Intact cortical bone over tooth #31. (B) Following osteotomy, curettage and root resection.**

### *Maxillary anterior segment*

Access is usually optimal in this area. However, the apices of lateral incisors are often more palatally placed than the adjacent teeth and the cortical topography not so apparent. A deeper osteotomy is required to expose the apices of these teeth. If the incisors or canine are particularly long, the operating site may be close to the structures of the floor of the nose. In these circumstances, the osteotomy should be cut some 4 mm coronal to the anticipated root apex. The root tip is then cut through and elevated rather than planed away from the apex.

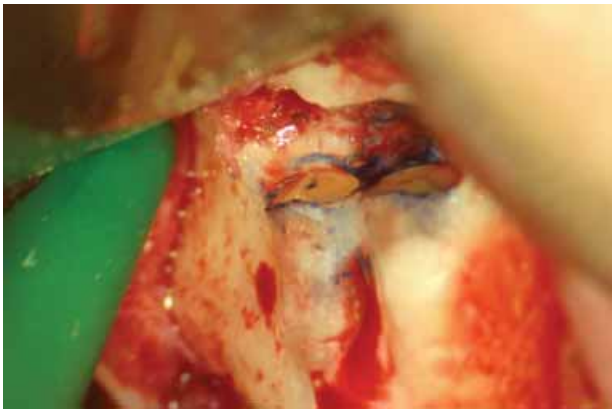

**Fig. 8. Methylene blue staining of periodontal ligament and exposed canal – the maxillary right first molar (#16).**

### *Maxillary premolars*

The position of the root tip or tips relative to the antrum should be ascertained before the procedure is commenced. Access itself is usually good and the apices close to or perforating the buccal alveolar plate. If the first premolar has two distinct roots, then the osteotomy will need to be larger than usual to allow good access to the palatal root once the buccal root has been more radically resected that is otherwise necessary.

### *Maxillary molars*

Access may be more difficult depending on the size and elasticity of the mouth and lips as well as the muscle attachments in the area, the depth of the vestibule and the proximity of the buccal root tips to the zygomatic process. Once again, the proximity of the maxillary sinus should be assessed, although it is not always possible to anticipate its exposure during surgical access or curettage. The opening will be more mesially positioned as the operator will be viewing the operating site at an angle from the front of the mouth, even with cooperative patient positioning. Care must be taken not to damage the buccal aspect of the root of the tooth mesial to the site. The first molar is obviously more accessible and surgery on a second molar should only be undertaken after considering all the options if access is particularly compromised. With the advent of osseointegrated implants as part of the routine restorative armamentarium, 'heroic' endodontic surgery may be far less predictable than extraction and replacement with an implant fixture.

Should it be necessary to apically resect the palatal root, access will depend on the position of the root tip. If it is close to the buccal roots, then a transantral (44) approach may be undertaken, although a larger opening in the cortical plate will be necessary. The advisability of proceeding if the sinus needs to be perforated is discussed later in the paper.

The alternative is a palatal approach. Although this is not mentioned in many of the current texts, it is described in some detail by Gutmann & Harrison (41) and Arens et al. (45), although the difficulties of such an approach are clearly indicated. A vertical releasing incision is made at the level of the premolars, well away from the greater palatine neurovascular bundle sited between the second and third molars approximately 1 cm superior to the gingival margin. Tissue retraction of the tough mucosa is difficult and there are no obvious surface landmarks on the rough cortical plate to assist orientation. It should only be attempted if there is a moderate-to-deep vaulted palate and requires a skilled and experienced operator and assistant. As above, the alternative of removal and implant placement should be considered.

### *Mandibular anterior segment*

Access may be limited because of a shallow vestibule. The mandibular anterior teeth may also have their root apices positioned lingually. In these cases, access to the root tips is deep and awkward. The direction of the osteotomy has to be slightly coronal rather than directly at right angles.

### *Mandibular premolars and molars*

The depth of the vestibule, together with any prominent muscle attachments, will dictate ease of access to the premolars. The second premolar root tip is easier to locate as it is more buccally placed (41). The incised tissue is reflected more easily over the molar region, but access may be limited by the amount of lip retraction possible.

The major complication of surgery at this site is the proximity of the mental foramen. According to Moiseiwitsch (46), the mental foramen lies usually between the premolars, but could also be adjacent or distal to the second premolar, although there may be slight ethnic differences in position. He also reported that the distance from the CEJ of the mandibular

second premolar to the mental foramen ranged from 8 to 21 mm, and that in 20% of his sample of 105 cadavers, the distance was less than 12 mm. If the foramen does appear to be in close proximity to the root apices of this tooth and a decision is made between surgeon and patient to perform the surgical procedure, the bundle must be identified during tissue elevation and retraction. As the flap is carefully retracted, a thin white line of blanched periosteal tissues will be seen. This will disappear and a narrow dark line become apparent in the region of the foramen as its superior border is exposed (41). Once found, it may be protected with a retractor to eliminate the risk of trauma to it. Kim et al. (39) have suggested that a horizontal groove, approximately 1 mm deep and 3–4 mm long may be cut slightly superior to the foramen, into which the tip of a retractor is firmly located. This refinement should minimize the opportunity of any accidental slippage and consequent damage to the neurovascular bundle.

It is unusual for the inferior alveolar nerve to be in close proximity to the apices of a mandibular first molar tooth – the average distance from the mesial root apex to the superior border of the mandibular canal is almost 6 mm – although it is less to a second mandibular molar (47). A surgical approach in this second molar area is difficult as the external oblique ridge thickens in this site and access to the root apices is very awkward – the distance between the buccal cortical plate and the mesial root apex has been measured at more than 7 mm, whereas it is only slightly more than 4 mm for the first molar (47, 48). It would therefore involve the removal of a considerable amount of cortical and cancellous bone to reach the apices and vision may be severely curtailed. As discussed in the section on maxillary molars, consideration should instead be given to the alternative of intentional replantation or extraction and implant placement, as this site is particularly suitable for such a technique.

For the mandibular first molar, access is still awkward and demanding, with a mesial inclination of resection being used to compensate for the operator's viewing angle, but the osteotomy must still be sufficiently large to allow visualization of the 3–4 mm of the roots. Should the pre-operative radiographs indicate that the mandibular canal is in close proximity to the root tips, resection then involves cutting through the roots at the 3–4 mm level and carefully elevating the apical segments to avoid contact with the inferior alveolar nerve bundle.

Khoury & Hensher (49) described a novel approach to accessing the apical regions of mandibular molars. A bony lid is opened over the roots by outlining the margins of the lid by cutting a series of holes through the cortical plate with a small round bur. The holes are then joined with the use of a chisel and the cortical plate elevated away and placed in normal saline during the course of the procedure. Subsequently the lid is replaced, occasionally with stabilizing resorbable sutures. While access is unparalleled, there has been some concern over transient mandibular paraesthesia, subsequent infection or sloughing of the lid itself. There may have been undue heating of the cortical bone as the small round bur head is unlikely to have been adequately washed by coolant as it travelled through the thick osseous tissue. There has been little further reference in the literature to the bony lid approach in the past 17 years, so it appears that this technique has not been widely adopted. The subsequent introduction of the operating microscope and its attendant armamentarium has facilitated access and visualization of the mandibular molar region with a more conservative approach and may have rendered the former technique obsolete.

## Size of the resected root face

Morfis et al. (50) and Kim et al. (39) have determined that the majority of unfilled lateral canals and other aspects of accessory canal anatomy are located in the apical 3 mm of the root. Thus, 3–4 mm of the apical portion of the root should be clearly exposed, at least to the buccal, mesial and distal. Following resection of the required 3 mm of root tip, there should still be good visibility of the resected root surface for the next stage of the procedure.

Gilheany et al. (51) proposed that the depth of the root-end preparation should be at least 3 mm. As a result, most root-end preparation tips, whether ultrasonic or sonic, are 3 mm in length. The osteotomy should therefore be large enough to allow such a tip to be positioned inside the crypt and engage the exposed canal in the resected root face in the long axis of the root, while the surgeon has good unimpaired visual access to the site. If osseous access has already been made to expose 3–4 mm of the root tip, there is no firm requirement to make the margins of the osteotomy larger than this, as the root-end preparation tip should fit without interference.

The other factor that will determine the outline of the osteotomy is the size and position of any soft tissue lesion surrounding the root tip or lateral opening from the root canal system. The osteotomy should be large enough to allow access to the full extent of the lesion, while retaining as much bone as possible, particularly cervical to the lesion itself. A bridge of healthy cortical plate between the gingival margin and the osteotomy is associated with a more successful outcome (Fig. 9). Indeed the prognosis is significantly poorer if no buccal bone is present over the root tissue (52–54).

## Surgical curettage

The aim of curettage is to remove the periradicular soft tissue lesion that represents the apical periodontitis to allow optimal access and visualization of the apical third of the relevant root or roots. Nair (55) has characterized this tissue as being granulomatous, predominantly infiltrated with lymphocytes, plasma cells and macrophages. The lesions may or may not be epithelialized. Additionally there may occasionally be foreign bodies such as root filling material or other forms of debris present in the periradicular area (56). However, the source of periradicular periodontitis is not the soft tissue lesion, but the presence of microorganisms and their inflammatory mediators within the canal system (57–60), and possibly in a bacterial plaque on the external root surface (61, 62). Therefore removal of the soft tissue lesion alone, whether or not it contains bacteria, will not resolve the persistent disease process. The exception to this dictate, however, may be the presence of an extraoral infection within the soft tissue lesion, caused by some species of actinomycosis or *Proprionibacterium proprionicum* (63–65), even when the root canal system has been successfully disinfected and sealed, or a foreign body reaction to root filling or other material. The difficulty the operator faces is that is not possible to decide clinically with any certainty the nature of the soft tissue lesion or whether it contains significant numbers of bacteria.

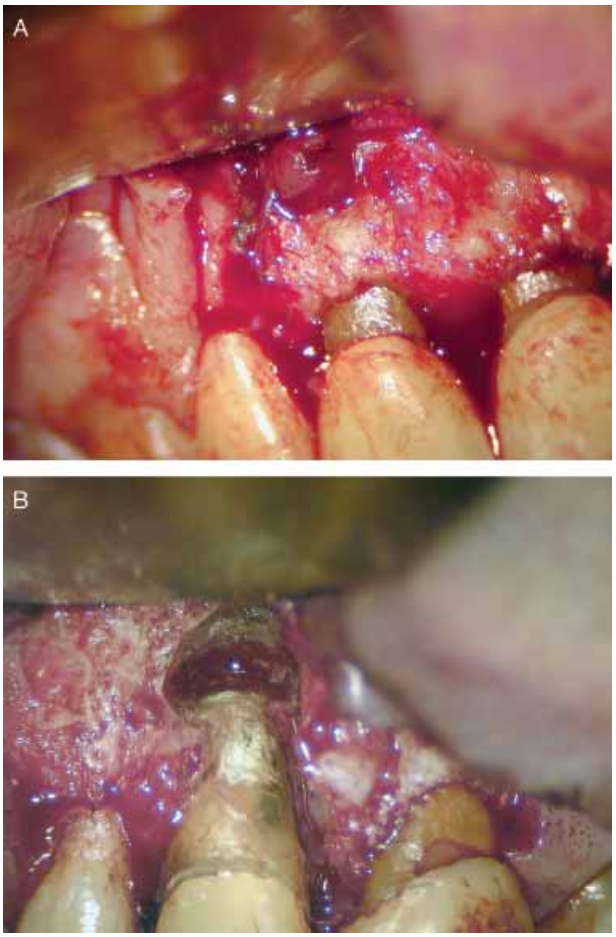


**Fig. 9. (A) Example of adequate bridge of buccal alveolar bone coronal to lesion. (B) Complete absence of buccal bone in this example. Note the calculus on the root face. Prognosis is very poor.**

There has been considerable debate on the necessity of removing all this tissue during the surgical procedure. As inflammatory periradicular lesions are the body's defence response to the inflammatory mediators that egress from the root canal system, the lesion should heal if the source of these irritants is eliminated or at least is sealed off. Lin et al. (66), in a review of the literature, stated that removal of the soft tissue lesion in its entirety is considered unnecessary, as remaining tissue remnants will be incorporated into the new granulation tissue as past of the healing process. Even if an epithelial lining were present, a radicular cystic lesion would be significantly disrupted by incomplete curettage and is likely to heal. An animal study involving cats (67) compared the rate of healing following periradicular surgery where in half the cases the soft tissue lesion was not removed. There were no significant differences between the two groups. While one should always be cautious of extrapolating data from an animal model to the human, it does corroborate with information in the existing literature.

There has been less agreement on the frequency and clinical relevance of a cystic lining to the lesion. While elements of epithelium may be detected in many biopsied specimens, the lesion itself may not be a true cyst. Simon (68) originally identified two different

types of radicular cyst – true cysts that were completely enclosed in an epithelial lining, and bay cysts, later renamed pocket cysts by Nair et al. (69), where the epithelium lined cavity was open to the root canal. Nair et al. (69) analyzed 256 periradicular lesions obtained *in toto* with extracted teeth, using a meticulous step-serial section technique. They reported the incidence of true cysts as 9%. They concluded that true cysts are unlikely to resolve following non-surgical root canal treatment or retreatment, whereas pocket cysts should resolve if the inflammatory mediators within the canal system are eliminated and the system satisfactorily sealed

Nair (56) has also reported foreign body reactions to gutta-percha, sealer, paper points and a variety of different materials such as vegetables, presumably forced into the canal and extruded through the apical foramina of teeth with severely damaged or carious coronal tissue and exposed pulp chambers, or during a period of open drainage with no coronal seal to the access cavity. Under these circumstances, if all micro-organisms and their by-products have been eliminated from the root canal system and an effective apical and lateral seal is present, apical curettage alone, including removal of the foreign body material contained within, should be sufficient to promote healing.

Because of the inability to predictably removal of all microbes and their by-products or to seal the canal system completely (70, 71), periradicular periodontitis may well persist following curettage unless the source of the infection is addressed by root resection and root-end filling. Although the surgeon may suspect extraoral infection within the soft tissue lesion, anticipate that the lesion may be a true cyst, or confirm the presence of foreign material within its confines, the exact nature of these conditions cannot be determined clinically. A final diagnosis would have to await a pathologist's histologic biopsy of the lesion. Thus there is general agreement that curettage alone is not adequate and must be accompanied by root resection and the root-end filling procedure.

## Technique of curettage

This is one area of the surgical procedure that has not changed over the past decade. Typical instrumentation would include a sharp bone curette – a Lucas 86 is a popular choice – and perhaps a sharpened endodontic excavator for smaller bony crypts, a suitably curved periodontal curette such as a Columbia #13/14 and a #34/35 Jaquette scaler (Hu-Friedy, Chicago, IL, USA) (39, 40) (Fig. 10). The soft tissue lesion is undermined by placing a sharp bone curette or large excavator at the junction of the bony crypt and the lesion itself, with the 'spoon' portion of the instrument positioned so the convex surface of the spoon faces the soft tissue. The instrument is advanced lingually and laterally, dissecting the lesion away from the walls of the crypt (Fig. 11). Once the lesion has been released from these surfaces, the curette is turned so the concave surface is in contact with the soft tissue at its lingual border. With care, the soft tissue may be released from the lingual bony wall, without piercing or fragmenting the tissue. It is generally more difficult to dissect the lesion from the root surface, to which it is firmly attached. The bone curette is no longer appropriate and the periodontal curettes should be employed to scrape the tissue away from the root – this is most difficult lingually where the operator cannot see except with the aid of micro-mirrors. The loose lesion is grasped with a pair of tissue forceps and eased buccally to aid viewing the areas where it is still attached and facilitate the last stages of the curettage, usually performed by the sharp Jaquette scaler (Hu-Friedy) in the lingual aspects of the bony cavity and on the lingual surface of the root. The complete soft tissue lesion may then be removed from the bony cavity. It should be placed immediately into a vial containing 10% neutral-buffered formalin, sealed and sent for histologic examination. Frequently, the root tip needs to be resected the required 3 mm before access is available to remove the remaining soft tissue adhering to the lingual root surface. Nevertheless, an attempt should always be made to remove the soft tissue lesion in one piece as it far more difficult to

**Fig. 10. Instrumentation for curettage. (A) Lucas 86 bone curette. (B) 34/35 Jaquette scaler. (C) Colombia 13/14 periodontal curette.**

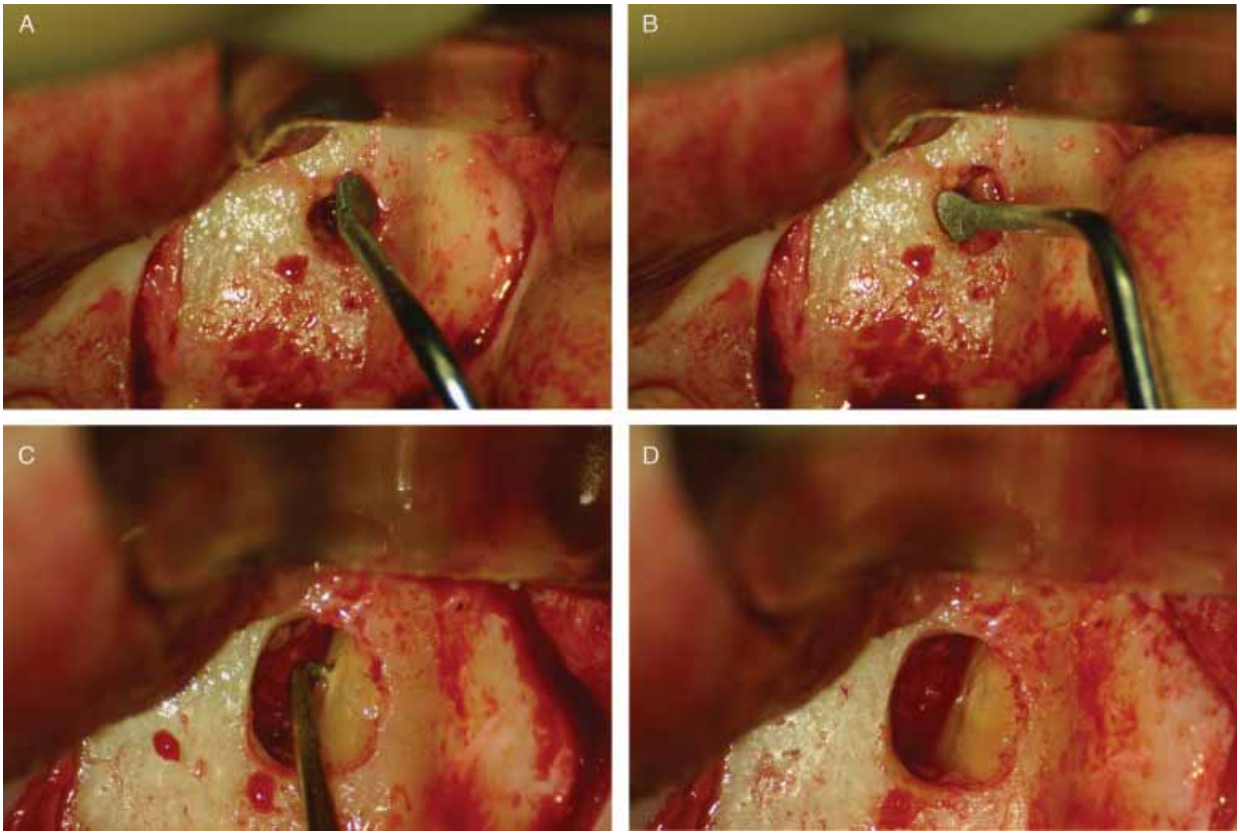


**Fig. 11. (A, B) Bone curette positioned so convex surface faces soft tissue lesion, and the concave surface faces the bone walls of the crypt. (C) Lesion removed and perforation located.**

dissect away shredded portions of tissue if the lesion is broken up and removed piece by piece. The pathologist's task is also made easier if a complete excisional specimen is available.

The bony crypt should then be examined under magnification to confirm that no obvious tissue tags are accessible for curettage, or that it would be inappropriate to attempt to remove them. This may be because the neurovascular bundles, or anatomical features such as the floor of the nose or the maxillary sinus, are in close proximity. Alternatively there may be inadequate local analgesia of these areas and the patient may experience pain. Despite apparently successful local analgesia during the procedure, areas of the soft tissue lesion can remain inadequately anesthetized (34, 40). Further local anesthetic solution may be injected directly into the soft tissue lesion, but, on occasions, even this procedure is not completely successful. Under all these circumstances, the remaining tissue may be left *in situ*.

Should the maxillary antral lining be involved in the soft tissue lesion, careful removal of the tissue is advocated, but again there is no necessity to curette the last portion of the lesion if perforation of the sinus is likely. Should the Schneiderian membrane be perforated, provided no solid tissue is allowed to drop into the sinus itself, a temporary oro-antral fistula does not present a problem (72–74). The transantral buccal approach to reach the palatal root apex of a maxillary molar is not usually mentioned in the various current texts on surgical endodontics, with the exception of Arens et al. (45), presumably because of the difficulty in preventing particles of resected root tip and associated root filling material, or root-end filling material placed into the prepared cavity, from dropping into the sinus. The exposed sinus should be protected by placing a temporary barrier such as a cotton pledget in the opening. This should have a suture attached and tied to it to allow recovery of the pledget should it be inadvertently displaced into the sinus (Fig. 12).

## Biopsy

Although there is unanimous agreement that the vast majority of soft tissue lesions are either granulomas or

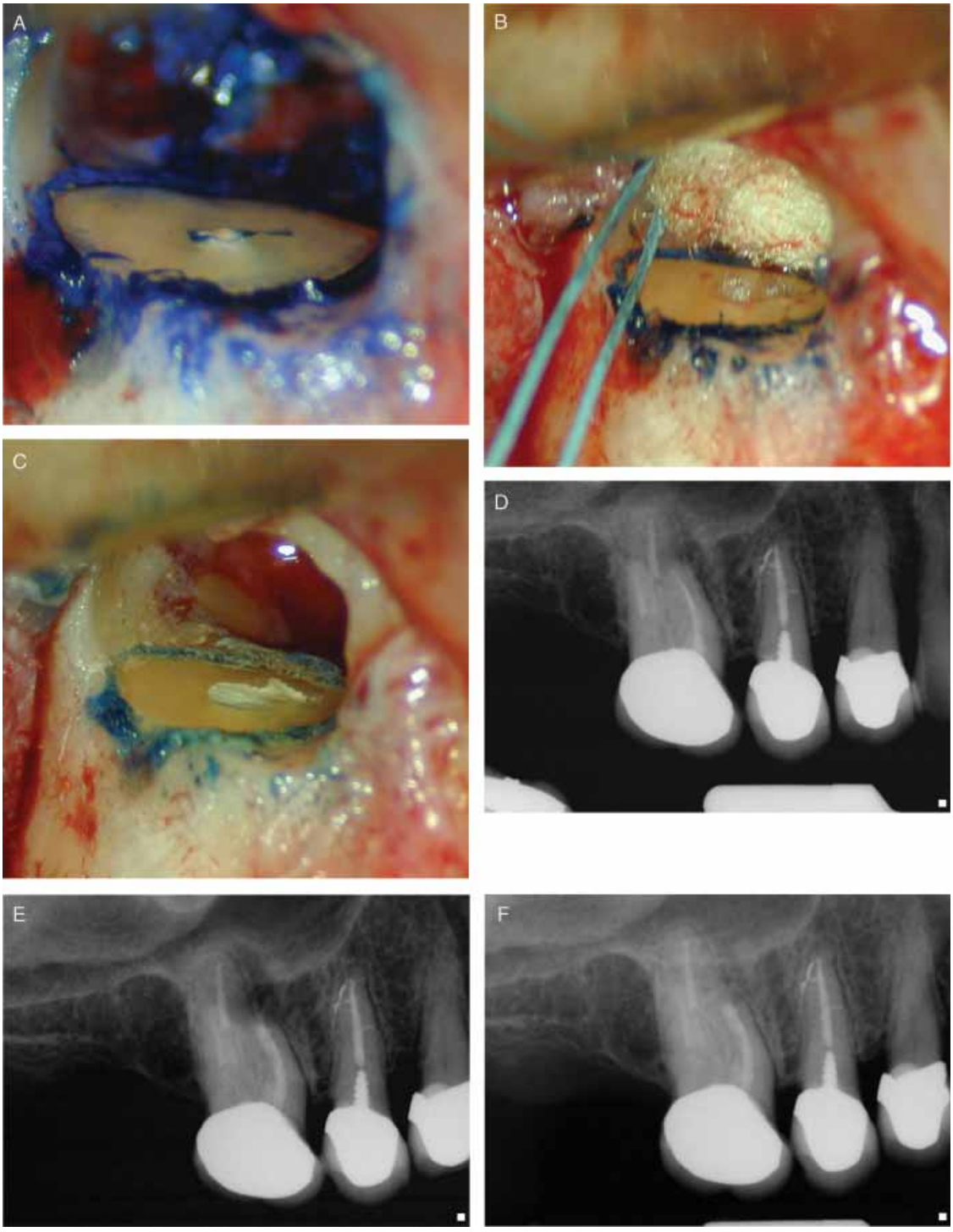


**Fig. 12. (A) Maxillary antrum perforated after root resection MB root of the maxillary right first molar (#16) (Methylene blue staining). (B) Sutured cotton pledget placed in fistula. (C) Pledget removed after root-end filling placed. (D) Periapical radiograph of the same case – note MB root apex not apparently in close proximity to lining of antrum. (E) Post-root-end filling view. (F) One-year follow-up indicating healing, despite the temporary oro-antral fistula.**

radicular cysts, any soft tissue lesion removed during the surgical procedure should be submitted for biopsy. However, this view was challenged by Walton (75) who argued that, provided an accurate diagnosis was made before surgery was initiated, the identity of the lesion should be known and that routine biopsy was therefore unnecessary and only undertaken if a lesion of non-odontogenic origin was suspected. Peters & Lau (76),

in a recent review of histopathologic examination to confirm the diagnosis of periapical lesions, stated that diagnoses that identified a lesion to be other than a granuloma or radicular cyst to be in the order of 0.7–5.0% of all periapical biopsies, but that there were no data on the frequency with which soft tissue lesions are submitted for histologic examination. They drew attention to numerous case reports in the literature describing the biopsy of lesions suspected, or provisionally diagnosed, as being inflammatory lesions of endodontic origin that have proved otherwise. There are several cystic lesions, which are not of such origin, including nasopalatine duct cysts, lateral periodontal cysts and contiguous residual cysts. The most aggressive of these lesions is the odontogenic keratocyst (OKC). Shears (77) determined that 10% of all jaw cysts in a sample of 2616 lesions submitted for examination were OKCs, although Stockdale & Chandler (78) encountered only one such example in a review of 1108 cases of periapical lesions. The OKC may be mistaken radiographically for a lesion of endodontic origin or a lateral periodontal cyst (79, 80). The relevance of this particular cyst relates to the extensive bony expansion and root resorption associated with this lesion, as well as the possibility of recurrence and, very rarely, the development of squamous cell carcinoma arising in an OKC.

Peters & Lau (76) also considered case reports of benign aggressive lesions such as central giant-cell granuloma, a lesion of varying and unpredictable progression, which may again mimic a periradicular lesion of endodontic origin (81). Other lesions reported included ossifying fibroma (82), Pindborg tumor (83), Langerhans cell disease (84), osteoblastoma (85) and central odontogenic fibroma (86).

The possibility of extraradicular bacterial infection has already been mentioned and the incidence of periapical actinomycosis in particular may not be as rare as previously thought. One review of the literature by Sakellariou (63) described some 45 case reports of the infection. A recent study (64) reported that the incidence of actinomycotic colonies located in lesions submitted for biopsy with a clinical diagnosis of granuloma or radicular cyst was 1.8% – uncommon but not rare! Treatment included a short course of antibiotic therapy to supplement the surgical procedure of curettage, root resection and root-end filling.

The major concern, however, is a misdiagnosis of a malignant neoplasm. Case reports abound in the literature and represent some 12% of documented cases (86–91). One paper alone presented seven cases, all initially treated for presumed periapical pathosis that were subsequently found to be neoplastic (92). While the level of evidence is obviously low – virtually all the papers discussed are just case reports – the inference is clear. Although careful clinical diagnosis may usually provide the correct histological diagnosis, there are many cases where such diagnosis has been shown to be mistaken. The limitations of special tests to assess pulp vitality and of radiographic interpretation are well known, quite apart from the incidence of less than thorough clinical examination or simple human error. Kuc et al. (83) examined the clinical and histopathologic diagnoses of 805 sequentially submitted periapical biopsy specimens. They concluded that in 5% of cases the histopathologic diagnosis added to or changed the original clinical interpretation, although they did warn against general extrapolation of this information.

In view of the possible serious consequences of a misdiagnosis, authors overwhelmingly agree that soft tissue lesions excised during surgical endodontic procedures should be sent for histopathologic examination (33–35, 38–40). The current AAE guidelines (93) also concur that a biopsy is indicated 'when an adequate amount of tissue or foreign material can be removed from the periradicular surgical site for histopathologic examination.'

## Conclusion

Unlike many aspects of periradicular surgery, the stages of osseous access and curettage have not altered significantly in the past decade or two. The literature is of a low level of evidence and techniques described in texts generally anecdotal. However, the availability of the operating microscope has provided vastly improved magnification and co-axial lighting to facilitate and refine these procedures. In particular, bone removal and root tip location with high-speed rotary instrumentation, and awareness of anatomic structures in close proximity to our surgical curettes, have become easier, safer and more predictable.

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# Root-end filling materials: rationale and tissue response

BUN SAN CHONG & THOMAS R. PITT FORD

The requirements of an ideal root-end filling are reviewed, before the demise of amalgam is considered. The focus is on tissue response to newer alternative materials: zinc oxide–eugenol cements, Mineral Trioxide Aggregate, glass ionomer cements, composite resins, compomers, and Diaket. The conflicting findings of *in vitro* and *in vivo* studies are analysed, as well as whether a root-end filling is necessary. The 'apical seal' is revisited with support for the concept of a 'double seal' that is physical and biological.

## Introduction

Periradicular surgery is the most frequently performed endodontic surgical procedure. The aims of periradicular surgery are to remove the causes of disease and to provide a favorable environment for healing of the surgical wound. Newer root-end filling materials, among other advances, including developments in surgical armamentarium, the implementation of microsurgical techniques, enhanced illumination and magnification, have helped to improve the outcome of periradicular surgery (1–6).

This review on root-end filling materials will examine the rationale for use and tissue response to these products. Given the variety of root-end filling materials, it is impossible to cover them all, so the focus is primarily on newer materials. A review of the methods of assessing biocompatibility is also beyond the remit of this paper.

## Role of a root-end filling

Management of the resected root end during periradicular surgery is critical to a successful outcome (7). The portion of root apex that is inaccessible to instrumentation and, as a consequence, cannot be cleaned, shaped or filled, or is associated with extraradicular infection that is unresponsive to non-surgical treatment, is removed. A filling material is then placed into a prepared root-end cavity as a 'physical seal' to prevent the passage of microorganisms or their products from the root canal system into the adjacent periradicular tissues. The placement of a root-end filling is one of the key steps in managing the root end.

The ideal healing response after periradicular surgery is the re-establishment of an apical attachment apparatus and osseous repair (8, 9). However, histological examination of biopsy specimens reveals three types of tissue response (10): healing with reformation of the periodontal ligament; healing with fibrous tissue (scar); and moderate-to-severe inflammation without scar tissue. The deposition of cementum on the cut root face is considered a desired healing response and a prerequisite for the reformation of a functional periodontal attachment (8). Resection of the root end results in an exposed dentinal root face surrounded peripherally by cementum with a root canal in the middle. Cementum deposition occurs from the circumference of the root end and proceeds centrally toward the resected root canal. The cementum provides a 'biological seal,' in addition to the 'physical seal' of the root-end filling, thereby creating a 'double seal' (11).

## Requirements of an ideal root-end filling material

The requirements of an ideal root-end filling material are well documented (12–14) (Table 1). Almost every

**Table 1. The requirements of an ideal root-end filling material**

After Gartner and Dorn (12), Kim et al. (13), Chong (14).

| Root-end filling materials should: |
|---|
| Adhere or bond to tooth tissue and "seal" the root end three dimensionally |
| Not promote, and preferably inhibit, the growth of pathogenic microorganisms |
| Be dimensionally stable and unaffected by moisture in either the set or unset state |
| Be well tolerated by periradicular tissues with no inflammatory reactions |
| Stimulate the regeneration of normal periodontium |
| Be nontoxic both locally and systemically |
| Not corrode or be electrochemically active |
| Not stain the tooth or the periradicular tissues |
| Be easily distinguishable on radiographs |
| Have a long shelf life, be easy to handle |

available dental restorative material or cement has at one time or another been suggested for root-end filling. As a result, there are a multitude of *in vitro* and *in vivo* studies reporting results, sometimes conflicting or inconsistent, claiming the superiority of certain materials for root-end filling. One of the most important requirements of any root-end filling material is biological tolerance. As root-end filling materials come into contact with periradicular tissues, knowledge of the tissue response is crucial. Regardless of the other desirable properties, a toxic product is unacceptable as a root-end filling material.

The biocompatibility of root-end filling materials is initially evaluated by *in vitro* cytotoxicity tests. Secondary assessments involving implantation are performed *in vivo*, followed by in-use testing, before clinical trials. The purpose of *in vivo* testing is also to determine whether the findings from laboratory studies are applicable to the clinical situation.

## Amalgam – its demise

Traditionally, amalgam was the material of choice for root-end fillings (14–17). Dentists are familiar with amalgam, and its usage for this purpose is also a reflection of its historical popularity as a restorative material. It is readily available, inexpensive, easy to manipulate, radiopaque and previously thought to be associated with a reasonable outcome. However, it has become clearly recognized that there are many disadvantages with amalgam (12, 18–22).

### Corrosion and dimensional changes

Amalgam corrodes at different rates depending on its composition. Electrochemical corrosion of amalgam was reported to be responsible for failures of amalgam root-end fillings (23).

### Unsightly amalgam tattoos

Scattering of excess amalgam particles during placement of the root-end filling can lead to tissue disfigurement. 'Focal argyria' results when the implanted material corrodes causing unsightly tattoos (24).

### Biocompatibility and safety issues

The biocompatibility of amalgam is cited as a current issue of concern in dentistry (25). Many *in vivo* usage studies in animals have reported unfavorable tissue response to amalgam (18–21, 26–30). Furthermore, regardless of the time period, no root end filled with amalgam was free from inflammation (20, 21), as all were associated with moderate or severe inflammation (Fig. 1).

The biological effects of amalgam are thought to be dependent on mode of manufacture and composition of the alloy (31). Zinc is known to be cytotoxic (32, 33) and its release from amalgam is considered a major cause of cytotoxicity (34, 35). Therefore, zinc-free amalgams are less cytotoxic compared with zinc-containing amalgams (36, 37).

There is also growing concern among the general public over the use of amalgam in dentistry especially the introduction of mercury into the body (38). The question of amalgam's safety has been examined meticulously in a number of reviews (39–44) and received attention from the World Health Organization (45). Moreover, no significant elevation of blood mercury levels in humans following the placement of freshly mixed amalgam root-end fillings has been noted (46). Nevertheless, the dental profession has long realized that amalgam usage is more than an emotive issue.

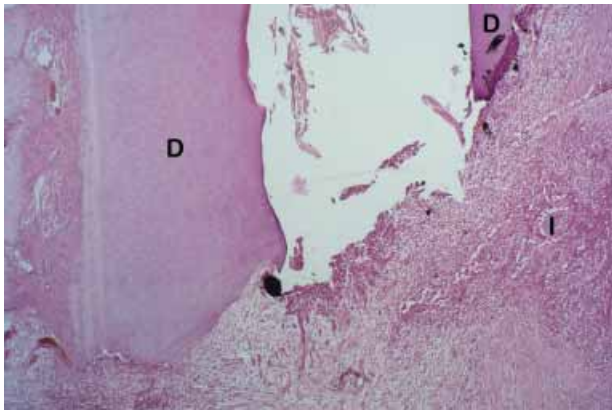


**Fig. 1. Tissue response to an amalgam root-end filling showing severe inflammation (I); dentine (D). Haematoxylin & eosin stain. Reprinted from Chong et al. (20) by permission.**

### Ineffective 'seal' from *in vitro* studies

Many *in vitro* leakage studies have demonstrated that amalgam does not provide an effective 'seal' (47). Although there are continuing questions on the validity and relevance of leakage studies (48, 49), they still have a place in providing an initial indication of a material's suitability.

### Poor outcomes reported in clinical studies

Many clinical studies have reported poor outcomes with amalgam root-end fillings when the results were carefully reviewed and strict healing criteria applied (50–53). Despite assertions that amalgam is still acceptable (54) or that there is not enough evidence to recommend alternative materials (55, 56), there is no shortage of opponents; amalgam can no longer be considered the root-end filling material of choice (13, 14, 22, 57–59). The use of amalgam as a root-end filling material can now be confined to history.

## Newer root-end filling materials

### Zinc oxide–eugenol cements

Zinc oxide-eugenol (ZOE) cements are among the materials currently considered more effective than amalgam for root-end filling. In an early report, Nicholls (60) expressed a preference for ZOE cements to amalgam for root-end fillings. The material was considered easy to handle and reportedly gave good postoperative results. However, the original ZOE cements were weak and had a long setting time (61). Another major disadvantage was their solubility. Indeed, the perceived view was that ZOE root-end fillings were likely to be absorbed over a period of time (62, 63) and therefore unsuitable for long-term use. Consequently, the use of modified forms of ZOE cements was suggested (64, 65).

Two approaches were adopted to improve the physical properties of ZOE cements:

(i) The partial substitution of eugenol liquid with ethoxybenzoic acid (EBA) and the addition of fused quartz or aluminum oxide to the powder to give an EBA cement – Stailine Super EBA cement (Staident International, Staines, Middx, UK).
(ii) The addition of polymeric substances to the powder.

  (a) polymethymethacrylate to the powder – Intermediate Restorative Material (IRM) (De Trey, Dentsply, Konstanz, Germany)
  (b) polystyrene to the liquid – Kalzinol (De Trey, Dentsply)

The biological properties of ZOE cements differ according to formulation and age of the material (37). Eugenol is the major cytotoxic component in ZOE cements (66–69). Zinc released from these cements was suggested as being partly responsible for the prolonged cytotoxic effect (32).

Free eugenol remains trapped in the set mass of zinc eugenolate and is released by progressive hydrolysis of the cement surface (70). Variations in the composition of the reinforced ZOE cements may affect the rate of cement dissolution and eugenol released, producing the observed differences in cytotoxicity (37). The disintegration rate of IRM and EBA is slower compared with Kalzinol (71). Plain ZOE mixtures were shown to release more eugenol and be more cytotoxic than Kalzinol (72) and IRM (73, 74). The zinc acetate in Kalzinol, which accelerates setting, increases the binding of eugenol, while the presence of polystyrene might inhibit the rate of diffusion of eugenol (72). In addition, in IRM, eugenol may have an affinity for the polymethylmethacrylate, limiting its release from this material (37).

The cytotoxicity of EBA is also because of eugenol; this was the only component in the cement to show a

cytotoxic effect when the components were tested separately (75). Over a period of time, the cytotoxicity of EBA gradually reduces to nil (76); the explanation being that EBA contained less eugenol at the start and it had all leached out. Another explanation was that the generation of eugenol radicals, responsible for the cytotoxicity, may be suppressed by the EBA (77). A reduction in cytotoxicity of EBA with time was also reported by Chong et al. (37) but Balto & Al-Nazhan (78) did not observe this. Nevertheless, Chong et al. (37) found that fresh IRM was the most cytotoxic while there was no difference between Kalzinol and EBA; when aged, Kalzinol was the most cytotoxic followed by IRM and then EBA. Lin et al. (79) regarded the marked cytotoxicity of IRM and EBA to periodontal ligament cells in their *in vitro* study as only a transient reaction to the eugenol, because the results from *in vivo* experiments with both materials as root-end fillings were more favorable than with amalgam.

Efforts were made to further improve the biocompatibility of reinforced ZOE cements by adding hydroxyapatite to IRM (80) and Type II collagen powder to EBA (81). In addition, a higher powder-to-liquid ratio of IRM is recommended, when used as a root-end filling material, because of the advantages of easier placement, shorter setting time, decreased toxicity and solubility (82).

Of the reinforced ZOE cements, EBA is the strongest and least soluble of all the formulations (83, 84). Hendra (64) recommended the use of EBA as a root-end filling material. EBA has a short setting time and because of its adhesive properties, an initial concern was difficulties in placing the material into the root-end cavity (85, 86). Oynick & Oynick (65) reported that collagen fibres grew over EBA root-end fillings and claimed the material to be biocompatible.

In an implantation experiment, IRM and amalgam showed complete healing at 56 days, whilst there was a slightly greater inflammatory response with EBA; but all three materials showed complete healing by 100 days (87). In contrast, Maher et al. (88) reported that amalgam root-end fillings showed decreased inflammation and good healing with time whereas IRM specimens showed persistent inflammation and slower healing. The validity of these surprising results, however, has been questioned (18).

The effect of IRM as a root-end filling placed in teeth prior to replantation was examined by Pitt Ford et al. (18), with the tissue response to IRM at 8 weeks being less severe and less extensive than that to amalgam. When the study was repeated with EBA (28), few inflammatory cells were observed and the response was mild compared with amalgam, with the result with EBA similar to that with IRM. Trope et al. (89) in a histological study confirmed the good tissue response to both EBA and IRM. Overall, EBA was the best although it was not significantly better than IRM.

Significant interest in reinforced ZOE cements as a root-end filling material was generated by the results of a retrospective study by Dorn & Gartner (50). They examined the results of amalgam, IRM and EBA as root-end fillings. A total of 488 cases from two practices were reviewed, the recall period ranged from 6 months to 10 years. A successful outcome of 95% was found with EBA, 91% with IRM and 75% with amalgam; the difference between EBA and IRM was not statistically significant.

In a clinical study of 100 patients, EBA was compared with amalgam as root-end fillings (90). At review 3 years later, 79 patients (39 in the EBA group, 40 in the amalgam group) remained. Complete bone regeneration was observed in 57% of teeth in the EBA group and 52% in the amalgam group. Uncertain healing with bone regeneration was evident in 20% of teeth in the EBA group and 29% in the amalgam group. However, the difference between the two materials was not statistically significant.

In another clinical report, Schwartz-Arad et al. (91) concluded that both amalgam and IRM were equally effective as root-end filling materials. Schwartz-Arad et al. (91) were critical of the study by Dorn & Gartner (50), yet their study had a smaller sample size with 122 teeth from 101 patients available at recall and their overall results using different evaluation criteria were poorer by comparison. Complete healing was observed in 44.3% of the teeth, incomplete healing in 21.3%, and unsatisfactory healing in 34.4%.

In a prospective clinical study, the use of IRM as a root-end filling material, adherence to a strict surgical protocol and the application of contemporary techniques resulted in a predictably successful outcome of 91.2% with 102 out of the 114 teeth treated were available for review (4). Good results were reported with EBA when periradicular surgery was performed with microsurgical techniques and with the aid of an operating microscope (1, 2). A 96.8% successful outcome was seen in 94 out of the 128 cases treated when reviewed at 1 year (1). When the cases considered

healed were reevaluated 5–7 years later, 54 out of the 59 roots (91.5%) recalled remained healed (2). In another study, when 120 teeth were followed-up for up to 3 years, a successful outcome of 92.5% with EBA was achieved when combined with modern periradicular surgery techniques (6). In contrast, traditional surgical techniques and amalgam as a root-end filling material were reported to have a negative effect on outcomes (3).

## Mineral Trioxide Aggregate (MTA)

MTA was developed as a new root-end filling material at Loma Linda University, California, USA. A study on the physical and chemical properties of MTA investigated the composition, pH, radiopacity, setting time, compressive strength and solubility of the material compared with amalgam and reinforced ZOE cements (92). Unlike a number of dental materials that are not moisture-tolerant, MTA actually requires moisture to set. The MTA powder consists of fine hydrophilic particles. When mixed with sterile water, hydration of the MTA powder results in a colloidal gel that solidifies into a hard structure. It has a long setting time (2 h 45 min) so the material must be protected before it is fully set. The pH of MTA rises from 10.2 after mixing to 12.5 after 3 h, remaining unchanged afterwards. Likewise, the compressive strength of MTA increases with time, from 40.0 MPa after 24 h to 67.3 MPa after 21 days.

The sealing ability of MTA was investigated using fluorescent dye and confocal microscopy (93), methylene blue dye (94), and bacterial marker (95); its marginal adaptation was assessed using scanning electron microscopy (96); the long-term seal was measured over a 12-week (97) and 12-month period (98) using different fluid transport methods. They all reported good results with MTA when ranked with other materials. This may be because of its moisture tolerance and long setting time.

The antibacterial activity of MTA was investigated using the agar diffusion inhibitory test (99) and the mutagenicity by the Ames test (100). The antifungal (101, 102), and both antibacterial and antifungal effects (103) of MTA were also evaluated.

The biocompatibility assessment of MTA encompassed *in vitro* cell culture techniques using established cell lines, primary cell cultures or a combination (Table 2) (79, 105–120). Apart from variations in sensitivity because of the cell type used, the results showed MTA to be biocompatible. Tissue response evaluated *in vivo* by intraosseous and subcutaneous implantation experiments (Table 3) (104, 121–125) found MTA to be well tolerated. MTA was also shown not to have an adverse affect on connective tissue microcirculation when assessed using an improved rabbit ear chamber (104). *In vivo* usage testing (29, 30, 127) revealed less inflammation with MTA root-end fillings compared with amalgam, in addition to the presence of new cementum formed adjacent to the MTA (Fig. 2).

MTA has the ability to encourage hard-tissue deposition and the mechanism of action may have some similarity to that of calcium hydroxide (128). Although hard-tissue formation occurs early with MTA (129), there was no significant difference in the

**Table 2. Cells used for *in vitro* evaluation of biocompatibility of Mineral Trioxide Aggregate**

| |
|---|
| Established cell lines |
| L929 mouse fibroblasts – Torabinejad et al. (104), Saidon et al. (105) |
| MG-63 human osteosarcoma cells – Koh et al. (106, 107), Mitchell et al. (108) |
| Saos-2 human osteosarcoma cells – Zhu et al. (109), Camilleri et al. (110) |
| U2OS human osteosarcoma cells – Huang et al. (111, 112) |
| ECV 304 human endothelial cells – De-Deus et al. (113) |
| L929 mouse skin fibroblasts, BHK21/C13 baby hamster kidney fibroblasts and RPC-C2A rat pulp cells – Koulaouzidou et al. (114) |
| Primary cell cultures |
| Human periodontal ligament fibroblasts – Keiser et al. (115), Balto (116) |
| Human gingival fibroblasts – Pistorius et al. (117) |
| Human periodontal ligament and gingival fibroblasts – Bonson et al. (118), Lin et al. (79) |
| Established cell lines and primary cell cultures |
| L929 mouse skin fibroblasts and human gingival fibroblasts – Osorio et al. (119) |
| Rat calvaria osteoblasts and MG-63 human osteosarcoma cells – Pérez et al. (120) |

**Table 3. *In vitro* implantation experiments on the biocompatibility of Mineral Trioxide Aggregate**

| |
|---|
| Intraosseous implantation |
| Guinea-pigs tibia and mandible – Torabinejad et al. (121) |
| Guinea-pigs mandible – Saidon et al. (104), Sousa et al. (122), Torabinejad et al. (123) |
| Subcutaneous implantation |
| Wistar albino rats – Yaltirik et al. (124) |
| Subcutaneous and intraosseous implantation |
| Sprague–Dawley rats – Moretton et al. (125) |

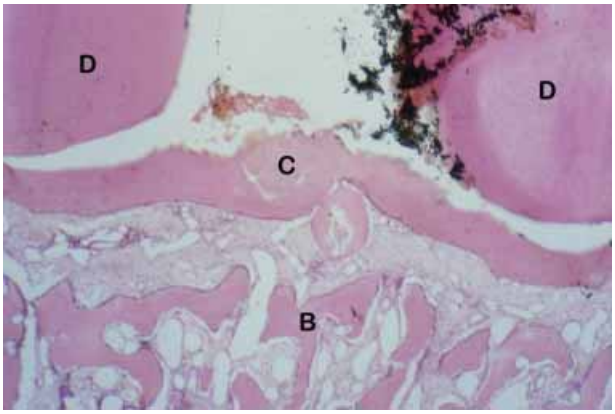


**Fig. 2. Root end filled with Mineral Trioxide Aggregate. New cementum (C) has grown over the cut root-end and root-end filling material. There is no inflammation in the adjacent connective tissue; dentine (D) and bone (B). Haematoxylin & eosin stain. Reprinted from Torabinejad et al. (29) by permission.**

quantity of cementum or osseous healing associated with freshly placed or set MTA (130). The patterns of osteogenesis for intraosseous implants of MTA and EBA were similar at 15 and 30 days but interestingly, at 60 days, EBA exhibited greater osteogenesis than MTA (125). If the assessment period were longer, the difference may not have been significant.

Investigations of why MTA appears to induce cementogenesis found that the material seemed to offer a biologically active substrate for osteoblasts, allowing good adherence of the bone cells to the material, while also stimulating the production of cytokines (106, 107). Cytokine release was not detected in another study on MTA (131) and the difference may be due to a number of factors including the cell types used with osteoblast-like cells (MG-63) used in the former studies (106, 107) and macrophages used in the latter (131).

The effects of MTA on cementoblast growth and osteocalcin production were investigated in a tissue culture experiment (132). Results suggested that MTA permitted cementoblast attachment and growth, whilst the production of mineralized matrix gene and protein expression indicated that MTA could be considered cementoconductive. MTA was found to stimulate extracellular regulated kinases, members of the mitogen-activated protein kinase pathway, which are involved with bone cell proliferation, differentiation and apoptosis (111). Subsequently, the effects of a calcium hydroxide liner, EBA, and MTA were evaluated on U2OS human osteosarcoma cells and the expression of inflammatory cytokines. The best cell attachment and the higher cytokine levels were found with MTA (133). MTA also induced fibroblasts to express genes associated with cementum formation of an osteogenic phenotype (118). When the *in vitro* behavior of bone marrow cells to MTA and IRM was investigated, MTA had low toxicity compared with IRM. However, it did not inhibit cell growth, but rather seemed to suppress their function as osteoblasts and promoted their function as fibroblasts (134).

A study to elucidate the physicochemical basis of the biological properties of MTA concluded that calcium, the dominant ion released from MTA, reacts with tissue phosphates yielding hydroxyapatite, the matrix at the dentine-MTA interface (135). The sealing ability, biocompatibility, and dentinogenic activity of MTA may be attributed to these physicochemical reactions.

ProRoot MTA (Dentsply/Maillefer, Ballaigues, Switzerland) is the first commercially available version of MTA. Initially, ProRoot MTA was grey in color but because of aesthetic concerns (108), a white version is now available. Both products have similar composition but tetracalcium aluminoferrite is absent in white MTA (102). Principle differences in the constitution of the two versions of MTA were confirmed by X-ray energy dispersive analysis and X-ray diffraction analysis (136).

The use of electron probe microanalysis of the elemental constituents indicated that the most significant differences between grey and white MTA were the measured concentrations of $Al_2O_3$, MgO and especially FeO (137). However, when two different osteoblast cell lines were evaluated morphologically to characterize their behavior when in contact with grey

and white MTA (120), the MG-63 osteosarcoma cells adhered to white MTA for periods twice as long as primary osteoblasts. While there was no difference between cell lines in their adherence to grey MTA, primary cell cultures were considered more appropriate for *in vitro* testing of endodontic materials.

The first randomized prospective clinical study on the use of MTA as a root-end filling material was published by Chong et al. (5). After 24 months, of the 108 patients reviewed (47 in IRM group, 61 in MTA group), the highest number of teeth with complete healing was observed with MTA. When the numbers of teeth with complete and incomplete (scar) healing were combined, the results for MTA were higher (92%) compared with IRM (87%). However, statistical analysis showed no significant difference in outcome between materials. The good results with both materials may be due to the strict entry requirements and stringent, established criteria for assessing treatment outcome. Similar results were reported by Lindeboom et al. (138) in a clinical study consisting of 100 single-rooted teeth; there were no statistically significant differences between MTA (92%) and IRM (86%) after 1 year.

A Brazilian version of MTA was developed to improve it handling and setting properties (139). The product is MTA-Angelus (Angelus Dental Solutions, Londrina, Paraná, Brazil) and is claimed by the manufacturer to have an initial setting time of 10 min. While the sealing ability and marginal adaptation of MTA-Angelus were shown to be good (140), the pH and calcium released from MTA-Angelus were slightly higher than those from ProRoot MTA (139). The cytotoxicity of MTA-Angelus on ECV 304 human endothelial cells was found to be similar to ProRoot MTA and a Portland cement (113). In another study, using different cells, no cytotoxic effect was found with MTA-Angelus, a grey and a white Portland cement (141).

Further attempts to improve the handling properties of MTA include the formulation of an experimental endodontic cement which handles like a gel (142). Viscosity Enhanced Root Repair Material (VERRM) is another recently formulated material based on Portland cement (143).

## Glass ionomer cement and related materials

Glass ionomer cement, based on the reaction of silicate glass powder with polyalkenoic acid, was introduced as a new restorative material in the early 1970s (144). Glass ionomer cements possess adhesive properties. Resin-modified glass ionomer cements, first described by Antonucci et al. (145), were developed to improve physical and handling properties. Resin-modified glass ionomer cements contain a monomer such as 2-hydroxyethyl methacrylate (HEMA) or bisphenol-A-glycidyl methacrylate (bis-GMA), together with a photoinitiator such as camphorquinone. The biocompatibility of glass ionomer cements and the resin-modified forms was reviewed by Sidhu & Schmalz (146) and Geurtsen (147), respectively. The use of glass ionomer cements in both non-surgical and surgical endodontics was reviewed by De Bruyne & De Moor (148).

The tissue response to glass ionomer cement was investigated by intraosseous implantation in femurs (149). Intense inflammation was observed at 2 months but this was less at 6 months. By 12 months, the inflammation had been replaced by new bone.

Silver-reinforced glass ionomer cement was found to be well tolerated when implanted into connective tissue (150) and into mandibular bone (151). However, it was reported that a significant amount of silver was released from this type of material (152). Therefore, theoretically, there are problems, common to amalgam, of silver corrosion and potential discoloration of soft tissues with silver-reinforced glass ionomer cement; the corrosion products are also cytotoxic (152, 153).

The tissue response to glass ionomer cement was compared with amalgam in a study of up to 6 months (154). Irrespective of time periods, the tissue response was good. Similar results were observed in a mandibular implantation study (155) when the tissue response was examined up to 90 days.

There was early resolution of inflammation when glass ionomer cement was investigated as root-end fillings in canine teeth (156). The inflammatory reaction to glass ionomer cement was less severe compared with gutta-percha with sealer. At 28 days, there was no inflammation with the glass ionomer cement and bone infill was also more complete in this group.

The tissue response to a tri-cure glass ionomer cement and EBA was compared by intraosseous implantation (157). At 4 weeks, the results with both materials were similar but at 12 weeks, the glass ionomer cement was better than EBA.

The periradicular tissue response to glass ionomer cement root-end fillings, in the presence or absence of

root canal fillings was investigated by Pitt Ford & Roberts (158). Where no root canal filling was placed and the root canal was left exposed to salivary contamination prior to surgery, the root-end fillings failed to prevent severe inflammation. Bacteria were found at the interface of glass ionomer cement and dentine in every tooth; this confirmed the importance of filling the entire root canal.

A number of clinical studies have reported on the use of glass ionomer cement for root-end filling. In a study of 105 teeth, at 1 year, the difference in the outcome with amalgam (91%) and glass ionomer cement (89%) was not statistically significant (159). In another study of 67 teeth in 64 patients, no differences were found in outcomes between amalgam and glass ionomer cement (160). Overall, the results with both materials reflected a high level of success (85%) at 5 years. Both research groups promoted glass ionomer cement as an alternative to amalgam for root-end filling.

The advantages of improved handling properties and command setting prompted the first study of a resin-modified glass ionomer (Vitrebond, 3M ESPE, St Paul, MN, USA) as a potential root-end filling material (161). The adaptation and sealing ability of Vitrebond used with (162) or without a root-end cavity (163) were generally favorable.

Following *in vitro* testing that confirmed its good antibacterial activity (164) and low cytotoxicity (37), the tissue response to Vitrebond was investigated *in vivo*. In an experimental model of teeth with infected root canals, Vitrebond and Kalzinol were compared with amalgam (20). After 8 weeks, the tissue reaction with Vitrebond was better than with the other test materials.

In general, chemically cured glass ionomer cements are slow setting, difficult to handle in the awkward environs of the surgical wound, and are susceptible to blood/moisture contamination. Although resin-modified glass ionomer cements are easier to handle and polymerization by light exposure allows controlled setting, the need for total dryness before placement remains an issue. Even when a dry field is maintained, some moisture is inevitable and this may affect the glass ionomer/dentine bond (89).

## Composite resin

Composite resins are based on a blend of aromatic and/or aliphatic dimethacrylate monomer such as bis-GMA, triethylglycol dimethacrylate (TEGDMA) and urethane dimethacrylate (UDMA). Retroplast (Retroplast Trading, Rørvig, Denmark), a chemically cured two-component BisGMA/TEGDMA composite resin plus the dentine-bonding agent, Gluma (Heraus Kulzer GmbH, Werheim, Germany), has been used as a root-end sealant, in a saucer-type preparation since 1984 (165). The histological response to this material was assessed 1 year after surgery (166, 167). In some cases, epithelium and inflammatory cells were seen in the periradicular tissues, while in the others there was no inflammation; cementum and Sharpey's fibres were observed in one case. Periodontal tissue regeneration including cementogenesis associated with Retroplast was also the subject of a clinical case report involving two teeth (168).

The silver in the early version of Retroplast that acted as a radiopaque agent was found to affect the properties of the material. As it might also cause tissue discoloration, it has been replaced with ytterbium trifluoride since 1990 (169). The change in formulation was reported to have no significant effect on healing outcome. Although other bonding agents may be used (170), the presence of glutaraldehyde in Gluma may be an advantage because of its disinfecting ability (171).

Maintaining a dry field is important when using Retroplast. In cases where there was poor hemostasis during surgery, there was an absence of complete healing, possibly because of bond failure between the Retroplast and root dentine (166). The percentage of cases with complete healing was also reduced if the root canal was unfilled (172).

The effect of Retroplast, MTA, amalgam, and IRM on cell morphology, cell growth, and cytokine production was investigated using mouse fibroblasts and macrophages (130). All the root-end filling materials tested exhibited an inhibitory effect on cell growth, and none induced cytokine production. Clinical studies on Retroplast and Gluma have reported good outcomes. Rud et al. (173) reported complete healing, measured radiologically, in 32 out of 33 roots (97%) when patients were recalled 8–9 years later. In another report of patients recalled after 6 months to 12.5 years, complete healing was seen in 771 out of 834 roots (92%) (171).

In a prospective randomized clinical study, Retroplast was compared with a metal-reinforced glass ionomer cement (174). A total of 122 patients were reviewed

after 1 year, with the proportion of successful cases with Retroplast (73%) being significantly higher than the metal-reinforced glass ionomer cement (31%). Most of the unsuccessful metal-reinforced glass ionomer cement cases failed because of loosening of the root-end filling.

The effectiveness of composite resin combined with a dentine-bonding agent for root-end filling may be dependent on the root-end cavity design. When a traditional root-end cavity design was used, composite resin did not fully enter the cavity because of the presence of dentine-bonding agent (89). With a concave root-face preparation, as used with Retroplast, pooling of the dentine-bonding agent is less likely. With an adhesive material, another option may be to apply the apical sealant directly onto the root face, without preparing a root-end cavity (163).

Dentine-bonding agents alone have been proposed for root-end filling (175). However, they should be used with caution because two polymerized dentine-bonding agents tested adversely affected the viability of monocytes in a cell culture assay (176).

## Compomers

Compomers are polyacid-modified composite resins. They have some glass ionomer component such as an acid-leachable glass and bonding of polyalkenoate acid molecules to the resin monomer, which forms a matrix.

The biocompatibility of a compomer and EBA was assessed when implanted into femurs (177). After 4 weeks, both materials showed inflammation but bone healing was observed at 12 weeks. The tissue response to two compomers, composite resin and amalgam was evaluated by subcutaneous implantation (178). All the materials produced an inflammatory response at 7 days but the response was most severe with composite resin. For all materials, the inflammatory response had resolved by 90 days with formation of a fibrous tissue capsule.

There is limited clinical data on the use of compomers as a root-end filling material. In a clinical study involving only 34 teeth for 1 year, a light-cured compomer combined with a light-cured dental adhesive in shallow concave apical preparations was compared with a glass ionomer cement in a traditional root-end cavity preparation (179). A significantly more successful outcome of complete healing was reported for the compomer (89%) compared with the glass ionomer cement (44%).

## Diaket

Diaket (3M ESPE), a polyvinyl resin-reinforced chelate formed between zinc oxide and diketone was initially intended for use as a root canal sealer. When mixed to a thicker consistency of two parts powder to one part liquid, it was advocated as a root-end filling material (180). The material has adequate radiopacity, and the mixed material has a firm consistency and a working time of $>30$ min. The sealing ability of Diaket as a root-end filling material was reported to be superior to amalgam and glass ionomer cement (181), EBA and IRM (182). A further study found the sealing ability to be similar to amalgam and not better than glass ionomer cement (183). Diaket also showed good biocompatibility when implanted in bone (184).

The healing of periradicular tissues was evaluated histologically when Diaket, with and without tricalcium phosphate was used for root-end filling (185). The root ends were conditioned with citric acid. At 30 and 60 days post-surgery, there were no statistically significant differences in the tissue response between Diaket with or without tricalcium phosphate, with the overall healing of the periradicular tissues considered to be favorable. Histologically, a hard tissue matrix was observed over the Diaket. The close approximation of periodontal tissue fibres suggested a regenerative response to the material. Diaket was used as a control in a study to evaluate the influence of growth factors on periradicular healing (186). Only Diaket stimulated a periradicular reaction consistent with regeneration. When the healing response to Diaket root-end fillings was compared with gutta-percha, Diaket showed a better healing response, characterized by bone apposition, reformation of periodontal ligament, and deposition of new cementum (187). There was some hard-tissue formation adjacent to the root-end filling material bordered by occasional multinucleated giant cells. However, the nature of both the hard tissue formation and the adjacent cells were difficult to determine.

Diaket was compared with MTA in a study to assess the potential to promote periradicular tissue regeneration (11). Both Diaket (Fig. 3) and MTA supported almost complete regeneration of the apical periodontium. However, the handling properties of Diaket were considered superior to those of MTA.

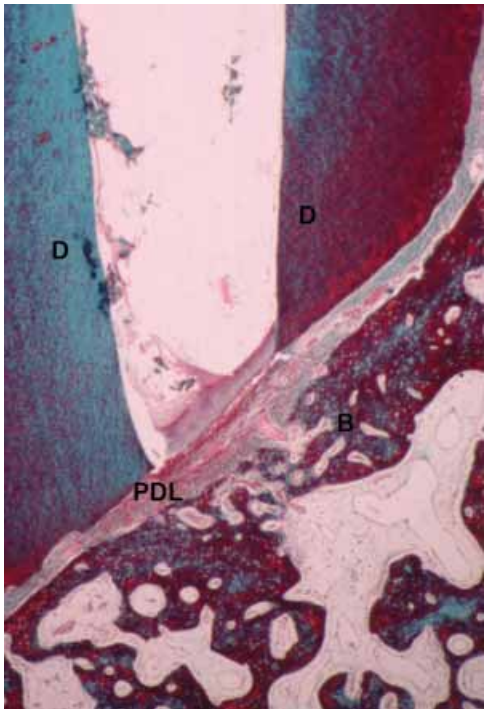


**Fig. 3. Diaket specimen showing regeneration of the periodontal architecture; periodontal ligament (PDL), bone (B) and dentine (D). Masson's trichrome stain. Reprinted from Regan et al. (11) by permission.**

# Discussion

## Correlation between *in vitro* and *in vivo* studies

The need for biological evaluation of a material prior to its clinical use is unquestioned. Despite the myriad of biocompatibility tests, the *in vitro* and *in vivo* results have not always been in agreement (47). Differences in experimental protocol and methods including target cells, choice of assay, laboratory animal and test site selected may influence the results. Often, *in vivo* studies on tissue response to root-end filling materials do not simulate the clinical situation as they were performed in infection-free periradicular tissues under ideal circumstances. There are fewer studies in which new or potential root-end filling materials were tested on infected teeth with periradicular inflammation. The good results reported in some studies, even with amalgam, may be erroneous as the experimental conditions were unrepresentative of the clinical situation in which infection is involved (20). The evaluation of tissue response should also include tests under non-ideal conditions. When testing the tissue response of dental materials, the first step is to define the use of the material (25). The appropriate test can then be devised and performed accordingly. When the experimental conditions simulate the typical clinical situation, only then is it possible to ascertain the true tissue response and the results extrapolated to clinical application (21).

Presently, the properties required of root-end filling materials are not standardized so they are not specifically included within the ISO technical standards for root canal filling materials (188). The lack of standardization means that even physical properties such as radiopacity, for example, of some root-end filing materials is inadequate and needs to be increased (189, 190). Yet, a root-end filling material is unlike a filling inside a crown or root because it is in close, permanent contact with periradicular tissues. Thus, an agreed testing protocol, more relevant to root-end filling materials is warranted (191).

## Is a root-end filling always necessary?

There has long been a debate on whether a root-end filling should always be placed and also whether a better 'apical seal' can be achieved by its placement especially when the root canal is already well filled (16, 54). Friedman (16) argued that a root-end filling should be placed routinely. A tooth lacking a root canal filling will need it and even if the root canal looks apparently well filled, it may still contain infection so a root-end filling should be placed. In cases of extraradicular infection, theoretically, a root-end filling is not necessary but clinically, the possible co-existence of intraradicular infection cannot be excluded so again a root-end filling is essential. However, these assertions need to be modified and should be better qualified. Numerous studies have inferred that the lack of a good root canal filling will or is likely to compromise the surgical outcome (157, 171, 192). In addition, a number of clinical studies on healing after periradicular surgery have confirmed the benefit of placing a good root canal filling prior to surgery (5, 53, 193–195). Therefore, surgery should never be performed if a root canal filling is absent and a good quality root filling could be placed beforehand. Even if a root filling is present but the quality is questionable, then it would be better to replace it. The need for a root-end filling should be decided at the time of surgery, after root-end resection, when there is opportunity to examine the quality of the

exposed root canal filling with magnification. If the portion of root apex that is inaccessible to instrumentation and consequently a source of infection is removed, provided the exposed root filling is of a good quality and there are no additional canals or canal extensions, a root-end filling is not necessary.

### Does an ideal root-end filling material exist and which to choose?

The question as to which is the best root-end filling material has received generous attention (12, 16, 54, 55, 196–198). The systematic review by Neiderman & Theodosopoulou (55) of *in vivo* success using root-end filling materials found that in studies using a randomized controlled trial design, of which there were only two, glass ionomer cement was more effective than amalgam. For studies using a non-randomized controlled trial design, the results were more variable. Some studies reported that amalgam was more effective than glass ionomer, while others showed that composites or EBA were more effective than amalgam. The authors undertook their review, however, prior to the publication of the first prospective clinical study on MTA (5). In addition, the review looked at studies conducted prior to recent advances in surgical endodontics. Therefore, it is not just materials but the procedures that must come under scrutiny. Randomized controlled trials cannot be considered the only research tool of value. Evidence-based treatment requires the integration of the best evidence with clinical expertise and patient preferences; therefore it informs, but never replaces, clinical judgement (199).

Currently, there does not appear to be an 'ideal' root-end filling material (13, 17, 200) as none fulfils all the desired requirements. Although there is insufficient evidence to specify a single material for root-end filling, the evidence points to ZOE cements, MTA, Diaket and Retroplast as being acceptable. The material to choose will depend on prevailing clinical conditions (151). For example, if there are difficulties in maintaining a dry surgical field, even if a material has excellent biological characteristics, it is unsuitable if it is sensitive to moisture.

### The elusive 'apical seal'

The 'apical seal' has long been considered paramount to the success of periradicular surgery (201). Over the years, numerous research and clinical studies involving a plethora of materials were conducted to identify the ideal apical sealing material. Interestingly, osseous wound healing was reported to be independent of the type, and presence or absence, of a root-end filling (202). Regan et al. (11) commented that the evidence collected during their histological study on Diaket suggested that formation of a complete cemental coverage over both the root end and the root-end filling material was possible, although not predictable. It is feasible to promote, at least in theory, the formation of 'a double seal' following periradicular surgery, incorporating both a physical and biological covering over the resected root end (11). However, no current root-end filling material can provide a perfect 'physical seal.' Yet surgical endodontic management of the root end can result in successful outcomes, suggesting that an impenetrable 'apical seal' may not be an absolute pre-requisite. There may be other factors apart from sealing ability that may influence the outcome of periradicular surgery. In addition, differences between individuals in terms of their ability to fight infection, tolerance of surgery and rate of healing will have an effect on the outcome of periradicular surgery.

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# Root-end management: resection, cavity preparation, and material placement

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Current protocols for root-end management in apical microsurgery are described. The dramatic increase in light and magnification as the advent of the surgical operating microscope (SOM) for use in endodontic apical surgery has caused a renewed examination of the rationale, indications, techniques, instrumentation, and materials for root-end procedures. Additional research and increased use of the SOM in endodontic surgery have elucidated many shortcomings of previous techniques. Root-end resection, root-end bevel, root-end preparation, and root-end filling are discussed. The steps necessary to achieve a predictable result in performing surgical root-end procedures using the enhanced vision of the SOM are presented.

## Root-end resection – rationale

Review of the literature over the last decade supports the following common indications for resection of the apical portion of the root during periradicular surgery (1) (Fig. 1):

- *Removal of pathologic processes* – Some examples include symptomatic fractured root apices, suspected contaminated apices (retained microorganisms and biofilms), root apices with tenaciously attached pathologic tissue, and removal of foreign material in the apical portion of the canal.
- *Removal of anatomic variations* – The anatomic variations most commonly encountered are apical deltas, accessory canals, apical canal bifurcations, severe curves, lateral canals, and calcifications.
- *Removal of operator errors in non-surgical treatment* – These include complications such as ledges, blockages, zips, perforations, and separated instruments.
- *Enhanced removal of the soft tissue lesion* – Root resection is often necessary to gain access to deeply placed soft tissue around the root in order to secure an adequate biopsy.
- *Access to the canal system* – In cases where the major canal systems are blocked with, for example, a post-core restoration, and the apical portion of the canal has not been properly cleaned, shaped, or obturated, root-end resection (RER) may be necessary to manage the untreated portion of the root canal system (Fig. 2).
- *Evaluation of the apical seal* – This can occur in conjunction with the previous indication, when the canal obturation is questionable, yet access to the entire root system with non-surgical retreatment is impractical or impossible.
- *Creation of an apical seal* – This is one of the most common indications for RER. In cases where the root canal treatment has already been performed non-surgically, RER may be necessary to create an environment for access and vision so that an adequate apical seal can be achieved.
- *Reduction of fenestrated root apices* – This situation is most common in maxillary teeth, but can occur anywhere in the dentition. Possible contributing factors include age, anatomical anomalies, orthodontics, and trauma.
- *Evaluation for aberrant canals and root fractures* – In some cases, the root canal obturation is judged to be satisfactory and the etiology of failure is not clinically or radiographically evident. RER will potentially expose these aberrant canal communications, complete, or incomplete vertical fractures, which can be detected on a stained root-end bevel (REB). (See following section on staining.)

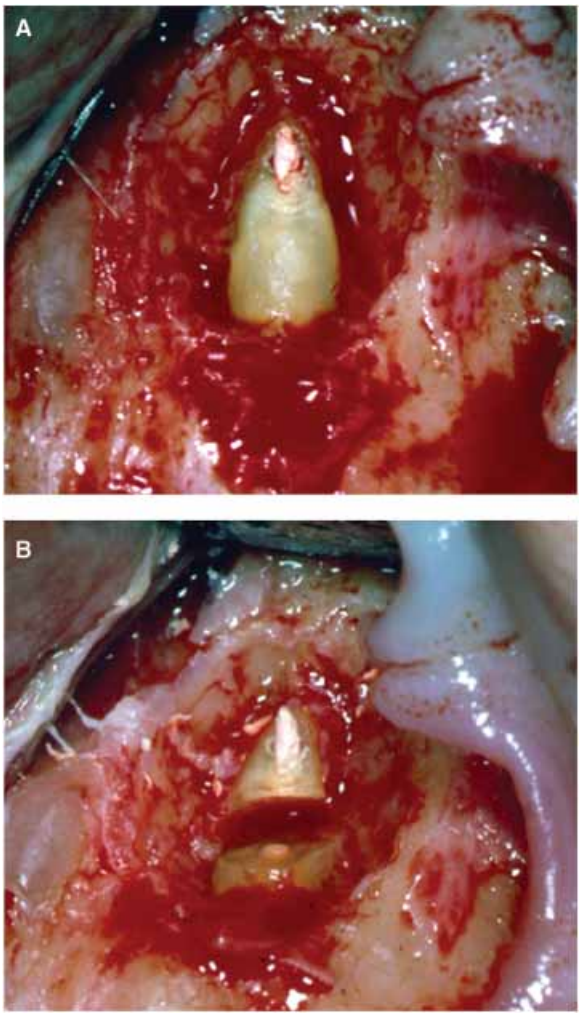


**Fig. 1. (A) Surgically exposed root apex with obvious laceration of the root canal at the root end and overextension of the filling material. (B) Root-end resection removing approximately 3 mm of the root apex.**

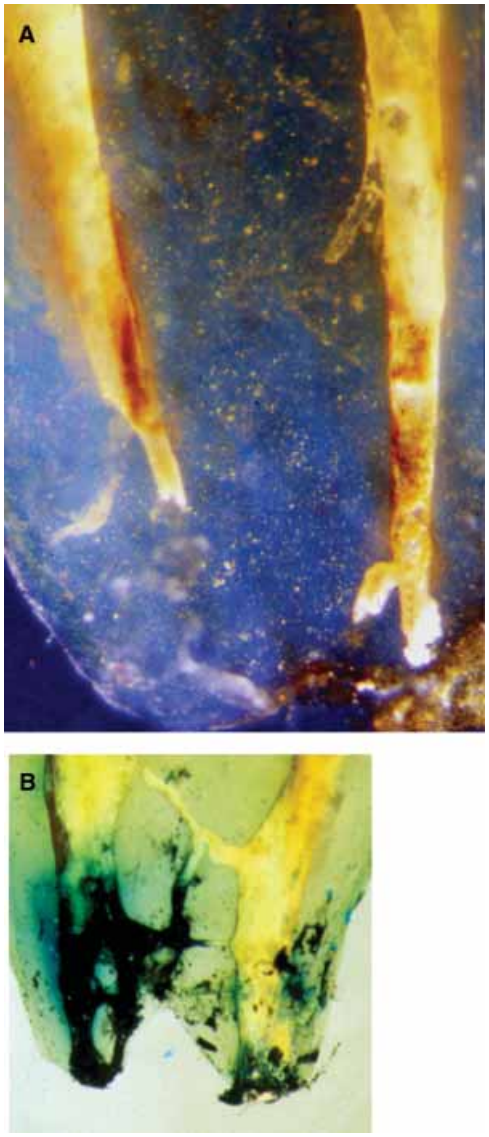


**Fig. 2. Double root canal systems in single roots. (A) Root with obturated canals; root had been placed in India ink dye for 5 days and cleared chemically. Note the complexity of the canal systems and the leakage pattern. Root-end resection (RER) would be necessary to remove these irregularities. (B) Cleared extracted root with two canals. Note that both canals are not clean (brownish material), and that one canal is cleaned and shaped significantly short of the desired length. Canal irregularities are present. RER of the apical 3 mm would be necessary to remove these uncleaned areas and enable proper cleaning and sealing.**

The validity of these indications, and the rationale for their use, resides in each individual case being treated.

## RER – the bevel

### Long bevel vs. short bevel

When the apical end of a root is removed, the remaining surface of the root is described as having been 'bevelled.' The amount and degree of the resected bevel are of utmost importance. The overall crown/root ratio, presence of posts or other obstacles, root anatomy, remaining crestal bone, and the periodontal status of the tooth must be considered. If the bevel is made in the traditional manner at a 20–45° buccolingual incline, more of the palatal or lingual aspect of the root will be left untreated (2–5). This situation occurs when the surgeon is trying to be conservative in order to maintain a more favorable crown/root ratio. Because 98% of apical canal anomalies and 93% of lateral canals system ramifications occur in the apical

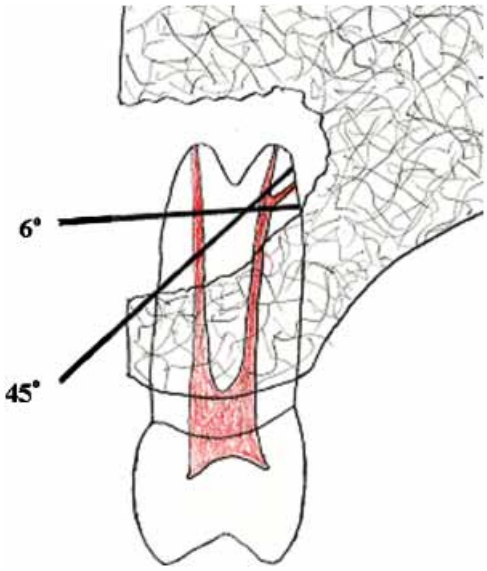


**Fig. 3. The 'long' bevel (45°) removes more root structure and increases the probability of overlooking important lingual anatomy. The 'shorter' bevel (6°) conserves root structure, maintains a better crown/root ratio, and increases the ability to visualize important lingual anatomy.**

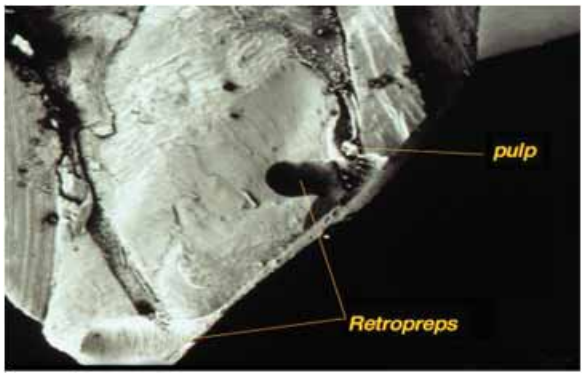


**Fig. 4. The 'long' bevel minimizes tooth structure to the lingual and makes it more difficult for the operator to visualize the long axis of the tooth. Courtesy Dr Gary B. Carr, San Diego, CA, USA.**

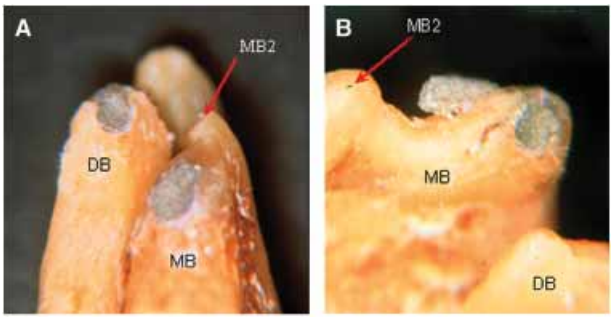


**Fig. 5. (A) The 'long,' but conservative bevel of the mesiobuccal (MB) root did not address the more the second mesiobuccal root canal (MB2) of this maxillary first molar. (B) Not only was the MB2 canal completely 'missed', but there was an inadvertent perforation of the MB root – and incomplete bevel of distobuccal (DB) root end.**

3 mm, it is essential that at least 3 mm of the root end is removed (6–8). Long bevels require the removal of an excessive amount of root structure to include the lingual, or palatal 3 mm of the root apex. If the bevel is closer to 0°, more root structure can be conserved, improving the crown/root ratio while meeting the objective of removing the vast majority of apical ramifications (Fig. 3).

The long bevel creates a spatial disorientation that is often difficult to overcome regarding the true long axis of the canal system (Fig. 4). As it is difficult to visualize the long axis of the tooth, the subsequent root-end preparation (REP) will usually not be within the long axis of the canal. Failure to comprehend this concept is the primary reason that perforations to the lingual, or palatal, occur (9) (Fig. 5). Another consideration for the 0° bevel is that the cavo-surface marginal dimensions of the preparation will be considerably decreased, therefore allowing an easier and more predictable seal. A good axiom to consider is this: whatever the angle of the bevel, it is almost always greater than it appears to be (7, 9).

Knowledge of root anatomy is especially important when there are more than two canals in one root. This anatomical complexity was identified and delineated over 100 years ago (10), and its implications in surgical endodontics were highlighted 70 years ago (11) (Fig. 6). This occurs most commonly in maxillary premolars and in the mesial roots of nearly all molars; however, multiple canals can occur in any root (12–14).

Ideally, the short bevel (0°) is as perpendicular to the long axis of the tooth as possible in order to predictably achieve several important criteria:

- *Conservation of root length* – When a long bevel (20–45°) is made, more tooth structure has to be removed in order to expose the anatomical apex of the tooth (5, 7, 9) (Fig. 7). With a long bevel, an inordinate amount of root structure would have to be removed in order to include the entire apical 3 mm.
- *Less chance of missing lingual anatomy* – The short bevel allows inclusion of lingual anatomy with less

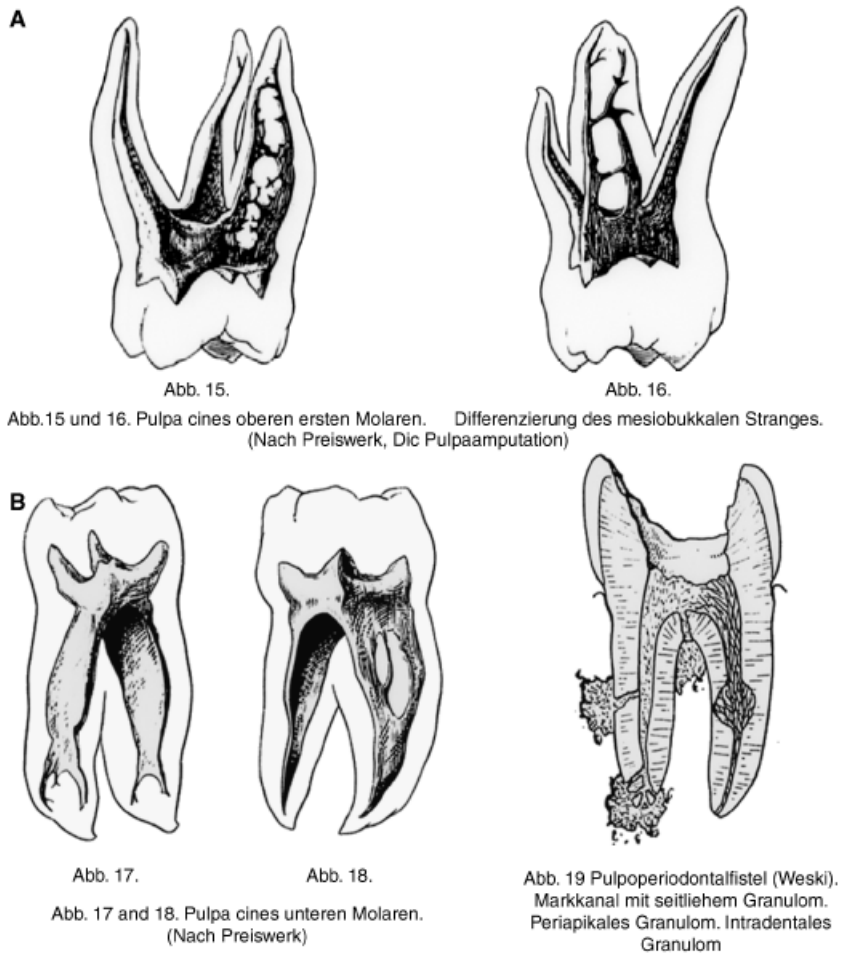


**Fig. 6. (A, B) Diagrams taken from Peter (11). These are drawings from the 1901 publication (10) by Gustav Prieswerk that emphasized the complexity of the root canal systems located in roots with multiple canals.**

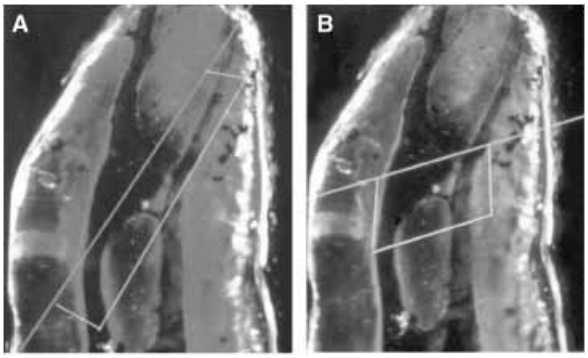


**Fig. 7. (A) The *long bevel* has a greater cavo-surface margin length with a greater probability of leakage. (B) The *short bevel* has a shorter cavo-surface margin length to seal and, therefore, decreases the chances of leakage. Courtesy Dr Gary B. Carr, San Diego, CA, USA.**

reduction. With the long bevel, there is a decreased probability of encroachment on the lingual root surface (Figs 2, 3 and 8, 9).

- *A shorter cavo-surface margin* – If multiple canals are present, the distance between them will increase as the angle of the bevel increases. As it is recommended that the isthmus also be prepared, a shorter bevel allows for a shorter cavo-surface margin length in the completed REP (7).
- *Less chance of an incomplete resection* – The shorter bevel makes it easier for the operator to resect the root end completely and not leave a 'lingual cusp,' or incomplete resection (7–9, 15).
- *Easier to detect multiple or aberrant canals* – When the short bevel is prepared, more lingual anatomy can be accessed (7–9, 15).
- *Less exposed dentinal tubules* – As the dentinal tubules are more perpendicularly oriented to the long axis of the tooth, the short bevel will expose fewer tubules (Fig. 10A). The long bevel opens more tubules to be exposed to the environment, which can allow more micro-leakage over a period of time.

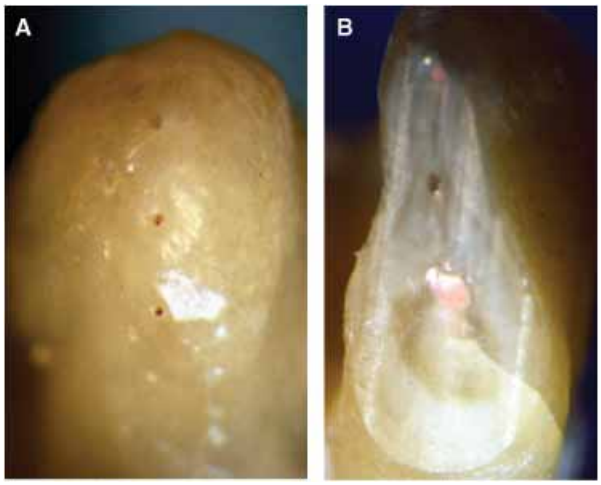


**Fig. 8. (A) Multiple apical foramina evident on the palatal surface of the mesiobuccal (MB) root of a maxillary first molar. If this were resected with a long bevel, the canals and exits would be overlooked. (B) Long bevel resection of an MB root of a maxillary first molar shows the main canal with gutta-percha and sealer; an isthmus is above it and a second, uncleaned canal is visible; then an isthmus is above this second canal, and at the very tip of the resected surface an additional canal is present with gutta-percha. Management of this complex anatomy requires a much shorter bevel and a significantly more resected root face around the most palatally placed canal to permit thorough debridement and preparation.**

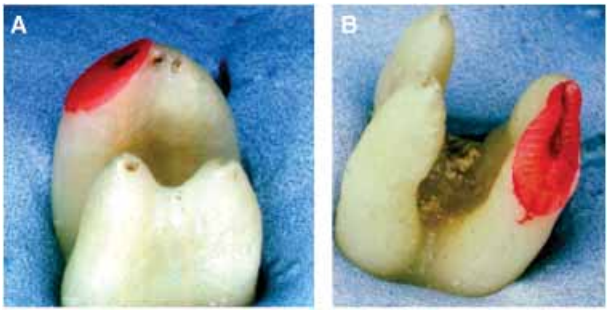


**Fig. 9. (A) The long bevel does not address an adequate amount of the lingual portion of the root apex and important apical anatomy is overlooked by the surgeon. (B) The apical portion of the long bevel causes the lingual wall to be very thin and more susceptible to perforation.**

- *Easier to maintain REP within the long axis* – Instrumentation of the REP should be kept within the long axis of the tooth to avoid unnecessary or excess removal of radicular dentin. The longer the bevel, the more difficult it is to envision and maintain the REP within the long axis of the tooth (7–9, 15) (Fig. 10B).
- *Easier to include the isthmus in the REP if multiple canals are present in a single root* – The cleaning and preparation of the isthmus that usually exists between the canals whether or not it is visible after the REB is very important. When there are multiple canals in a root, isthmus tissue is present 100% of the time at the 4 mm level (16). The short bevel facilitates the isthmus preparation by allowing a better 'mental picture' of the long axis of the tooth (3, 7–9, 15).

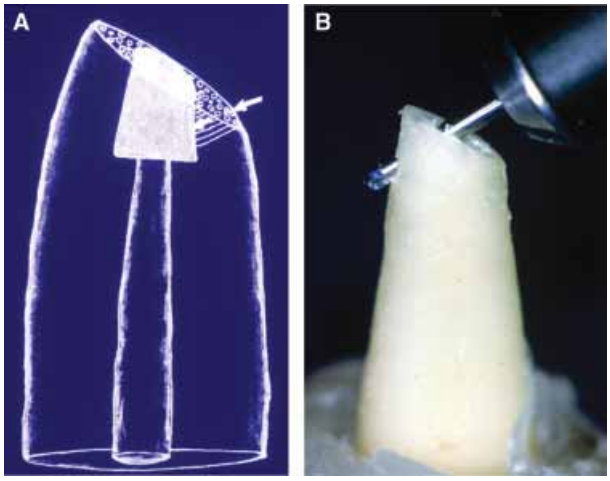


**Fig. 10. (A) The long bevel exposes more dentinal tubules at an angle so they are left open to cause possible future contamination, or leakage, to the REF. (B) The long bevel disorients the surgeon, and the tendency for a lingual perforation of the root-end preparation is increased.**

Ideally, the root-end bevel (REB) is kept as short, or as perpendicular to the long axis of the root as practical, to facilitate complete resection and to expose the entire apical canal system (3, 8, 9, 15). However, after positive identification of the features on the surface of the bevel has been made, it may be necessary to increase the angle of bevel slightly, to achieve better access for instruments, for improved vision, and/or to enhance ergonomics for the patient and clinician.

## Instrumentation and technique

After the cortical bone is removed to unroof the lesion, the soft tissue is curetted from the crypt and the root-end exposed. Adequate hemostasis is established if necessary with appropriate hemostatic agents such as ferric subsulfate (Cut-trol, Ichthys Enterprises, Mobile, AL, USA), Telfa pads (Tyco Healthcare, Mansfield, MA, USA), CollaCote (Sulzer Dental, Carlsbad, CA, USA), calcium sulfate (LifeCore, Chaska, MN, USA), SurgiPlaster (ClassImplant, Rome, Italy), CollaCote

**Fig. 11. Three essential surgical length burs will accomplish all that is necessary to achieve an efficient root-end resection and refinement of the root-end bevel. (top) Lindemann bone cutting bur, (middle) #6 or #8 Round bur, (bottom) #1170 or #1171 tapered-fissure surgical length bur.**

(Integra™, Plainsboro, NJ, USA), and the root end is resected as quickly and efficiently as possible.

Although many instruments and burs are available to complete the RER and REB, there is no need to complicate a rather straightforward procedure. Essentially, there are only three surgical length burs necessary to accomplish the required tasks regarding the RER and REB. They are: (1) the #6 or #8 round bur (S. S. White, Lakewood, NJ, USA), for osseous access and gross removal of the apex; (2) the Lindemann bone bur (Brasseler USA, Savannah, GA, USA), for rapid hard tissue removal and cutting the initial root bevel; and (3) the #1170 or #1171 bur (S. S. White), for refinement of the bevelled surface (Fig. 11). Note that, removal of a minimum of 3 mm of the root apex is necessary, as most canal aberrations and/or abnormalities that may have contributed to the unfavorable response to non-surgical treatment are within this zone (6, 8, 15, 16).

A high-speed handpiece that has no air exiting from the working end, such as a Palisades Dental Impact Air 45 handpiece (Star Dental, Lancaster, PA, USA) (Fig. 12), should be used to eliminate the possibility of air emphysema or an air embolism beneath the flap in the soft tissues (9, 17). For these reasons, a standard high-speed handpiece should never be used.

As the anesthetized bone in the endodontic surgical site has a temporary decrease in blood supply, it is more sensitive to heat. Therefore, small changes in the technical aspects of osseous removal may significantly

**Fig. 12. The Impact Air 45 hand piece, with fiber optics, enhances efficiency, safety, and vision.**

affect bone physiology and viability (1). Bonfield & Li (18) reported that at temperatures from +50°C to 90°C, there was an irreversible bone deformation because of both a reorientation of the structure of collagen and a weakening of the bonds between the collagen and hydroxyapatite. These findings are consistent with protein denaturation subsequent to a burn injury. Eriksson and co-workers (19–23) noted that above 40°C, a hyperemia occurred as the blood flow increased. At a thermal stimulus of 50–53°C for 1 min, there was blood flow stasis with ultimate death of the vascular network within 2 days. Heating of bone to 60°C, or more, resulted in permanent cessation of blood flow and tissue necrosis.

Most studies using rotary instruments to generate heat are confounded by such variables as speed of drilling, pressure, air conduction, amount of coolant, accumulation of chips and debris, and friction (1). In any event, during the removal of osseous tissue, adequate coolant must be applied and the cutting must be performed with a light, brushing stroke. All burs used in apical surgery must have shapes that cut sharply and flutes that are far enough apart to shed debris and avoid 'clogging.' Clogging can result in decreased efficiency and unintentional over heating of tissue (24). The use of diamond burs to remove osseous tissue is not recommended because of their inefficiency and tendency to overheat the osseous tissues. The excessive heat causes necrosis, and can result in an extremely slow healing rate (24, 25) Using newer burs with sharp cutting edges will also improve efficiency and accuracy while decreasing the chances of over heating the osseous tissues.

During RER, REB, or the refinement of the bevel, some new bleeding may occur. Hemostasis must be re-established before continuing with further root-end procedures as it is imperative that the operator maintains complete control of the surgical environment. Note that it is of utmost importance to complete one step fully before proceeding to another!

### Methylene blue staining

After complete hemostasis is achieved, the bevelled surface is ready for close inspection to be certain that the REB has been properly completed. The resected root end is rinsed and dried with an irrigator (Stropko Irrigator, Vista Dental, Racine, WI, USA). The dried surface is then stained with 1% methylene blue (MBS) (8, 15, 26), which is allowed to remain undisturbed on the resected surface for 10–15 s before once again gently flushing with a sterile solution and drying with an irrigator (Fig. 13A). As the MBS only discolors organic material, it readily defines the anatomy within, or around, the resected root end with a deep blue color. If there are any fractures, tissue remnants in the isthmus, or accessory canals present, the staining process will greatly enhance the operator's ability to see them. When used properly, the MBS will delineate the periodontal ligament and the operator can be sure the apex has been completely resected (7) (Figs 13B and C).

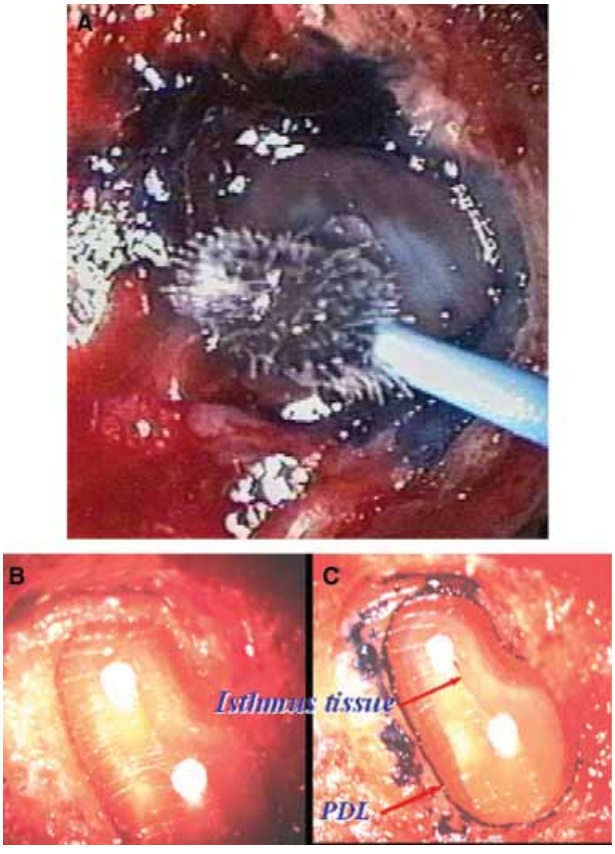


**Fig. 13. (A) MBS is applied to the root-end bevel with a micro-applicator and allowed to remain on the surface for a short period of time. (B, C) Methylene Blue staining enhances vision and defines possible fractures, accessories, lateral canals, isthmus tissue, contaminated root surface, periodontal ligaments, etc. Courtesy Dr Gary B. Carr, San Diego, CA, USA.**

To obtain the maximum benefits of MBS, and to inspect the bevelled surface thoroughly:

- the surface must be clean and dry before applying the MBS;
- the MBS must be applied for 10–15 s to saturate the surface and periodontal ligament;
- the surface must then be rinsed and dried thoroughly; and
- the REB should be examined using varying powers of the SOM to see whether the RER is complete and to insure that no abnormalities are present.

If after MBS there is an accessory canal present, the easiest way to manage this anatomical entity is to bevel past it and re-stain the surface to be sure that the defect is completely eliminated. Alternately, the accessory canal can be simply 'troughed out,' leaving the bevel as it is. If a white background such as Telfa pads, CollaCote, or calcium sulfate has been used to aid in hemostasis, or vision enhancement, it should be replaced after staining so that more light is reflected and vision renewed.

## REP

### Ultrasonic REP

Prior to ultrasonic instrumentation, various types of rotary handpieces and 'mini-burs' were used. Because of the necessity of using a 'straight-in approach,' it was not possible to maintain the REP within the confines of the long axis of the tooth and perforation of the lingual surface could easily occur (see Fig. 10B). With the advent of ultrasonic instrumentation, and the array of angled tips currently available to the operator, it is now possible to prepare a REP that will adequately and predictably accept several different root-end filling (REF) materials. The requirements for an REP include (3, 7–9, 15):

- the apical 3 mm of the canal system is thoroughly cleaned and shaped;
- the preparation is parallel to, and centered within, the anatomic outline of the pulpal space;
- there is adequate retention form for the ref material used,
- all isthmus tissue is removed; and

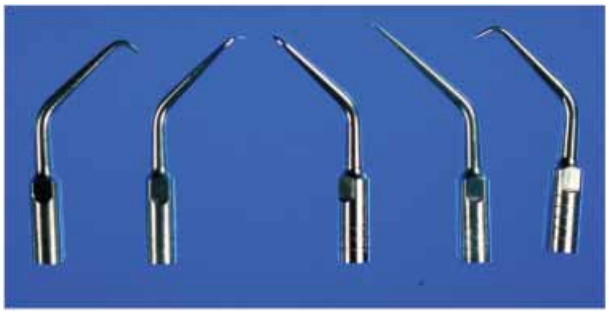

**Fig. 14. The first ultrasonic tips available – CT tips (www.eie2.com).**

- the remaining dentinal walls are not weakened.

The use of any one of a number of ultrasonic units will allow the operator to complete the REP. The Satelec P-5 (Mount Laurel, NJ, USA), EMS MiniEndo (SybronEndo, Orange, CA, USA), NSK (Brasseler, Savannah, GA, USA), and Spartan (Obtura-Spartan, Fenton, MO, USA) units are currently the most common and all have a good reputation for performance, reliability, and versatility (27). Some older EMS units only accept tips made for its European thread, but the newer models accept all of the common tips manufactured in the United States.

There are a multitude of ultrasonic tips to choose from and they come in all shapes and sizes. The first tips made for endodontic apical microsurgery were the CT series tips (PERF online at www.eie2.com or SybronEndo). They are made of stainless steel, very popular, and are still in widespread use today (Fig. 14).

Some tips have special surface coatings to increase their cutting efficiency. Diamond-coated tips are very efficient and especially useful for removing gutta-percha from the REP. Because of their efficiency, the surgeon must avoid the tendency to overprepare the REP. In addition, care must be exercised when using diamond-coated tips because they can leave a heavily abraded surface. The debris generated by these tips can collect in these abrasions surface and if not removed can affect the apical seal of the REF (28). The KiS ultrasonic tips (Obtura-Spartan, Fenton, MO, USA) use port technology and deliver a constant stream of water aimed directly at the working end of the tip (8, 15) (Fig. 15). Ticonium-coated tips (ProUltra, DENTSPLY Tulsa Dental, Tulsa, OK, USA) are also very efficient. Like all tips, they provide excellent vision for the operator during the REP. These are just two of the hundreds of tip designs available today in the worldwide market.

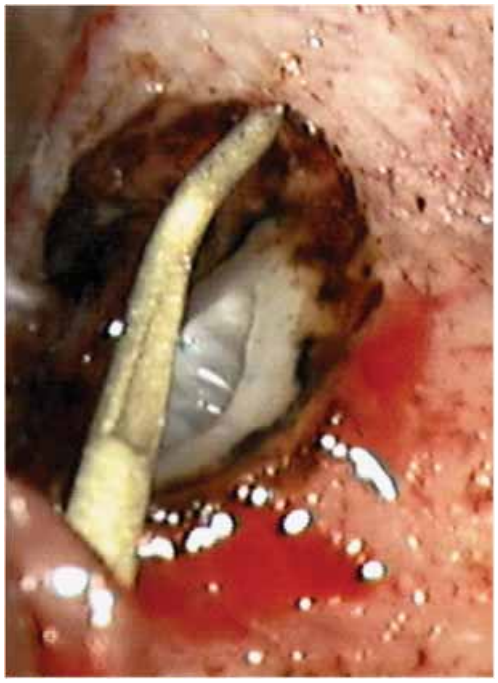

**Fig. 15. The diamond-coated KiS ultrasonic tips are very effective and utilize newer vent technology. The water spray is directed into the root-end preparation , efficiently eliminating debris and helping to prevent overheating of the root end.**

The most important consideration in the use of ultrasonics is not the brand of the unit, or type of tip, but how the instrument is used. The tendency for the new operator is to use the ultrasonic in the same manner (pressure-wise) as the hand piece. The secret is an extremely light touch! In general, the lighter the touch, the more efficient the cutting efficiency will be. The correct amount of water is also important. If too much spray is used, visibility and cutting efficiency are both decreased. If too little water is used, the necessary amount of cooling and rinsing of the debris will not occur. This can cause overheating of the REP. Microcracks and decreased vision may be the undesired result (3, 7–9, 15). Numerous studies have shown that when ultrasonic instrumentation is used properly, microcracks are uncommon and should be of no concern to the clinician (29–31). In addition, use of ultrasonic instrumentation for REP, in place of the traditional, or miniature, hand piece results in cleaner preps and fewer perforations (30, 32). With the advent of ultrasonic techniques for the preparation of the root end, the use of a rotary hand piece is not advocated for root-end cavity preparation in apical surgery.

**Fig. 16. After root-end resection and visualization of the resected surface, two canals with a uniting isthmus are usually visible and need to be addressed.**

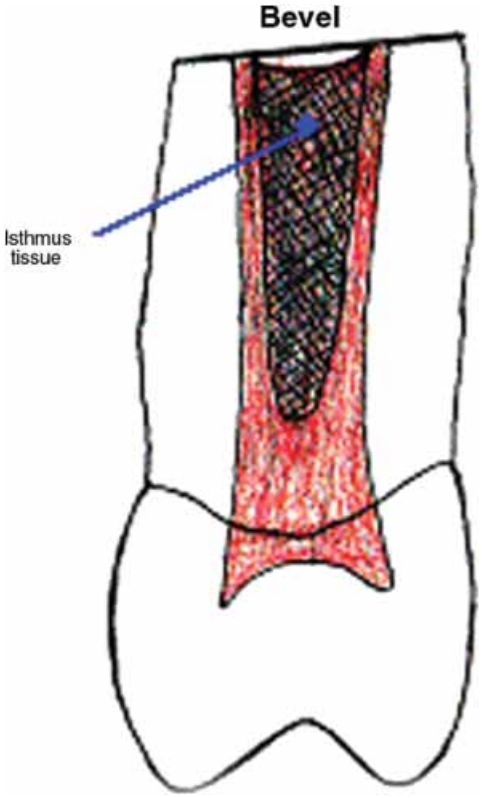


**Fig. 17. When the isthmus is just coronal to the bevelled surface, the isthmus must be prepared or the contaminated pulp tissue just beneath the surface will not be eliminated. Postsurgical remodelling of the bevelled root surface could possibly result in the entire canal system becoming susceptible to bacterial invasion.**

If the canal is large and/or filled with gutta-percha, a diamond-coated anterior KiS tip can be used most effectively. The various left- and right-angled tips are necessary on occasion, but in most cases, the anterior-type tips will suffice. The keys to successful preparation are to apply the cutting tips slowly, using a gentle, light, brushing motion.

The use of ultrasonic instrumentation is especially useful in the preparation of an isthmus between two canals present in one root. This is a commonly required procedure during apical microsurgery. For example, two canals can be present as much as 93% of the time in the mesiobuccal root of the maxillary first molars, and 59% in maxillary second molars (12, 15, 34). Following RER and visualization of the resected surface, two canals with a uniting isthmus are usually visible (Fig. 16). For this reason, it is important to routinely prepare the isthmus, whether it is defined by staining, or not, because if the isthmus is just coronal to the bevelled surface, post-surgical remodelling of the bevelled root surface may expose the entire canal system to the periradicular tissues. If the non-surgical root canal treatment fails to clean the canal system thoroughly or coronal leakage is present, failure may ensue (Fig. 17). A good rule to follow is to always prepare an isthmus when there are two canals in one root.

For the preparation of an isthmus, a CT-X explorer (SybronEndo), or a sharp restorative chisel (1) may be used to 'scratch' a 'tracking groove' between the canals. With the water spray turned off, a CT-1 tip (SybronEndo), or any sharp, pointed ultrasonic tip can be used, at low power, to deepen the tracking groove. Not using a water spray allows excellent vision for the creation of the 'tracking groove,' but the groove should only be deepened enough without the water spray to make it more definitive and easy to follow. The water spray should be resumed as soon as possible to allow for appropriate cooling and cleaning of the REP.

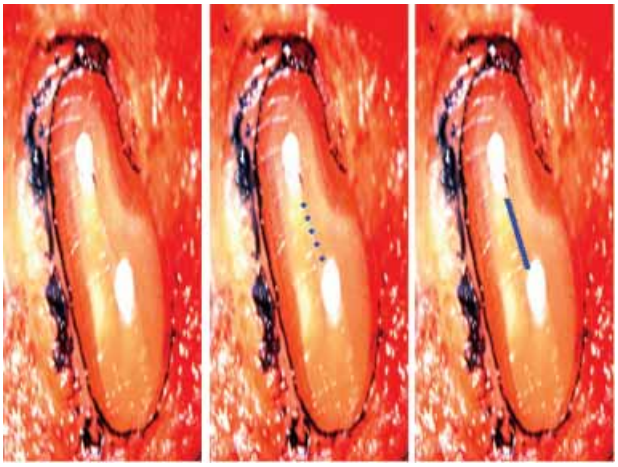

**Fig. 18. Left to right: 'tapping' the rheostat until a series of 'dots' are created on the isthmus as a guide. It is then a simple matter of connecting the dots to create the initial 'tracking groove' to prevent inadvertent 'slipping-off' from the desired isthmus track.**

If difficulty is experienced when trying to establish a tracking groove, the 'dot technique' may be used. With the CT-1 tip inactivated and no water spray, place the pointed tip exactly where desired and just lightly 'tap' the rheostat for an instant. The process is repeated again, and again, as many times as necessary, until there are a series of 'dots' created on the isthmus. It is then a simple matter of connecting the dots to create the initial 'tracking groove' as described in the preceding paragraph (Fig. 18). The accuracy of cutting is then maintained and the probability of 'slipping off' a small, or thin, bevelled surface is eliminated.

After the groove is deep enough to guide the tip, the water spray is turned back on and the preparation is deepened to 3 mm while using a similar small, pointed tip. Then, a larger and more efficient coated tip is used to finish the walls and flatten out the floor of the REP to the desired finish.

Of particular interest in the development of the apical preparation is the buccal aspect of the internal wall of the prep. Often, this area is not cleaned adequately because of the angulations of the ultrasonic tip within the canal system (Fig. 19). If there is some gutta-percha 'streaming up' the side of the wall, it is usually very time consuming, or futile, to remove this gutta-percha with an ultrasonic tip. The most effective way to finish the REP is to use a small plugger and fold the gutta-percha coronally, so the wall is clean once more.

A clean and dry apical root-end cavity preparation is essential for good visibility when using the SOM.

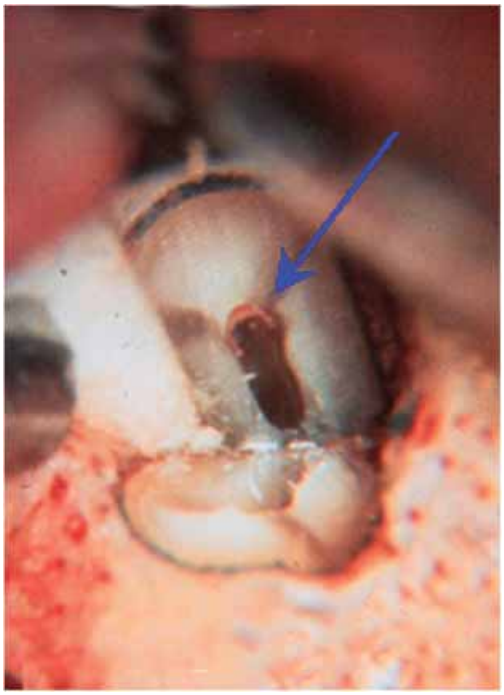

**Fig. 19. Close attention must be given to the buccal wall of the root-end preparation. There is a tendency for debris (in this case, gutta-percha) to collect there while preparing the REP and can be easily overlooked. Courtesy Dr Gary B. Carr, San Diego, CA, USA.**

Throughout the process, and after completion of the REP, the cavity should be rinsed and dried with a small irrigator/aspiration tip if possible. If a 25- or 27-gauge-irrigating needle has been 'pre-bent' to a similar shape as the ultrasonic tip used for the REP, the ergonomics of using the irrigator will be more efficient (Fig. 20). Subsequently, the cavity is inspected using various levels of magnification and sizes of micro-mirrors (Fig. 21) to confirm that the preparation is within the long axis of the canal system and all debris has been removed (Fig. 22). As an alternative, some surgeons choose to use small segments of paper points to dry the cavity; however, this may leave particles of paper in the preparation or may fail to provide a thorough drying in all dimensions.

The smear layer consists of organic and inorganic substances, including fragments of odontoblastic processes, microorganisms, and necrotic materials (35). The presence of a smear layer prevents penetration of intracanal medication into the irregularities of the root canal system and the dentinal tubules and also prevents complete adaptation of obturation materials to the prepared root canal surface (36). If the surgeon is satisfied that all other requirements for the REP have

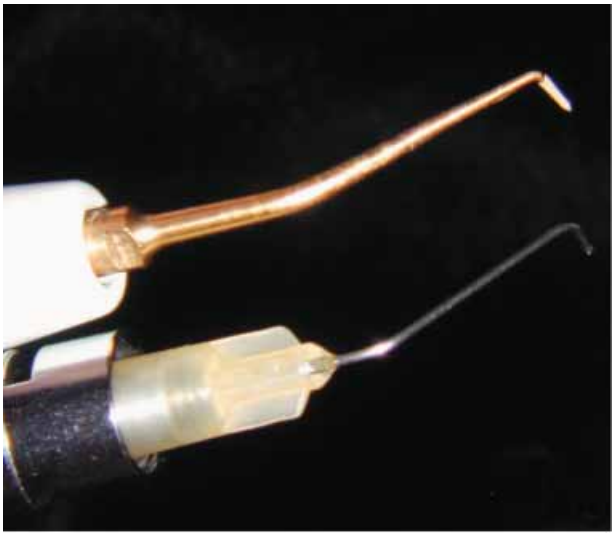

**Fig. 20. 'Pre-bending' of a 25- or 27- gauge irrigating needle to a shape similar to the ultrasonic tip used for the root-end preparation; the ergonomics of using the irrigator will be more efficient.**

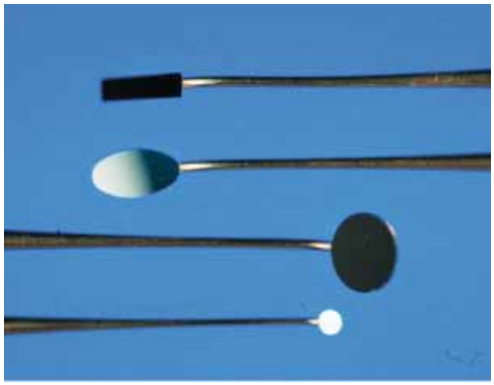

**Fig. 21. Various sizes and shapes of micro-mirrors are used to monitor the progress of the entire root-end procedure.**

been met, the smear layer can be effectively removed by etching with either 10% citric acid gel (Ultradent, Salt Lake City, UT, USA), 17% EDTA (Pulpdent, Watertown, MA, USA), BioPure™ (DENTSPLY Tulsa Dental), or 35% phosphoric acid gel (Ultra-Etch, Ultradent) (36–38). After etching, the REP is again thoroughly rinsed, dried, and re-examined under varying powers of magnification (Fig. 23).

The underlying reason for endodontic failures is almost invariably because of persistent infection of the root canal space (39). In the majority of cases requiring non-surgical retreatment, *Enterococcus faecalis* is the main and persistent microbial species (40–44). If the vast majority of teeth requiring endodontic surgery do

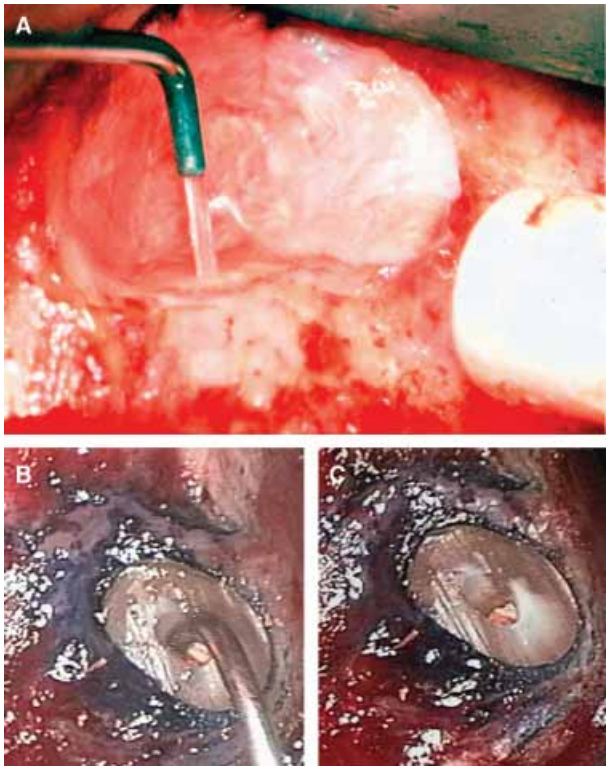


**Fig. 22. The Stropko irrigator can direct a precise stream of water or air into the root-end preparation (REP), enhancing the inspection process. (A) Water is used to flush out debris; then, (B) air is used to dry the REP for better vision, and (C) the clean and dry REP is ready for inspection.**

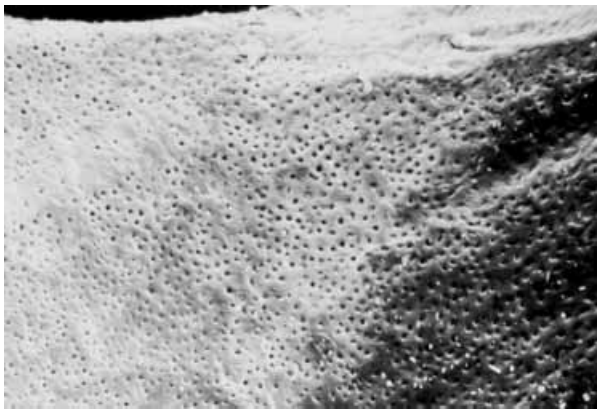

**Fig. 23. SEM of an apical root cavity that has been subjected to acid etching using 10% citric acid combined with 3% $Fe_2Cl_3$) ( × 420). Note the patent dentinal tubules and clean walls. Photo previously unpublished used to support data found in (38).**

not responding favorably to previous non-surgical endodontic treatment, it is imperative that treatment be directed at eradicating bacterial infection including *E. faecalis* from within the REP. Two percent

chlorhexidine (CHX) gluconate is an effective antimicrobial irrigating agent for this purpose, and is available as a liquid or gel (Ultradent) (45–50). Once the REP has been cleaned, dried, thoroughly inspected, and the smear layeres removed, it should be irrigated with 2% CHX liquid for 15 s or 2% CHX gel for 1 min (47), then once again, thoroughly rinsed and dried. The use of the CHX in a gel, rather than the liquid, may take slightly more time but, the surgeon has better control over its placement. The REP is now complete and ready to be filled (Fig. 22C).

# REF

## Filling materials

At this point in the microsurgical procedure, the tissues have been retracted, bleeding in the surgical crypt is well managed, and the REP is ready to fill. The ideal material for use as an REF should meet the following requirements (8, 9, 15):

1. Provide for easy manipulation and placement with adequate working time.
2. Maintain dimensional stability after being inserted.
3. Seal the REP completely.
4. Conform and adapt easily to the various shapes and contours of the REP.
5. Be biocompatible and promote cementogenesis.
6. Be non-porous and impervious to all periapical tissues and fluids.
7. Be insoluble in tissue fluids, not corrode or oxidize.
8. Be non-resorbable.
9. Be unaffected by moisture.
10. Be bacteriostatic, or not encourage bacterial growth.
11. Be radiopaque, or easily discernable on radiographs.
12. Not discolor tooth structure of the surrounding tissues.
13. Be sterile, or easily and quickly sterilizable immediately before insertion.
14. Be easily removed if necessary.
15. Be non-carcinogenic, and non-irritating to the periapical tissues.

There are several materials currently available for the REF, each having been used with varying degrees of success (51–58). They include, among many others, amalgam, IRM (DENTSPLY Caulk, Milford, DE, USA), Super-EBA (S-EBA, Bosworth, Skokie, IL, USA), Optibond (Kerr, Orange, CA, USA), Geristore (DenMat, Santa Maria, CA, USA), and, most recently, mineral trioxide aggregate (Pro Root™ MTA, DENTSPLY Tulsa Dental).

### *Amalgam*

For many years, amalgam was the only commonly available REF material. Its radiopacity is the better than any other REF materials (Fig. 24). Retrospective studies demonstrate both long-term success and long-term failure. Research indicates that amalgam exhibits the greatest amount of leakage when compared with newer materials such as S-EBA and MTA (1, 44, 51, 59, 60), oftentimes ending in amalgam corrosion and significant tissue argyria (Fig. 25). Furthermore, there is no evidence to demonstrate its ability to support tissue regeneration (1). Moreover, in many parts of the world, there is a general controversy over the presence of mercury in amalgam, and therefore, there appears to be no valid reason to continue its use as REF material (61).

### *Zinc oxide-eugenol cements*

Historically, zinc oxide-eugenol cements have been used extensively as REF materials. The two most widely accepted are IRM (DENTSPLY Caulk) and Super EBA

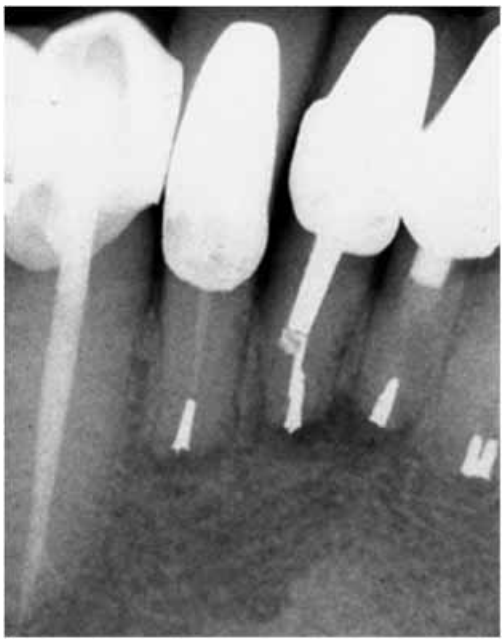

**Fig. 24. Radiopacity of amalgam is better than any currently used root-end filling materials.**

**Fig. 25. Corrosion and breakdown of apically placed amalgams often lead to extensive tissue argyria.**

(S-EBS, Bosworth, Skokie, IL, USA). Dorn & Gartner (57) reviewed REFs in 194 cases and evaluated the success rates of S-EBA, IRM, and non-zinc high copper amalgam. The success rates over a 10-year period were reported to be 95% for EBA, 91% for IRM, and 75% for amalgam. Tissue responses demonstrated repair as opposed to regeneration, a response no different from that observed with gutta-percha (58, 62). Both IRM and S-EBA exhibit similar and favorable properties and are clinically and histopathologically better than amalgam (9): some of these desirable properties include:

- ease of manipulation,
- adequate working time,
- dimensional stability,
- placement and ease of adaptation in the REPs,
- biocompatibility,
- imperviousness to tissue fluids,
- lack of corrosion or oxidation,
- unaffected by moisture,
- bacteriostatic,
- radiopaque,
- will not discolor tooth or surrounding tissues,
- easily removable,
- non-carcinogenic, and
- predictable over time.

When solubility was measured in a buffered phosphate solution, both IRM and S-EBA exhibited no significant signs of disintegration after a 6-month period (62). The addition of ortho-ethoxybenzoic acid to the formulation of S-EBA decreased the amount of the tissue-irritating eugenol in the liquid portion of the formula to 37.5% vs. 99% eugenol in the IRM liquid (63).

The ability to create a conservative, anatomically correct REP with ultrasonic armamentarium demanded an alternative to amalgam as an REF material and led to the popularity of S-EBA for this purpose. While leakage patterns with the use of S-EBA as a filling material following ultrasonic REPs were disturbing (64), Rubinstein & Kim (65) reported the short-term success of endodontic surgery using microsurgical techniques and S-EBA as an REF. All 94 cases included in the study were treated by a single clinician. Postoperative radiographs were taken every 3 months for a 12-month period until the lamina dura was completely restored, or the case had clinically failed. Successful healing, evaluated radiographically, was 96.8%. In a follow-up study (66), clinical examinations were made and radiographs were evaluated 5–7 years after the cases had first been considered healed. The same criteria for evaluating successful healing were applied. Of the 59 cases examined, 54 (91.5%) remained healed, whereas five (8.5%) showed evidence of apical deterioration.

The setting time of S-EBA can be unpredictable, sometimes setting too quickly, and at other times, taking too long. Ambient temperature and humidity have a profound effect on the setting time. An increase in temperature and/or humidity will shorten the setting time (67–69). If the setting time needs to be increased, the glass slab used to mix the S-EBA can be cooled (70). The powder/water ratio of SEBA has to be correct to ensure a thick, dough-like consistency, permitting the assistant to roll it into a thin tapered point. The 'dough-like' tapered end of the thin S-EBA 'roll' is segmented and passed to the doctor on the end of either a small Hollenback, or spoon, and subsequently inserted into the REP, and gently compacted coronally with the appropriate plugger. Two to five of these small segments are usually necessary to overfill the REP slightly.

After the REF is complete, an instrument and/or a multi-fluted finishing bur are used to smooth the surface, producing the final finish. It has been demonstrated that the use of a 30-fluted tungsten carbide finishing bur creates a better marginal adaptation to the set S-EBA REF (71). An etchant may be used, once again, to remove the 'smear layer' that was created during the final finishing process. The removal of the 'smear layer' and the demineralization of the resected

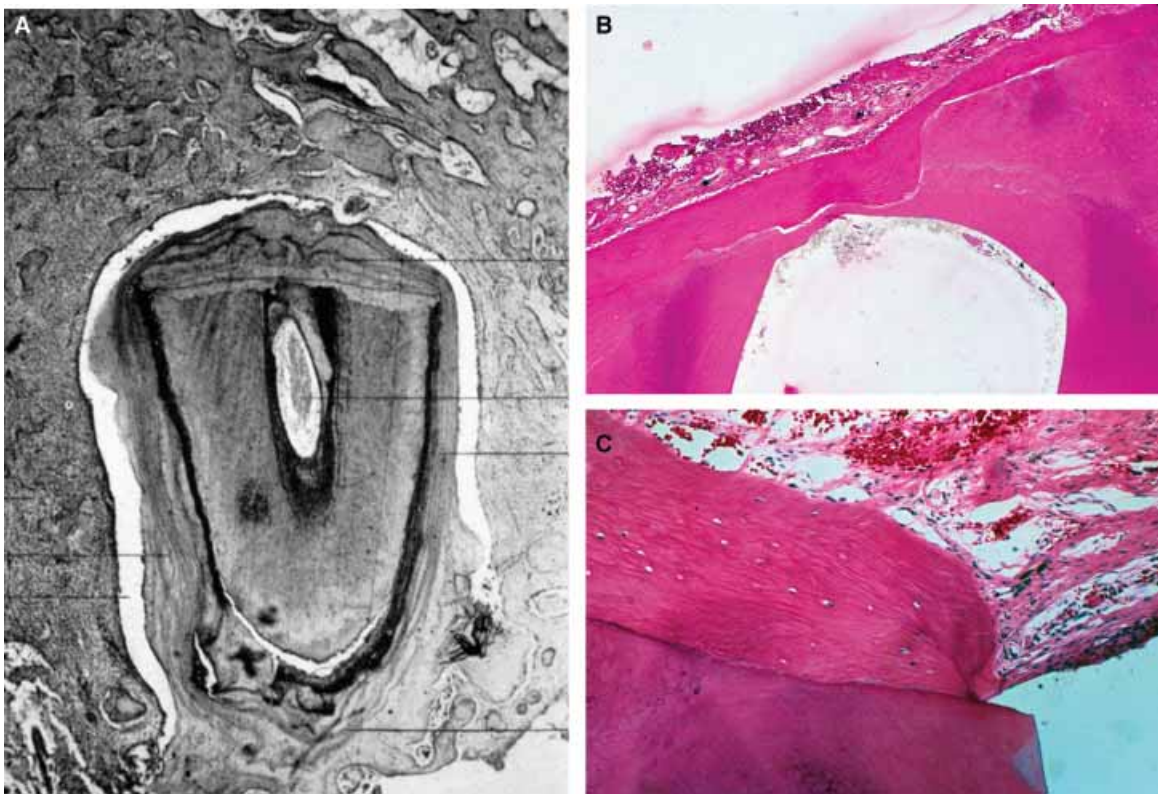


**Fig. 26. Evidence for the formation of cementum on exposed human dentine without the use of an acid etchant. (A) Photomicrograph of a retained fractured root tip from Boulger EP. Histologic studies of a specimen of fractured roots. J Am Dent Assoc 1928; 15: 1787–1779. The coronal portion of the root segment shows significant cement formation. (B, C) Histological demonstration of significant cementum formation on a resected root surface; tooth had a coronal fracture and was extracted. No etchant was used subsequently to remove the smear layer from the resected root end. Note how the cementum ceased to form adjacent to the root-end filling in (C), which was a zinc oxide-eugenol-based product.**

root end are thought to enhance cementogenesis, the key to dentoalveolar healing, by exposing the collagen fibrils of the dentin and cementum (72). However, these data have only been supported in an animal model, while the use of this approach has been shown to be unfavorable for cementum deposition when MTA was used as an REF material (73). For decades, the presence of cemental deposition has been observed to occur on exposed dentinal surfaces, which supports the fact that acid etching of the surface may not be essential to obtain full tissue regeneration. Further research to provide clinical directives in this matter is warranted (Fig. 26).

One of the earlier disadvantages of S-EBA was that it was not as radiopaque as amalgam (Fig. 27). When initially used in apical microsurgical procedures, dentists sometimes had difficulty determining that an REF had, indeed, been placed. This is no longer an issue because the profession is more familiar with the radiographic appearance of the various currently accepted REF materials. Most newly advocated REF materials have a radiographic appearance similar to S-EBA and gutta-percha (74).

### *Composites*

The use of dentin-bonding techniques requires uncompromised control of the surgical crypt. Even a small amount of contamination can cause a failure of the bond to the dentin surface, resulting in micro-leakage (75). The ability to have total control of moisture in the apical surgical environment has led to the use of bondable composite resins as REF materials. Theoretically, any composite can be used as an REF material, whether it is auto, dual, or light cured. Two advantages of dual cure materials are the increase in working time and lowered requirement for direct light necessary to initiate and complete the set.

Optibond (Kerr) is an example of a flowable, dual cure hybrid composite that is easily placed into the REP.

**Fig. 27. Super EBA has a radiopacity similar to that of gutta-percha.**

Etching, conditioning of the dentin, insertion of the selected material, and curing by chemical or light are accomplished in the usual manner when bonding into the REP. *Because the light source for the SOM is so intense, premature setting of the light cured material is possible*. For most microscopes, an orange filter is available that easily and inexpensively replaces the 'blood filter' and eliminates this concern (Fig. 28).

Studies have shown very favorable healing when bonded composites are utilized as an REF (74–79). However, there is controversy as to whether the resected surface of the root should also be coated, or 'domed' with the bonding material. A 'cap' or 'dome' of bonded composite can be placed with the intention of sealing the exposed tubules of the entire resected surface (76). The exposed tubules may, or may not be, a factor in the healing process, as their exposure has been controversial for decades (80).

### *Compomers (polyacrylic-modified composite resins)*

Because of their ease of use and other favorable characteristics, resin-reinforced glass ionomers, such as Geristore (DenMat), and Dyract (DENTSPLY Caulk ), are popular. They exhibit good flowability, dentinal self-adhesiveness, and demonstrate excellent biocompatibility (81). Dyract and Geristore have been shown to be equal or superior to IRM and equivalent to S-EBA in their ability to reduce apical leakage when used as an REF (54). Geristore is a dual-cure material, whereas Dyract is light cured. After the compomer is completely cured, the REF is finished with a high-speed finishing bur or an ultrafine diamond, and the resected root end is etched to remove the smear layer and to demineralize the surface for enhanced healing (72). When the entire root surface was covered, the failure rate was 50% for the compomer, vs. 10% for the bonded composite (76–79).

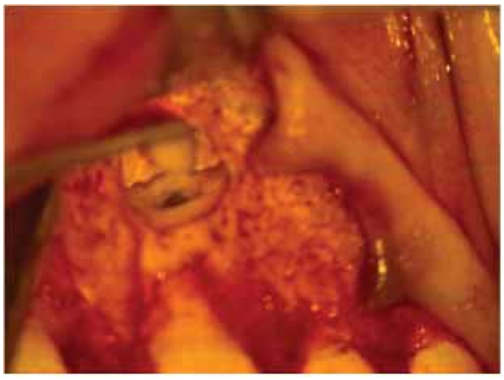

**Fig. 28. Flowable composite is easily placed with a small CX-1 Explorer. An orange filter is available that easily and inexpensively replaces the 'blood filter' on the surgical operating microscope light source.**

### *MTA*

MTA has become very popular and is widely used as an REF material. There are numerous publications extolling the virtues of this material regarding its sealing capabilities and its favorable biocompatibility (59, 82, 83). MTA has been shown to have superior sealing qualities when compared with S-EBA and amalgam (60). The cellular response to MTA has also been shown to be better than IRM and it stimulates interleukin production, indicating biocompatibility with adjacent cells. One of the most important advantages of MTA is that histological responses show evidence of tissue regeneration (reformation of bone periodontal ligament and cementum as a functional unit) as opposed to tissue repair (fibrous connective tissue) (84–87) (Fig. 29).

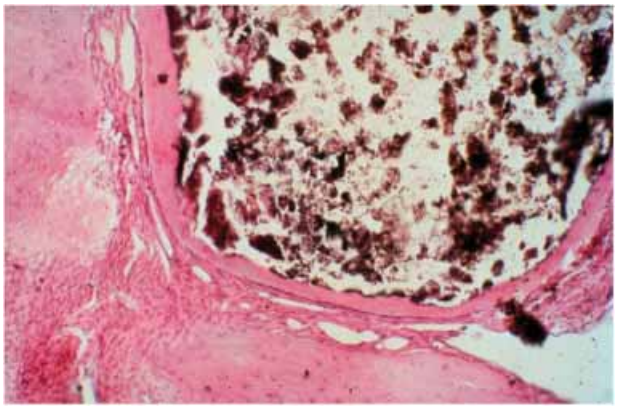

**Fig. 29. Histological responses have evidenced tissue regeneration as opposed to tissue repair. A cementoid-like substance has been demonstrated to cover the mineral trioxide aggregate root-end material.**

Many clinicians complain of the unforgiving handling characteristics of MTA. The correct powder/water ratio is three parts powder to one part sterile aqueous solution. After mixing for about 30 s, the material should exhibit a putty-like consistency (88). If the mixture is too wet, it acts like wet sand and 'slumps,' but when too dry, it has a 'crumbly' and unmanageable texture, similar to that of dried mud. In either case, when not mixed properly, MTA can be very difficult, if not impossible, to handle.

The central problem with MTA is that this material can be difficult to deliver to a small REP. Most clinicians use a syringe or carrier-type device to deliver MTA. These devices have several limitations (89):

1. The diameter of the syringe or carrier may be too large for small root preps.
2. The syringe and carrier devices may not reach difficult areas of the mouth.
3. The syringe and carrier devices deliver large amounts of MTA, resulting in excessive amounts of material being deposited into the field.
4. The syringe devices can clog and become useless if not properly cleaned immediately after every procedure.

Some of the available carriers used to place MTA into the REP include the Retrofill Amalgam Carrier (Miltex, York, PA, USA), the Messing Root Canal Gun (Miltex), Dovgan MTA Carriers (Quality Aspirators, Duncanville, TX, USA) (Fig. 30A), the MAP System (PD, Vevey, Switzerland) (Fig. 30B), and the Lee MTA Pellet Forming Block (G. Hartzell & Son, Concord, CA, USA) (Fig. 31).

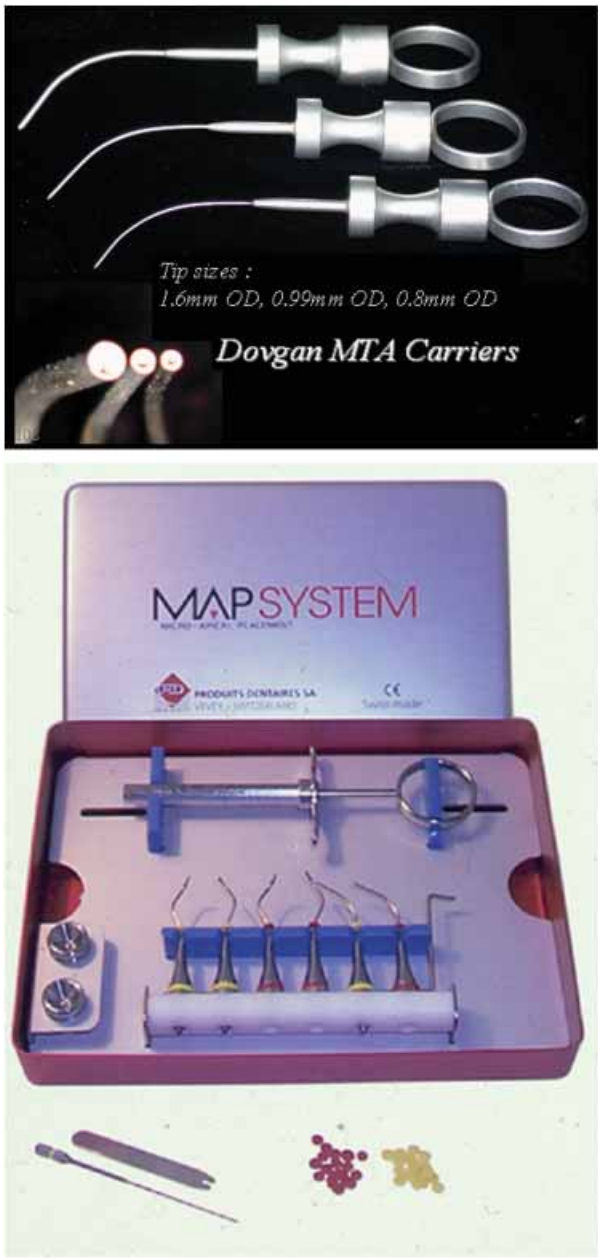


**Fig. 30. (A) Dovgan carriers come in three sizes and can deliver mineral trioxide aggregate to the root-end preparation in most situations. (B) Map system is also a versatile system for placing root-end filling materials.**

The Lee MTA Pellet Forming Block is a very simple and efficient device for preparing MTA to be carried to the REP (88, 89). Properly mixed MTA is simply wiped onto a specially grooved block and the Lee Instrument is used to slide the desired length of MTA out of one of the appropriately sized grooves (Fig. 31). The MTA adheres to the tip of the instrument, allowing for easy placement into the REP. With this method of delivery,

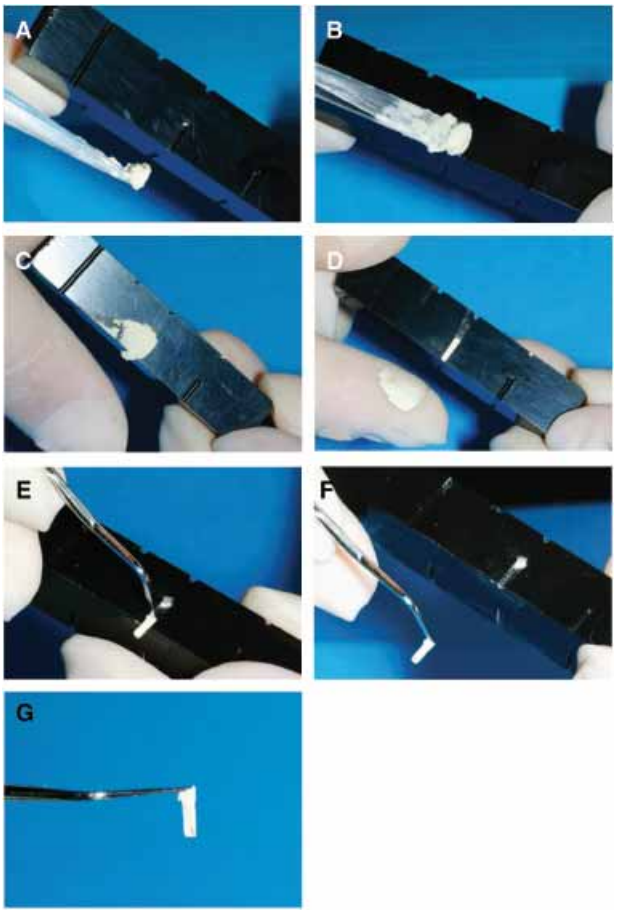


**Fig. 31. The Lee mineral trioxide aggregate (MTA) pellet forming block greatly simplifies the process of delivering MTA to the root-end preparation (REP). (A) The MTA mixed to a 'putty-like' consistency on a spatula is (B) placed onto the appropriate size groove in the Lee MTA block, (C) pressed into the groove with a finger, (D) the surface around the groove is wiped clean with a finger, (E) the desired length of the MTA is selected, (F) to be removed by instrument, and (G) carried to the REP in an efficient manner. Slides courtesy Dr Arnaldo Castellucci, Florence, Italy.**

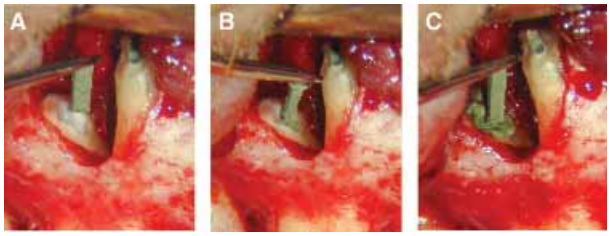


**Fig. 32. (A) Pre-measured aliquot of mineral trioxide aggregate (MTA) is easily delivered into the root-end preparation. (B) A sufficient quantity of MTA can be carried on the instrument to minimize the number of 'passes' needed to be made to the surgeon. (C) Because of the efficiency of the system, in many cases, two to three aliquots will suffice to overfill the REP with MTA slightly.**

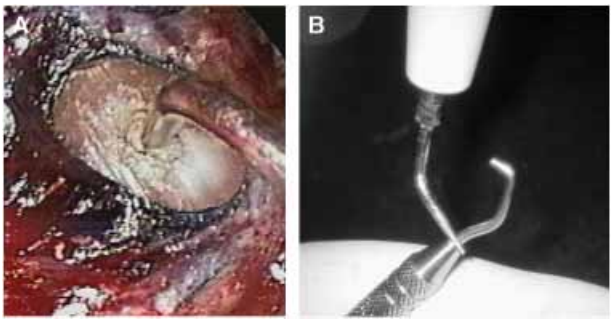


**Fig. 33. (A) A plugger, or explorer tip, is placed just in contact with the mineral trioxide aggregate (MTA) and (B) while the doctor activates the ultrasonic hand piece with a rheostat, the assistant gently touches the non-working end of the instrument with an activated ultrasonic tip to 'ultrasonically densify' the MTA.**

fewer 'passes' are required to fill the REP adequately (Fig. 32). As with any other MTA carrier, use of the Lee Pellet Forming Block requires the correct powder/water ratio of MTA for ease of use. The mix must be wet enough not to crumble, but dry enough to prevent 'slumping.' Adding or removing water from the mixture leads obtains the desired 'working consistency.' Either a cotton pellet, used dry or moistened with sterile water, or an irrigator, delivering air or water, may be used for this purpose.

After the MTA is delivered into the REP, it is 'patted' or 'persuaded' to place with an appropriate plugger-type instrument. Compaction, as we normally perceive it in dentistry, should be avoided while placing this material. If a plugger or small explorer is placed in contact with the MTA, and the assistant gently touches the 'non-working end' of the instrument with an activated ultrasonic tip, the material 'flows,' entrapped air is released, and the density of the fill is increased (90) (Fig. 33). The radiographic appearance may also improve with 'ultrasonic densification' (74) (Fig. 34). Currently, however, there are no studies evaluating which techniques are most efficacious for the placement of MTA.

MTA has a 2–3 h working time (68), which is more than adequate for apical microsurgery and takes the 'time pressure' out of the procedure. The surface of the MTA is finished by carving away excess material to the level of the resected root end. This is done in a dry

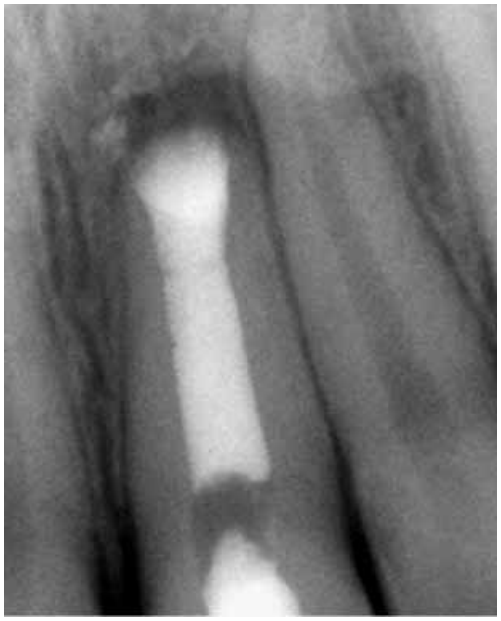

**Fig. 34. The radiopacity is similar, if not slightly better than gutta-percha.**

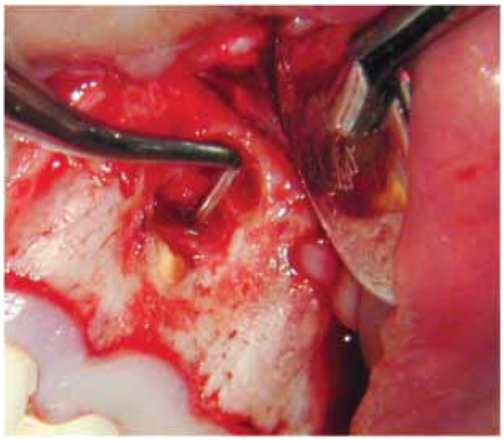

**Fig. 35. Gentle curettement of the surgical crypt can initiate fresh bleeding, if necessary, to have assurance the hydrophilic mineral trioxide aggregate is covered with fluid and the surgical crypt fills with blood.**

field, as the moisture necessary for the final set is derived from blood that fills the surgical crypt once the tissue is repositioned and sutured. MTA is very hydrophilic and requires moisture for the final set. It is imperative that enough bleeding be re-established to ensure that the crypt is filled with blood. If necessary, gentle curettement of the surgical crypt will initiate the required hemorrhage (1, 90). This is the final step in 'crypt management,' or hemostasis, especially when MTA is used as the REF material (Fig. 35).

## Pre-surgical restorations

Whenever apical microsurgery is treatment planned in areas with difficult access such as the palatal root of maxillary molars or either root of some lower molars, the placement of a 'pre-surgical restoration' should be considered (86). Placement of the REF prior to apical surgery may radically simplify the procedure without compromising hard tissue healing (87). In such cases, the canal(s) should be slightly 'over prepared' non-surgically to approximately 1 mm short of the apical terminus so that it can be more easily and completely filled with MTA. Because ultrasonic REP results in a larger than normal canal size at the apex, and the apex will be resected at the 3 mm level anyway, fears of excessive 'overenlargement' during conventional canal preparation techniques are of no concern. The MTA should be placed, 'ultrasonically densified,' and allowed to set for 24–48 h. When the set of the MTA is confirmed, the rest of the coronal seal, or foundation restoration, should be completed under sterile conditions before apical microsurgery is performed. By placing the foundation restoration at this time, coronal micro-leakage is minimized and the predictability of a favorable postsurgical result is enhanced. The subsequent apical surgical procedure is now less complicated as the set MTA is unaffected by the root resection procedure and placement of an REF is no longer required (86). A similar technique may be used when entire roots are to be resected or teeth hemisected (1).

As stated previously, the underlying reason for apical surgery is almost invariably because of persistent infection and residual necrotic tissue left in the root canal space (38–40). Therefore, treatment must be directed at reducing or eradicating these contaminants from within the REP. The use of either 17% EDTA, 10% citric acid, 35% phosphoric acid, or MTAD, followed by irrigating with 2% CHX (41–43), will decrease bacterial load and increase the predictability of success. Before placement of the MTA, temporarily filling the prepared canal space with calcium hydroxide (Pulpdent or UltraCal XS, Ultradent) for a minimum of 7 days, has been demonstrated to reduce contamination of the dentinal tubules in the canal walls and will also increase predictability of complete healing (91–93).

## Conclusion

As the SOM became popularized for use in endodontic apical surgery, the expected outcome of the surgical

procedure has become more predictable. The 'technological explosion' since 1990 has led to unprecedented advancements and improvements in all areas of surgical treatment, including root-end procedures. Newer techniques, instruments, and materials can be used to effectively overcome the factors that prevented favorable responses to previous surgical endodontic treatment. There is much to consider when performing the root-end procedures, but if the above steps are followed properly in an orderly fashion, healing should be successful and uneventful.

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# Surgical repair of root and tooth perforations

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A root perforation is a mechanical or pathological communication formed between the supporting periodontal apparatus of the tooth and the root canal system. Three broad categories of etiological factors exist and these are procedural mishaps, resorption and caries. The diagnosis, management and repair of root perforations require skill and creative thinking. Unfortunately, much of what has been written on the subject of root perforation repair is unsubstantiated and empirical in nature and contributes little to evidence-based support for any specific repair procedure. However, perforation repair frequently provides a very attractive and frequently successful alternative to extraction of the involved tooth. In recent years, the procedure has become more predictable owing to the development of new materials, techniques and procedures.

## Introduction

A root perforation is a mechanical or pathological communication formed between the supporting periodontal apparatus of the tooth and the root canal system (1). Perforations result in the destruction of the dentine root wall or floor along with the investing cementum. This communication compromises the health of the periradicular tissues and threatens the viability of the tooth (2–7). In a recent outcomes study (8), a group in Toronto found that in retreatment cases only two factors affected the success rate of the treatment significantly: (1) the presence of a preoperative radiolucency and (2) the presence of a preoperative perforation.

Perforations are regarded as serious complications in dental practice and pose a number of diagnostic and management problems (9). However, when teeth are of strategic importance perforation repair is clearly indicated whenever possible (10). Unfortunately, however, there is a paucity of evidence-based research upon which treatment decisions can be based.

Traditionally, the presence of radicular perforations has been both difficult to determine and manage (11–13). Most frequently, they were managed surgically, but in recent years non-surgical correction (14) of many perforations has been facilitated by the use of improved magnification and illumination provided by the use of loupes or the surgical operating microscope (SOM) (9, 10, 15–28). In practice, however, the indications for surgical correction of root perforations are being eroded from two directions: on the one hand by the improved non-surgical management of perforations and on the other by the use of implants.

Perforations occur primarily through three possible mechanisms: procedural errors occurring during root canal treatment or post-space preparation (29, 30) (Fig. 1A, B), resorptive processes (31) (Fig. 1C, D) and caries (Fig. 1E). Most perforations result from procedural errors (32, 33). Errors leading to these defects include bur perforation during access opening or during the search for canal orifices, excessive removal of dentine in the danger zone (32, 34–42), either with hand or rotary instruments (Fig. 2A), misdirected files during canal negotiation, unsuccessful attempts at bypassing separated instruments (Fig. 2B) and misaligned instruments during post-space preparation (25, 43–48).

Resorption is either a physiologic or a pathologic process resulting in loss of dentine, cementum and sometimes bone (1). In terms of establishing a treatment plan, it can be classified as external, internal

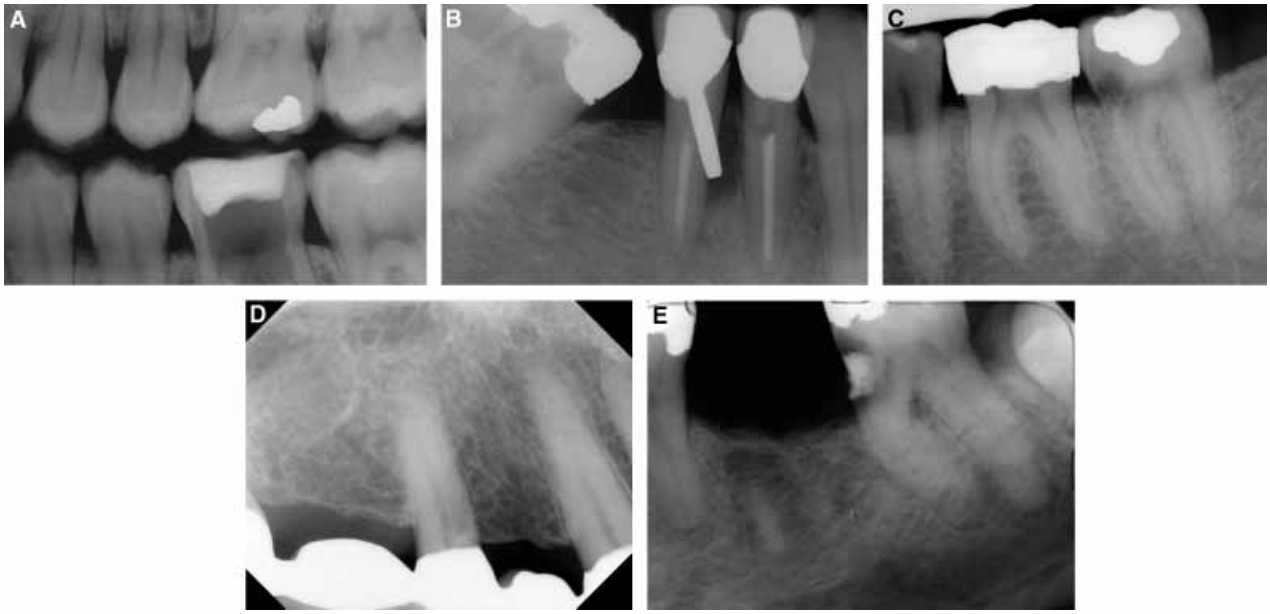


**Fig. 1. (A) Furcation perforation following misguided access preparation. (B) Mandibular premolar root perforation by misaligned post placement. (C and D) Resorptive processes resulting in root perforation. (E) Carious destruction resulting in perforation of the root from the external into the pulp canal space.**

or cervical as these frequently necessitate different approaches or a combined approach. Resorption is a perplexing problem for all practitioners. Diagnosis is frequently complicated by the lack of radiographic evidence until extensive demineralization has occurred (49, 50).

Unmanaged carious lesions can proceed to perforation or near-perforation in the cervical region of the tooth, at or below the level of the crestal bone (2, 51, 52). This is particularly common in older patients where salivary quality and quantity is diminished and gingival recession has led to dentine exposure.

Management of perforations will depend on a number of factors, including:

- diagnosis,
- etiology,
- location of the perforation,
- access to the perforation site,
- visibility,
- adjacent anatomical structures (including adjacent roots),
- perforation size,
- periodontal status,
- time lapse since the creation of the perforation,
- strategic importance of the tooth and
- experience of the operator.

## Diagnosis

As time lapse between the creation of a perforation and its repair is critical to the prognosis for the tooth (53, 54), early and accurate determination of the presence of a perforation is of paramount importance (2). The etiology for a perforation will play a major role in determining the management protocol. A diagnosis is established based on clinical and radiographic assessment. At times, it is immediately apparent, either clinically or radiographically, or both, that a perforation has either been created or exists (Fig. 1C, D). However, it is frequently difficult to determine the presence or location of a perforation and careful consideration of all diagnostic information is essential. Radiographs from multiple angles, including bitewing radiographs, will dramatically improve the clinicians diagnostic acuity (55, 56) (Fig. 3A, B). This is especially evident when trying to assess the location of the defect, particularly when it is located either buccally or lingually, as the image of the defect is often superimposed on that of the root (57).

The apex locator, normally used to determine canal working length, is an invaluable instrument in confirming the presence of a perforation when other clinical indicators are inconclusive (58, 59). This is especially true during access preparation or during the search for a


**Fig. 2. Perforations resulting from procedural errors. (A) Excessive dentin removal from the 'danger zone' resulting in strip perforation of the mesial root of this mandibular molar. (B) Excessive dentin removal during attempt to remove separated instrument resulting in perforation of the root.**

canal orifice. The use of the apex locator will provide the clinician with an early warning of the existence of a perforation and may prevent further extension of the defect or the extrusion of obturating materials or irrigating solutions into the defect (Fig. 2A).

## Etiology

As mentioned previously, root perforations can be classified into three main groups: procedural errors, tooth resorption and caries.

### *Procedural errors*

Procedural errors can occur at any stage during endodontic treatment and are very likely to influence


**Fig. 3. (A and B) Radiographs from multiple angles, including bitewing radiographs, will facilitate diagnosis of pre-existing perforations.**

the prognosis for the tooth (2, 14, 28, 60–63). Coupled with an aging population and an increased demand to retain their natural dentition, patients are receiving more complex dental treatment (54, 64). Consequently, clinicians are treating increasingly more difficult endodontic cases, which in turn is associated with a greater occurrence of procedural errors (54, 64). Iatrogenic perforation of the tooth may occur during access preparation, canal instrumentation or during the creation of post-space prior to definitive restoration of the tooth (Fig. 4A, B). The perforation may be the

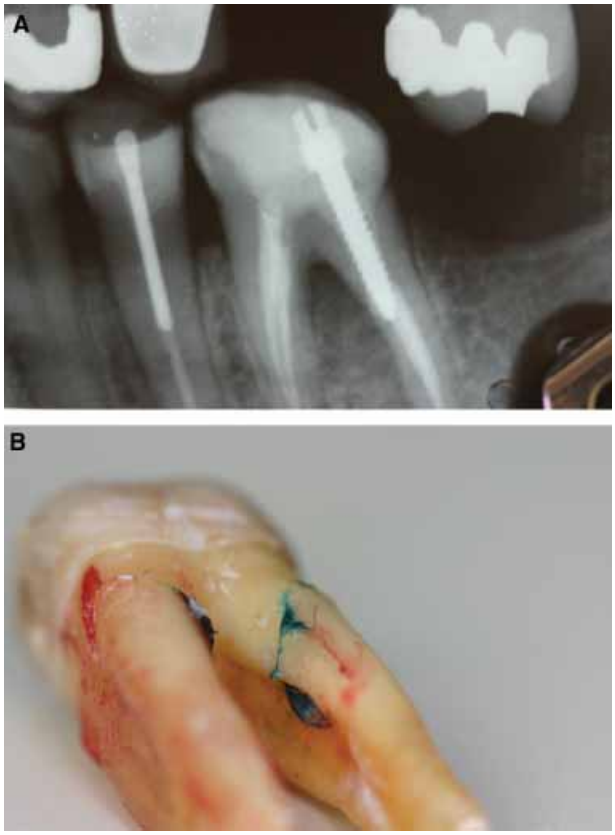


**Fig. 4. (A) Radiographic appearance of post-perforation. (B) Clinical appearance of extracted tooth showing post-perforation in the concavity in the distal root of a mandibular molar.**

result of a lack of attention or experience on the part of the clinician or may result from an attempt to locate a pulp chamber or canal orifice or to negotiate a calcified canal system.

Perforations may also result from excessive removal of tooth structure during instrumentation of the canal system and this tends to occur in anatomically vulnerable locations such as the danger zones on the mesial roots of lower molars (32, 35). In all cases, prevention is preferable to cure and is facilitated by a thorough knowledge of the anatomy of the tooth and by careful assessment of the available radiographic and clinical information prior to treatment (65). The physical dimensions of an iatrogenic perforation will be determined in part by the instrument that created it. Typically, perforations formed in the floor of the chamber with a round bur tend to be large and circular. On the other hand, perforations formed during preparation of a post-space tend to be elliptical and large. Perforations caused by an endodontic instrument during negotiation of a canal system tend to be smaller and relate to the particular diameter of the last instrument used.

**Fig. 5. Clastic cells resorbing dentine. The mineralized tissue of the tooth does not normally undergo resorption.**

### *Tooth resorption*

The mineralized tissue of the tooth does not normally undergo resorption. The actual reason for this is not entirely understood, but a number of theories have been proposed to explain the resistance of the tooth tissue to clastic cellular activity (Fig. 5). Firstly, it is believed that the root is protected by the remnants of Herthwig's epithelial root sheath that surrounds the root in a mesh-like manner (66). The second hypothesis suggests that the non-mineralized covering of the dentine provided by pre-dentine internally or the external cementoid layer externally provides the protection (67). The clastic cells require the presence of extracellular proteins containing the aginine–glycine–aspartic acid (RGD) sequence of amino acids for binding (68–77). The RGD sequence is missing in these non-mineralized layers. The third hypothesis suggests that the pre-dentine and cementoid layer contain an intrinsic factor osteoprotegrin (OPG) that inhibits osteoclastic activity (78–83).

Resorption is most frequently categorized into discrete entities, either internal or external, and guidelines leading to the systematic differential diagnosis have been described in detail (84). Frank (13) suggested that internal resorption is the result of external resorption that has progressed to internal involvement. However, most authorities now agree that internal resorption is a discrete entity. While the pathogenesis of internal resorption is not fully understood, it is more easily managed than external resorptive defects provided that the process has not

led to perforation of the root. On the other hand, external root resorption demands more complex treatment, which is in turn determined by the site, nature and extent of the lesion. External root resorption can be classified according to the site, nature and pattern of the process. Many different classifications (7, 85–87) have been proposed. Those suggested by Ne et al. (88) includes, *External Surface Resorption, External Inflammatory Root Resorption, Ankylosis and External Replacement Resorption*.

### *Caries*

The carious process involves destruction of dental tissues as a result of microbial action (1). An untreated carious lesion may invade the floor of the pulp chamber or extend along the root, resulting in perforation of the root. Treatment of these perforations may require a combination of crown lengthening, root extrusion (surgical or orthodontic) or tooth/root resection in order to retain valuable radicular segments (2, 89–93).

## Location of the perforation

When treatment planning for perforation repair, the location of the perforation is probably the most important and overriding factor in the decision-making process. Fuss & Trope (7) presented a classification that emphasized the relationship of the perforation site to the 'critical crestal zone.' This classification divides the root into *coronal*, *crestal* and *apical* portions: *coronal* being defined as 'coronal to the crestal bone and epithelial attachment'; *crestal* being defined as 'at the level of the epithelial attachment and crestal bone' and *apical* being defined as 'apical to the crestal bone and epithelial attachment.' In addition to considering the position of the perforation in relation to the 'critical crestal zone,' its position in the mesial distal and facial lingual planes must also be taken into account (2, 57, 61).

Non-surgical treatment is indicated, whenever possible, in the management of perforations. Surgical intervention is reserved for cases not amenable to, or which have not responded to, non-surgical treatment, or in which the concomitant management of the periodontium is indicated (57). There is no clear-cut distinction between those cases that are best treated non-surgically and those treated surgically, and, frequently, creative combinations of both non-surgical and surgical approaches must be adopted. The decision to repair perforations surgically can only be made when a number of considerations have been addressed. These considerations include the following:

Will access and visibility be adequate?

Can adjacent structures be protected?

Will the perforation repair result in the creation of an untreatable periodontal defect?

Management of individual perforation scenarios relative to the location of the perforation will be discussed later in this article.

## Access and visibility to the perforation

Access and visibility are determined, in the main, by the location of the perforation. Irrespective of the location relative to the critical crestal zone, the location of the perforation relative to the horizontal axis of the tooth will greatly influence its management. Buccally placed perforations (Fig. 6) are invariably easier to manage than those located lingually or proximally, and consequently afford a more varied opportunity for repair; this will in turn favor a surgical approach (2, 57, 63, 94, 95). Lingually located defects, especially in the mandible,

**Fig. 6. Buccally placed perforations are invariably easier to manage than those located lingually or proximally. (courtesy of Dr J He, Dallas, TX, USA).**

frequently exclude the surgical option (57) and are either managed non-surgically, orthodontically or, alternatively, the tooth may be destined for extraction.

The introduction of improved illumination and magnification provided by the SOM has been beneficial in the management of perforations both surgically and non-surgically (17–20, 22, 23, 96–98). In fact, many cases are now managed non-surgically that previously would have had a very poor surgical prognosis (Figs 1B and 7). While many perforations of iatrogenic or carious origin have well-defined limits, those owing to resorption frequently undermine the radicular tissue in all dimensions and are difficult to visualize or to determine the extent of their boundaries. Unless the boundaries of a perforation can be adequately visualized, accessed and isolated, repair becomes difficult if not impossible (49, 99).

## Adjacent anatomical structures

Protection of adjacent anatomical structures is a major consideration when planning to repair a perforation surgically. The anatomical structures most likely to be damaged include adjacent radicular structures, neural structures, the maxillary sinus and the soft tissue of the reflected tissue flap. Location, identification and isolation of the structures will usually prevent long-term permanent damage during the surgical procedure (57, 100, 101).

## Management of perforations

Gutmann & Harrison (57) reported in the classic surgical text, Surgical Endodontics, that the surgical repair of perforations has received sporadic attention in the dental literature and has been supported primarily by case reports or limited studies (33). Since then, little has changed and the surgical management of root perforations continues to be a poorly understood and executed endodontic procedure. As with all surgical specialties, the endodontic clinician must possess a thorough understanding of the anatomy and physiology of the oral soft tissues, osseous tissues and tissues that comprise the periodontium (57).

Perforation size, interval as the defect was created and periodontal status are factors that have major influences on the prognosis for success (2, 5, 7, 14, 20, 25, 28, 29, 61, 62, 102–105). These will be discussed in the overall discussion on surgical management of the perforation defect. As discussed by Weine (106), management of perforations demands 'spontaneity and creative approaches.' The management of the perforation will be discussed in terms of the critical crestal concept as described above (7).

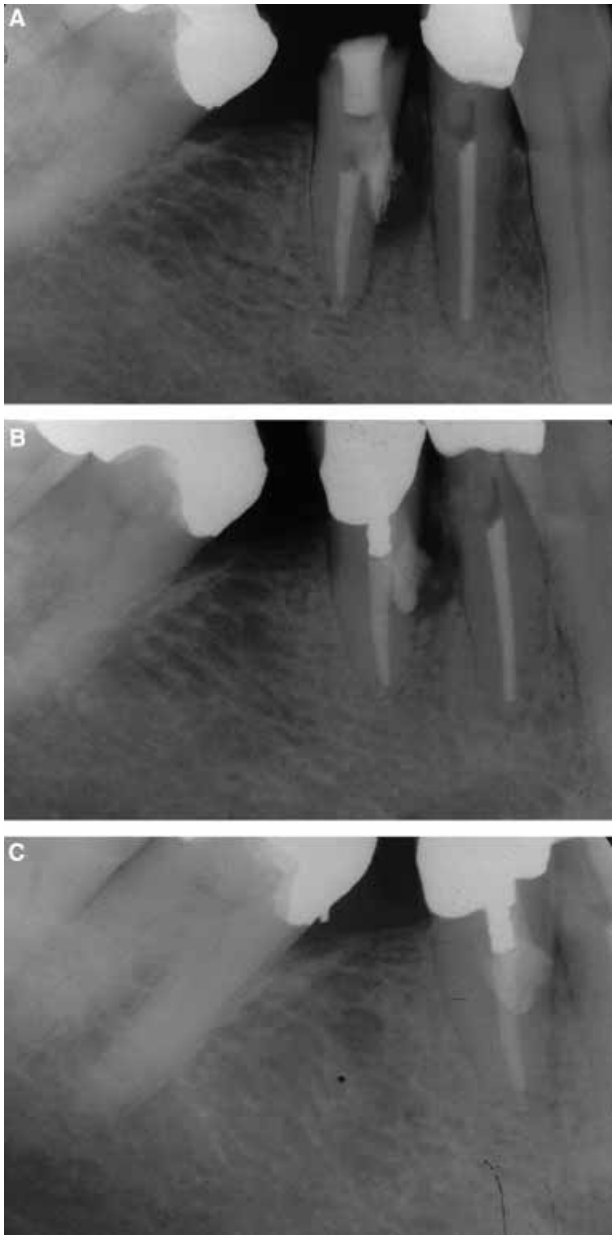


**Fig. 7. (A) Internal approach to repair of post-perforation of mesiolingual aspect of the root of a mandibular premolar (see Fig 1B). (B) Retreated tooth and definitive restoration of tooth. (C) Two-year follow-up of tooth.**

### *Supracrestal perforations*

Perforations coronal to the crestal bone can frequently be managed non-surgically. The perforation can usually

be repaired with standard restorative materials such as amalgam, gold, composite or cast metal restorations. The margins of cast restorations can be extended so as to include the defect. In order to facilitate the repair, it may be necessary, at times, to extrude the tooth orthodontically to a point where the perforation defect becomes supragingival and unlikely to impinge on the biologic width. (Biologic width denotes the combined connective tissue and epithelial attachment from the crest of the alveolar bone to the base of the gingival sulcus.) (1, 92, 93, 107–111) Alternatively, the defect may be exposed surgically or the tooth may be intentionally replanted surgically following repair of the perforation defect (112, 113).

Surgical crown lengthening may be indicated or used to assist in the surgical access to coronal-third root perforations, especially when the subgingival defect can be transformed into a supragingival defect (114–120). A minimum of 4 mm of sound tooth structure must be exposed by the surgical procedure (116, 117, 119, 121). Four millimeters corresponds to the measurement from the bony crest to the edge of the sound tooth structure and includes a minimum of 2 mm for 'biologic width' (122). Biologic width is the amount of space required for health by the gingival tissues (1.07 mm connective tissue attachment and 0.97 mm junctional epithelium) and was first reported by Gargiulo et al. (123) working on cadavers. In addition, they found the average sulcus depth to be 0.69 mm. This measurement of 2 mm is an average for biologic width that varies among patients (124) and even among sites in the same patient.

If a restoration violates this space below the base of the sulcus, it will result in inflammation of the tissues. How the gingival tissues respond to a biologic width violation depends on tissue 'biotype' (125–127). Patients with a thick 'biotype,' which is thick gingiva and thick bone, will demonstrate persistent inflammation unless the biologic width re-establishes itself and the probing depth around the tooth deepens as a result of this inflammation-induced bone resorption. A moat-like crater may form in the bone around the tooth if it is very thick. A patient with a thin biotype will respond to biologic width violation by gingival recession and bone resorption.

To determine if crown lengthening is a practical solution to managing a perforation, it is important to consider the anatomical relationship to the adjacent teeth and their supporting tissues. The bone supporting the adjacent teeth will also require recontouring if the formation of a bony step is to be avoided. If a bony step is created during the surgical procedure, the gingiva will proliferate coronally instead of remaining at the new, planned, more apical position. In addition, teeth with subgingival restorations and narrow zones of keratinized gingiva have statistically significant higher gingival scores (plaque and bleeding) than teeth with submarginal restorations and wide zones of keratinized gingiva (128, 129). Therefore, if a tooth already has little keratinized tissue (less than 2 mm), it is important to aim to preserve this during surgery (130). In the molar area, the length of the root trunk must be taken into consideration because a tooth with a short root trunk is more likely to have furcation involvement as a result of the surgery than a tooth with a medium or long root trunk.

Crown lengthening may be performed either by using a simple gingivectomy technique that will sacrifice attached gingiva and not permit any bone contouring or surgically reflecting tissue and performing an ostectomy and/or osteoplasty. If no bone is removed, care must be taken to ensure that there will be enough biologic width space created or the gingival margin will creep back towards its original position, resulting in a 'shortening' of the clinical crown (128, 129).

Following administration of anesthesia, the surgical procedure is initiated by placing a reverse bevel incision at the crest of the free gingiva to the gingival attachment extending from the mid-labial aspect of the adjacent teeth. It is important to maintain as much attached gingiva as possible. The resected tissue lining the sulcus and the interproximal tissue is then curetted. A second incision is made running parallel to the surface of the gingival tissues from the crest of the gingival tissue to the bone. The second wedge of tissue is removed with the curette. The tissue can now be retracted as an envelope flap. In most cases, vertical-releasing incisions will not be required and should in fact be avoided if possible to facilitate repositioning of the reflected tissue. Bone can be removed with chisels (such as Wiedelstadt chisel) or burs. End-cutting friction grip burs are very effective instruments and can be used safely without damaging adjacent tooth structure. Alternatively, a no. 6 or 8 round burs can be used to thin the bone sufficiently so that the chisel can then be used. The bony contours should follow a smooth path into the interproximal areas avoiding the

creation of sharp ledges or grooves. Following completion of the bone removal and osseous recontouring, the flap is positioned apically and sutured into place. Periodontal dressings such as Coe-Pak are placed routinely to provide protection for the healing tissues and reduce discomfort for the patient (131).

### *Apical third perforations*

Perforations in the apical third of the root can be considered simply as an extra exit from the canal system and managed either non-surgically or surgically (2, 95, 99). If the defect cannot be managed non-surgically, resection of the root apex is usually the most efficacious method for repair provided that the crown–root ratio remains favorable. These types of perforation include apical perforation of the root during instrumentation of the canal system or placement of a post, perforation following zipping of the apical portion of the canal, deviation of the root canal instrument during cleaning and shaping or in an attempt to bypass an obstruction in the canal system. Perforations in the apical portion of the root rarely communicate with the oral cavity and are therefore not exposed to constant microbial contamination (62).

### *Critical crestal zone perforations*

Perforations in the 'critical crestal zone' are invariably associated with a less favorable outcome and are frequently more difficult to manage (2, 7, 132). These perforations are most susceptible to epithelial migration and rapid periodontal pocket formation (133, 134). Management of the repair of these defects will depend on many factors. Those necessitating surgical intervention include the following:

- Perforations in areas not accessible by non-surgical means alone.
- Perforations of the root with a concomitant periodontal component.
- Perforations that have not responded favorably to non-surgical repair.
- Extensive defects that provide no physical boundaries against which to apply repair material.
- Perforations of a root that require a separate apical surgical procedure.
- Perforations owing to resorptive activity not easily managed from within the canal system.
- Defects into which excessive amounts of a foreign body, such as obturating material, has been extruded.

## Surgical management of perforation defects

The aim of surgical perforation repair should be to produce an environment conducive to the regeneration of the periodontium (28, 132, 135, 136). Periodontal tissue reactions to experimentally induced perforations in animals (137, 138) and accidental perforations in humans (5, 139–141) have been studied. Successful regeneration of the periodontal tissue will return the tooth to an asymptomatic functioning unit of the dentition (142–145).

Three broad categories of crestal zone perforation defects exist that can potentially be repaired surgically. These are:

(1) *Strip perforations*: Complete penetration of a root canal wall owing to excessive lateral tooth structure removal during canal preparation (6, 48, 103, 146).
(2) *Furcation perforation*: A mechanical or pathological communication between the root canal system and the external tooth surface and occurs in the anatomic area of a multi-rooted tooth where the roots diverge (6, 26, 34, 35, 137, 147–154); and
(3) *Perforations related to external cervical root resorption*: A relatively uncommon, insidious and often aggressive form of external root resorption, which may occur in any tooth in the permanent dentition (13, 87, 88, 155–160) (Fig. 1D, E; see Fig. 14B).

Ideally, furcation and strip perforations should initially be managed using a non-surgical technique. This approach will preserve the periodontium, thus increasing the probability of long-term success. Only when disease persists should surgical management of strip and furcation perforations be considered.

On the other hand, management of external cervical root resorption ideally should be managed from an external approach while attempting to maintain pulpal viability if at all possible. Only when the pulp is already irreversibly inflamed or necrotic, or when removal of the diseased dentine tissue unavoidably causes irreversible pulpal injury, should a root canal procedure be performed. With this in mind, the management of category I and II external cervical root resorption

defects as described by Heithersay (159) should be approached from the external or periodontal structure. Management of category III (Heithersay) resorptive defects can be attempted by either an internal or external approach depending on which procedure produces the least amount of tooth and periodontal destruction. Category IV defects are deemed unrestorable. The external approach to the management of cervical root resorption has been achieved using two techniques: (1) a chemical cauterization of the lesion using 90% trichloroacetic acid (159, 161, 162) and (2) surgical removal of the lesion (2, 14, 61, 62, 94, 132, 134, 142, 147, 163–169). The discussion in this paper will be limited to surgical management. For the sake of discussion, the surgical repair of any perforation defect can be broken into soft-and hard-tissue management even though they are clinically inseparable.

## Soft-tissue management during surgical repair of perforation defects

The basic window for soft-tissue access is similar for each type of perforative defect with slight modifications introduced as necessary to accommodate the surgeon's need in managing the underlying hard tissues. In designing the soft-tissue access window, several factors must be taken into consideration including frenal and muscle attachments, bony eminences and the position of the defect itself (57, 170, 171). The soft-tissue access window is formed by combining a horizontal relieving incision and if necessary vertical relieving incision(s). Given that the defect is frequently close to the marginal tissues, a vertical relieving incision may not be required or if required may not need to extend to the depth of the vestibule. As with periradicular surgery, vertically orientated relieving incision will limit the number of vessels severed (172, 173) diminishing the potential for hemorrhage, which is especially critical if bonded materials are planned for the restoration of the defect.

### *Horizontal relieving incision*

In view of the fact that a defect may extend interproximally, the only appropriate form of horizontal relieving incision in the region of the tooth being treated is one where the entire dental papilla is completely mobilized. Thus, the horizontal intrasulcular incision should extend from the gingival sulcus through the periodontal ligament fibers and terminate at the crestal bone and pass adjacent to each tooth (57, 128, 129, 174, 175). Occasionally, when a defect extends interproximally, the tissue is reflected on both the lingual and buccal sides of the tooth. As the horizontal relieving incision extends beyond the tooth with the defect, other forms of intrasulcular incisions such as the papillary-base incision (176–178) can be used.

### *Vertical relieving incision*

If a vertical relieving incision is required to improve access to the defect, several general principles should be followed. The incision should be parallel to the long axis of the tooth where possible and should not involve frenae, muscle attachments or bony eminences unless necessary. The incision should be made over healthy bone distant from the site of the defect, beginning at the midpoint between the dental papilla and the horizontal aspect of the buccal gingival sulcus, thereby avoiding dissection of the dental papilla (57, 129, 174).

### *Soft-tissue access window design*

Combinations of vertical and horizontal incisions are used to achieve various soft-tissue access window designs. A full mucoperiosteal reflection is required, lifting the entire body of soft tissue as one unit, including the alveolar mucosa, the gingival tissues and periosteum. Three variations of soft-tissue access window can thus be established (57, 171, 179, 180):

- *Limited triangular*: One vertical relieving incision (see Fig. 10B).
- *Limited rectangular*: Two vertical relieving incisions.
- *Envelope*: No vertical relieving incision (see Fig. 14D).

### *Tissue reflection*

Elevation and reflection of the entire mucoperiosteal complex are essential and will help to minimize hemorrhage during the procedure (181). If a vertical relieving incision is used, tissue elevation and reflection should begin from this vertical incision within the attached gingivae (57, 100, 174, 182). However, if a horizontal incision alone is used, then elevation and reflection should begin at the region of the diseased

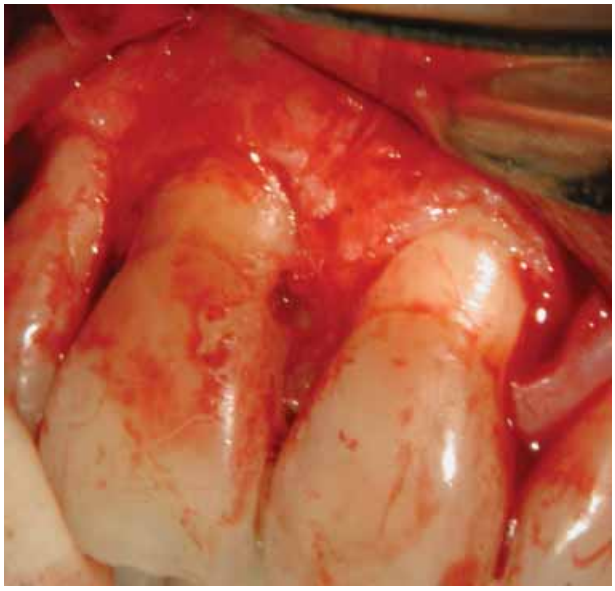

**Fig. 8. Design of the surgical flap to allow for tissue over teeth adjacent to the tooth with the defect to be reflected. This will provide for good access and visibility.**

tissues. Once the tissue adjacent to the defect has been elevated, the surgeon should use a gentle rocking motion to continue the elevation and reflection in a mesial and distal direction as required (57). Typically, the tissue should be reflected to include teeth adjacent to the tooth with the defect (Fig. 8). Defects that involve the furcation and mid-root region will require either a limited triangular or limited rectangular soft-tissue access window.

As the underlying bone of the cortical plate is undulating (183) (Fig. 9), damage to the fragile soft tissues during elevation should be avoided. The surgeon should take great care to prevent slipping of the elevator during the tissue reflection; this can be achieved by using an appropriate instrument that is stabilized with adequate finger support. As the interdental papilla is approached, a narrower instrument may be required to gently undermine and elevate the tissue in this region. This process should be continued gradually until the osseous tissues overlying the diseased tooth structure are adequately exposed.

Once the tissue is elevated, it must be retracted to provide adequate access for management of damaged radicular tissues. The main goal of tissue retraction is to provide a clear view of the bony surgical site and to prevent further soft-tissue trauma (57). When a horizontal incision alone is used, the major concern during elevation and retraction of the tissue is

**Fig. 9. As the underlying bone of the cortical plate undulates, care must be exercised to avoid damaging the fragile soft tissues during elevation (courtesy of Dr JL Gutmann, Dallas, TX, USA).**

avoidance of tearing or crushing of the tissue. A tear will usually occur at the point of maximum tension where the tissue is being retracted most (174, 182). This occurs most frequently in close proximity to the defect and a tear in the tissue in this region can complicate wound closure. The surgeon should therefore carefully consider the use of a simple envelope access window.

### *Hard-tissue management*

As with any surgical procedure involving bone, the aim should be to remove the affected tissues, conserve the healthy hard tissue and to minimize heat generation during the process (57). Similar to root-end surgery, hard-tissue management involves five phases. Firstly, removal of healthy tissue to gain access to the diseased tissues followed by removal of the diseased tissues and foreign material. These two phases are then followed by the third stage, which is the formation of an appropriate cavity form to receive the restorative material. The fourth phase of the process aims to achieve a dry surgical field using appropriate hemostatic techniques and materials (181) followed by placement of the restorative material in the cavity. Finally, in the fifth phase, the root surface is conditioned (184, 185), if appropriate, prior to tissue re-approximation. Typically, a surgical high-speed bur is used in phase one and two of the procedure. As the need for a greater refinement of the perforation site increases and the space in which to achieve this refinement decreases,

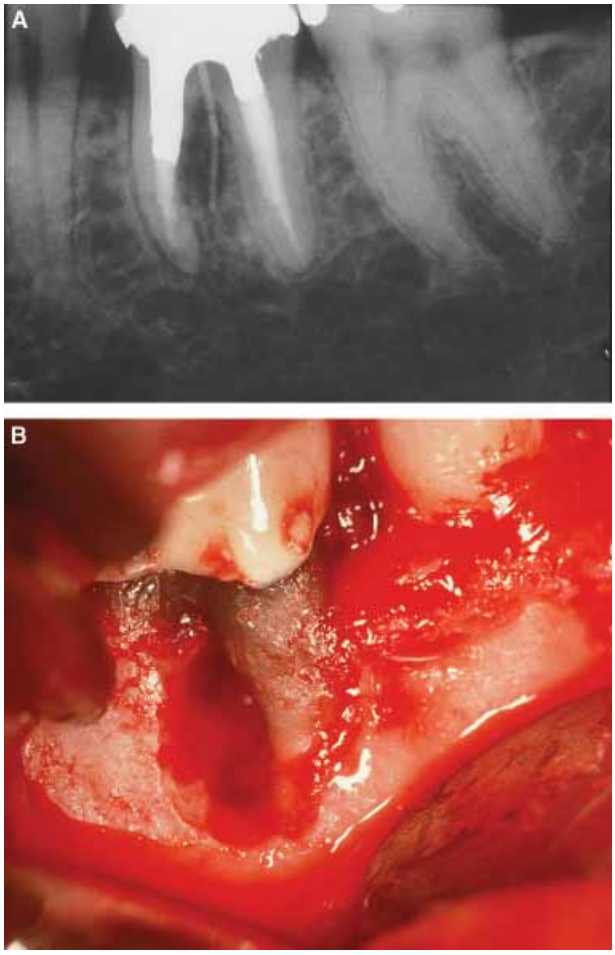


**Fig. 10. (A) Radiographic image showing strip perforation. (B) Associated bone destruction exposed following reflection of overlying soft tissues.**

ultrasonically energized tips can be used in phases two and three. It is useful to have a wide array of ultrasonic tips available during the surgical procedure, as the various clinical scenarios that may arise are not often easily managed using a single ultrasonic tip.

### *Hard-tissue management: furcation and strip perforation*

These defects (Fig. 10A, B) have similarities with the conditions found in periradicular surgery. There is a typically a region of persistent disease associated with an iatrogenic defect. This leads to a bacterial-stimulated growth of granulomatous tissue and associated bony loss (186–196). The goals of the surgical procedure are to debridé and then seal the defect to prevent further egress of microorganisms from the canal system or from the oral cavity into the periradicular tissues (57). Thus, the surgeon may view this procedure as simply a root-end surgery carried out in a different region of the tooth. The management of such a defect thus requires the same systematic approach as that used in root-end surgery. If the lesion perforates the cortical plate, then the soft tissue should first be peeled away from the osseous crypt, starting at the lateral borders. This can be accomplished efficiently by using the curette with the concave surface facing the internal envelop of the osseous opening. Once the soft-tissue lesion has been separated from the bone to the point where the crypt changes its convexity, the curette can be used in a scraping manner to remove the remainder of the granulomatous tissue from the opposing wall of the osseous defect (57, 101, 179, 197, 198). If the cortical plate is intact, then a hard-tissue access window can be made using a multi-fluted round bur in a rear vented high-speed hand piece (199) applying copious sterile irrigation. This combination in conjunction with an effective irrigation system reduces the heat generated in the bony crypt (200–206). Temperature increases above normal body temperature have been shown to be detrimental to the osseous tissue (207–222). The surgeon should collate information gleaned from multiple radiographs, clinical examination and knowledge of the relevant tooth anatomy to establish the most appropriate access point to the defect. Once the lesion proper is entered and the access window expanded sufficiently, the soft-tissue lesion can be removed as described previously. Having removed the lesion, the focus of the procedure is now to identify and clean the perforation. As with root-end surgery, an appropriate ultrasonic root-end preparation tip can be used to clean and simultaneously establish a cavity form. The use of the SOM in conjunction with microsurgical instruments and mirrors greatly facilitate this procedure (20, 163). As this type of perforative defect is typically encased in bone, the material of choice to restore this type of defect is mineral trioxide aggregate (MTA).

### *Hard-tissue management: cervical root resorption*

In order to manage this type of defect properly, it is important to understand the clinical nature and appearance of cervical root resorption. Clinically, the lesion that forms adjacent to cervical root resorption can vary from a small defect at the gingival margin

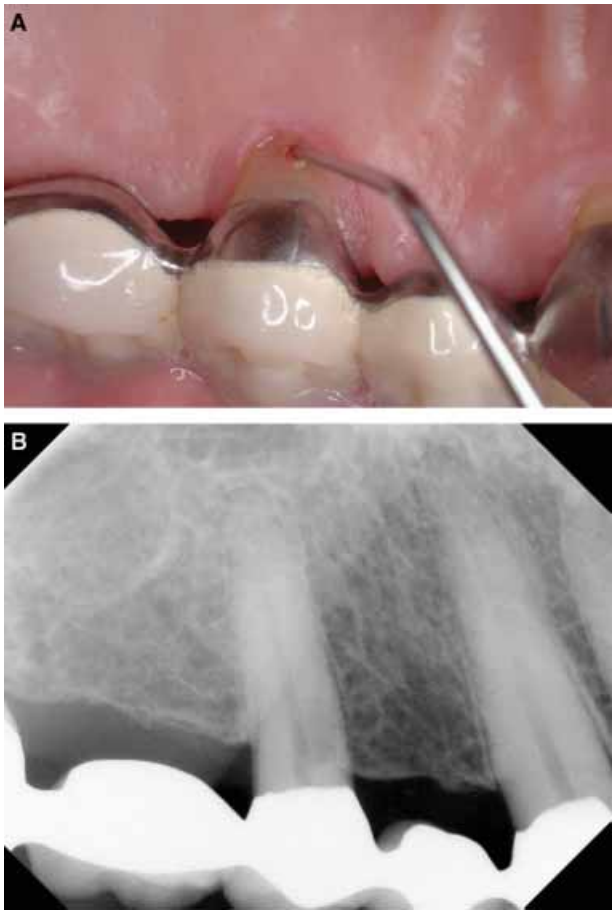


**Fig. 11. (A and B) Resorptive processes frequently begin as small defects at or below the gingival margin. As shown in the radiograph, the lesion appear to progress by penetrating deep into the dentin structure of the tooth through small channels initially. These channels gradually become enlarged and contain fibro-osseous tissue.**

(Heithersay Class I) to extensive undermining cavitations of the tooth enamel that produces a pink coronal discoloration of the tooth crown (49). The resorbing tissue is fibro-vascular in nature with odontoclastic cells adjacent to the dentine surface. The lesion appears to progress by penetrating deep into the dentine structure of the tooth through small channels initially (Fig. 11A, B). These channels gradually become enlarged and contain fibro-osseous tissue. An overlying inflammatory response can be present when a secondary invasion of microorganisms occurs.

Successful surgical intervention requires that the entire pathological process be eliminated. (A diagrammatic representation of these procedures is illustrated in Fig. 12.) The use of magnification and powerful illumination can enhance the ability of the surgeon to visualize the diseased tissues and thus ensure adequate removal. The basic principle is to use a small instrument to remove the ingrowths of fibro-osseous tissue (49, 99) into the dentine and preserve the dentine where it is normal. Several different types of burs are useful in removing resorptive tissue. These include slow-speed burs such as the Müller bur, the LN bur and round #1 surgical length latch burs. High-speed surgical length round #1 bur can also be used but require a greater degree of control owing to their superior cutting ability. Diamond-coated ball and pear-tipped ultrasonic instruments are also useful, both to remove small increments of bone and affected dentine (223–225). Once all of the diseased tooth structure has been removed, the tooth needs too be thoroughly examined to assess the viability of the pulp. If the long-term integrity of the pulp is compromised or a pulpal exposure is present, then non-surgical root canal treatment is indicated. If rubber dam isolation can be established (Figs 12E–G and 13), performing root canal treatment through the existing defect, if possible, can prevent further destruction of the tooth. An ultrasonic root-end preparation tip can be used to clean the pulp chamber proper. If adequate isolation cannot be established, then the defect should be restored first and the non-surgical root canal treatment completed subsequently. The integrity and patency of the pulpal space can be maintained by placing a gutta-percha cone in the canal itself. This will prevent the restorative material from flowing into and occluding the canal system (Fig. 12F). As aesthetics are frequently important in this type of perforative defect, a bonded tooth-colored restorative material that is tissue 'friendly' to the gingivae is most appropriate (Fig. 14). An alternative is to reposition the flap apically to the base of the resorption repair. Should this be aesthetically unacceptable, orthodontic extrusion can be used to improve the gingival contour (109, 114, 226).

### *Hard-tissue management temperature changes*

Temperature increases above normal body temperature within osseous tissues have been shown to be detrimental (207, 214–217, 222). A round bur used with a gentle brush stroke action has been shown to prevent rapid increase in temperature of the bone and produces a wound site with less inflammation (200, 201, 204–207). The use of a coolant during bone cutting is essential, as the absence of an appropriate irrigant can

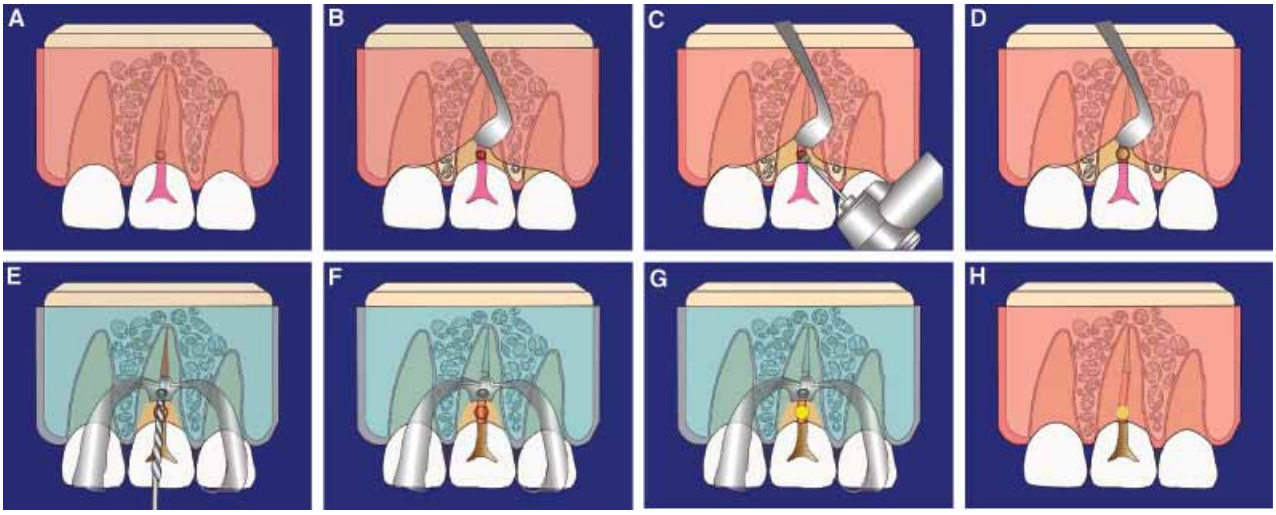


**Fig. 12. Diagrams demonstrating techniques for the management of a resorptive perforating defect of the root of a maxillary central incisor. (A) Radiographic image of perforating defect. (B) Reflection of tissue where an envelope tissue flap design has been used. (C) Use of rotary instrumentation to remove the fibrous-osseous tissue and to prepare the root for a restoration. (D) Completed preparation. (E) Placement of dental dam and root canal system debridement. (F) Temporary occlusion of the canal system with a gutta-percha cone and restoration of perforation defect. The gutta-percha cone prevents blockage of the root canal system by the restorative material used in restoration of the perforation defect. (G) Completed root perforation repair. (H) Replaced soft tissue flap.**

**Fig. 13. Clinical example of dental dam isolation of perforation defect prior to restoration with composite restorative material.**

result in temperature increases in excess of those known to impair bone healing (227). Temperatures can rise above 100°C by applying excess pressure during cutting, by burying the bur into the bone, or where little or no irrigant reaches the cutting tip (206).

All ultrasonic surgical tips should contain an irrigation port. Using an ultrasonic instrument in the wound without adequate irrigation can also result in an extreme temperature increase within the tissues, although this specific effect has not been demonstrated during endodontic surgery. However, the effect of scaling without irrigation produces an increase in dentine temperature of up to 35°C above baseline temperatures (228). This increase in temperature during scaling and root planning was described as being injurious to pulpal and periodontal tissues (228, 229). Recently, the use of non-cooled ultrasonic instruments within the canal system has been cited as the cause of extensive thermal injury to the periodontium (230).

### *Placement of the restorative material: localized hemostasis*

Localized hemostasis throughout the surgical procedure, particularly during placement of the restorative material, is essential to ensure the successful repair of the perforating defect. Good hemostasis will minimize surgical time, blood loss, postoperative hemorrhage and swelling (57). Hemostatic agents used during endodontic surgery are intended to control bleeding from small blood vessels or capillaries. Localized hemorrhage control enhances visibility and facilitates assessment of root structure and ensures establishment of a dry environment for the placement of restorative materials. Several agents have been advocated to


**Fig. 14. Clinical procedures involved in managing a resorptive perforating defect. (A) Preoperative photograph. (B) Preoperative radiograph. (C) Radiograph showing temporary occlusion of root canal system during repair of the buccal resorptive defect. (D) Completed restoration before repositioning of soft-tissue flap. (E) Postoperative radiograph of completed case.**

control hemostasis during surgery. The action of these materials, their ability to control bleeding and their effects on healing vary considerably. They aid in coagulation either through a physical tamponade action, enhancement of the clotting mechanism, vasoconstriction or a combination of each of these effects. No one local hemostatic agent is ideal; each of the available materials has advantages and disadvantages. Local hemostatic agents include collagen-based materials, ferric sulfate, calcium sulfate, epinephrine-soaked cotton or cotton pellets or cautery/electrosurgery (181). Unlike many periradicular surgical procedures, surgery in the cervical region of the tooth can sometimes be isolated using a rubber dam. The use of a rubber dam, if physically possible, provides ideal control of bleeding (Fig. 13).

Frequently, in cervical resorptive defects, the lesion will be in the region of the junction of the coronal and middle third. A small amount of bone can be chiselled away to reveal a collar of sound tooth structure ( $\sim$ 1 mm). This collar of tooth structure can be used as support for an anterior rubber dam clamp. This form of 'hemostatic control' is ideal in cases where bonded restorative material is used to restore the defect.

### *Root surface preparation*

The presence of healthy cementum on the root surface is necessary for the successful regeneration of periodontal tissues (135). A number of substances found in cementum stimulate the migration, growth and attachment of periodontal fibroblasts. Cementum extracts also activate fibroblast protein and collagen synthesis, which is necessary to re-establish a functional periodontal ligament (231–233).

Root surface conditioning is designed to remove the smear layer, thereby providing a surface that is conducive to cellular adhesion and growth. It exposes the collagenous matrix of dentine and retains biologically active substances, such as growth factors, contained in the dentine. In experimental studies, demineralized dentine induced the development of cementum-like mineralized tissue (234–238). It is argued that this treatment produces a biocompatible surface, conducive to periodontal cell colonization without compromising the adjoining periodontium. A number of solutions have been advocated for root surface modification: citric acid, tetracycline and ethylenediamine tetra-acetic acid (EDTA) (239–248). All three solutions have been shown to enhance fibroblast attachment to the root surface *in vitro* (249, 250).

Traditionally, citric acid has been the solution of choice. A 2–3 min application of an aqueous solution of citric acid (pH 1) has been recommended to etch diseased root surfaces in order to facilitate formation of new attachment and cementogenesis (251–254). Craig & Harrison (184) examined the effect on periradicular healing of citric acid demineralization of resected root ends of dogs. Use of a 1–2 min application of 50% citric acid at a pH 1 resulted in demineralized root ends, with earlier complete healing than the non-demineralized root ends. However, the beneficial effect of etching dentine surfaces with low pH solution has been

questioned. Low pH may jeopardize the adjacent vital periodontal tissues. Extended applications (3 min) have been shown to discourage alveolar bone growth (242, 255–261).

EDTA, a solution with a neutral pH is equally effective in exposing collagen fibers on dentine surfaces. The benefit of EDTA over the lower pH solution is that it is not injurious to the surrounding tissues (260). An application of 15–24% EDTA for approximately 2 min produces the optimum root surface conditioning. At this concentration and time of application, EDTA at neutral pH selectively removes mineral from a dentine surface and exposes the collagen matrix. Lower pH solutions not only removed the inorganic structure but also denature the collagen matrix (242, 256, 257).

Tetracycline has also been promoted for root surface conditioning. A 30 s application removes the smear layer leaving clean and open tubules (244). There is a trend for greater connective tissue attachment following tetracycline treatment of periodontally diseased human roots. Studies comparing the effect of a 3-min application of either EDTA (pH 7.3) or tetracycline HCl (pH 1.8) showed no significant difference in the treated tooth surfaces (246). However, the application of EDTA enhanced periodontal ligament cell attachment (243).

Although the root surface conditioning effects of citric acid, EDTA and tetracycline are well documented in the periodontal literature, this treatment modality has not translated into significant gains in periodontal attachment when treating periodontally diseased teeth (248). The use of conditioning agents is not recommended when using MTA either as a perforation repair material or as a root-end filling material (262).

### *Guided tissue regeneration and repair of root perforations*

Surgical procedures to repair perforation defects involve loose or compromised cortical bone, the result of either the disease process or the surgical procedure itself (263). This damaged cortical bone may result in reduced success for the corrective surgical procedure. Furthermore, the presence of an apico-marginal defect (264, 265) or dehiscence that is distinguished by a total loss of alveolar bone over the entire root length decreases the success of periradicular surgery significantly (266, 267). The cause of failure in these scenarios has been identified as an in-growth of non-osteogenic tissues into the surgical site and down-growth of epithelial tissue along the root surface. In these cases, successful treatment outcomes may depend more on control of the epithelial proliferation than management of defect. Guided tissue regeneration techniques have been advocated for use in such cases (6, 132, 142, 147, 263, 264, 268–284).

The basic principle of guided tissue and bone regeneration is based on the fact that different types of cells repopulate a wound at different rates during healing. The soft-tissue cells are considerably more motile than the hard-tissue cells. Therefore, they tend to migrate into the wound more rapidly during healing. A barrier interposed between the gingival tissue and the exposed root surfaces and supporting alveolar bone prevents colonization of the exposed root surface by gingival cells. This encourages the selective repopulation of the root surface by periodontal ligament cells. The use of a semi-permeable barrier theoretically would allow periodontal ligament cells and other cells with osteogenic potential to repopulate the defect, resulting in new connective tissue attachment and bone formation (271, 281, 285–290). Several case reports have also discussed the use of guided tissue regeneration techniques in conjunction with surgical perforation repair (6, 132, 142, 147, 149, 263, 272–274, 278, 291, 292).

Barriers can be grouped into two broad categories: non-resorbable and resorbable membranes. Resorbable membranes are generally better suited for endodontic applications, as a second surgical procedure is not required to remove the membrane. Frequently, membranes will require support so that the membrane does not collapse into the defect itself. In these cases, use of either a titanium-tented membrane or a supporting graft material may provide the necessary support for the membrane. Graft materials have two main functions: first as a mechanical substructure to support a membrane and the overlying soft tissues and second as a biological component that enhances bone formation.

The use of guided tissue techniques raises several additional issues that should be discussed with the patient prior to surgery. These include the cost of the additional material, the origin of the material (synthetic, animal or human), the need to manage the wound for a longer period of time and potential postoperative complications related specifically to these techniques and materials.

If guided tissue regeneration techniques are to be used in surgical perforation repair, it is advisable to use a resorbable membrane. The membrane must be extended 2.0–3.0 mm beyond the margins of the bony opening. The wound must be sutured to ensure that the tissue covers the membrane in its entirety. Compression of the tissues postoperatively is not recommended as this will collapse the membrane into the underlying defect. Furthermore, postoperative administration of antibiotics has not been shown to enhance the prognosis for these cases; however, many clinicians empirically recommend antibiotic use (129). Finally, it is not advisable to use guided tissues techniques in smokers as smoking has consistently been shown to affect the outcome adversely (293–298).

In addition to conditioning solutions and regenerative membrane techniques, the use of enamel proteins to enhance new attachment has been advocated (299–305). Emdogain is a derivative of porcine enamel proteins.

## Materials available for repair of perforation defects

Historically, a plethora of materials have been suggested for use in perforation repairs (5, 27, 29, 30, 53, 63, 136, 144, 306–308). The list is expansive and the number of materials too numerous to list. Many of these materials were obviously unsuitable for use in perforation repair, while others such as amalgam (137, 309), Cavit (137, 309), indium foil, zinc-oxide cements, ethoxybenzoic acid (Super EBA) (139), composites and glass ionomers (134, 148, 309, 310) have been used quite successfully for many years. However, many of these repair procedures have resulted in the development of periodontal defects, thereby compromising the prognosis for long-term tooth retention.

The choice of material will be determined in part by the site of the perforation. Supracrestal perforations demand the use of a material such as amalgam or composite that will be resistant to dissolution by oral fluids or abrasion and erosion by foods, dentifrices or oral hygiene aids. Materials such as Intermediate Restorative Material (IRM), Super EBA, Diaket or MTA are not considered suitable materials in these situations. However, a recent report (10) demonstrates a 15-month follow-up on a case where a supracrestal perforation was repaired with MTA.

A number of materials have been developed specifically for repair of tooth structure in the subgingival area following root caries, perforations or cervical erosions. These include resin-ionomer suspensions such as Geristore and compomers such as Dyract. This group of materials attempts to combine the various properties of composite resins and glass ionomers. Both Geristore and Dyract have been recommended for use in restoring subgingival surface defects such as root surface caries, external root resorption lesions, iatrogenic root perforations and subgingival oblique fractured roots. Geristore has been shown to be an acceptable material for repair of root caries and cervical erosions in a number of clinical studies (21, 311–316). When used to repair root perforations and as an adjunct to guided tissue regeneration, results have been favorable in isolated case reports (25, 113, 317–319). When used as root-end filling materials *in vitro*, leakage assessments of Geristore and Dyract indicate that they leak less than IRM, amalgam or Super EBA (320, 321). Compared with MTA root-end fillings, Geristore has a similar leakage pattern (322). Geristore and Dyract are less sensitive to moisture than conventional glass-ionomer cement; however, dry environments produced stronger bonds (323) Geristore appears to facilitate regeneration of the periradicular tissues (324). Studies investigating epithelial and connective tissue adherence to the material show evidence of cellular attachment to the material when placed in subgingival cavities (312, 315, 316).

Repair of perforations in the subcrestal region has been greatly facilitated recently in recent years by the development of a number of new materials (105, 144, 307, 325–327) and some innovative techniques (29, 54, 64, 328). True regeneration of the periodontal architecture is possible.

Regeneration of the periradicular tissues subsequent to surgery or owing to the ravages of disease processes implies replacement of the various components of the tissue in their appropriate locations, amounts and relationships to each other (329). Repair, on the other hand, has been defined as a biological process by which continuity of disrupted tissue is restored by new tissues, which do not replicate the structure and function of the lost ones (330, 331).

Without doubt, the material that has had the greatest impact on the management of these cases is MTA. MTA

was introduced to the market in the mid-1990s by Torabinejad & colleagues (10, 14, 28, 30, 144, 145, 153, 154, 306, 325, 326, 332–352). It has subsequently received FDA approval for use in pulp capping, root-end filling and perforation repair procedures (30, 144, 306). Other contemporary repair materials include Diaket, a polyvinyl resin (307, 353, 354), composite resins (148, 355), glass-ionomer materials (274, 310, 356) and compomers (113, 134, 136, 308, 312, 315, 316). When combined with tissue regenerative procedures (132, 142, 278, 281), the prognosis for many perforated teeth has been greatly improved. Both MTA and Diaket have been shown to facilitate regeneration of the periodontal apparatus following wounding (307) and have been described as osteoconductive in nature. Regeneration of the periodontal apparatus can occur when these materials are used as a root-end filling or perforation repair.

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# Soft tissue management: suturing and wound closure

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The healing capacity of oral tissues is excellent. Flap design should allow maintenance of optimal and sufficient blood supply to all mobilized and immobilized portions of the soft tissues. With prolonged duration of the surgical procedure, especially when a high degree of hemostasis has been achieved, there is a risk of drying out of tissues. The surgical site must be kept moist to minimize shrinkage of the reflected tissue flap. In surgical endodontics, the marginal epithelium and connective tissue are not removed, but are left intact on the tooth surface subsequent to tissue incision, elevation, and reflection. The treatment is aimed at maintaining vitality and survival of these tissues in order to facilitate and expedite the healing process. Ideally, wound healing does not result in new attachment formation, but preferably in reattachment, or healing by primary intention. The re-approximated tissue flap should rest passively in the desired place before suturing, reducing tension on the flap margins. In general, tissue trauma, such as stretching, tearing, or distortion should be avoided at all times. Gentle and careful manipulation with microsurgical instruments is helpful. As every placement of a suture poses additional injury to the wound margins, the smallest possible number of sutures should be used. Non-absorbable suture materials in sizes 6-0 to 8-0 are preferred and absorbable material is only recommended in multilayered closure. Sutures must not act as ligatures and should exert minimal tension. Time required for the wound to heal is closely related to the gap between tissue wound margins. Therefore, perfect adaptation will allow earlier suture removal. Wound support is only needed until the healing process has progressed to such an extent that the tissue can withstand functional forces.

## Introduction

Endodontic periapical surgery requires reflection of a mucoperiosteal flap that exposes the underlying cortical bone covering the root(s) in question and their respective apices in order to eliminate the apical pathosis. In principle, a tissue flap consists of gingival and mucosal tissues as well as periosteum. Various modes of incisions can be selected prior to tissue elevation and reflection (1). The prime objective of periapical surgery is to provide conditions such that healing and repair or regeneration can occur.

The surgical endodontic literature has identified a multitude of factors that may influence the surgical prognosis. Assessment of surgical outcomes is based mainly on radiographic and clinical criteria of healing of periradicular tissues (2, 3). Soft tissue healing after endodontic surgery has received comparatively little attention. Much of the knowledge has been drawn from the periodontal literature, where extensive research has been conducted regarding healing following various treatment protocols and pathologic conditions. Applying this knowledge to endodontic surgeries can only be justified, if the tooth in question has both a periradicular and periodontal problem at the same time. Many teeth treated for endodontic reasons have no or only minor periodontal involvement. Limited research on soft tissue healing in periodontally intact areas is probably because of the perception that periodontal wound-healing studies are directly applicable to endodontic surgeries. Extrapolation of findings can be misleading, as manipulation of soft tissues in periodontics and endodontics are not the same, as they do not address comparable pathologic conditions. In a situation with an inflamed periodontium, reflection of mucoperiosteal flaps is aimed at enabling the surgeon

to excise diseased gingival tissues, curette infected root surfaces, re-contour marginal bone, frequently apically reposition the flapped tissues and rely mostly upon secondary intention healing (4). These surgical procedures differ markedly from endodontic soft tissue goals of obtaining rapid healing by primary intention, ideally without attachment loss and no recession, or scarring.

Some common knowledge between periodontics and endodontics can be drawn from plastic and reconstructive surgery principles. Recently, periodontal surgery has shifted its focus from mere elimination of pathosis to a combination of achieving functional goals of disease elimination, while concomitantly obtaining or regaining aesthetic results. If the aesthetic outcome is considered the main reason for a surgical intervention (recession coverage, regenerative treatment) predictability of the treatment becomes a centrally important issue.

Periodontal plastic surgery, first suggested by Miller (5), was defined in a consensus report as surgical procedures performed to prevent or correct anatomical, developmental, traumatic or plaque disease-induced defects of gingiva, alveolar mucosa, or bone (6, 7). Subsequently, periodontal microsurgery was introduced, which is defined as refinements in existing surgical techniques that were made possible by the use of the surgical operating microscope, microsurgical instruments, and materials (8). Furthermore, improvements in flap design and enhanced soft tissue manipulation hold great promise to further improve predictability of periodontal treatment (9). Similar principles can be applied to endodontic soft tissue management (10–12).

## Soft tissue healing

The healing capacity of oral tissues is excellent. Only seldom are there serious post-surgical complications, such as tissue necrosis, nerve damage, profound bleeding, or serious infections. When general basic rules are followed, fair healing of the soft tissues can be expected. Oral wounds heal faster and with less scarring than other wounds such as dermal wounds (13, 14). One of the potential reasons is the way angiogenesis is initiated, via the vascular endothelial growth factor (VEGF) (15). Angiogenesis in skin occurs more rapidly than in the well-perfused oral mucosa and gingiva and the turnover of those vessels when initial healing has occurred may initiate scarring (15). However, the same general principles apply and the sequence of events is the same. Healing is a complex phenomenon and takes place in several phases that overlap and coexist, such as wounding, clotting and inflammation, epithelial healing, connective tissue healing, proliferation, maturation and remodelling (Fig. 1) (16–19).

Within 24 h, polymorphonuclear leukocytes and macrophages start migrating into the blood clot. As the inflammatory and reparative cells migrate along fibrin strands, capillary buds follow them. The microvascularization in the flap and surrounding tissues is provided from contributions from periosteal, periodontal, and bone microvascular networks (20). Epithe-

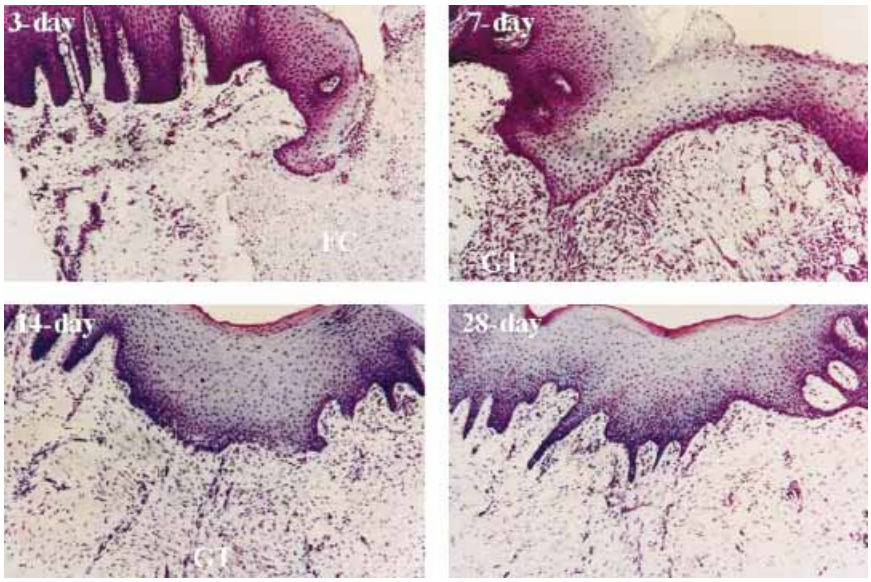


**Fig. 1. Stages of healing of full thickness gingival wounds over 4 weeks (hematoxylin & eosin staining). FC, fibrin clot; GT, granulation tissue. Reprinted with permission from (34).**

lial streaming as a sheet or as fingers is observed after 2 days, eventually resulting in a multilayered seal (21, 22). After 4 days an epithelial barrier has formed. Healing and reattachment of the elevated tissue to cortical bone is a slower process, as the periosteum does not survive the reflection (23). Granulation tissue replaces the thin fibrin clot between tissue flap and cortical bone after 4 days and fibrous connective tissue substitutes granulation tissue after 2 weeks (Fig. 1) (23). Because of early epithelial bridging, suture removal is recommended after 2–3 days (24). Some authors suggest suture removal after 4 days as collagen content in granulation tissue, which determines tensile wound strength, was only present after 3 days (16). When the wound is protected against excessive forces, small amounts of mechanical stress result in increased collagen strength and collagen formation. Larger forces disrupt the neovasculature and collagen fibres and thereby delay healing.

## Epithelial repair

The epithelium has a great regenerative capacity to react to trauma or injury. After the epithelium has been disrupted, re-epithelialization must occur to cover the defect. During and following injury a set of changes takes place that stimulate the complex process of repair and healing. This involves a series of controlled events which include the formation of extracellular matrix, that is mainly composed of fibrin, fibronectin, and vitronectin and the migration of epithelial cells from the edges of the wound (25–28).

Integrins play an important role in re-epithelialization and granulation tissue formation during wound healing through their function in cell adhesion and signalling. Integrins are cell surface associated dimeric glycoproteins that function as cell to extracellular matrix adhesion receptors (29–31). Through binding to extracellular matrix proteins, integrins mediate information transfer from the matrix to the cell interior, leading to alterations in cell functions and ultimately in cell behavior. Integrins are known to play an important role in regulating a wide range of cell functions during growth, development, differentiation, and immune response (29). So-called integrin-associated proteins appear to have a regulatory function on integrins. Growth factor receptors accumulate in the same structures as integrins, regulating integrin functions and thereby controlling cell proliferation (32, 33). Under this influence undamaged cells from the wound margins begin to migrate with the purpose of covering the exposed connective tissue. It is still unclear which cells in the epithelium first move into the wound. There is some evidence, that the suprabasal keratinocytes are the first migratory cells sliding over the basal keratinocytes (34). The epithelial cells dissolve their hemidesmosomal connections, detach from the basement membrane and move across the wound defect (34, 35). The cells migrate over the exposed connective tissue surface covered with a matrix of fibrin and fibronectin. Migrating keratinocytes are highly phagocytic and thus able to penetrate through tissue debris or a fibrin clot (36). It seems likely that integrins play a role in the fibrin clot removal. New hemidesmosomes form between the migrating cells and a new basement membrane is deposited. The covered wound surface has a thickness of only two to three cells and forms the new stratum basale. The described healing process continues from both wound edges until the damaged surface is covered. This phase takes place during the days 1 and 2 depending on the distance between the wound edges. By day 7 the epithelium has matured into multiple layers and new stratum corneum is usually evident (27).

When marginal wounds are created during surgical treatment, distinct differences have to be made between a periodontal flap and an access flap for apical surgery. In periodontal situation the epithelial and connective tissue attachment are excised for the purpose of removing diseased tissues. This results in only one epithelial wound edge located at the incisal edge of the flap. In these wounds the epithelium has to migrate apically along the root to a level where attached collagen fibres are present. This process is fundamental in the formation of a 'long junctional epithelium.' Epithelium migrates apically much faster than new connective tissue attachment forms, resulting in epithelial attachment formation at the expense of connective tissue attachment. The fact that connective tissue requires more time to regenerate is being used in guided tissue regeneration by means of preventing or delaying the epithelial cells in colonizing the wound surface intended for connective tissue repair.

In surgical endodontics marginal epithelium and connective tissue are not removed but are instead left intact on the tooth surface. The treatment is aimed at maintaining the vitality and survival of these tissues in order to facilitate and expedite the healing process.

Wound repair does not result in new attachment formation but preferably in reattachment, or healing by primary intention.

## Connective tissue repair

Connective tissue possesses also a good healing and regenerative capacity because of its high turnover rate. In contrast to the skin, wound healing in oral gingiva results in little scar formation (37–39). However, compared with periodontal ligament and epithelial tissues it has the slowest healing rate. The reparative reaction begins with a break down phase, followed by synthesis of granulation tissue, organization, contraction, and finally remodelling. The processes involve intricate interplay between inflammatory cells, fibroblasts and the newly synthesized matrix. The role of inflammatory cells in wound healing is the secretion of mediators that attract cells for repair process. Angiogenesis is also a very important feature of healing, as endothelial cells are responsible for the events taking place in revascularization.

Activation and migration of fibroblasts are critical steps in wound healing. Wound repair involves a change of fibroblasts from the resting stage to proliferating cells, subsequently to migratory and finally to stationary, matrix producing and contractile cells. Serum present in the blood clot stimulates fibroblasts to change the metabolic activity. Many serum-activated genes are known to be involved in the physiology of wound repair, including control of the cell cycle and proliferation, coagulation and hemostasis, inflammation, angiogenesis and re-epithelialization (40). The multiple functions of wound fibroblasts raise the questions of cell origin and if all tasks are performed by a single cell type or by multiple different phenotypes. There are indications that fibroblasts are heterogeneous in several properties, such as responsiveness to growth factors and in the ability to produce specific extracellular matrix proteins. This suggests that signals released during the actual surgical trauma may stimulate certain subpopulations to enter the wound space. On the other hand there are indications, that some migrated fibroblasts in fact change phenotype and differentiate into myofibroblasts (34). The myofibroblasts likely play a role in the wound contraction and matrix deposition. Wound contraction brings the wound margins closer together to allow faster wound closure. The differentiation of myofibroblasts occurs between 6 and 15 days after wounding (41, 42).

## Role of saliva and gingival crevicular fluid in oral wound healing

The excellent healing potential of oral tissues is a result of the presence of cells with potential for tissue regeneration, dense vasculature and high turnover rate of connective tissue and epithelium. Saliva also provides a unique environment for rapid tissue repair. These advantages include pH, ionic strength, and presence of calcium and magnesium required for healing (43). Lubrication of the wound with saliva prevents tissue dehydration and cell death, and promotes increased breakdown of fibrin and tissue debris. Saliva contains various growth factors and bacteria that appear to promote tissue repair as well.

Growth factors are synthesized by salivary glands or derived from fluid through gingival crevices. As the concentration of growth factors in gingival tissues is higher than elsewhere in the oral cavity, the periodontium is a structure with favorable conditions with respect to tissue healing.

The wound-healing process involves increased proliferation, adhesion and migration of cells of connective tissue and epithelium, inflammatory reactions and remodelling of extracellular matrix, which are directed by growth factors (44–46). Different growth factors have specific functions and target cells in wound healing, and their delicate balance is required for optimal tissue repair. VEGF found in saliva is involved in many aspects of angiogenesis and inflammation for endothelial growth, permeability and leukocyte adherence (47).

Both the oral cavity and saliva contain bacteria and bacteria definitely affect healing in the oral cavity. Wounds colonized by pathogenic bacteria have shown delayed healing (48, 49). On the other hand small numbers of bacteria may increase the rate of healing. An inflammatory reaction that is a prerequisite for tissue repair is accentuated by bacterial contamination. Bacteria attract macrophages into the traumatized area and induce cytokine secretion. This in turn increases the blood supply and granulation tissue formation in the wound. Bacteria contain substances that can either stimulate or inhibit host cell proliferation, depending on its concentration in the tissue. Different bacteria act

at a given concentration with accelerated or delayed wound regeneration.

In an experiment on gingival fibroblasts in culture, Larjava & Uitto (50) found increased proliferation when *Prevotella intermedia* was present, as compared with the same concentration of *Porphyromonas gingivalis*, where the fibroblast proliferation decreased. There were also great variations in effects in fibroblasts populations obtained from different patients. These findings suggest that repair depends both on bacterial flora as well as on the individual cell populations in a specific patient.

## Surgical site closure

Tissue flap designs should allow the maintenance of optimal and sufficient blood supply to all parts of the mobilized and immobilized portions of the soft tissues (1). With prolonged duration of the surgical procedure, especially when a high degree of hemostasis has been achieved, there is a risk of drying out of the tissues. The surgical site must be kept moist at all times to prevent shrinkage of flap tissue during the procedure and to minimize shrinkage during the healing process. Certain types of flap are more problematic than other regarding shrinkage, in particular the submarginal flap design. Shrinkage results in difficulties with tissue re-approximation and higher tension on the wound margins. Tension promotes impairment of the blood circulation of the wound margins (51), thereby resulting in a dehiscence and ultimately scar formation.

Prior to wound closure, the surgical site is irrigated with saline solution to remove debris, and tissue edges are re-approximated in their correct position to promote primary intention healing (52). Compressing the repositioned tissue with a saline-moistened piece of gauze will reduce the coagulum to a thin fibrin layer between the repositioned tissue and cortical bone (17, 23, 53). Tissue margins should rest passively in the desired place before suturing (8). When pulling force is necessary to reposition the tissue margins correctly, small periosteal incisions at the most apical portion of the flap should be made. This will reduce tension on the margins. In general, tissue trauma, such as stretching, tearing, or distortion should be avoided at all time. This is facilitated by gentle and careful manipulation with microsurgical instruments. Tissue pliers frequently used during suturing are greatly traumatic, if the tissue is held and compressed, or even punched during needle insertion through the tissue. Although technically more difficult, the tissue should not be held, but only lifted by placing open pliers under the tissue and sliding the needle through the tissue from the surface down and between the separated pliers ends. When tension-free wound adaptation has been achieved, the sole purpose of sutures is to hold the re-approximated tissue margins in place until the wound has healed.

### Suture materials

The required length of wound support through sutures varies in different tissues from a few days for oral, muscle and subcutaneous tissues, weeks or month for fascia and tendon, to long-term stability for vascular prostheses. This wound support must remain sufficiently stable until the tissue regains enough strength to keep the wound edges together on their own. Selection of suture material should be therefore based on its physical and biologic properties in relation to the healing characteristics of the wounded tissues it is to be used for.

Suture materials can be divided into two groups: absorbable and non-absorbable. Regardless of the allocation to a specific group, all suture materials cause a certain foreign body reactions in the tissue. The degree of irritation varies considerably between the materials. Absorbable sutures of biologic origin (surgical gut) are gradually digested by tissue enzymes, while synthetic materials are hydrolyzed in tissue fluids. Non-absorbable suture materials are encapsulated and surrounded by fibroblasts until they are removed. Consequently, absorbable materials will show irritation in the tissue until the suture has been absorbed. Depending on the material this will vary in time and degree. Polyglactin 910 (coated Vicryl®, ETHICON INC, Somerville, NJ, USA), which is absorbed in 7–10 days, has shown mild inflammatory reaction that diminishes after 3 days (53, 54). Therefore, in sutures involving gingival wounds non-absorbable materials are recommended as the inflammation reaction ceases, after the sutures have been removed. If a multilayered tissue flap has been elevated, absorbable suture materials (e.g. polyglecaprone, polyglactin) are used for inner layers only and non-absorbable materials (e.g. polypropylene, polyamide) for outer layers and whenever else possible, to minimize inflammation during the healing process (8, 55).

Monofilament and multifilament sutures are available. Multifilaments are twisted or braided together and while these sutures have generally good handling and tying properties, they allow rapid bacterial colonization (53, 56). Monofilament sutures are made of a single strand of material. When comparing histological tissue response of different suture materials, monofilament sutures (e.g. nylon, gut, steel and chromic gut) produced smaller inflammatory reactions than multifilament materials (e.g. silk, siliconized silk, polyester, teflonized polyester, cotton, or linen), although certain materials are no longer recommended for use (56–59). Systemic antibiotics did not alter these reactions (57), but the fact remains that bacteria invade suture tracks. This phenomenon is most predominant with multifilament materials with wicking action (53, 56).

Non-absorbable silk sutures are easy to tie and handle but are no longer recommended as they accumulate plaque, allow rapid bacterial colonization and are uncomfortable to remove because of ingrowth of tissue (53, 54). Instead, coated multifilament sutures (polyamide, polytetrafluorethylene), which resemble monofilament materials in handling and bacterial growth, may be used. In general, monofilament synthetic sutures are least traumatic, allow less bacterial migration and are the materials of choice (53).

The size denotes the diameter of the suture material, which is stated numerically. As the number of zero's increases, the diameter of the thread decreases; size 4-0 being 0000, has a smaller diameter than size 3-0 or 000. There is a direct correlation between the tensile strength of the suture and its size. The tensile strength of the tissue should have comparable values as the suture material. As suture material is irritating, the smallest possible size for adequate wound support should be used. Every placement of a suture poses additional injury to the wound margin, by passing a needle and suture through the tissue. The larger the needle size with the respective suture diameter the greater is the traumatic effect on the tissue (Fig. 2). Microsurgical techniques tend to increase the number of sutures, but at the same time substantially reducing the suture size (Figs. 3 and 4).

A surgical needle is necessary for the placement of a suture. The needle must be designed to create minimal trauma during penetration of the tissue. A sharp needlepoint, small body diameter and the thread swaged at the end are key properties for the least traumatic applications (Fig. 5). Needle length is selected depending on the site of suture placement. The size of the suture generally correlates with the needle length (Fig. 6). When interproximal sutures are needed, needles of 11–13 mm in length are required (Fig. 3). Needle shapes are 3/8 circle (the most frequently used shape in dentistry) 1/2 circle and 5/8 circle, as summarized in Fig. 7 (10).

Modern microsurgical wound closure requires non-absorbable suture material in sizes 6-0 to 8-0. As monofilament 6-0 sutures are difficult in knot tying and extremely uncomfortable for the patient because of their stiffness, polyamid, pseudomonofilament (coated multifilament) are recommended (Supramid®,

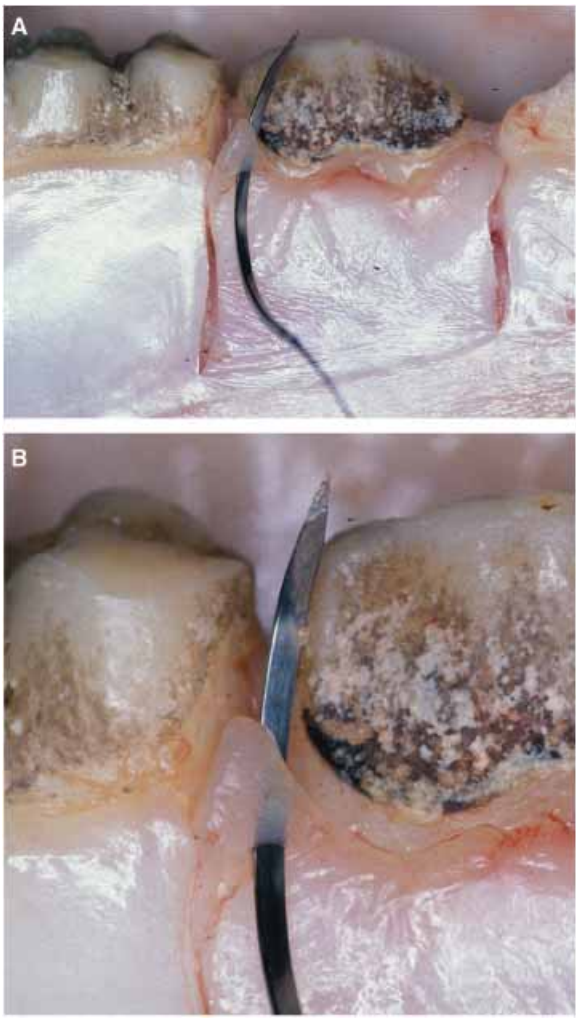


**Fig. 2. Experimental passing of a needle with a 4-0 suture, through an interdental papilla (A) and the same area in × 5 magnification (B). Note the overly traumatic tract as needle penetrates through the papilla almost dissecting the tissue just by mere penetration of the needle. Reprinted with permission from (12).**

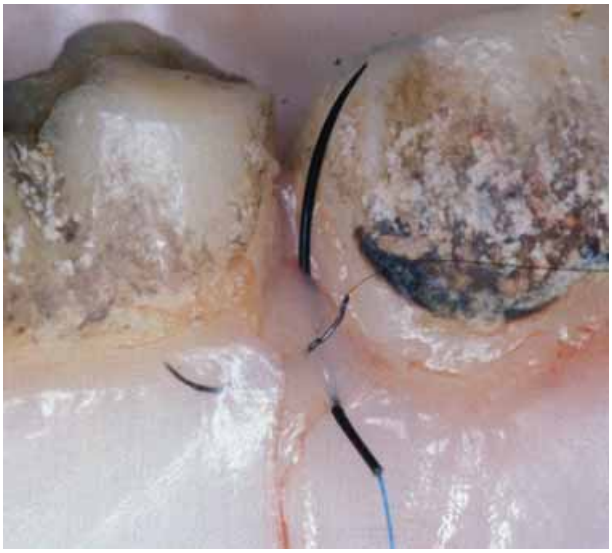

**Fig. 3. Animal model as seen in Fig. 2. The use of microsutures 7-0 for the vertical papilla suture, and 8-0 for horizontal fixation of the wound margins. The tissue is minimally traumatized because of minute dimensions of the needles. Reprinted with permission from (12).**

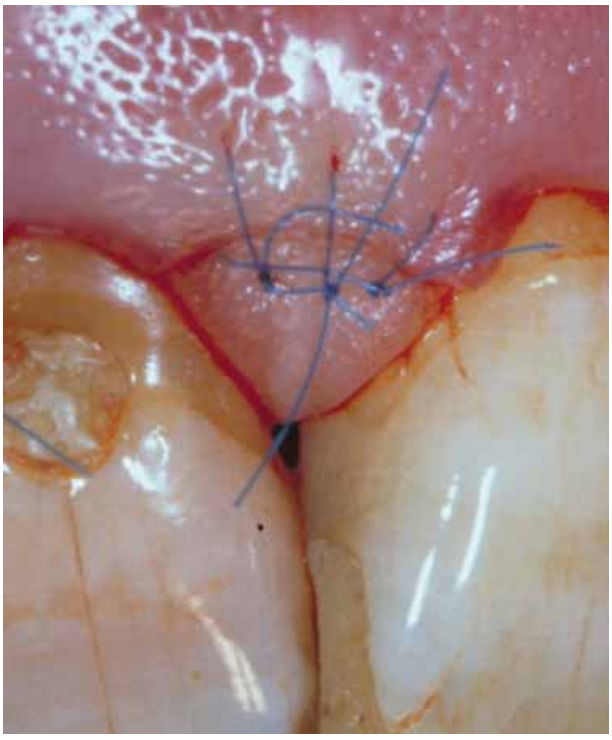

**Fig. 4. Wound closure after papilla base incision with three polypropylene 7-0 sutures at the base of the papilla.**

B.Braun, Melsungen, Germany). These sutures are available with 11 and 13 mm long needles and are ideal for interproximal wound closure. Releasing incisions or

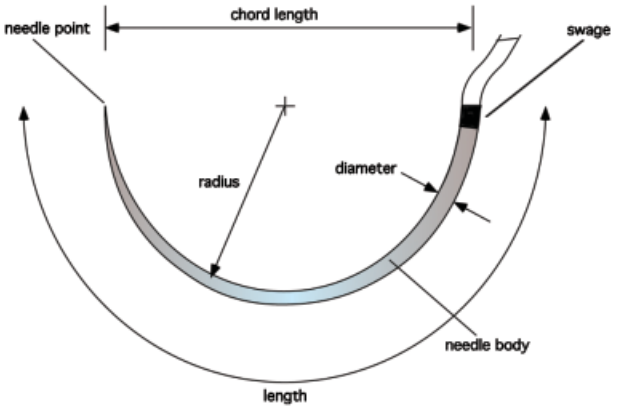


**Fig. 5. Schematic drawing of the elements and measurements of a suturing needle.**

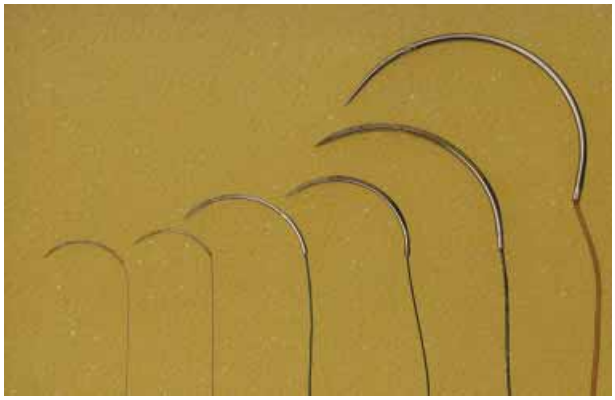

**Fig. 6. Various sizes of sutures. Note needle length increase with increased suture size.**

partial thickness, split flaps are best closed with monofilament, polypropylene 7-0 or 8-0 sutures (8, 60–62). In multilayered flaps, for inner layer closure absorbable, monofilament, polyglactin 7-0 or smaller (coated Vicryl®) is recommended (8).

## Suture techniques

Postoperative gingival recession and delayed healing is a difficult therapeutic problem that can be a sequel to traumatic tissue elevation and suturing techniques (Fig. 8) (63, 64). Aesthetically disappointing results are a major concern to the patient and the clinician as well. Suture materials and knots themselves cause irritation and foreign body reactions, therefore some authors recommend using only minimal numbers of sutures to secure the flap (52). By choosing microsurgical materials (size 7-0 or 8-0), the number of sutures within a given area can be increased without further compromising the

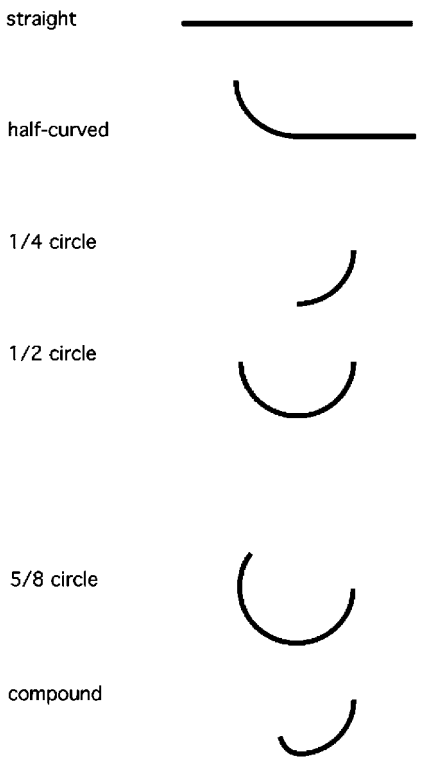


**Fig. 7. Schematic drawing of various needle shapes used in dental surgery.**

**Fig. 8. Delayed healing following overly traumatic tissue handling.**

blood supply. Handling such materials, however, requires a magnification device and delicate instruments to control their exact manipulation (8).


**Fig. 9. Scanning electron micrograph reveals excessive pulling after the knot has been tied. At the needle insertion point the tissue is torn and below the knot the tissue is highly compressed ( × 30 magnification). Reprinted with permission from (11).**

**Fig. 10. Wound closure after submarginal flap has been raised. The incision line follows the contour of the gingival margin, thereby generating reference points used during suturing.**

Sutures should not act as ligatures and exert minimal tension (51). Tissue flaps must be elevated in a way that upon re-approximation they will rest passively in the desired position. Pulling the tissue into position with the help of the suture will markedly increase tension. Preventing drying out of the tissue and thus avoiding tissue shrinkage as a consequence is helpful. The knot must secure the suture in a way that passive fixation of the two wound edges is obtained. Figure 9 demonstrates highly traumatic adaptation of the wound parts with excessive pulling. The tissue looks crushed and

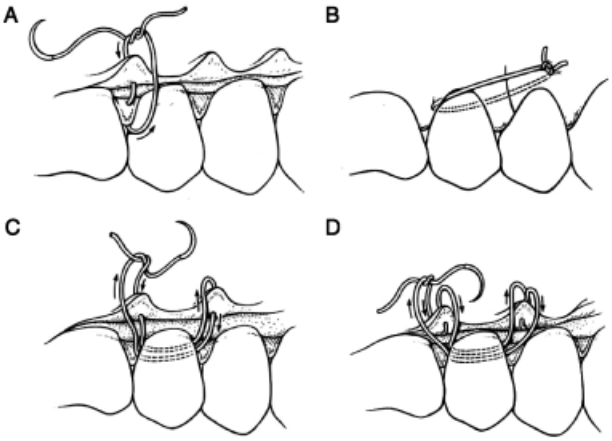


**Fig. 11. Examples of employed suturing techniques. (A) Interrupted sutures; (B) anchor suture; (C) sling suture; (D) vertical external mattress suture. Reprinted with permission from (78).**

**Fig. 12. Wound closure using vertical mattress suture. The mesial papilla is secured with internal mattress suture and the distal interproximal space shows internal vertical mattress suture.**

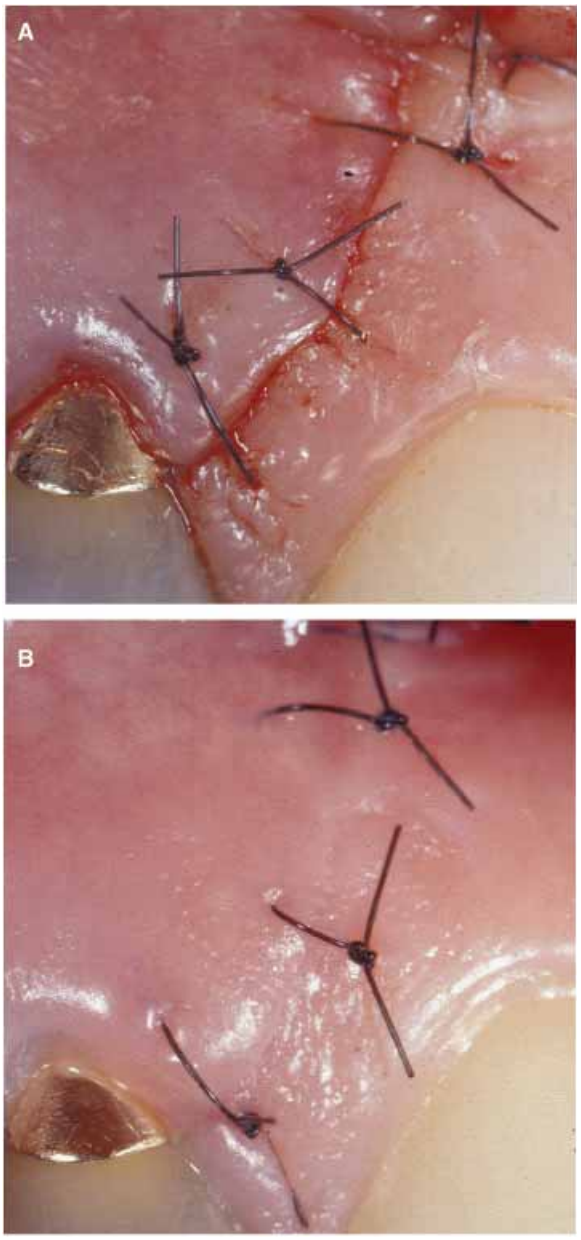


**Fig. 13. Single interrupted sutures. (A) Releasing vertical incision closure postoperatively, (B) healing at suture removal.**

under tension. Besides wound margins being torn because of pulling forces, tissues beneath the knot are compressed and deprived of blood supply. Substantially delayed wound healing will result as the tissue damage has to be repaired first. Best healing can be expected, when wound edges are brought together in closest possible proximity. Neighboring areas before the surgery should rejoin at wound closure. For this reason precise reference points should be created during incision placement. When a papilla has been mobilized and included in the flap, its repositioning is well defined. This relationship does not exist when using a submarginal incision, as it frequently is performed as a straight-line incision. Correct repositioning is all but impossible and excessive scar formation will result. For proper repositioning the horizontal incision preferably follows the marginal contour of the gingiva, creating a

scalloped line (Fig. 10). This will enable the surgeon to re-approximate the wound edges precisely. There is no rule as to how many sutures are needed to retain the re-approximated tissue in position. Depending on the functional forces generated during mastication or speaking certain areas require more than others. Wound margins showing a gap require an additional fixation with a suture.

Suture techniques commonly used include interrupted sutures, anchor sutures, continuous sling sutures, and vertical mattress sutures (Fig. 11) (10, 65). Full-thickness, mucoperiosteal tissue flaps involving mobilized papilla are best secured using vertical mattress sutures. These can be placed internally or externally (Fig. 12). The internal vertical mattress suture supports the interdental papilla in a coronal direction and results in less loss of papillary height.

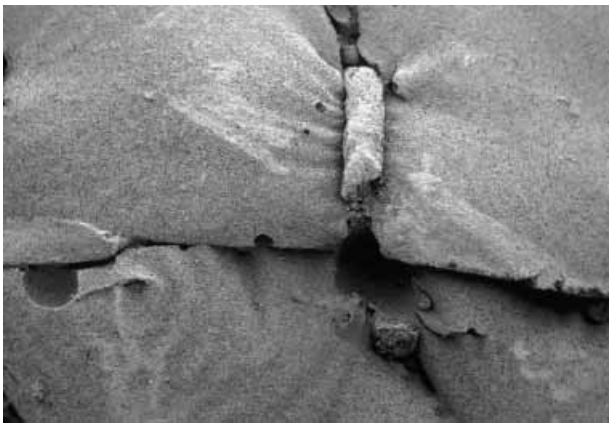

**Fig. 14. Scanning electron microscopy image of a single interrupted suture. Close adaptation of wound edges in the left side of the image, adjacent to a small vertical discrepancy in alignment on the right. Reprinted with permission from (12).**

In a series of investigations on papillary healing following complete mobilization of the papilla, marked loss of height was found even when internal vertical mattress sutures were used (64, 66, 67). It seems that mobilization of the papilla should be avoided, when interproximal soft tissue loss is aesthetically undesirable (upper anterior area, or high lip line). All other incisions are preferably retained using interrupted, fine-diameter sutures (Fig. 13) (22). Minimal tension during re-approximation and after suturing is important to avoid impairment of circulation in a flap (Fig. 14) (51, 63). Sling sutures, especially anchor sutures, are rarely indicated, as these do not promote good adaptation of the wound margins.

## Suture removal

A perisutural epithelial sleeve develops at 3 days and can enrobe the entire suture track after 7 days (53). An intense inflammatory response to suture materials combined with the trauma of the suture placement is visible after 3 days (53). The epithelial sleeve itself also causes inflammation during its resorption. Since the epithelial seal at the wound edges is evident within 2 days, suture removal can take place earliest after 48 h but not later than 4–5 days (16, 17, 22, 24, 62, 66). Time required for wound closure is closely related to the gap between tissue wound margins. Therefore perfect adaptation will allow earlier suture removal. More and more variables of wound healing, including patient nutritional status, bacterial infection, wound care and available tissue oxygen, are being researched. Consequently, novel therapies are evolving, such as growth factor therapy (68). Growth factors may lead to new strategies in improvement of soft tissue healing,


**Fig. 15. (A) Preoperative status of upper lateral incisor with a sinus tract prior to surgical treatment. Note healthy and recession-free periodontal conditions. (B) Tissues as present just after sutures have been removed 3 days postoperatively. (C) Healing 1 month postoperatively.**

including skin, mucosa, and nerve tissue (69). Management of bacterial growth in the oral environment during the healing phase has been successfully influenced by 0.2% chlorhexidine rinse in the first postoperative weeks (70).

## Clinical review of the soft tissue healing

As stated earlier the healing capacity of oral tissues is excellent, if certain general basic rules are followed. However, recession is a frequent sequel to healing after periodontal and endodontic surgery. Its extent and differences in terms of recession location have been studied extensively. The goal of periodontal surgery is to alter, treat and heal diseased structures, by improving oral hygiene, modifying hard and soft tissues and by removing selected areas that are not retainable (23, 52, 71). This therapy is often disfiguring. In recent years such outcomes are not acceptable anymore and therapeutic modalities have evolved that prevent soft tissue loss. In cases where attachment has been lost, but the periodontal situation is healthy, treatment mainly aims at restoration of lost attachment and augmentation procedures (7, 72). There is now a definite tendency toward restoration of natural shape, position, color and appearance of soft tissues as present before trauma, disease, or treatment-induced changes of the tissues (7, 72).

In surgical endodontics marginal tissues are frequently healthy. The goal is to maintain position, and contour of the marginal hard and soft tissues at the preoperative levels (Fig. 15). This is particularly important, when restorations have been placed to cover discolored root structure and require endodontic surgical intervention at a later point in time. Figure 16 shows a representative result of wound closure using traditional macrosurgical techniques. This was accomplished with polyamide 4-0 interrupted sutures. The vertical releasing incision was closed using four interrupted sutures and the papilla with a single knot suture. Wound adaptation was considered as sufficient at that time as was the healing after 1 week (Fig. 16A) and after the suture removal (Fig. 16B). When the wound area is examined more carefully and critically, it reveals a wound dehiscence in the apical area of the vertical incision and a discrete indentation in the entire extent of the incision line. This indentation is most pronounced in the marginal area, which is aesthetically most critical. Healing of the vertical incision must be judged as by secondary intention, resulting in scar tissue formation. The area of the papilla seems to be well preserved during the surgical procedure and sutured at its proper position using a single knot

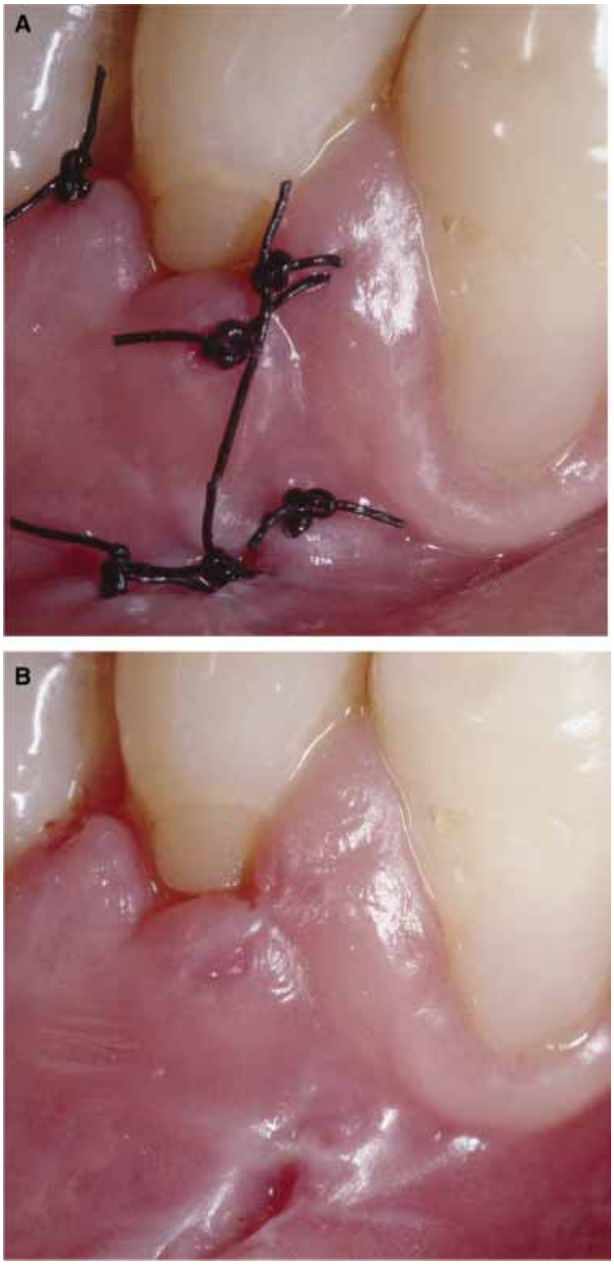


**Fig. 16. Flap closure using a macrosurgical technique and 4-0 sutures. (A) Situation prior to suture removal after 8 days postoperatively. (B) Immediately following suture removal. Note the wound dehiscence in the apical part of the vertical incision and a clear indentation in the marginal area. Also marked loss of papilla height with rounded shape in most coronal portion.**

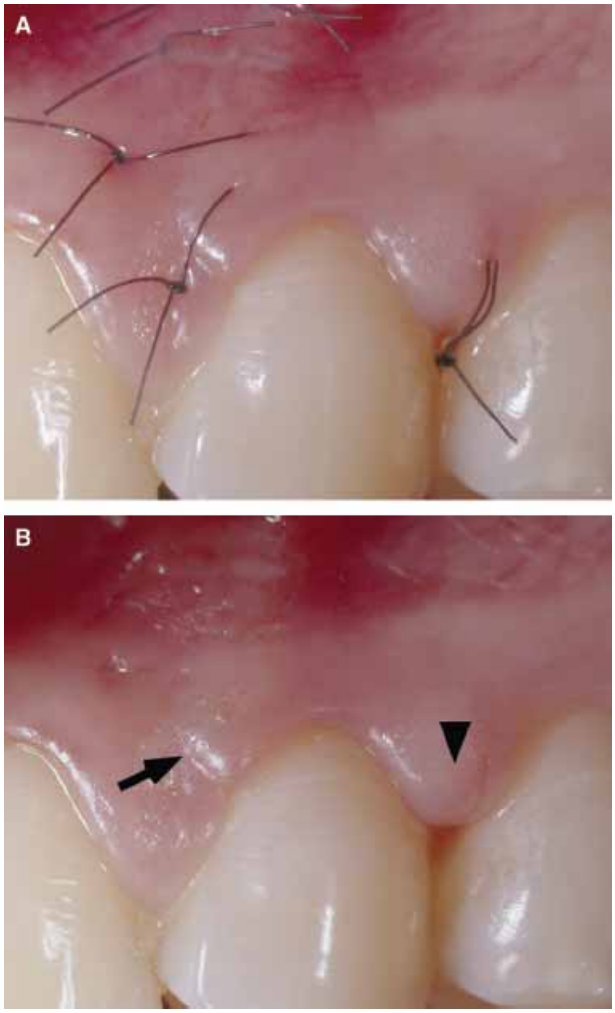


**Fig. 17. Wound closure using microsurgical techniques and 6-0 sutures. (A) Situation prior to suture removal after 3 days and (B) just after the suture removal. Advanced healing process with barely visible incision (arrow). Note the loss of papilla height and also rounded papilla tip configuration (arrowhead), despite careful and microsurgical technique.**

suture. However, the most coronal portion of the papilla has shrunk, resulting in a rounded papilla shape and loss of height. The healing process requires closure of the hiatus between the reflected and unreflected tissue with connective tissue and epithelium (24). When adaptation of the tissue edges is ideal and the tissues are positioned in very close proximity both in vertical and horizontal dimension to each other, only few cells need to be generated to bridge the gap (Fig. 14). Close adaptation will expedite wound closure; epithelial cells being the fastest (see 'soft tissue healing').

This same scenario can be observed in another case, where a similar flap design has been used, but more careful, microsurgical approach has been applied (Fig. 17). Tissue closure was performed with interrupted sutures in the vertical as well as in the papilla area using polyamide material as shown in Fig. 16, but in the smaller 6-0 size. At suture removal after 4 days, areas with better healing than others are visible and the incision is barely recognizable. It is obvious, that there is a potential for improved healing after a very short period of time.

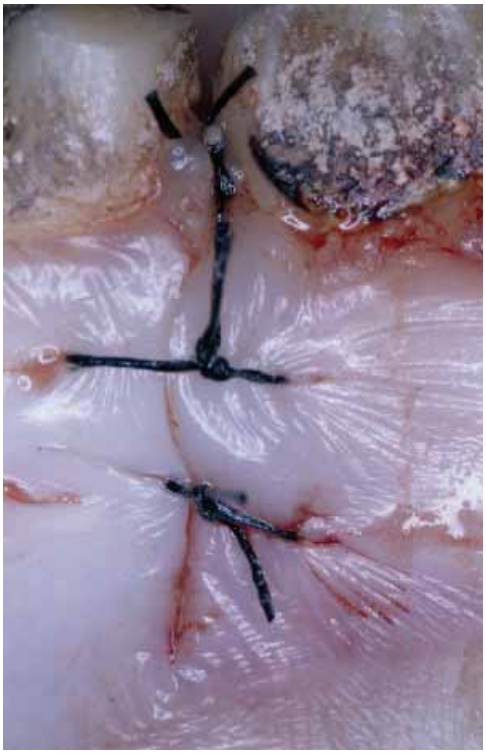

**Fig. 18. Wound closure in an animal experiment showing traumatic suturing technique. Three 4-0 polyamid sutures were placed using high knot tying forces. The tissue is highly compressed beneath the knot and tearing is evident in the area of needle insertion through the tissue.**

Healing results seem to be quite dependent on how and to what extent the wounds have been traumatized during treatment. Tissue incision, reflection, elevation and flap design influence the postoperative wound-healing process in terms of blood supply and tissue survival. But perfect adaptation of the tissue margins and passive and tension-free wound closure are fundamental for proper healing and for successful functional and aesthetic outcomes (51).

In an animal experiment a vertical incision was closed with different suture materials and techniques. Figure 18 demonstrates the use of a 4-0 suture with pulling forces. The tissue was partially severed and highly

compressed during knot tying. Such a suture is highly traumatic and will require prolonged time for repair and healing. To the contrary in Fig. 19, a 7-0 suture with minimal tension was used to re-approximate the wound edges passively. Wound closure in such a manner allows for rapid healing and early suture removal (Fig. 17). Traditionally, it was customary to leave the sutures in place for 7–10 days and the clinical findings seemed to confirm this protocol (Fig. 16). Currently sutures are best removed after 2 days and at the latest, 5 days after surgery.

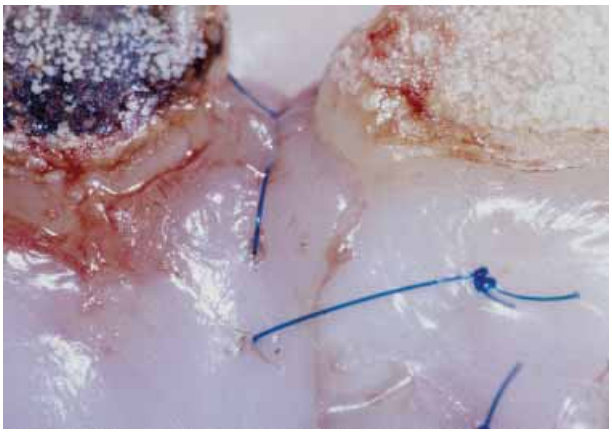

**Fig. 19. Wound closure in an animal experiment showing minimal traumatic suturing technique. The wound edges are readapted using interrupted, polypropylene 7-0 sutures exerting limited pulling forces.**

## Papilla preservation and protection

The interdental papilla is critical for functional, phonetic and aesthetic reasons. Complete and predictable restoration for lost papilla is difficult (60). Therefore, it is imperative to maintain and preserve the integrity of the papilla during surgical procedures. Most frequently a full-thickness mucoperiosteal tissue flap is used during apical surgery. In this technique the papilla is mobilized and becomes part of the flap (73). Ideally, the buccal papilla should be dissected from the lingual in the area of the col. This is particularly difficult in narrow interproximal spaces (Fig. 20).

Shrinkage of the papilla during healing can occur and results in loss of papilla height. In series of investigations the shrinkage of the papilla was studied, when microsurgical techniques were used and great care was taken to minimize the trauma inflicted during the surgical process (64, 67, 74). There appears to be a gradual decrease in papilla height during the healing process. The comparison of results obtained with macrosurgical techniques do not differ from those observed after microsurgical treatment of the inter-

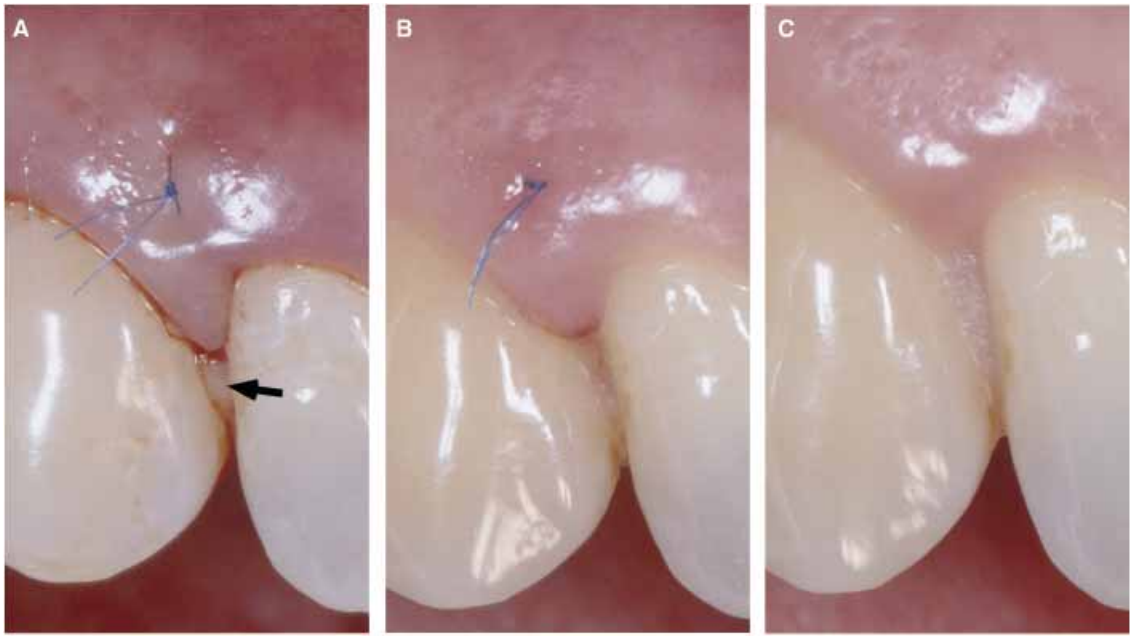


**Fig. 20. Incomplete separation of the buccal papilla in a narrow interproximal space. (A) Status after suture using vertical mattress suture. Most coronal portion of the papilla remained immobilized (arrow) and is too small to survive during healing. (B) Situation prior to suture removal after 3 days; the coronal tissue has been lost and results in loss of papilla height. (C) Healing after 1 month shows persisting tissue deficit.**

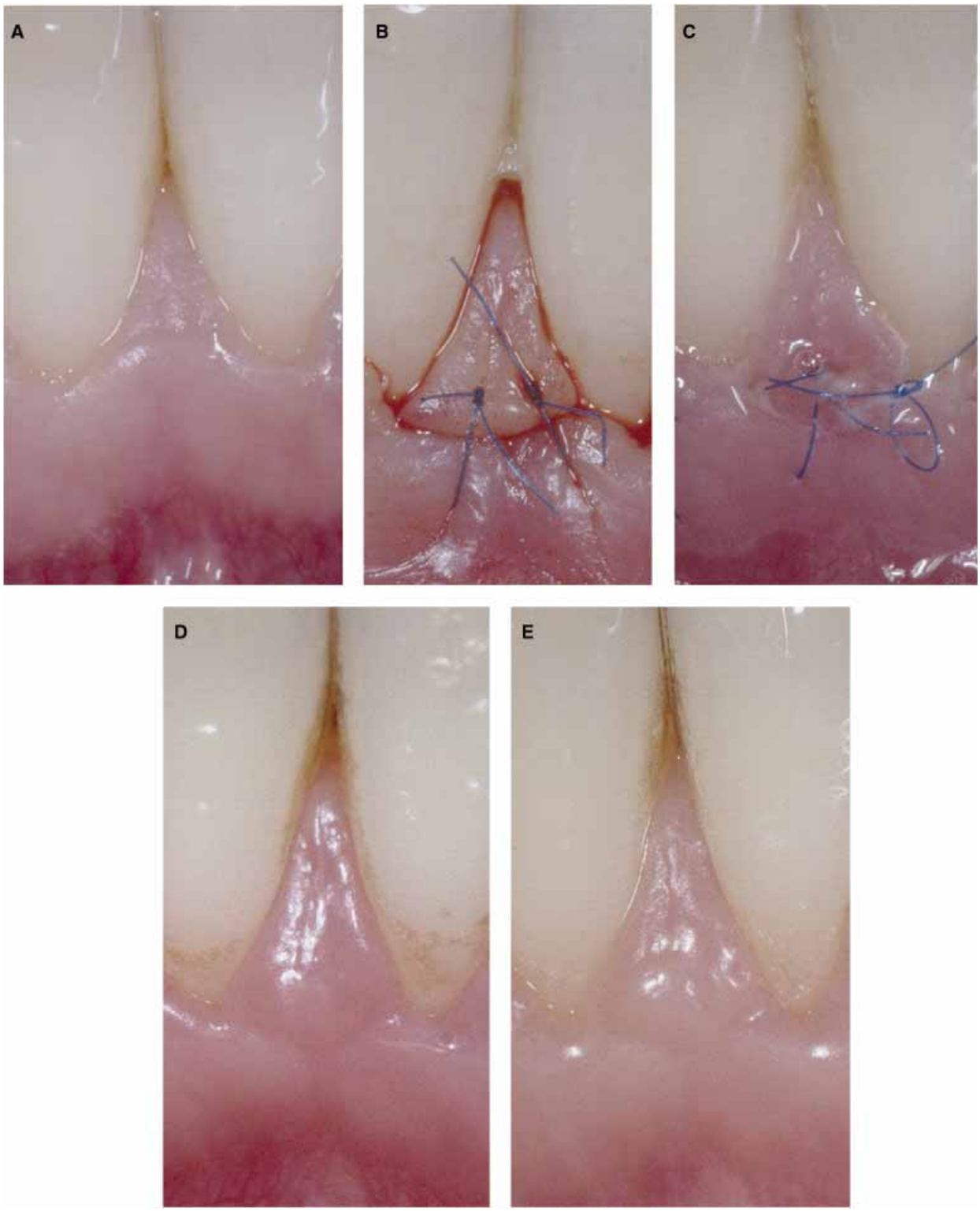


**Fig. 21. Interproximal space in the lower incisal area treated with a papilla-base incision. (A) Preoperative situation. (B) Wound closure using two interrupted sutures (polypropylene 7-0). (C) Healing prior to suture removal after 3 days. (D) Healing after 1 month, the incision line is slightly visible. (E) Excellent healing after 3 months displaying a virtually undetectable incision line.**

dental papilla (Figs 16 and 20). Therefore, when possible elevation of the interproximal papilla should be avoided if possible.

Similar problems have been observed in periodontal and implant therapy. In anterior periodontal surgery, papillary retention procedures are advocated to maintain papillary height and maximize postoperative aesthetics (54, 75–77). Recently, the papilla-base flap was suggested to eliminate any loss of height in endodontic surgery (62). This technique uses two different incisions at the base of the papilla resulting in split thickness flap at the base of the papilla. Split thickness flaps are also used in cosmetic surgery to reduce scar formation. Wound closure after a papilla-base incision is performed with fine atraumatic 7-0 or 8-0 sutures. As the treated tissues are very delicate atraumatic handling of the soft tissues is mandatory to obtain good results. The wound edges should be perfectly adapted to each other, depending on the dimensions of the papilla with two or three interrupted sutures (Fig. 21). Short-, mid-, and long-term investigations of papilla-base flap healing compared with classical full mobilization of the papilla, have shown significant differences in loss of papilla height (62, 66, 67). The papilla-base incision demonstrated insignificant changes of the height between preoperative values and during the entire observation period. To the contrary full mobilization resulted in marked recession of the papilla that exhibited either further recession or certain degree of creeping. However, the observed gain of papilla height was not significant. In cases of full-thickness tissue elevation, mean papilla loss of height after 1 year was 0.98 mm (67). In aesthetically relevant areas the use of the papilla-base flap is recommended, to avoid opening of the interproximal space, when periradicular surgical treatment is necessary.

## Conclusion

The introduction of microsurgery to surgical endodontics attempts to minimize trauma and enhance surgical results. In combination with magnification and illumination as well as microsurgical instruments and techniques more careful tissue handling is possible. Although application of basic surgical rules leads to fair soft tissue healing after endodontic surgery (78), in today's critical clinical assessments, satisfactory aesthetic outcomes are challenging to obtain. As in other dental fields, 'pink aesthetics' becomes increasingly important and efforts must be made to predictably minimize scar formation and recession after surgical interventions. Using microscopes and fine instruments alone will not accelerate healing rates. It is the understanding of pathologic processes and healing principles which will enable the application to be most effective and less traumatic, which in turn enables the surgeon and patient to expect rapid and satisfactory healing of all involved tissues. These goals require a multitude of measures, including accurate diagnosis, proper treatment planning in reference to the condition and quality of the tissues to be manipulated. Minimal trauma should be inflicted during incision, elevation and reflection of the tissue. Both reflected and unreflected tissue must be kept moist during entire procedure. Finally, careful and precise re-approximation of the wound edges without exerting tension is important. Atraumatic non-absorbable sutures in sizes 6-0 or smaller should support the wound only until the healing process has progressed to such an extent that the tissue can withstand functional forces, as early suture removal promotes healing.

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# Surgical endodontics: post-surgical care

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The post-surgical management of the patient is as important as the treatment planning for surgery and the surgical management of the patient. Patients who do not receive adequate and contemporary post-surgical instructions or who ignore these instructions are predisposed to untoward sequelae, including pain, swelling and possible infection, in addition to the potential for altered healing of both the oral soft tissues and supporting osseous structures. It is the endodontic surgeon's professional responsibility to ensure that verbal and written instructions are provided to patients that clearly define activities during the critical, early healing process. Furthermore, it is imperative that the endodontic surgeon have a complete understanding of and rationale for the instructions being given to the patient.

## Introduction

While there are details given in most endodontic textbooks on the management of patients following surgical endodontics, little literature documentation is available that deals directly with this type of patient and the potential outcomes. Most of the data and directions available come for the oral surgery and periodontal literature and may or may not be specific to the surgical endodontic patient.

This paper will focus on the following key issues that are part of the comprehensive care that must be made available to all surgical endodontic patients.

- Post-surgical patient management.
- Management of post-surgical bleeding and swelling.
- Prevention and management of post-surgical pain.
- Post-surgical infection and antibiotic considerations.
- Post-surgical supportive therapy.
- Prevention and assessment of untoward sequelae.

In the majority of cases issues such as the use of analgesics to prevent pain, or antibiotics used prophylactically, are part of the initial treatment planning for the surgical procedure. Furthermore, detailed informed-consent forms provide the patient with an overall appraisal of the potential, post-surgical, untoward sequelae – Appendix 1.

## Post-surgical patient management

The post-surgical management of the patient is important as the surgical management of the patient. Patients who do not receive adequate post-surgical instructions or who ignore these instructions are predisposed to untoward sequelae. It is the endodontic surgeon's responsibility to ensure that verbal and written instructions clearly define the patient's activities during the critical, early period of tissue healing. An example of written post-surgical instructions is provided in Appendix 2.

## Management of post-surgical bleeding and swelling

Leakage or oozing from torn blood vessels will occur for several hours after surgery. However a little saliva mixed with blood may be perceived by the patient as a large amount of blood and a sign of hemorrhage. The forewarned patient will not make that mistake. Slight swelling of oral and facial tissues may also result from this leakage of blood into surrounding tissues and the ensuing inflammatory response. These are inconsequential, normal sequelae that require no additional treatment and should not alarm the endodontic surgeon or the patient.

Compression of the surgically repositioned tissue before and after suturing greatly diminishes post-operative bleeding and swelling. As additional supportive therapy, the patient is instructed to apply an ice pack with firm pressure to the facial area over the surgical site. The pressure and reduction in tissue temperature slows the flow of blood, counteracts the hemorrhagic rebound phenomenon, promotes coagulation in several microvessels, and ultimately decreases post-surgical bleeding and swelling. Application of cold is also an effective analgesic, reducing the sensitivity of peripheral nerve endings. The ice pack is applied for approximately 20 min, and then removed for 20 min. This regimen is repeated for 6–8 h following the surgical procedure and should be initiated in the surgeon's office prior to dismissal. Continuous application of cold, rather than intermittent application, is counterproductive and will trigger a physiologic mechanism which protects surface tissues from frostbite, resulting in increased blood flow in the surgical site (1). After 8 h, intermittent ice pack application is discontinued because reduced blood flow is no longer desirable and may impede tissue healing by interfering with the inflammatory response. Any mechanism that interferes with the inflammatory response (such as corticosteriod therapy) will markedly delay the healing response (2).

With proper soft and osseous tissue management during surgical endodontic intervention, bleeding rarely presents a problem in healthy patients. Severed vessels retract and constrict, reducing the diameter of the lumen through which blood can escape. Platelets accumulate at the severed end of the vessel, forming a platelet plug, around which clotting takes place with the formation of a dense matrix of fibrin strands. Final occlusion of the vessel occurs when the fibrin strands contract, become firm, and seal the vessel from further leakage of blood (3). Pressure application resulting in tissue compression aids the occlusion of vessels in the soft tissues, as does a reduction in blood flow through cold application. Severed vessels in osseous tissues, however, are not affected by pressure application. Fortunately, the excisional wound in bone is created with a rotary instrument, or, if a periradicular lesion is present, the osseous defect is curetted to remove soft tissue. Both of these mechanical forces tend to burnish severed vessels against bone, reducing the diameter of the lumen and aiding the final occlusion of the vessel. Prior to reposition of the reflected tissue, a final check of the osseous defect should reveal a slow oozing of blood from the internal surfaces. If a free flow of blood from a particular site is noted, it should be clamped or crushed with a mosquito hemostat until the flow is reduced to a slow oozing. Intentionally curetting the internal osseous surfaces just to promote blood flow prior to wound closure has no scientific basis and therefore, is contraindicated.

Minor bleeding from a localized area during the first 12–18 h after surgery, can usually be managed with firm finger pressure to a moistened gauze pad or flannel placed over the bleeding site for 10–15 min. If unsuccessful, pressure can be applied in the same manner using a tea bag or gauze pad soaked in tea. Tannic acid, contained in tea, is an effective hemostatic agent. A common cause of minor bleeding during the early postoperative hours is the extravasation of partially formed intravascular clots in severed blood vessels, caused by increased hemostatic pressure as the blood flow returns to normal and then exceeds normal flow during the rebound phenomenon (4, 5). Firm pressure will result in new blood clot formation (3). If these directives fail to control the hemorrhage, the patient should return to the dental office where the surgeon can apply tissue compression after injection of a cartridge of local anesthetic with 1 : 50 000 (if available) or 1 : 80 000 epinephrine/adrenalin. Unless there is an undiagnosed bleeding disorder, this will resolve the problem.

When blood leaks into the surround tissues from the vessels damaged during the surgery, external, facial discoloration may occur. This is termed *ecchymosis*. The potential for ecchymosis and facial discoloration may last for up to 2 weeks. This is an aesthetic problem only, requires no special treatment, and is observed commonly in elderly or fair-complexioned patients.

Moist heat application to the facial tissues overlying the surgical site is recommended, but should not begin until 18–24 h (first and second post-surgical day) period. When ecchymosis occurs, the application of moist heat may be beneficial for up to 1 week or longer after surgery as it promotes fluid exchange and speeds resorption of discoloring agents from the tissues. Application of moist heat is best achieved by wetting a small cotton towel with hot tap water, and holding this against facial tissues for 30 min or as frequently as the daily schedule permits. The towel should be replenished with hot tap water every 10–15 min. The hot towel may also be wrapped in a plastic bag and

placed on the face and held in place with an electric heating pad. This will provide a consistent level of heat over the application period. Application of moist heat during the first 18–24 h after surgery, however, will result in increased bleeding and swelling.

## Prevention and management of post-surgical pain

Pain following periradicular surgery is usually minimal. The pain, if any, is of short duration and reaches its maximum intensity on the day of surgery. A significant reduction in pain usually occurs on the first post-operative day, followed by a steady, progressive decrease in discomfort each succeeding day (6). Few patients experience pain that cannot be managed by mild analgesics (6–9). As it is easier to prevent pain than to eliminate pain, analgesic therapy should be initiated prior to surgery (5, 10–12)). Non-opioid (nonnarcotic) analgesics are recommended with the initial dosage timed so that the selected analgesic is approaching peak blood levels before the local anesthesia has worn off. For example, 500–600 mg of acetaminophen, or 800 mg of ibuprofen are given orally just prior to injection of lidocaine with vasoconstrictor for periradicular surgery. Recent studies would support the use of both acetaminophen (1000 mg) and ibuprofen (600 mg) in combination to eliminate or minimize pain (13). The duration of lidocaine-induced local anesthesia with 1 : 50 000 epinephrine/andrenalin is approximately 1.5–2 h, therefore, oral analgesic dosages should be repeated every 4 h during the day of surgery and every 4–6 h on the first and second post-surgical days (10).

Another method of post-surgical pain control is the use of long-acting local anesthetics such as bupivacaine or etidocaine, which provide 6–8 h of local anesthesia (14, 15). These may be injected immediately after surgery or used for nerve block anesthesia during surgery, but do not provide adequate hemostasis for surgical endodontic procedures because they contain a low concentration of epinephrine/adrenalin (1 : 200 000). The return of sensation is much more gradual than with shorter acting agents (11), the onset of discomfort is less dramatic, and thus less anxiety is produced as sensations develop very gradually (15).

Mild analgesics should be a prescribed part of the post-surgical regimen and not made a matter of choice by the patient. To obtain maximum analgesic effectiveness, the practitioner must express confidence in the drug. The confidence that the patient has in the practitioner will then be conveyed to the analgesic (5, 16). A similar effect is observed if a patient has developed confidence in the pain relieving property of a specific drug that effectively relieves headaches, muscular pains, and other minor disorders. The wise practitioner takes advantage of that established confidence. As much as 80% if the effectiveness of any analgesic drug may be attributed to its placebo effect (16). Therefore, post-surgical analgesic therapy should be tailored to the individual patient.

Patients rarely require narcotic analgesic therapy following periradicular surgery. Some practitioners prefer to give patients a prescription for a narcotic with instructions that the prescription be used only if the prescribed non-narcotic drug is ineffective. Consideration should be given to the possibility that this seemingly innocuous act may undermine the patient's confidence in: (1) the non-narcotic drug prescribed; and (2) the surgeon's knowledge of the degree of post-surgical pain that will be encountered. Unfortunately, some patients demand narcotic therapy immediately, but this should be strongly discouraged by the surgeon, as narcotic analgesics are not the drug of choice (10, 16).

Requa-Clark & Holroyd (16) and others (17, 18) report that certain non-steroidal anti-inflammatory agents are significantly better than narcotics (codeine), aspirin, and acetaminophen in treating dental post-surgical pain. Clinical evidence strongly supports this position and indicates that ibuprofen (in 400–600 mg doses) should be recommended as the analgesic of choice following endodontic surgery (19–21). Dionne and coworkers (18, 19) and Lokken et al. (22) have provided convincing evidence that the initiation of pre-surgical ibuprofen therapy delays the onset and suppresses the intensity of post-surgical pain to a greater extent than traditional oral analgesic therapy with post-surgical administration of other non-narcotic or narcotic analgesics.

## Post-surgical infection and antibiotic considerations

Post-surgical infections following surgical endodontic procedures are very rare. For this reason, the admin-

istration of antibiotics is seldom required and cannot be justified as part of the routine post-surgical regimen (23–26). The oral mucoperiosteal tissues are highly resistant to the invasion of oral microorganisms. However, infection may still result from non-oral microorganisms, as a result of inadequate aseptic surgical techniques, or from bacterial penetration of the surgical site because of poor re-approximation and stabilization of elevated and reflected tissues, which can result in a continuous influx of oral microorganisms that overwhelm the tissues' defensive mechanisms. These causes are under the direct control of the endodontic surgeon and appropriate preventive measures must be taken to ensure adequate infection control methods and proper soft tissue manipulation (5). Most post-surgical infections, however, are caused by normal oral flora (26–28).

If an infection should develop, signs and symptoms of infection are usually present 36–48 h after the procedure and include increased and progressive swelling and pain, which may or may not be associated with suppuration, fever, and lymphadenopathy (23). Antibiotic therapy is initiated promptly and the patient is monitored to ensure the selected antibiotic is effective. There is a tendency to use penicillinase-resistant drugs, extended spectrum drugs such as ampicillin and amoxicillin, cephalosporins, azithromycin, clarithromycin or clindamycin, or some combination of the above. However, there is no scientific evidence available to support the choice of these drugs for the antibiotic therapy following surgical endodontic intervention. The drug of choice, however, continues to be penicillin VK (29). If laboratory cultures from the infected site indicate a change in antibiotic, or if the clinical signs and symptoms show no response to penicillin VK, another anti-infective drug should be considered, such as penicillin VK with metronidazole, amoxicillin with clavulanic acid, or clindamycin (29, 30). As this information is not available at the time of initial antibiotic administration, penicillin VK is the choice for initial therapy. In patients allergic to penicillin, the primary alternative agent is a cephalosporin, or clindamycin (29).

No evidence is available from randomized, prospective clinical trials regarding the incidence of infection following periradicular surgery. Clinical experience indicates that it is extremely low and involves very localized areas, such as suture sites, marginal gingival, interdental gingival, or gaping incision sites, and rarely requires systemic antibiotic therapy as the normal body defenses can control the process. As a comparison, the incidence of post-surgical infections reported after periodontal surgery is also quite low (23, 24).

Prophylactic antibiotic therapy for surgery (not for systemic complications) remains a controversial issue in both medicine and dentistry despite overwhelming evidence that it does not lower the incidence of post-surgical infection and may actually contribute to a great risk of infection (31, 32).

## Post-surgical supportive therapy

Supportive therapy includes proper diet and fluid intake, oral hygiene, and a restriction of activity. Although supportive therapy is more complicated for the medically compromised patient, the uncompromised patient also requires specific instructions regarding supportive therapy in the first 3–5 post-surgical days (33, 34).

### Dietary and fluid intake

Dietary management and fluid intake are extremely important and should not be ignored or trusted to the whims of the patient's hunger or thirst. High protein and a high carbohydrate diet coupled with plentiful fluid intake of liquids are essential following periradicular surgery. A specific dietary and fluid intake regimen for the patient should be detailed by the endodontic surgeon and explained to the patient. Soups, fruit juices, and any variety of soft foods, along with the use of available liquid food supplements are recommended (5). These supplements are readily available and encompass a wide range of brands globally. Usually two to three supplements in addition to their prescribed post-surgical diet will assure adequate nutritional intake.

### Oral hygiene

Because oral hygiene usually presents a problem during the early post-surgical period, during the treatment-planning phase of surgical endodontics, proactive intervention is essential. This may include a thorough periodontal assessment, scaling and tissue preparation if needed (35), and the use of pre-surgical rinses with chlorhexidine (CHX) (36). In fact pre-surgical rinsing with CHX has been reported to reduce significantly

adverse post-surgical sequelae following the removal of third molars (37, 38).

Even with pre-surgical preventive measures, patients often report as their chief complaint following surgery the foul taste caused by lack of oral hygiene. Therefore, specific instructions must be provided as follows:

- The teeth should not be brushed for the remainder of the day of surgery because of the potential for dislodging the flap.
- A cotton swab moistened with an antiseptic mouthrinse, 3% hydrogen peroxide or 0.12% CHX can be used to remove food debris and reduce foul taste.
- On the day following surgery, brushing in the surgical site is limited to the occlusal or incisal surfaces of teeth, with careful brushing of all other teeth.

CHX gluconate is a highly efficient antibacterial and mycostatic agent in the oral milieu (39). Although long available in Europe and Canada in various concentrations, the use of therapeutic entity was only approved in 1988 by the Council on Dental Therapeutics of the American Dental Association as a mouthrinse marketed as Peridex (Zila Pharmaceuticals, Phoenix, AZ, USA) that contains 0.12% CHX gluconate (40–42). CHX mouthrinse provides excellent post-surgical supportive therapy by decreasing the population of the oral flora and inhibiting plaque formation (43).

Oral rinsing provides a simple but effective method of application of CHX to reduce or eliminate plaque formation (44–47). Approximately 30% of CHX may be retained in the oral environment after rinsing for 1 min (48) and once bound, CHX was released over an 8–12 h period, with weak concentrations detectable in saliva for 24 h providing a prolonged bactericidal effect (42, 49, 50).

As previously mentioned, CHX mouthrinses prior to and subsequent to periradicular surgery, play an important adjunctive role in promoting rapid healing. Ideally, the patient should begin CHX rinsing the day before surgery and continue for 1–2 days following surgery. Longer-term use may result in the development of bacterial-resistant species in the oral cavity (51). Likewise, the use of forceful or vigorous rinsing is not indicated as it may result in a bacteraemia (52). Therefore, the American Heart Association recommends that pre-surgical rinses should be gentle in nature (53). A regimen of rinsing for 1 min with one or two tablespoons of 0.12–0.20% CHX solution, twice each day (mornings and evenings, including the day of surgery), produces the desired results (45, 46). Rinsing the evening of the day of surgery is also important and should be performed thoroughly but with care. The reduction in numbers of microorganisms and the inhibition of plaque formation during the early post-surgical period produces a markedly improved environment for the myriad of healing mechanisms that follow surgery. The antiplaque properties of CHX may be important if silk sutures have been placed, as bacterial wicking into the multifilaments of the suture material occurs (54). However, use prior to suture removal did not significantly reduce the incidence of bacteraemia when compared with no rinsing (55).

The advantages of CHX rinsing greatly outweigh some of the nuisances that are occasionally associated with this supportive therapy. CHX is bitter tasting and attempts to mask this by flavoring agents have been only partially successful (56). In a study by Delilbasi et al. (37), when CHX was used pre-surgically to prevent post-surgical alveolar osteitis, 66% of the patients indicated that they were pleased with the CHX solution. Some patients report a dulling of the taste sensation for several hours after rinsing (56). There is also the potential for a cosmetic nuisance that requires professional removal (prophylaxis), with the formation of a yellow-brown stain in the cervical areas of some teeth, on composite restorations, and in pit and fissure defects (44, 57, 58). The tongue may also be stained but normal epithelial desquamation makes this temporary (44). The exact staining mechanism is not known but may be associated with the precipitation of iron sulfide, with sulfur resulting from CHX-denatured proteins and iron originating from the diet. Tea, coffee, wine, and smoking may enhance the potential for staining (57, 58). A clinical comparison of 0.1% and 0.2% CHX mouthrinses following oral surgical procedures showed no significant differences in the side-effects, but a far greater patient acceptance of 0.1% because of less impairment of the taste sensation (59).

## Important patient restrictions

Restriction of activity simply involves common sense and minor alterations in daily activity levels for healthy patients. Any activity that raises the blood pressure significantly, such as jogging or any strenuous form of exercise should be avoided for 1–2 days after surgery.

This is to prevent dislodgement of intravascular clots in severed blood vessels because of increased hydrostatic pressure. A slow, progressive return to the patient's routine strenuous exercise level can begin on the third day post-surgically and return to normal within 1 week.

Restriction of activity during the 6–8 h following endodontic surgery is necessary, when rest and the intermittent application of ice compresses are necessary. Patients can usually return to work the day following surgery, but those in strenuous occupations should limit their activity for 2 days. Medically compromised and geriatric patients may require longer periods of activity restriction.

## Prevention and assessment of post-surgical sequelae

As seen from the previous discussion, bleeding, swelling, pain, and infection are potential untoward post-surgical sequelae following surgery. These problems should be discussed with the patient at the pre-surgical treatment planning appointment and reinforced prior to dismissal from the surgery appointment. While their occurrences are minimal, abnormal sequelae should be reported immediately to the surgeon. Interestingly, this aspect of surgical endodontics had received little attention and assessment until recently. Previously, most data on post-surgical sequelae were gleaned from the oral surgery and periodontal literature.

No comparative evidence exists regarding post-surgical untoward sequelae when surgery is performed purely for the management of diseased or altered periodontal tissues vs. that limited exclusively to endodontic surgical intervention. Curtis et al. (60) concluded that periodontic surgery resulted in minimal or no post-surgical complications (bleeding, infection, swelling, tissue necrosis, moderate-to-severe pain) in 94.5% of 304 consecutive periodontal surgical procedures, while 5.5% had moderate-to-severe postoperative complications, and less than 5% missed time from work or school. Most recently, Powell et al. (24) did a retrospective analysis of 395 patients that included 1035 fully documented periodontal surgical procedures. There were 22 infections reported for an overall prevalence of 2.09%. Patient who received antibiotics as part of the surgical protocol (pre- and post-surgically), developed eight infections in 281 procedures (2.85%) compared with 14 infections in 772 procedures (1.81%) where antibiotics were not used. Procedures in which CHX was used during post-surgical care had a lower infection rate (17 infections in 900 procedures or 1.89%) compared with procedures after which CHX was not used as part of a post-surgical care (five infections in 153 procedures or 3.27%). These results overall confirmed a low incidence of post-surgical infection following periodontal surgical procedures.

Subsequent to surgical endodontics, Rud & Rud (61) found in 200 cases of root-end resection in the maxillary first molars showing sinus perforations that only two cases developed sinusitis, with antibiotic administration indicated in 3% of the cases prior to surgery because of acute symptoms and 5% post-surgically. Post-surgical symptoms included pain and swelling that were moderate. To the contrary, however, Kvist & Kvist (62) in a randomized controlled clinical trial comparing non-surgical root canal retreatment with surgical retreatment, found that significantly more patients reported discomfort after surgical retreatment than after non-surgical procedures. High pain scores were most frequent on the surgical day, while swelling reached its maximum on the first post-surgical day followed by progressive decrease in frequency and magnitude. Analgesics were significantly more often consumed after surgical intervention. Furthermore, patients reported absence from work mainly because of swelling and skin discolouration.

Tsesis et al. (63) indicated in a population of 92 surgical endodontic patients that 76.4% of the patients reported with no pain at 1 day post-surgically, with less than 4% having moderate pain and 64.7% reporting no swelling. However, patients were premedicated with a single dose of oral dexamethasone (8 mg) and two single doses of 4 mg at 1 and 2 days post-surgically. Patients with pre-surgical pain were, however, more prone to have post-surgical pain. In a subsequent study, Tsesis et al. (64) performed surgical endodontics on a population of 66 patients, dividing the patients into equal groups, while using two different technique approaches to tooth management. Group 1 was treated using traditional techniques without a surgical operating microscope and Group 2 was treated using an operating microscope and minimal osteotomy. All patients were given a questionnaire with 15 questions to evaluate their quality of life for 7 days post-surgery. On day 5, patients in Group 1 reported significantly more pain and took significantly more analgesics ($P<0.05$). On days 1 and 2, patients in Group 2 reported significantly more difficulty in mouth open-

ing, mastication, and the ability to speak ($P<0.05$). Patients in both groups reported a high incidence of symptoms. The technique using the surgical operating microscope provided significantly less postoperative pain, but more difficulties in mouth opening, mastication, and the ability to speak immediately postoperatively. While attempts have been made to correlate enhanced post-surgical radiographic outcomes with the use of contemporary surgical techniques, including the use of the microscope (65, 66), correlations in the use of the newer technology and the reduction in post-surgical sequelae cannot be made based on the limited data available to the endodontic surgeon.

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# Appendix 1

**Sample Consent Form for Surgical Endodontics**
**Consent for Surgical Endodontic Procedures**

Root canal therapy is an attempt to save a tooth which otherwise may require extraction. Sometimes different types of treatment are necessary, such as a surgical procedure, to address those issues that cannot be managed with straightforward root canal procedures. We like our patients to be informed about the nature of this surgical procedure and its risks and potential complications, and to have their consent before we begin treatment.

1. I hereby authorize Dr ———— and any other agents or employees of ———— and such assistants as may be selected by any of them to treat the condition(s) described below: ————
2. The procedure(s) necessary to treat the condition(s) have been explained to me, and I understand the nature of the procedure(s) to be: ————
3. I agree to the use of local anesthesia and I understand that the endodontist will consult with me prior to administering any form of oral and/or conscious sedation.
4. The prognosis for the above procedure(s) was described as: ————
5. I have been informed of possible alternative methods of treatment, such as nonsurgical retreatment, no treatment or tooth extraction.
6. The doctor has explained to me that there are certain inherent and potential risks that may be present in any treatment plan or occur during any procedure. I understand that the following may be inherent or potential risks for the treatment I will receive: swelling, sensitivity, bleeding, pain, infection, cold sores, numbness and/or tingling sensation in the lip, tongue, chin, gums, cheeks, and teeth which is transient but on infrequent occasions may be permanent; reactions to injections, changes in occlusion (biting); jaw muscle cramps and spasms (trismus), temporomandibular (jaw) joint difficulty, loosening of teeth, crowns or bridges; referred pain to ear, neck and head; nausea, vomiting, allergic reactions, delayed healing, sinus perforations and treatment failure. Fractures of the tooth (teeth) or crown(s) may occur during or after treatment.
   Complications of endodontic surgery may include: swelling, discoloration of the face, bleeding, pain, infection, numbness and tingling sensation (paraesthesia) in the lip, tongue, chin gums, cheeks, and teeth, which is usually transient but on infrequent occasions may be permanent; damage to adjacent teeth that may require root canal treatment or extraction; sinus perforation, which could necessitate sinus drainage surgery, should an infection develop; and changes in the gum height in the surgical site causing exposure of crown margins, which then may need to be remade for aesthetic reasons.
7. I understand that prescribed medications and drugs may cause drowsiness and lack of awareness and coordination, which may be exaggerated by the use of alcohol, tranquilizers, sedatives or other drugs. I have been informed that it is not advisable to operate any vehicle or hazardous device until I recover from the effects of any drugs or medications prescribed. I understand that certain medications may cause hives and intestinal problems, and if any of these reactions occur, I am to call the endodontist immediately. I have been informed that the use of antibiotics may have an adverse action on the effects of birth control pills. I understand that it is my responsibility to notify the endodontist of any changes in my medical history.
8. It has been explained to me and I understand that a perfect result is not guaranteed or warranted and cannot be guaranteed or warranted.
9. I have been given the opportunity to question the doctor concerning the nature of treatment, the inherent risks of the treatment, and the alternatives to this treatment.
10. This consent form does not encompass the entire discussion I had with the doctor regarding the proposed treatment, and I am making an informed decision of giving my permission to have surgical endodontic treatment.

**Patient's signature** ————**Date** ————

**Doctor's signature** ————**Date** ————

**Assistant's signature** ————**Date** ————

# Appendix 2

**Instructions for postoperative care following surgical endodontics**

1. Avoid strenuous activity for the remainder of the day. Routine, nonstrenuous activity is not harmful, unless otherwise directed. Smoking and alcohol consumption delay the healing process and should be avoided or minimized for 3 days following surgery.
2. Maintain an adequate diet with proper solid and fluid intake during the first 3 days following surgery. In addition to fruit juices, soups and other soft foods, liquid food supplements are recommended.
3. Avoid manipulation of the facial tissues as much as possible. Do not raise the lip or retract the cheeks to inspect the surgical site as you may dislodge the sutures (stitches).
4. Apply an ice bag with firm pressure to the face directly over the surgical site. Apply the ice bag alternately 20 min on, 20 min off, for 6–8 h following surgery. After 8 h, the ice bag should not be applied. Frequent moist heat applications to the face are recommended on the first and second post-surgical days. Some oozing of blood from the surgical site is normal during the day and evening of surgery. Slight swelling and facial skin discoloration (bruising) may be experienced. This is temporary, and will resolve on its own in a few days.
5. Post-surgical discomfort should be minimal, but the surgical site will be tender and sore. For this reason you should follow the analgesic regiment prescribed: ————tablets/capsules of ————every 4–6 h for 48 h following surgery.
7. The sutures (stitches) that have been placed must be removed to ensure proper healing. It is important that you return at the appointed time for suture removal. This will generally occur in 2–4 days.
8. Rinse with one tablespoon (15 mL) of chlorhexidine mouth rinse twice each day for 5 days following surgery.
9. Post-surgical evaluation is important and short appointments will be scheduled to monitor the healing. Two appointments may be scheduled during the first 6 weeks and our office will contact you later to schedule an additional appointment 6 months after surgery.
10. Should any complications arise, do not hesitate to call (phone#) during office hours or (phone#) on weekends or evenings.

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# Considerations in the revision of previous surgical procedures

WILLIAM P. SAUNDERS

The microbial etiology of periradicular periodontitis requires that efforts must be made to eliminate infection from the root canal system and the periradicular tissues. Periradicular surgery is an option of endodontic re-treatment when non-surgical root canal treatment and re-treatment fails. Unfortunately, surgery is not always successful for a number of reasons including, extraradicular infection, associated marginal periodontal disease, inability to seal the root canal system from the periradicular tissues, anatomical anomalies and poor surgical technique. This paper reviews the use of re-surgery in the treatment of failed surgical cases, discussing some of the problems that may be encountered and how they may be managed.

## Introduction

Surgical endodontics carries with it a published success rate that varies from 25% to over 90% (1–3). Further treatment for the cases that fail may include extraction of the affected tooth and replacement with an implant, or a fixed or removable prosthesis. Consideration can also be given to undertaking further periradicular surgery in an attempt to retain the tooth as a functional unit in the dental arch.

## Outcomes for surgical revision

Prior to surgery it is important to ensure that a reasonable prognosis can be given. A number of factors influence the outcome of periradicular surgery and these have been described by Zuolo et al. (3) and include patient demographics and systemic condition, the tooth involved, the amount and location of bone loss, quality of the previous root canal treatment, the coronal restoration and the skills of the surgeon.

Unfortunately, there is little information available on the success of endodontic surgical revision. Peterson & Gutmann (4) undertook a systematic review of the literature and reviewed 42 papers published between 1970 and 1997, of which eight qualified for inclusion. Of 330 cases reported by meta-analysis, 35.7% healed successfully after re-surgery, 26.3% healed with uncertain results and 38% had not healed at the 1 year follow-up. However, five of the eight cited papers were published over 30 years ago, before the advent of micro-surgical techniques and more biocompatible materials for root-end fillings.

A further search of Medline via OVID was undertaken (Table 1), applying the Cochrane Highly Sensitive Search Strategy for Controlled trials (Table 2). This was complimented by hand searching. Two papers were forthcoming addressing specifically the issue of outcomes with re-surgery (5, 6). This lack of evidence is supported by Mead et al. (7). They examined the literature since 1970, pertaining to clinical outcomes for surgical endodontics *per se* and assigned levels of evidence. Seventy-nine studies were identified but no randomized clinical trials (level 1) were found. Only two level 2 (low-quality randomized control trials) were found and these compared non-surgical and surgical root canal treatment only.

Gagliani et al. (5), in a study comparing surgical and re-surgical cases, found an overall healing rate of 78%, after 5 years. Eighty-six percent ($n = 140$) of teeth subjected to one surgical procedure showed complete healing, 7% showed incomplete healing and 6% had persistent disease. In the re-surgery group, 59% ($n = 41$) healed completely, 17% showed incomplete

**Table 1. Search strategy for Medline via OVID**

| |
|---|
| 1. Exp TOOTH ROOT |
| 2. Exp PERIAPICAL DISEASES |
| 3. ((tooth adj6 root$) or (teeth adj6 root$) or (tooth adj6 apex) or (teeth adj6 apex) or (teeth adj6 apices) or periapical$ or periapical$ or periradicular or peri-radicular) and (disease$ or periodontitis$ or abscess$ or granuloma$ or lesion$ or cyst$ or infect$ or inflamm$ or pathosis$ or pathology$)) |
| 4. OR/1-3 |
| 5. APICOECTOMY |
| 6.(Apicoectomy$ or apicectom$) |
| 7. Exp ENDODONTICS |
| 8. (Endodontic$ and (treat$ or therap$)) |
| 9. (Surgery or surgical$ or non-surgical$) |
| 10. ((Root near fill$) or (root near therap$) or (root near treat$) or root-canal treat$ or root-canl therap$ or (root-end near resect$) or (root-end near fill$) or (root near resect$) or (orthograde near fill$) or (retrograde near fill$)) |
| 11. pulp$ |
| 12. ROOT CANAL THERAPY |
| 13. Or/5-12 |
| 14. retreat$ or retreatment or retreated) |
| 15. 4 AND 13 AND 14 |

healing and 23% showed continuing disease. There was a statistically significant difference between the two groups. They concluded that revision of surgery was a valid alternative to extraction. Conversely, Schwartz-Arad et al. (6) examined 19 teeth where re-surgery had been undertaken, in a cohort of 122 teeth examined from between 6 and 45 months following periradicular surgery. Only 21% ($n = 4$) showed complete healing, while 31.6% ($n = 6$) showed incomplete healing and 47.4% ($n = 9$) showed unsatisfactory healing. Despite the low numbers of cases involved in re-surgery, the authors concluded that re-surgery should be avoided if possible.

There is a lobby of dental professionals who believe that teeth with failed endodontic treatment should be extracted and replaced with an implant (8). Their argument against endodontic treatment is based upon predicted longevity, aesthetics and financial implications and should, logically, include re-surgery cases. However, Ayango & Sheridan (9) have shown in a series of case reports that implant placement in a site of a previously failed surgical or non-surgical endodontically treated tooth may develop perimplantitis. The reasons for this are outlined and these include bacterial contamination of the site, overheating of the bone during the osteotomy, premature loading of the implant leading to micro-fractures, or the presence of pre-existing infection in the bone. Furthermore, bacteria that may exit from the root canal system often persist in the periradicular tissues (10, 11), even after tooth extraction.

## Unfavorable outcomes with surgical endodontics

### General issues

The etiology of periradicular periodontitis is microbial (12) and the resultant inflammatory response in the periradicular tissues, modulated by the immune response, causes bone destruction. This may or may not

**Table 2. Cochrane Sensitive Search Strategy for Randomised Control Trials**

| |
|---|
| 1. randomized controlled trial. pt. |
| 2. controlled clinical trial. pt. |
| 3. randomized controlled trials. sh. |
| 4. random allocation. sh. |
| 5. double blind method. sh. |
| 6. single blind method. sh. |
| 7. l.e./1-6 |
| 8. (ANIMALS not HUMAN). sh. |
| 9. 7 not 8 |
| 10. clinical trial. pt. |
| 11. exp clinical trials/ |
| 12. (clin$ adj25 trial$).ti. ab. |
| 13. ((singl$ or doubl$ or trebl$ or Tripl$) adj25 (blind$ or mask$)).ti. ab. |
| 14. placebos.sh |
| 15. placebo$.ti. ab |
| 16 random$.ti. ab. |
| 17. research design. sh |
| 18. or/10-17 |
| 19. 18 not 8 |
| 20. 19 not 9 |
| 21. 9 or 19 |

be accompanied by symptoms, including intermittent pain and tenderness of the tooth and the adjacent soft tissue. Radiological examination reveals loss of radiopacity within the periradicular bone. Occasionally symptoms may be acute in nature with severe pain and swelling, or a chronic suppurative state may prevail with a sinus tract present that can be traced to the periradicular tissues.

## Specific issues

Although the causes for lack of healing following surgical endodontic treatment are the same as for all endodontic cases, a number of specific issues should be addressed as part of the examination and diagnostic protocols prior to consideration for re-surgery.

## Quality of cleaning of root canal

The principle of achieving as clean a root canal as possible must apply. Surgical endodontics may have been performed because it has been impossible to negotiate the root canal system fully because of impediments coronally. These include sclerosis of the root canal or the presence of an extensive coronal restoration such as a post. This may not allow sufficient cleaning of the root canal system. Residual bacterial contamination of the root canal after the initial surgery has been completed may trigger failure subsequently. Possibly the coronal restoration is not of suitable quality and a decision may then be made to dismantle and revise the root canal treatment in the presence of the root-end filling.

## Leakage of bacteria from mouth

Coronal leakage of micro-organisms through faulty restorations or cracks in the tooth structure may affect the host response and promote breakdown of the periradicular tissues to occur (13).

## Anatomical aberrations

The difficulty in cleaning the apical portion of the root-end following root-end resection, especially in the presence of an isthmus, may lead to failure (14, 15). If this is suspected then the use of a surgical operating microscope (SOM) and careful cleaning of the root end with ultrasonically powered instruments during revision may improve the prognosis (14). Missed infected root canals, or the presence of lateral canals that were not removed during the root resection may also cause failure.

## Iatrogenic damage to the tooth

The angle at which the root end was resected will also affect the ability to seal the root end (16), as the greater the angle the more dentinal tubules are exposed. Thus the root-end filling will be deeper in these cases. Other damages that may have occurred during the previous surgery include, incomplete removal of the root end and perforation of the root during previous root-end


**Fig. 1. (A) Tooth 23 showing inadequate root-end filling with amalgam and perforation repair. Symptoms were present and a discharging sinus tract was evident. (B) Tooth 23 as shown in (A) after re-surgery, removal of amalgam root-end filling and perforation and replacement with mineral trioxide aggregate. Three months post-operatively, no symptoms present.**

preparation, especially if a bur has been used that was not directed in the long axis of the root. In addition, if there has been overzealous removal of the root end, the root–crown ratio may be so poor that long-term prognosis is jeopardised.

Amalgam was a popular root-end filling material for many years although it is not biocompatible (17) and has no adhesive properties to tooth structure. Occasionally this root-end filling material may become detached from the tooth especially in cases where a bur has been used to prepare a cavity in the root end (Fig. 1). These cavities are often saucer-shaped and have very poor retention and resistance form.

## Iatrogenic damage to the supporting tissues

During the previous surgery, injudicious removal of the bone in the periradicular region, with perforation of the palatal or lingual cortical plate may lead to healing by scarring, with a residual periradicular radiolucency evident. These radiolucencies may be remote from the apex of treated tooth and should be recognized during the radiological examination so that an informed differential diagnosis can be made.

Poor flap design during the previous surgery, especially the use of a semilunar incision in the maxillary anterior region, may cause residual scarring (Figs. 2 and 3). These may give a poor aesthetic result especially in patients with a high lip line. In addition, the semilunar incision is perpendicular to the pathway of many of the superficial nerves and vessels in the mucosa. Although there is no record in the literature of post-endodontic surgical pain as a result of damage to nerves, a very small number ($n = 4$) of cases have been seen by the author where patients complain of pain in relation to the scar resulting from semilunar incisions. This pain has been of two main types; a constant low level dull ache associated with the scar or a searing pain induced by contact with the scar. Radiological examination showed complete healing of the periradicular tissues. The tooth in each case was not tender to percussion. This pain is reminiscent of causalgia or complex regional pain syndrome, type II and is linked to peripheral nerve damage (18–20). A careful history is required to ensure a correct diagnosis is made. As part of the diagnostic process, it is important to understand the reasons why previous periradicular surgery had been undertaken. In a study of 120 patients with chronic orofacial pain, 38

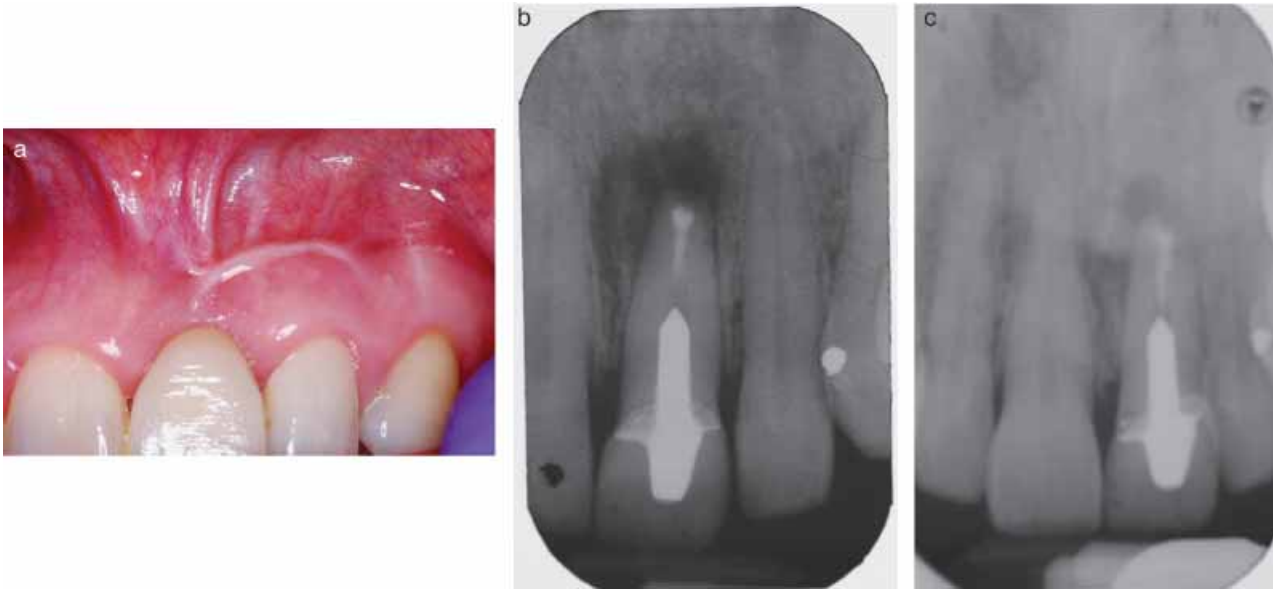


**Fig. 2. (A) Scar resulting from a horizontal incision. Faint scar on attached mucosa on the mesial side of tooth 23 can be seen associated with re-surgery 3 months post-operatively. (A) full thickness mucoperiosteal tissue flap was reflected from tooth 11 to tooth 23. (B) Periapical radiograph of tooth 21 after initial surgery, persistence of periradicular radiolucency and symptoms. (C) Periapical radiograph after re-surgery and replacement of root-end filling with mineral trioxide aggregate (immediate post-operatively).**

had undergone previous oral and maxillofacial surgical procedures, of which 12% were periradicular surgery (21). The surgical intervention exacerbated the pain in 55% of the patients. The importance of establishing the correct diagnosis in patients with pain associated with failed periradicular surgery cases is clearly important and it is necessary, in cases of intractable pain that the patient is treated with sensitivity. Finally, the use of amalgam as a root-end filling material may form an amalgam tattoo in the adjacent soft tissues that may be aesthetically unpleasing (Fig. 4).

## Periodontal status

There is an intimate relationship between the marginal periodontal tissues and those in the periradicular region. There are several ways in which bacteria may affect the periodontal tissues from the root canal system (22). Rud et al. (23), in a clinical study noted that teeth with marginal periodontitis at the time of periradicular surgery more frequently exhibited apical inflammation 4–15 years post-operatively. This was explained as a progression of the marginal periodontitis to the apical tissues.

The relationship between marginal periodontal attachment loss and periradicular surgery has been investigated by Jansson et al. (24). They undertook periradicular surgery on 59 teeth and followed them up for 1 year. Eighty-five percent of the teeth showed successful or uncertain healing. Teeth within the surgical area showed a significant loss of marginal attachment compared with controls. Interestingly, the teeth that were judged not to have healed in the periapex showed more attachment loss than those that were considered to have healed; 0.15 vs. 0.85 mm. However, the follow-up period was rather short. It is essential, therefore, to examine the periodontal tissues of a tooth that is being considered for re-surgery, including the presence of pocketing, isolated deep pockets (which may indicate a root fracture or perforation site) and the level of marginal bone as examined radiologically.

## Root fractures

Root-filled teeth, especially those restored with a post are liable to suffer vertical root fractures (25). In a series of 154 teeth with vertical root fractures Tamse et al. (26) found that 61.7% ($n = 95$) were restored with posts. These fractures are often difficult to diagnose (25) and it may not be until a further flap is reflected that a fracture is recognized. These fractures are often

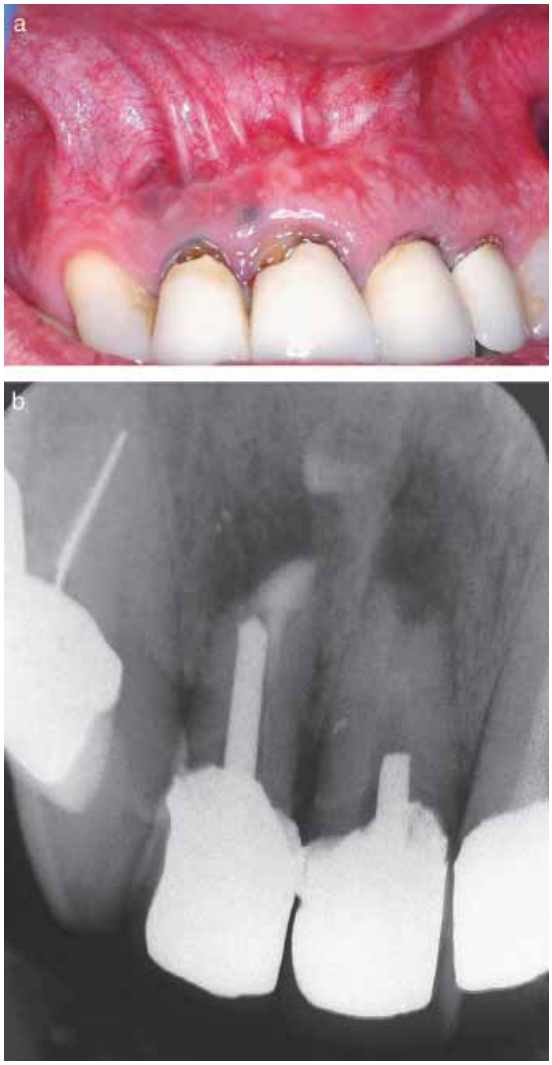

**Fig. 3. (A) Scarring resulting from three attempts at periradicular surgery. An amalgam tattoo is also visible. (B) Radiograph of patient shown in (A). No root-end filling present in tooth 11.**

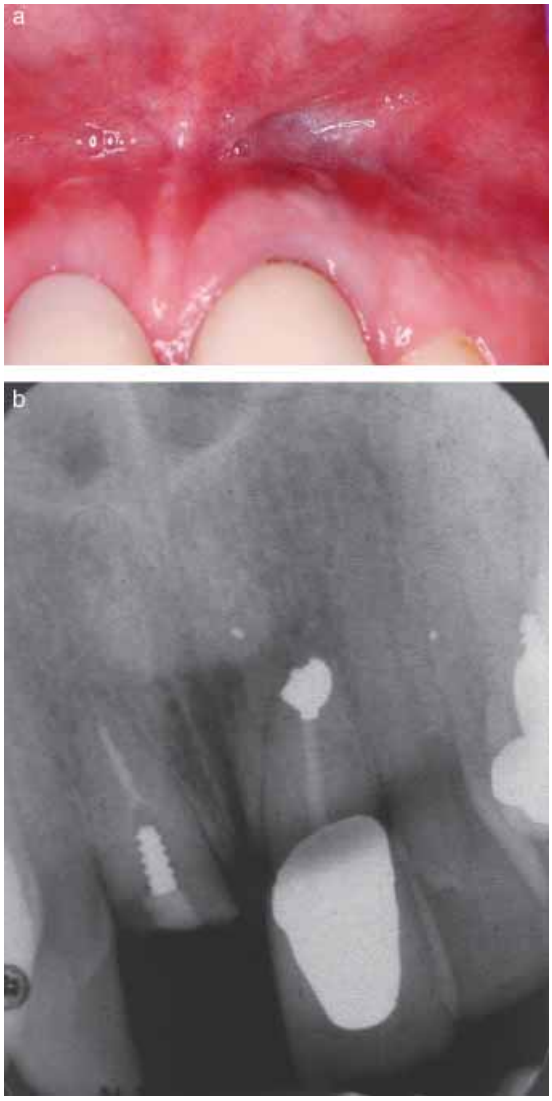

**Fig. 4. (A) Amalgam tattoo evident in buccal mucosa adjacent to tooth 21. (B) Amalgam root-end filling in tooth 21 causing amalgam tattoo in (A).**

linked to marginal bone loss in the region of the fracture and in cases where there is loss of labial cortical bone, the tooth should be carefully examined under magnification for fracture and crack lines (Fig. 5).

## Treatment planning for revision of surgery

It is important to reach a diagnosis prior to determining a treatment strategy for teeth that present with failed endodontic surgery. If a cause for the failure of the previous surgery can be found, then a decision must be made as to whether this can be corrected with further surgery. Decision making in endodontics has been studied extensively (27–29) and is a complicated issue. This applies as much to re-surgery as other endodontic treatments. However, there is no study in the literature pertaining specifically to re-surgery decision making.

The concept of failure in endodontic treatment has been discussed by Friedman (30). He argues strongly for a classification of the outcome of treatment in terms of healing and disease. Healing is indicated by the absence of signs and symptoms and the reduction and eventual elimination of the periradicular radiolucency. The development or persistence of the periradicular radiolucency, even without other clinical signs and symptoms, indicated the presence of disease. Other signs and symptoms such as pain, swelling, presence of

**Fig. 5. Extracted tooth 24 demonstrating a vertical root fracture and a periradicular granuloma; no labial bone present.**

a sinus tract, tooth and tissue tenderness are all indicative of disease.

The treatment options for the failing endodontic surgical case are: no treatment, observe, extraction, non-surgical endodontics and re-surgery. The decision made is influenced by the type of graduate training that has been received and the experience of the dentist (31). Rawski et al. (32) found that endodontists tended to favor re-treatment more than general dental practitioners, and that if the tooth was to be used as an abutment more emphasis was placed on the condition of the coronal restoration than the periradicular status.

Balto & Al-Madi (33) compared the decisions made by endodontists and general practitioners. They found that endodontists favoured re-treatment but generalists preferred to observe, extract or not treat the cases.

## Previous experience of patient

Patients are influenced by their previous dental treatment experiences (34). Kvist & Reit (35) showed that there were more post-operative complications following surgical endodontics than after non-surgical treatment. This included pain and swelling. They also concluded that this contributed to increased indirect costs for treatment. This may enhance the patient's reluctance to undertake another surgical procedure. The way in which the surgery is carried out may affect the post-operative sequelae. Tsesis et al. (36) showed that, by using strict protocols to reduce:

(a) swelling, by prescribing an oral steroid anti-inflammatory and the use of cold compresses; and
(b) infection with chlorhexidine mouthwashes, 76.4% of patients were pain free after 24 h.

Contemporary periradicular surgery is often performed using micro-surgical techniques. These methods have been shown to have some advantages over previous techniques (37). Tsesis et al. (38), in a prospective study, examined the quality of life of patients treated using a traditional technique for surgery; which involved incorporating a 45° bevel to the root-end resection and root-end cavity preparation with a bur, without the use of magnification. This was compared with a contemporary technique that incorporated the use of an operating microscope, root-end resection with minimal bevel and root-end preparation with an ultrasonically driven instrument. The patients treated traditionally had more pain post-operatively whereas those where the microscope was used had more difficulties in mouth opening, eating and the ability to speak post-operatively. These problems were, however, shortlived and most symptoms were resolved seven days post-operatively. Education of the patient is very important in preparing them for surgery and reassurance will help persuade patients to consider the full range of treatment options.

## No treatment and monitoring

This option may be considered if there are no symptoms and yet there may be radiographic signs of disease. No literature is available on the prognosis of teeth that have received periradicular surgery, remain symptom free and yet continue to show signs of periradicular radiolucency. If there is little radiographic evidence of disease then monitoring may be an option (39).

## Extraction

Extraction of the tooth should be considered:

(a) if the crown of the tooth is unrestorable,
(b) if there are already many missing teeth and a removable partial denture is worn, or
(c) if, by undertaking further surgery, the crown–root ratio is jeopardised. This especially includes teeth that are affected by marginal periodontal disease.

Single tooth implants are now commonly prescribed after extraction of compromised teeth and the argument continues regarding success rates for implants compared with endodontically treated teeth. Creugers et al. (40) provided a rigorous systematic review of single-tooth restorations supported by implants. Although they considered that the quality of the research was less than ideal, they were able to identify nine papers out of 320 references that satisfied their criteria. Four-year survival rates for implants were 97% but complications with the crown superstructure were common.

## Non-surgical root canal re-treatment

If the surgery has failed as a result of inadequate cleaning of the root canal system it may be possible to revise the root canal treatment, while leaving the root-end fillings from the previous surgery intact. The introduction over the last few years of new methods for dismantling coronal restorations and removing obstructions in the root canal system makes this a possible alternative to re-surgery (41, 42).

## The case for re-surgery

The retention of the tooth allows the integrity of the marginal alveolar bone to be retained, and helps preserve the anatomical characteristics of the gingival contour. It also allows the preservation of marginal bone for the provision of an implant or a fixed partial denture at a later date, if necessary. In addition, patients are concerned about the loss of anterior teeth especially with regard to aesthetics (43).

### Operative considerations for re-surgery

Basic surgical principles apply to re-surgery as they do to primary surgery.

### Anesthetic considerations

Good tissue anesthesia is essential for re-surgery and protocols are available (44). Agents containing lidocaine with epinephrine are well tolerated by most patients, including those with stable cardiovascular disease (45, 46). In addition, the use of an epinephrine-containing agent enhances hemostasis (47) and concentrations of 1 : 50 000 have been shown to have little systemic effect if used judiciously (48).

### Soft tissue management

The tissues may have been damaged during the previous surgery, especially if a semilunar incision has been used. This leads to scar tissue formation that may be very difficult to elevate from the underlying bone. Great care must be taken to avoid puncturing the mucoperiosteal flap during elevation but considerable force may be required to lift the soft tissues from the bone. A sharp mucoperiosteal elevator is required. If a full mucoperiosteal tissue flap has been elevated previously and there is some evidence of scarring where the relieving incision was made then, providing it was of a satisfactory design, a further incision can be made in the same line.

Flap design is dependent on the amount of scarring, the extent of the attached gingiva, the disease status of the marginal tissues and the choice of the operator. While it is commonly understood that an intracrevicular marginal incision should not be used in the presence of crowns, there is little evidence to support the view that marked gingival recession will take place following this type of incision (49). It is unacceptable to use a semilunar incision that follows the line of scarring from the previous surgery.

An amalgam tattoo may be present in the soft tissue adjacent to some teeth with root-end fillings of amalgam. These may be dark gray or bluish in appearance and are a result of leaching of metallic components from the corroding set amalgam. These tattoos do not give symptoms but may be very unsightly especially in the maxillary anterior region in patients with a high lip line. It is important to be aware of the differential diagnosis which, although very rare, could include malignant melanoma and Karposi's sarcoma (50). On reflection of the tissue flap it may be possible to pare down the mucosa on the inner side to remove some of the obvious contamination,

together with the amalgam root-end filling and any obvious dispersed metallic particles. However removal of the tattoo may not be possible. The use of free gingival flaps and laser treatment has been shown in case studies to be helpful (51, 52). This treatment is best delayed until there is healing of the soft tissues after the re-surgery.

## Hard tissue management

The amount of bone supporting the root should be determined. Loss of the labial plate of bone in anterior teeth may be because of

(a) natural dehiscence exacerbated by the periradicular disease process,
(b) concomitant periradicular and marginal periodontal disease,
(c) presence of a perforation, from for example, a post or the
(d) presence of a vertical root fracture.

A diagnosis of the cause of the bone loss should be made following close inspection of the root with an SOM. Pitts & Natkin (53) provide a useful guide to the diagnosis of root fractures. A decision should be made whether the tooth can be saved and if so, whether operative steps should be taken to accept the bone loss or attempt guided tissue regeneration. Skoglund & Persson (54) undertook periradicular surgery on 27 teeth that had no labial bone and followed them up for between 0.5 and 7 years. They found that 37% were successful, 33% were uncertain and 30% failed. More recently a number of animal studies and clinical reports have indicated the value of guided tissue regeneration in surgical endodontics. Rankow & Krasner (55) provided a general overview of the use of guided tissue regeneration in endodontic surgery, including the treatment of dehiscence. Histological studies using animal models have also shown the value of the use of bioresorbable membranes over buccal dehiscences (56, 57). In both studies the use of a bioresorbable membrane significantly increased the amount of


**Fig. 6. (A) Amalgam root-end filling in tooth 21 showing poor shape of root-end cavity and excess material in periradicular tissues. The tooth was tender to percussion and there was tenderness to palpation labially. The patient had experienced one acute exacerbation that had been treated with systemic antimicrobials. (B) Re-surgery of tooth 21 shown in (A). A severe bevel had been placed on the root end that precluded reducing the angle of cut without compromising root-crown ratio; root end filling of mineral trioxide aggregate. This was taken 4 months post-operatively; the patient was symptom free and repair of the periradicular tissues continues.**

regenerated alveolar bone compared with controls. Clinical studies have also shown that guided tissue regeneration principles can be applied to these cases. Dietrich et al. (58) showed that 19 out of 23 defects were successful clinically and radiographically, with periodontal probing depths being reduced. A mean relative attachment gain of 2.8 mm was achieved. Periosteal grafts have also shown to be useful although only a limited number of cases were reported (59). Von Arx & Cochran (60) have provided a classification for periradicular lesions depending on the extent of bone loss and have linked this to treatment regimes using guided tissue regeneration.

## Bony crypt

Access to the root end must be gained to allow proper cleaning of the root canal system apically. In addition any extruded filling material from the previous surgery should be removed, if possible (Fig. 6A). This may be difficult as particles may have become embedded in bone or the soft tissue and are often very difficult to detect. The removal of excessive amounts of alveolar bone in an effort to clear all traces of material is not warranted. Curettage of the bony crypt to remove soft tissue should be performed with a sharp bone excavator. A careful examination of the crypt after removal of the soft tissue will help to establish if any damage was done during the initial surgery, for example, perforation of the lingual cortical plate.

## Root end

The root end should be examined carefully, preferably under magnification. The position and quality of the root-end filling should be noted as well as the angle at which the root was resected previously. While the root-end bevel should be as shallow as possible (16), it may be difficult to improve the bevel angle of roots that have been resected at an acute angle without jeopardizing valuable root length (Fig. 6B). It may be possible to 'freshen up' the root-end especially if the previous surgery has left a rough surface with spicules of root remaining. The presence of isthmuses should be noted so these may be incorporated into the root-end preparation.

The anatomy of the root end will almost certainly have been altered by the previous surgery. The cavity in the root end may have poor retention and resistance form (Fig. 7A) and, in some cases the root-end filling may have become detached from the root. These

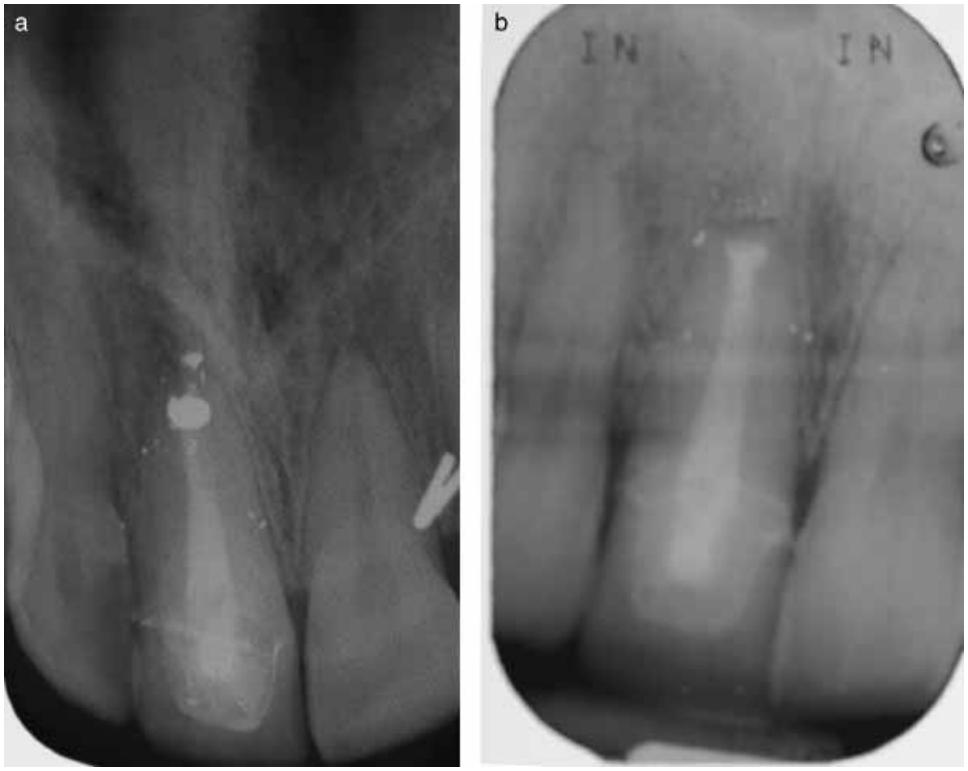


**Fig. 7. (A) Failed surgical case tooth 11; persistent symptoms including tenderness to percussion and tender to labial palpation. (B) Re-surgery of tooth 11 with root-end filling of MTA, good periradicular healing. Amalgam particles remain in the tissues.**

should be removed. Root-end preparation should be undertaken to

(a) clean the root canal system as well as possible and
(b) provide a retentive form for the new root-end filling.

The use of ultrasonically powered instruments is now accepted as the best way to prepare the root end (61–64). An attempt should be made to clean the accessible root canal and it may be possible to bend hand files to allow entry into the root canal from the apical direction. These can then be used to clean the wall of the root canal. Irrigation should be with sterile saline or chlorhexidine. It is not advisable to use sodium hypochlorite because of possible contamination of or damage to the periradicular tissues.

### Root-end filling

When it is clear that the preparation of the root-end and root canal system is complete a root-end filling should be placed. The choice of the material used is dependent to a large extent on the operator but mineral trioxide aggregate (MTA; Dentsply Int, York PA, USA) and Diaket (ESPE 3M, St Paul, MN, USA) are among the most biocompatible (65–67) (Fig. 7B).

### Suturing

Suturing principles are the same in re-surgery cases as for initial surgery. The advent of micro-surgical techniques means that finer sutures can be used, such as 5/0 or 6/0.

### Post-operative instructions

There are no specific post-operative instructions for re-surgery cases that are different from initial surgery and these have been discussed elsewhere (1). Sutures can be removed after 48–96 h.

### Follow up

An immediate post-operative periapical radiograph should be taken and the patient followed up regularly to examine for signs and symptoms.

## Summary

Periradicular re-surgery is an option for teeth that have had previous surgery and there are now signs and symptoms. Retention of the tooth allows preservation of the gingival contour and maintenance of marginal bone levels. The advent of new techniques and more biocompatible materials increases the possibilities of a successful biological outcome.

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# The prognosis and expected outcome of apical surgery

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Clinicians should possess current knowledge about the prognosis and expected outcome of endodontic treatment, including apical surgery. This knowledge cannot be acquired by indiscriminate review of the many available studies because they vary in the level of evidence they provide. Therefore, seven studies that best comply with methodology criteria defining the levels of evidence were selected and used as the basis of this review. In spite of their methodological consistency, the outcomes reported in these studies still differ considerably, mainly because of differences in inclusion criteria. According to these studies, 37–91% of teeth can be expected to be healed, while up to 33% can still be healing several years after surgery. Importantly, 80–94% of teeth can remain in symptom-free function, even if they are not healed. Several pre-operative factors may influence the outcome of treatment; the outcome may be better in teeth with small lesions and excessively short or long root canal fillings, and it may be poorer in teeth treated surgically for the second time. With regard to intra-operative factors, the choice of the root-end filling material and the quality of the root-end filling may influence the outcome, while the retrograde retreatment procedure clearly offers a better outcome than the standard root-end filling. In summary, the expected outcome of apical surgery is good and therefore, before considering tooth extraction and replacement, apical surgery should be attempted when it is feasible.

## Why study prognosis and treatment outcomes?

In an excellent review article on the essential elements of evidence-based endodontics (1), the authors describe a scenario of a patient who requires detailed answers to specific questions before he consents to having root canal treatment. The questions concern the clinician's certainty about the diagnosis, the expected outcome of treatment using different therapeutic regimens, and the chances of survival compared with those of alternative treatment, mainly extraction and replacement. Although fictional, this scenario highlights the current climate in today's society regarding treatment decisions. On the one hand, health care providers are required to respect the concept of 'patient autonomy' (2–6). Patients should be fully informed about the benefits and risks of available treatment alternatives, and allowed to select a specific treatment. On the other hand, patients can readily access information about available treatments via the Internet, and use it to challenge the clinician's recommendations. To be able to function in this new climate successfully, clinicians must be well versed in the evidence that supports endodontic treatment procedures. A key element of this evidence is current knowledge about the prognosis and expected outcome of treatment.

When used in the context of health care, the term 'prognosis' is defined as the forecast of the course of disease. Accordingly, this term applies to apical periodontitis, to describe the *time course* and *chances of healing* after treatment. It appears awkward to use the terms prognosis and healing of apical periodontitis with regard to apical surgery, because the diseased tissue is actually eradicated and does not require healing. Nevertheless, apical surgery is performed to treat a tooth affected by apical periodontitis; therefore, the term prognosis can still apply while healing can relate to the surgical wound. Use of these terms is particularly helpful when apical surgery is to be weighed against alternative non-surgical therapy.

**Table 1. Follow-up studies reporting on the outcome of apical surgery**

| Study | Follow-up (years) | Cases observed | Recall rate (%) | Appraisal categories | | | | Treatment approach (%) | | Outcome (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Cohort | Exposure | Assessment | Analysis | Orthograde and surgery | Surgery | Healed | Healing | Functional* |
| Mattila & Altonen (1968) | 0.8–5 | 164 | 81 | Yes | No | Yes | No | 39 | | 63 | 11 | ⩾74 |
| | | | | | | | | | 61 | 49 | 17 | ⩾66 |
| Harty et al. (1970) | 5 | 1016 | 74 | Yes | No | Yes | No | 83 | | 90 | | ⩾90 |
| | | | | | | | | | 17 | 89 | | ⩾89 |
| Nord (1970) | 0.5–6.5 | 354 | 80 | No | Yes | No | No | | 100 | 60 | 13 | ⩾73 |
| Nordenram & Svärdström (1970) | 0.6–6 | 697 | 87 | No | Yes | No | Yes | 15 | | 82 | 11 | ⩾93 |
| | | | | | | | | | 85 | 60 | 16 | ⩾76 |
| Lehtinen & Aitasalo (1972) | NA | 460[p] | 33 | No | No | No | No | NA | NA | 78 | 11 | ⩾89 |
| Rud et al. (1972) | 1–15 | 1000 | 72 | No | No | Yes | Yes | 100 | | 90 | 6 | ⩾96 |
| Ericson et al. (1974) | 0.5–12 | 314 | 94 | No | No | No | No | | 100 | 54 | 25 | ⩾79 |
| Persson et al. (1974) | 1 | 220 | 95 | Yes | Yes | No | No | | 100 | 41 | 36 | ⩾77 |
| Altonen & Mattila (1976) | 1–6 | 46 | 80[p] | No | No | No | No | 69[rt] | | 84 | 8 | ⩾92 |
| | | | | | | | | | 31[rt] | 65 | 6 | ⩾71 |
| Finne et al. (1977)[a] | 3 | 218 | 94 | Yes | Yes | No | No | | 100 | 50 | 19 | ⩾69 |
| Tay et al. (1978)[b] | NA | 86 | NA | No | No | No | No | NA | NA | 78 | | |
| Hirsch et al. (1979) | 0.5–3 | 572 | 88 | No | No | No | Yes | 87 | 13 | 47 | 48 | ⩾95 |
| Malmström et al. (1982) | 2.4 | 154 | 25[p] | No | Yes | No | No | 57[l] | | 74 | 24 | ⩾98 |
| | | | | | | | | | 43 | 54 | 33 | ⩾87 |
| Persson (1982) | 1 | 26 | 96 | Yes | Yes | No | No | | 100 | 73 | 15 | ⩾88 |
| Ioannides & Borstlap (1983) | 0.5–5 | 182[rt] | 81 | No | Yes | No | No | 75 | | 72 | 18 | ⩾90 |
| | | | | | | | | | 25 | 73 | 11 | ⩾84 |

**Table 1. Continued**

| Study | Follow-up (years) | Cases observed | Recall rate (%) | Appraisal categories | | | | Treatment approach (%) | | Outcome (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Cohort | Exposure | Assessment | Analysis | Orthograde and surgery | Surgery | Healed | Healing | Functional* |
| Mikkonen et al. (1983) | 1–2 | 174 | 100 | Yes | Yes | No | No | 93 | | 56 | 28 | ⩾84 |
| | | | | | | | | | 7 | 75 | 17 | ⩾92 |
| Skoglund & Persson (1985) | 0.5–7 | 27 | 100 | No | Yes | No | No | | 100 | 37 | 33 | ⩾70 |
| Reit & Hirsch (1986) | 1– ⩾ 4 | 35 | 100 | Yes | Yes | No | No | | 100[r] | 71 | 26 | ⩾97 |
| Forssell et al. (1988) | 1–4 | 358 | NA | No | No | Yes | No | 71 | | 68 | 21 | ⩾89 |
| | | | | | | | | | 29 | 69 | 7 | ⩾76 |
| Allen et al. (1989) | ⩾ 0.5 | 695 | NA | No | No | No | No | | 100 | 60 | 27 | ⩾87 |
| Amagasa et al. (1989) | 1–7.5 | 64 | 100 | Yes | Yes | No | No | | 100[r] | | | 95 |
| Crosher et al. (1989) | 2 | 85 | 91 | No | Yes | No | No | 100 | | 92 | | ⩾92 |
| Dorn & Gartner (1990) | 0.5 | 488 | NA | No | No | No | No | NA | NA | 63 | 18 | ⩾81 |
| Grung et al. (1990) | 1–8 | 473 | 88 | Yes | No | Yes | No | 66 | | 96 | 3 | ⩾99 |
| | | | | | | | | | 34 | 72 | 12 | ⩾84 |
| Friedman et al. (1991) | 0.5–8 | 136[rt] | NA | No | No | Yes | Yes | 7 | 93 | 44 | 23 | ⩾67 |
| Lasaridis et al. (1991) | ⩾ 0.5 | 24 | 100 | Yes | Yes | No | No | 100 | | 79 | 17 | ⩾96 |
| Lustmann et al. (1991)[c] | 0.5–8 | 134[rt] | NA | No | No | Yes | Yes | 7 | | 70 | 30 | ⩾100 |
| | | | | | | | | | 93 | 43 | 22 | ⩾65 |
| Molven et al. (1991)[d] | 1–8 | 222 | NA | Yes | No | Yes | No | 50 | | 96 | 3 | ⩾99 |
| | | | | | | | | | 50 | 73 | 14 | ⩾87 |
| Rapp et al. (1991)[e] | ⩽0.5–⩾2 | 428 | 60 | No | No | No | No | | 94 | 66 | 29 | ⩾95 |
| | | | | | | | | 6[2] | | 56 | 33 | ⩾89 |
| Rud et al. (1991)[Rp] | 0.5–1 | 388 | 97 | No | Yes | Yes | No | | 100 | 78 | 15 | ⩾93 |

**Table 1. Continued**

| Study | Follow-up (years) | Cases observed | Recall rate (%) | Appraisal categories | | | | Treatment approach (%) | | Outcome (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Cohort | Exposure | Assessment | Analysis | Orthograde and surgery | Surgery | Healed | Healing | Functional* |
| Waikakul & Punwutikorn (1991) | 0.5–2 | 62 | 94 | Yes | Yes | No | No | | 100 | 81 | 17 | ⩾96 |
| Zetterqvist et al. (1991) | 1 | 105 | 100 | Yes | Yes | No | No | | 100 | 61 | 31 | ⩾92 |
| Frank et al. (1992) | ⩾ 10 | 104 | NA | No | No | No | No | NA | NA | 58 | | |
| Cheung & Lam (1993) | ⩾ 2 | 32 | NA | No | No | No | No | NA | NA | 62 | 22 | ⩾84 |
| Pantschev et al. (1994) | 3 | 79 | 79 | No | Yes | Yes | No | | 100 | 54 | 21 | ⩾75 |
| Jesslén et al. (1995) | 5 | 93 | 94 | Yes | Yes | No | No | | 100 | 59 | 28 | ⩾87 |
| August (1996) | 10–23 | 39 | 18 | No | No | No | No | | | 74 | 15 | ⩾89 |
| Danin et al. (1996) | 1 | 19 | 100 | No | Yes | Yes | No | | 100 | 58 | 26 | ⩾84 |
| Rud et al. (1996) | 0.5–1.5 | 351[rt] | 62 | No | Yes | Yes | No | | 100 | 82 | 12 | ⩾94 |
| Sumi et al. (1996) | 0.5–3 | 157 | 100 | Yes | Yes | No | No | | 100 | | | 92 |
| Jansson et al. (1997) | 0.9–1.3 | 62 | 100 | Yes | Yes | No | No | | 100 | 31 | 55 | ⩾86 |
| Rud et al. (1997)[f] | 0.5–1.5 | 551[rt] | 61 | No | Yes | Yes | No | | 100 | 79 | 16 | ⩾95 |
| Bader & Lejeune (1998) | 1 | 254 | 79 | No | Yes | No | No | | 100 | | | 81 |
| Danin et al. (1999) | 1 | 10 | 100 | No | Yes | Yes | no | | 100 | 50 | 50 | |
| **Kvist & Reit (1999)** | **4** | **45** | **100** | **Yes** | **Yes** | **No** | **Yes** | | **100** | **60** | | |
| Rubinstein & Kim (1999) | 1.2 | 94 | 73 | No | Yes | No | No | | 100 | 97 | | ⩾97 |
| Testori et al. (1999) | 1–6 | 134 | 76[p] | No | Yes | No | No | | 100 | 78 | 9 | ⩾87 |
| von Arx & Kurt (1999) | 1 | 43 | 96 | Yes | Yes | No | No | | 100 | 82 | 14 | ⩾96 |
| **Zuolo et al. (2000)** | **1–4** | **102** | **96** | **Yes** | **Yes** | **Yes** | **No** | | **100[2]** | **91** | | **92** |
| **Rahbaran et al. (2001)** | **⩾ 4** | **129[en]** | **61[p]** | **Yes** | **Yes** | **Yes** | **Yes** | | **100[3]** | **37** | **33** | **⩾80** |
| Rud et al. (2001) | 0.5–12.5 | 834[rt] | 84 | No | Yes | Yes | No | | 100 | 92 | 1 | ⩾93 |

**Table 1. Continued**

| Study | Follow-up (years) | Cases observed | Recall rate (%) | Appraisal categories | | | | Treatment approach (%) | | Outcome (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Cohort | Exposure | Assessment | Analysis | Orthograde and surgery | Surgery | Healed | Healing | Functional* |
| von Arx & Kurt (2001) | 1 | 25 | 96 | Yes | Yes | No | No | | 100 | 88 | 8 | ⩾96 |
| Rubinstein & Kim (2002)[g] | 5–7 | 59 | 86 | Yes | Yes | No | No | | 100 | 92 | | ⩾92 |
| **Jensen et al. (2002)** | 1 | **60[Rp]** | **91** | **Yes** | **Yes** | **No** | **Yes** | | **100** | **73** | **17** | **⩾90** |
| **Chong et al. (2003)** | **2** | **108** | **59** | **No** | **Yes** | **Yes** | **Yes** | | | **90** | **6** | **⩾96** |
| Maddalone & Gagliani (2003) | 0.3–3 | 120 | 82 | No | Yes | Yes | No | | 100 | 93 | 3 | ⩾96 |
| Schwartz-Arad et al. (2003) | 0.5–0.9 | 262 | 47 | No | Yes | No | Yes | | 100 | 44 | 21 | ⩾65 |
| **Wang et al. (2004)** | **4–8** | **94** | **85** | **Yes** | **Yes** | **Yes** | **Yes** | | **100[4]** | **74** | | **91** |
| **Gagliani et al. (2005)** | **5** | **231[rt]** | **89** | **Yes** | **Yes** | **No** | **Yes** | | **100** | **78** | **10** | **89** |

Bold font highlights studies conforming to at least three out of the four appraisal categories.
*Asymptomatic, without or with residual radiolucency (⩾ = not reported; rate is sum of healed and healing)
NA, not available;
p, patients (as opposed to teeth);
rt, roots (as opposed to teeth);
en, only teeth treated in the endodontic clinic included;
r, retrograde retreatment;
Rp, only teeth treated with Retroplast included;
1, 31% of cases treated for persistent disease after orthograde retreatment;
2, all teeth treated for persistent disease after orthograde retreatment;
3, 39% of cases treated for persistent disease after orthograde retreatment;
4, 37% of cases treated for persistent disease after orthograde retreatment;
a, sample as in Persson et al. (1974);
b, sample as in Harty et al. (1970);
c, sample as in Friedman et al. (1991);
d, sample as in Grung et al. (1990);
e, sample as in Allen et al. (1989);
f, sample as in Rud et al. (1991) and Rud et al. (1996);
g, sample as in Rubinstein et al. (1999).

Different components or variations of what is contemporarily defined as apical surgery have been used clinically for over 100 years. Garvin (7) reported in 1919 on the follow-up of teeth treated by root-end resection and filling, with additional reports being published in the 1930s and in the early 1940s (8–10). Since these pioneering reports, over 70 studies have been published that focused on the treatment outcome of apical surgery. Most of these studies, encompassing data from over 10 000 treated teeth, had been reviewed and comprehensively discussed to summarize the state-of-the-art knowledge at different times; Rud et al. (11) reviewed studies reported up to 1970, and Friedman (12) reviewed studies reported from 1966 to 1997. These reviews clearly demonstrate that the reported outcomes of apical surgery have been incoherent and, at times, contradictory (12). Thus, in spite of the vast information available, answers to the main questions related to the outcome of apical surgery have remained obscure owing to the poorly standardized materials and methods of many studies (12). Furthermore, the clinical procedures in apical surgery have considerably evolved, particularly in the past decade. The current strategies for tissue incision, elevation and reflection, hemostasis, root-end cavity design, preparation and filling, magnification and illumination, and suturing have possibly rendered the results of specific studies less relevant today than they had been in the past. The methodological and technical variability mentioned above suggests that *indiscriminate review of the many available studies would be futile and potentially misleading*. To answer questions about the prognosis of a disease following state-of-the-art treatment, a review must focus on studies that are selected according to well-defined criteria. The purpose of this article is to review and discuss selected articles, reporting on the outcome of apical surgery performed on teeth with apical periodontitis.

This review follows a previous one on the prognosis of initial endodontic therapy (13). Both reviews share a similar structure and several components. Although an effort was made to avoid repetition, inclusion of all the components is essential for the comprehensiveness of this review.

## Why are the reported outcomes diverse?

Studies where information can be gleaned on the prognosis and expected outcome after apical surgery (11, 14–72) are listed in Table 1. This body of literature

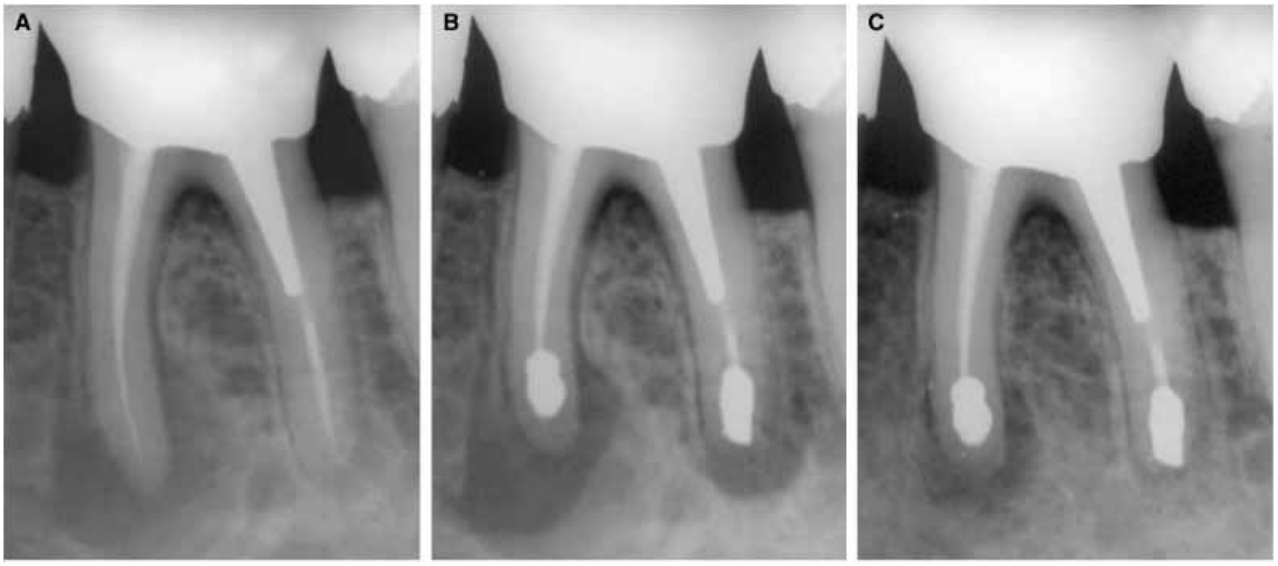


**Fig. 1. Multi-rooted teeth – individual roots vs. the whole tooth as the evaluated unit. (A) A root-filled mandibular first molar with persistent apical periodontitis. The mesial lesion is considerably larger than the distal one. (B) Completed surgery, including root-end filling with amalgam and varnish. (C) After 2.5 years, the distal radiolucency is resolved, but the mesial one is not. The presence of symptoms suggests persistence of apical periodontitis. The whole tooth was the evaluated unit in a clinical study (38), contributing one unit recorded as persistent disease. In contrast, if the roots were evaluated independently, the tooth would contribute two units: one healed and the other having persistent disease.**

is characterized by great diversity in the reported outcomes. As suggested by Friedman (12), indiscriminate summaries and direct comparisons among these studies are inapt because of differences among the studies with regard to the following factors.

## Composition of study material

### *Tooth location, number of roots*

The majority of studies on apical surgery include primarily anterior or single-rooted teeth. Fewer studies include a substantial proportion of multi-rooted teeth (20, 42, 43, 50–53, 55, 56, 59–61, 63, 69, 71, 73), whereas only a few studies include primarily multi-rooted teeth (22, 27, 28, 38, 39, 64, 65, 74). The surgical procedure performed on a multi-rooted tooth is more complex than that on a tooth with a single root, and the access to multi-rooted, posterior teeth is generally more restricted than to the anterior, single-rooted ones. Furthermore, the results of a study can differ between single- and multi-rooted teeth if the tooth as a whole is defined as the evaluated unit, judged by the worst-appearing root. In this scenario, the risk of observing persistent apical periodontitis after treatment is multiplied (Fig. 1).

### *Sample size*

The size of the sample included in a clinical study is important for the study's internal and external validity (75). The sample size also determines the power of the statistical analysis of differences between groups, when variables are assessed for their effect on the outcome of treatment. The smaller the difference in the outcome, the larger the sample required in each group to achieve sufficient power for significance to be demonstrable (75). For example, Wang et al. (71) report a non-significant, 10% difference in the 'healed' rate between teeth treated surgically for persistence of disease after initial treatment (74%), or after orthograde retreatment (84%). The power analysis performed by the authors to estimate the sample size required to establish significance between these groups under the conditions of their study (with 80% power and a 5% significance level) revealed that 400 teeth would be required in the initial treatment group and 220 teeth in the retreatment group. Thus, in studies with relatively small samples (Table 1), specific variables may emerge as non-significant whereas in larger studies the same variables may emerge as significant outcome predictors.

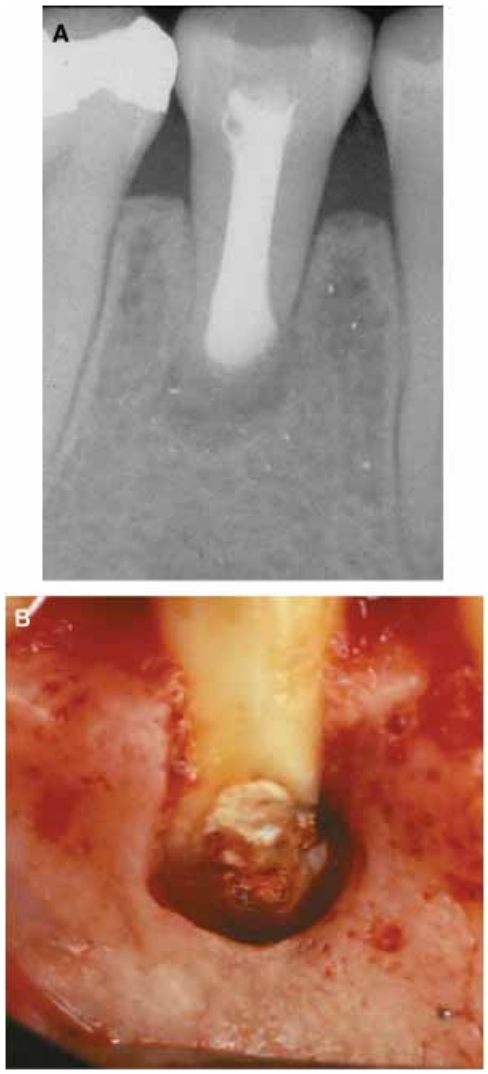


**Fig. 2. Case selection – inclusion of teeth with a compromised prognosis in the study sample. (A) A mandibular second premolar with dens evaginatus, immature root formation, and apical periodontitis, after combined orthograde and surgical treatment and root filling with glass-ionomer cement. (B) Clinical view showing a total loss of the buccal bone plate, suggesting a poor probability of healing. If the sample of a clinical study includes many teeth with a compromised prognosis, such as this one, the healing rate is lower than if such teeth are not included.**

### *Case selection criteria*

The process of case selection involves the differentiation of potential candidates for treatment according to their prognosis; therefore, it is likely to determine the results of a clinical study (76). Teeth with clinical features that

could adversely affect the prognosis, such as deep periodontal defects, have been excluded in several studies (58, 59, 62, 67, 68, 72), while specific studies include only teeth with poor prognosis, for example those affected by loss of the buccal bone plate (30) (Fig. 2). In the majority of studies, consecutive cases were included without specific inclusion or exclusion criteria. Therefore, the reported outcomes may have been influenced by inclusion of teeth with poor prognosis.

### *Previous endodontic treatment – initial treatment or retreatment*

Generally, the majority of the teeth in studies on apical surgery had persistent disease after initial root canal treatment, that was sustained by bacteria harbored within the root canal system. The surgical attempt to seal the bacteria within the canal may be ineffective; therefore, the treatment outcome may be compromised (71, 77). In one study, however, all the teeth had persistent disease after 'at least one non-surgical retreatment to enhance canal debridement' (62), and 91% of them healed following surgical intervention. Persistent disease after orthograde retreatment (Fig. 3) is likely to be sustained by bacteria colonizing an inaccessible, possibly extra-radicular site. Because such sites can be eradicated by the surgical procedure, a healing rate in the range of 90% can be expected (71, 77). Thus, the previous treatment history of cases included in a given study is expected to influence the reported outcome; however, the vast majority of the studies do not characterize their cohorts in this regard.

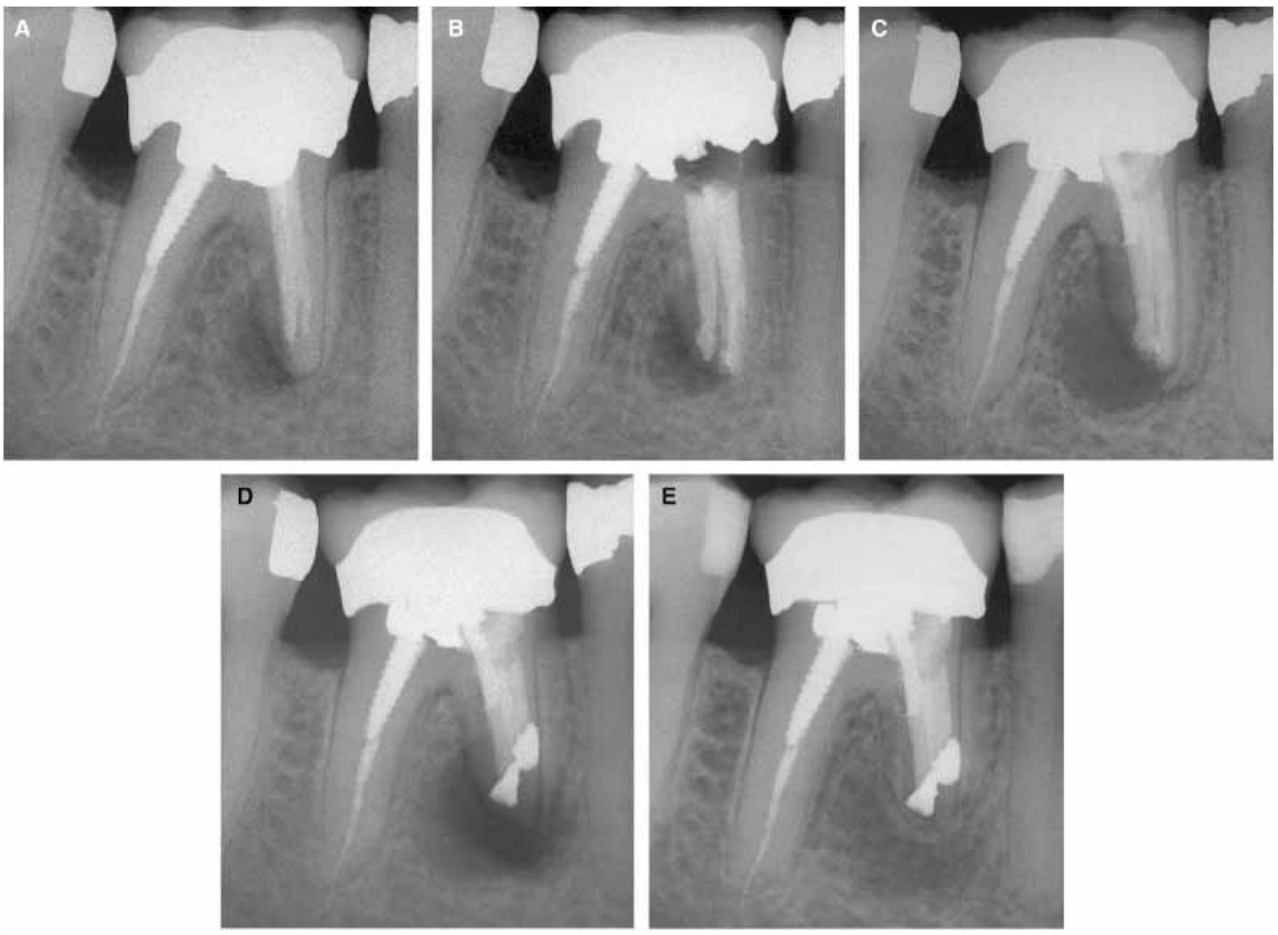


**Fig. 3. Persistent disease after previous retreatment – increased probability of extra-radicular infection. (A) A root-filled mandibular first molar with persistent apical periodontitis affecting the mesial root. (B) Completed orthograde retreatment of the mesial canals. (C) After 1 year, the expanded lesion indicates persistence of apical periodontitis. As the previous retreatment may have eliminated intra-canal bacteria, the infection may be sustained by extra-radicular bacteria. (D) Completed surgery, including root-end filling with Super-EBA. (E) One year after surgery, the lesion is healed. (Apical surgery and follow-up courtesy of Dr Steven Cohen, Toronto, Canada.)**

## Intra-operative procedures

### *Treatment providers*

Apical surgery has been performed predominantly by oral and maxillofacial surgeons; however, in the past two decades, it has gradually become the domain of endodontists. The endodontic community has drastically modified the techniques of apical surgery, and now routinely uses operating microscopes and microsurgical instruments, ultrasonic cavity preparation devices, novel materials for root-end filling, and improved strategies for hemostasis and suturing. It appears, however, that oral and maxillofacial surgeons have not fully embraced these modified strategies (70), and that their treatment outcomes may have fallen behind those of endodontists (63). Providers of treatment in the different studies varied from oral and maxillofacial surgeons to endodontists, and from resident students to qualified specialists, with the reported outcomes varying accordingly (12).

### *Root-end management*

The traditional root-end cavity preparation with round burs is inferior to the currently used cavity preparation with ultrasonic tips (61, 78–83). Likewise, root-end filling with amalgam has been shown to be inferior to the currently used intermediate restorative material (IRM), ethoxy benzoic acid (EBA) cements, or mineral trioxide aggregate (MTA) (84–88). In specific studies (43, 52, 55, 64, 67, 73, 74, 89), none of the above was used, but rather a composite resin 'cap,' suggested to be superior to the above, was bonded to the root-end. The reportedly less-effective strategies have been used in the majority of studies in the past and in several recent ones (51, 54, 56–58, 60, 69, 70), whereas the current strategies assumed to be more effective have been used in other recent studies (53, 56, 59–63, 65, 66, 68, 71). The variability with regard to the root-end management procedures is indeed striking, and it is likely to obscure the reported outcomes of apical surgery.

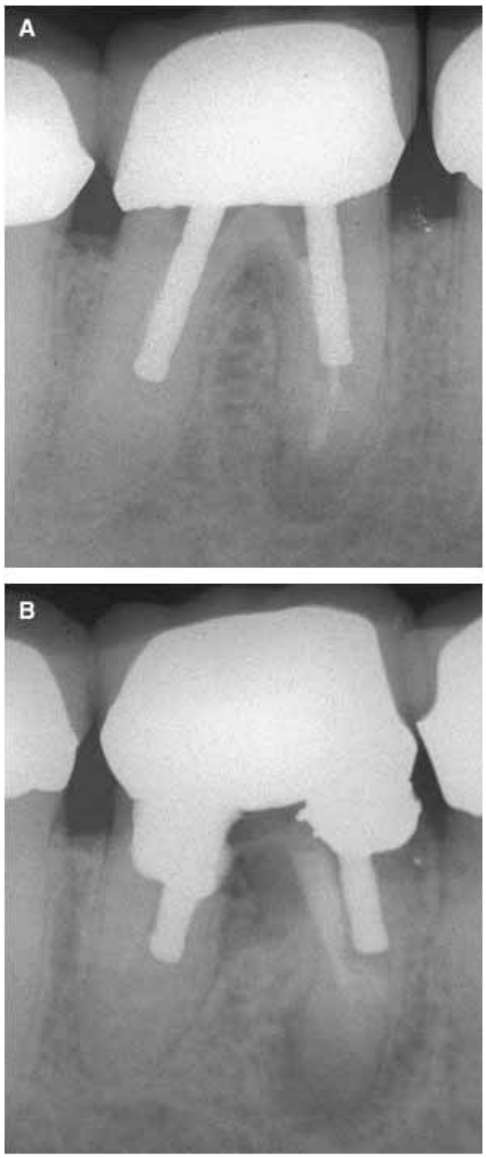


**Fig. 4. Defective restoration – outcome classification as 'persistent disease.' (A) A mandibular first molar, 1 year after surgery including root-end filling with Super-EBA in the mesial canals. Note the voids around both posts, undermining the core and crown. (B) After 6 years, the restoration appears to have been patched with amalgam, suggesting the occurrence of secondary caries, and disease persists about the mesial root while bone loss is also evident in the furcation area. The adverse outcome may have been caused by the defective restoration. (Courtesy of Dr Richard Rubinstein, Farmington Hills, MI, USA.)**

### *Pre- and post-operative restoration*

When apical surgery is performed, the pre-operative restoration is often left in place post-operatively. The outcome of treatment is impaired by the lack of a definitive restoration or by the presence of a defective restoration (42, 63, 71) (Fig. 4). The majority of studies do not provide detailed information about the restorative status of the treated teeth, but it is likely that in many studies the reported outcomes are adversely influenced by inclusion of teeth with defective or missing restorations.

### *Concurrent orthograde-surgical treatment*

In a review article, Friedman (90) highlighted the considerable difference in outcome between concurrent surgical and orthograde treatment, consistent with the historic management of teeth with large lesions, and apical surgery performed alone on teeth where disease persisted after previous orthograde treatment. The former had been commonly applied in the past, and in fact, represented the majority of the samples in many studies (Table 1). In those studies, authors frequently summarized results for the entire study cohort, resulting in better outcomes reported than what should be expected if only apical surgery is performed (90). Thus, in many studies, the proportion of teeth that receive not just apical surgery but also concurrent orthograde treatment determines the reported outcomes.

## Methodology

The current emphasis in the health care community on evidence-based practice has raised the awareness of the critical role of appropriate methodology in assigning relative importance to clinical studies. Hierarchies of evidence have been developed for differentiating studies, by ranking them according to methodology (see the section What is the best evidence for prognosis and treatment outcome?). Among the studies on apical surgery, there is considerable variability in the methods of collecting, recording, processing, and reporting of the data. Consequently, some studies may rank higher in the hierarchy of evidence, and may be assigned more importance than others.

### *Study design and availability of detailed data*

Retrospective and prospective studies differ, particularly in the possibility of bias influencing the reported outcomes. Also, many of the studies on apical surgery lack important pre-, intra-, and post-operative data, including composition of the material, treatment procedures, and complications. The prognosis under specific clinical conditions cannot be estimated based on studies where important information is lacking. Similarly, results of specific studies designed to answer one research question (18, 21, 23, 36, 42, 45, 48, 49, 57, 58, 67, 68, 89) may not be directly compared with those of other studies with regard to general prognosis.

### *Recall rate*

When subjects included in the inception cohort of a study are not available for follow-up, their treatment outcome is unknown. In the best-case scenario (if all missing subjects experienced a favorable outcome), the reported outcome would be better, while in the worst-case scenario (if all missing subjects experienced an unfavorable outcome) the reported outcome would be poorer. For example, with a recall rate of 85%, Wang et al. (71) report that 74% of the teeth have healed. According to their calculation, in the best-case scenario 80% of the teeth would be healed, while in the worst-case scenario 57% would be healed. Because the overall 'healed' rate is farther from the lower value than from the upper one, it appears to be overestimated (71). Thus, when a large proportion of the inception cohort is unavailable, the results of the study may be considerably skewed. The results may be considered invalid, unless the unavailable subjects are deceased or cannot be reached, suggesting that their absence is not related to the outcome (75). For this reason, a recall rate of at least 80% is required for a high level of evidence (91–93). The recall rates in the different studies vary from 18% to over 90%, while in many of the studies the recall rate is not even reported (Table 1). This may be one of the reasons for the inconsistent outcomes reported among all the studies.

### *Interpretation of radiographs*

Outcome of apical surgery is predominantly assessed by radiographs; however, radiographs are poorly standardized, being subject to changes in angulation and contrast. More importantly, interpretation of radiographs is subject to bias (94–98). These limitations of radiographs may undermine the reliability of the results. Therefore, to minimize bias and inconsistency, assessment by blinded examiners who are calibrated for standardized interpretation is essential (96, 98–102). This requirement has not been fulfilled in the majority of studies, and thus the reported outcomes are likely to reflect differences in radiographic interpretations.

### *Follow-up period*

Healing after apical surgery is a dynamic process, requiring sufficient time for completion (12) (Fig. 5). As a result, short-term observation periods, particularly

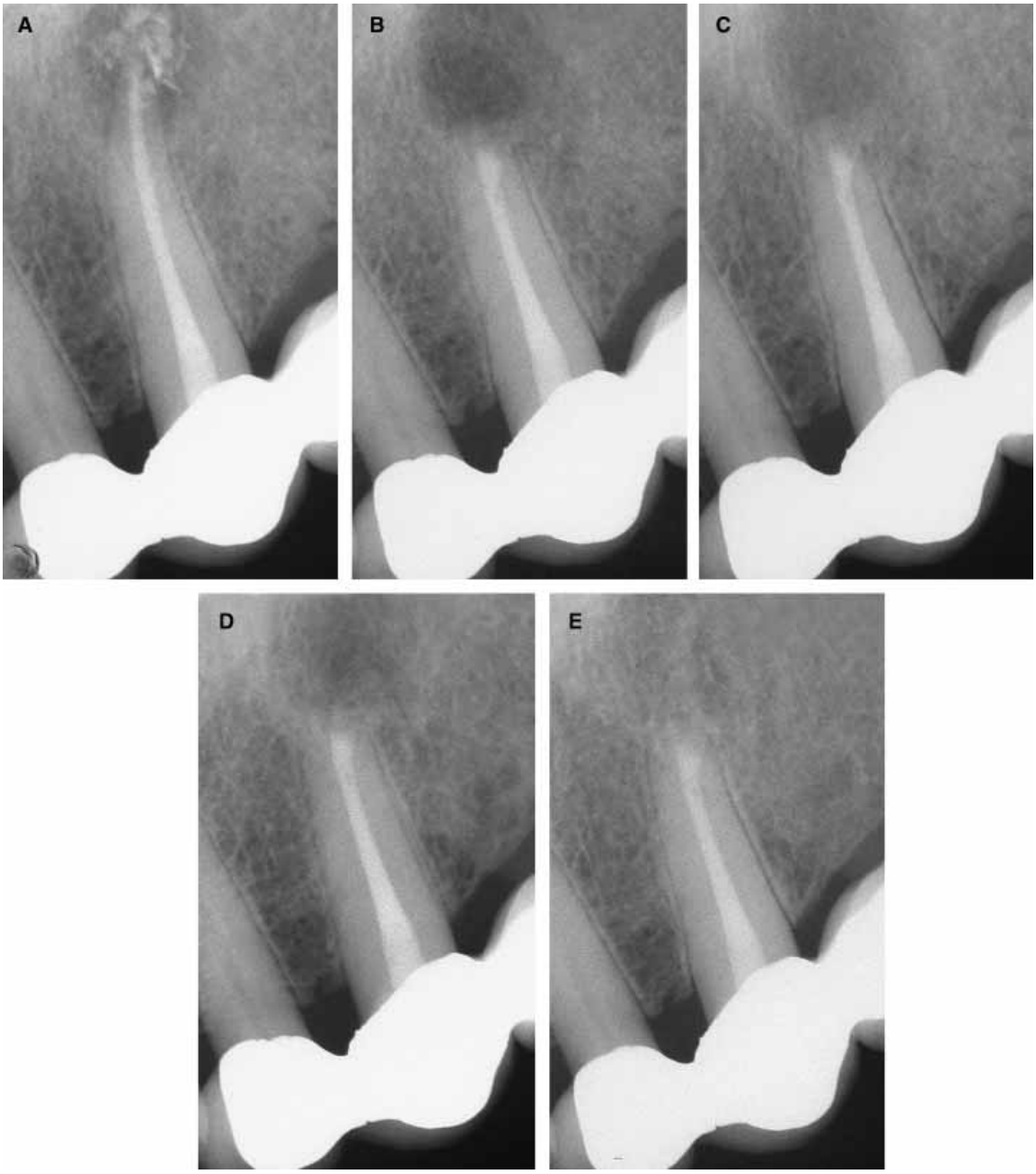


**Fig. 5. Extent of the follow-up period – outcome classification as 'healing' vs. 'healed'. (A) A root-filled maxillary canine with a large excess of sealer and persistent apical periodontitis. (B) Completed surgery, including root-end filling with MTA. (C) After 3 months, some bone deposition is suggested but the lesion is not reduced. (D) After 6 months, there is little further improvement; if assessed at this and the previous end-points, the outcome would be recorded as 'healing,' (E) After 1 year and 8 months, the lesion is replaced with new bone; at this longer-term end-point, the outcome is assessed as 'healed.'**

under 1 year, may underestimate the chances of healing considerably. Furthermore, a particular concern in apical surgery is recurrence of disease, shown to occur in 5% to 42% of healed cases after periods of 4 years or longer (17, 23, 46, 49, 58, 66, 103). For example, of 45 teeth that were healed at the 1-year follow-up, Kvist & Reit (58) report recurrence of disease in four teeth (9%) at the 4-year follow-up. Thus, short-term studies (Table 1) may not reflect the true, long-term outcome of apical surgery (Fig. 5). Because studies vary considerably in the extent of follow-up periods, their reported outcomes are likely to reflect this variability.

### *Analysis*

Statistical analyses are used in treatment outcome studies mainly to investigate the influence of different variables on the prognosis. This issue can be considerably confused by the nature of the analysis, or the lack thereof. In the vast majority of studies, only bivariate analyses are used that ignore the potential confounding effects of multiple variables. For example, the presence or absence of a root-end filling has often been compared in the past, disregarding the fact that some teeth received orthograde treatment in conjunction with surgery, while others did not. When concurrent orthograde treatment was performed, this had a strong positive impact on the outcome (37, 41). Because root-end fillings were usually absent in these teeth, researchers concluded that teeth without root-end filings had a better outcome than teeth with root-end fillings (12). Thus, different analyses or use of only bivariate analysis may lead to different conclusions among studies regarding the prognostic importance of specific variables.

### *Unit of evaluation*

The outcome of apical surgery can be recorded for each root or for each tooth. Considering individual roots as units of evaluation raises concerns with regard to multi-rooted teeth (12). If roots are counted as units, more weight is assigned to studies with a large proportion of multi-rooted teeth than to studies that include primarily single-rooted teeth. Also, the healing rate becomes higher than if the teeth are counted as units (13) (Fig. 1). The majority of the studies consider the tooth as the evaluated unit, but in several studies the individual roots are evaluated as independent units (Table 1).

### *Outcome assessment criteria*

The main cause for the diverse outcomes reported in studies on apical surgery is the inconsistency of the criteria used to assess the outcome. In at least one study (42), the radiographic appearance is used as the only outcome measure, possibly overestimating the 'success' rate by not noting teeth that could be radiographically normal but symptomatic (12). The rate of 'success' is overestimated to an even greater extent when healed and reduced lesions are grouped together, as has often been the case. This important cause of variability of the reported outcomes is debated in detail in the following section.

## How is the outcome assessed and defined?

The classification of outcome has been inconsistent among follow-up studies on apical surgery (12). Considerable confusion is caused by the use of non-specific ambiguous terms, such as 'success' and 'failure', to define the outcomes. The confusion is increased by the frequent lack of calibration of the examiners who assess the outcome, and the use of different observer strategies to record radiographic findings.

### Consistent assessment

The assessment of radiographic images is highly inconsistent (94–98). To improve the consistency of outcome assessment, specific observer and calibration strategies have been suggested for studies on apical surgery (96, 98–102, 104). These strategies, however, have been applied infrequently. The periapical index (PAI), introduced by Ørstavik et al. (105) for the radiographic appraisal of root-filled teeth, has not been validated for teeth followed after apical surgery (68). Nevertheless, the PAI has been used in one recent study on apical surgery (71), to assist in unbiased interpretation of the radiographs and to promote comparisons with studies on non-surgical endodontic treatment by the same group (106–108).

### Success and failure – ambiguous terms

The main disparity among studies on apical surgery is between the use of 'strict' and 'lenient' classifications of a successful outcome, as outlined below.

### *'Complete' and 'incomplete' healing – strict classification*

In the majority of the studies in Table 1, a successful outcome is defined by *full normalcy*, comprising both normal *radiographic* (absence of radiolucency) and *clinical* (absence of signs, symptoms) presentations. It is often referred to as 'complete healing,' and occasionally as 'success.' A typical radiographic appearance of a periapical scar (Fig. 6), referred to as

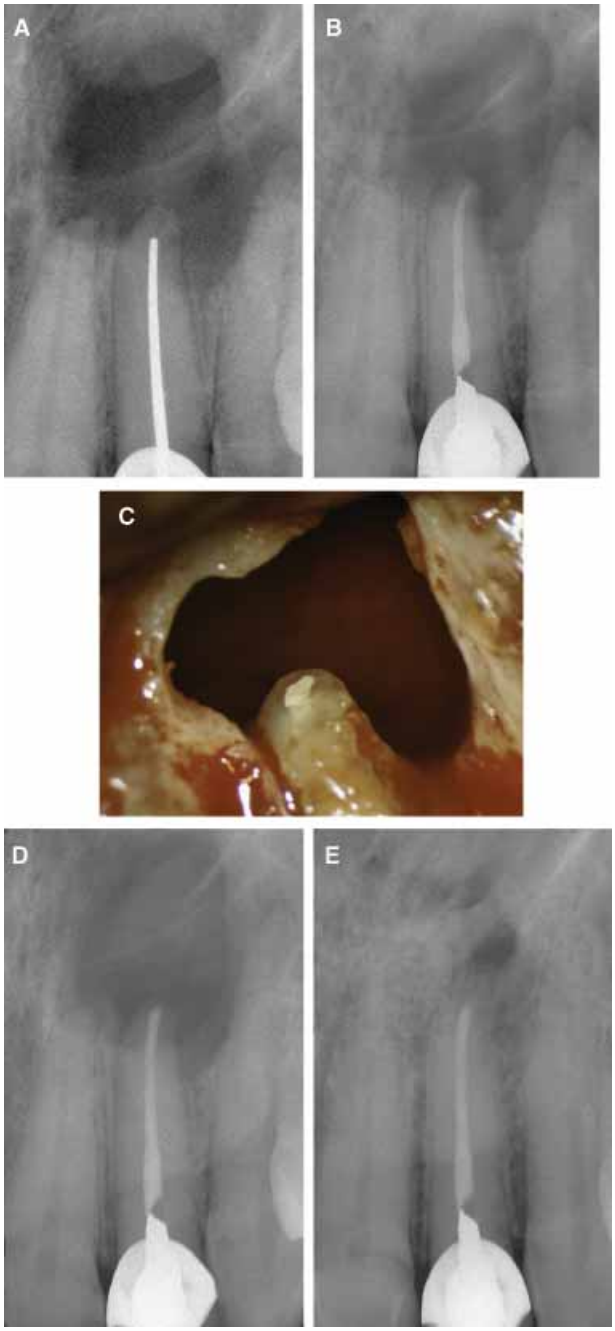


**Fig. 6. Persistent disease after previous retreatment – formation of a scar. (A) A root-filled maxillary lateral incisor with extensive persistent apical periodontitis. (B) Completed orthograde retreatment. Examination after 6 months showed no signs of healing. (C) Clinical view of the large crypt and root-end filling with Super-EBA. (D) Completed surgery. (E) After 2 years, the lesion is healed with a scar formed several millimeters from the root end. (Courtesy of Dr Richard Rubinstein, Farmington Hills, MI, USA.) See also Fig. 7.**

'incomplete' healing or 'cicatrice,' is also considered to be a successful outcome (17, 104, 109–111). Apparently, the 'complete' healing category is particularly subject to observer variation (102), and the 'incomplete' healing category has been subject to interpretation errors; in one report (111), one of 24 teeth classified as 'incomplete' healing was later considered as not healed.

### *'Incomplete' healing – lenient classification*

The category of 'incomplete' healing has often been misused to describe reduced lesions rather than the typical scars, but still considered as a successful outcome. Furthermore, in specific studies (34, 53) a successful outcome is defined primarily by the *normal clinical presentation*, even if it is accompanied by different degrees of residual radiolucency.

### *'Uncertain,' 'improved', or 'doubtful' categories*

These categories add to the inconsistency of outcome classification. In many studies (14, 17, 19–21, 23, 27, 29, 33, 39, 48, 61–63, 65, 70, 112, 113), these terms have been used to describe decreased radiolucency, and considered to be a successful or uncertain outcome. In other studies (11, 32, 37, 38, 41, 43, 51, 52, 55, 57, 60, 62, 64, 69, 73, 74, 103, 111), 'uncertain' healing represents decreased lesions whose appearance is different from those classified as 'incomplete' healing. In these studies, if 'uncertain' healing persists for 4 years or longer it is considered to be an unsuccessful outcome.

The use of the 'lenient' outcome criteria, requiring clinical but not radiographic normalcy, increases the 'success' rate in comparison with the 'strict' criteria requiring both clinical and radiographic normalcy. For example, in the study by Wang et al. (71), 74% of the teeth were healed and a further 15% appeared to be healing (reduced lesion), but only 9% had clinical signs or symptoms. By the 'strict' criteria their success rate is 74%, whereas by the 'lenient' criteria the success rate is 89% if reduction of the lesion is required, or 91% if only clinical normalcy is required.

As long as different researchers and clinicians continue to use different criteria for its definition, the term 'success' will remain ambiguous and its use will continue to confuse communication within the profession and with patients. Because the same term is also used for alternative treatments such as implants, but with a different meaning, there is the risk that indiscriminate use of the term 'success' may mislead

the patients who are weighing apical surgery against replacement of the tooth with an implant. Based on the specific definition of 'success' for single-tooth implants (114, 115) that is very different from that used in endodontics, the reported 'success' rates (115–119) are considerably higher than those reported for apical surgery (Table 1). Being unaware of the differences in the definition of 'success,' the patient is likely to select the treatment alternative that suggests a better chance of 'success,' and give up a tooth that can remain functional for many years. Another concern is the term 'failure,' used in many of the studies on apical surgery to classify an unfavorable outcome. This term is also ambiguous, and it does not imply the necessity to pursue any course of action. According to Ørstavik (120), communication with patients can be promoted if the value-laden terms 'success' and 'failure' are replaced with more neutral expressions, such as 'chance of healing' and 'risk of inflammation.' Thus, it is advisable to avoid the use of the terms 'success' and 'failure' when classifying the outcome of apical surgery.

## Healing, disease, and function – clear terms

Success is generally defined as 'the accomplishment of an aim or purpose' (Oxford Dictionary). The outcome, therefore, *is best defined in direct relation to the specific aim*. The aim of endodontic treatment is to eliminate the cause of apical periodontitis (121). In the context of apical surgery, the aim is to eradicate the disease and allow healing of the site. Accordingly, in order to promote effective communication within the profession and with patients, the outcome of apical surgery should be related to '*healing*' (13). Indeed, the outcome classification introduced by Rud et al. (104) referred to healing (complete, incomplete, uncertain, unsatisfactory), but was construed to represent 'success' and 'failure' (37, 41, 62, 67). Rather than depending on interpretations of 'success' and 'failure,' the terms 'healed,' 'healing', and 'disease' clearly describe the actual observation, as follows:

- *Healed*: A combined clinical (no signs and symptoms) and radiographic (no residual radiolucency) normalcy (Figs 3 and 5). Included in this classification is the strictly defined, typical appearance of a scar (37, 41, 102, 104, 109–111) (Figs 6 and 7).
- *Healing (in progress)*: Reduced radiolucency combined with clinical normalcy, in follow-up periods shorter than 4 years (Fig. 8). This is consistent with the strict definition of 'uncertain' healing (37, 41, 102, 104).
- *Persistent disease*: Persistence of radiolucency – an expression of apical periodontitis – with or without


**Fig. 7. Apical surgery in a tooth with extruded root filling – outcome classification as 'healed.' (A) A maxillary lateral incisor with a root filling extruded beyond the root end, and persistent apical periodontitis. (B) Completed surgery, including root-end filling with Super-EBA. (C) After 1 year, the lesion is healed, with a small scar present several millimeters away from the root end. (Courtesy of Dr Richard Rubinstein, Farmington Hills, MI, USA.) See also Fig. 6.**

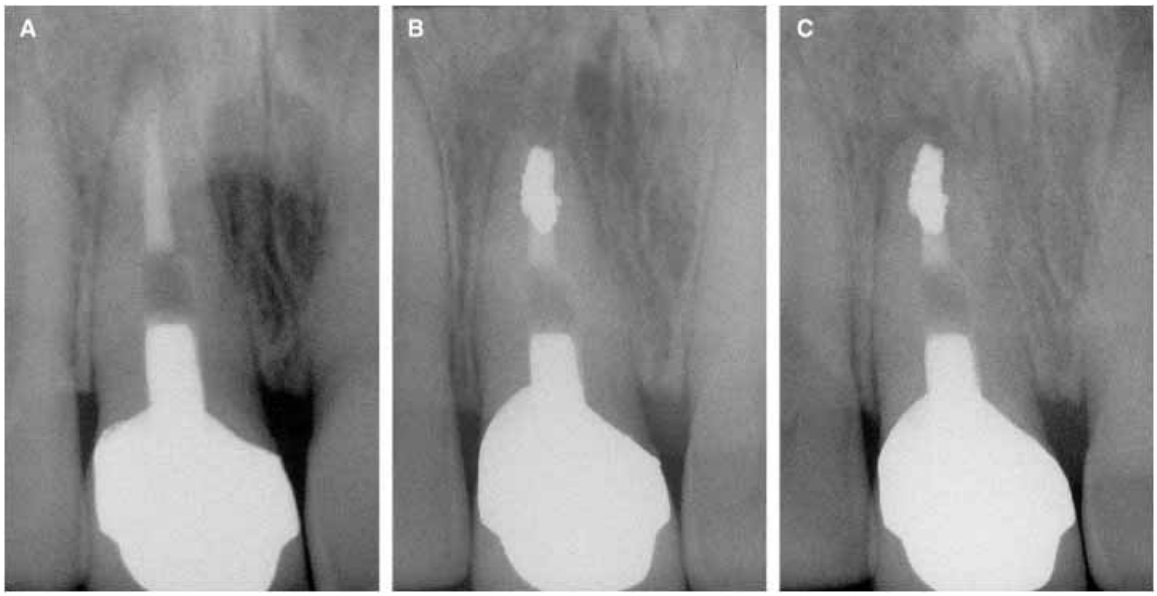


**Fig. 8. Outcome classification as 'healing,' (A) A root-filled maxillary central incisor with persistent apical periodontitis. (B) Completed surgery, including root-end filling with amalgam and varnish. (C) After 1 year, the lesion is considerably reduced but not healed and the tooth is symptom free, indicating that healing is in progress. See also Fig. 5C, D.**

clinical signs and symptoms (Fig. 9), or presence of symptoms even when the radiographic appearance is normal (Fig. 10).

As suggested above, for patient autonomy to be respected, clinicians should encourage individual patients to select from among treatment alternatives based on the patient's own values (2, 6). Similarly, *patients should be encouraged to specify their expectations and thus define what outcome should be considered as successful*. Although the majority of patients may expect healing as the ultimate outcome, individual patients may only expect the elimination of clinical signs and symptoms. Furthermore, patients who would normally require healing may encounter clinical conditions that can compromise the outcome of apical surgery, such as the presence of extensive loss of supporting bone (30). If a patient is still motivated to attempt treatment with the understanding that healing is unlikely to occur, the retention of the tooth in asymptomatic function then becomes the aim of the treatment, and the outcome defined as follows:

- *Asymptomatic function*: Clinical normalcy combined with persistent radiolucency, reduced in size, or unchanged (Fig. 11).

In the review of studies on apical surgery below, the terms 'healed,' 'healing,' 'asymptomatic function', and 'disease' are used, in lieu of the commonly used terms 'success' and 'failure,' The inconsistencies among studies outlined in the previous sections of this article preclude direct comparisons or grouping of studies to calculate average outcomes (12).

## What is the best evidence for prognosis and treatment outcome?

When clinicians seek evidence about the course and prognosis of a disease after a specific intervention, they are advised to go beyond personal experiences and expert opinions, and to consult the clinical literature for applicable information (122). Typically, however, there is great amount of inconsistency among the reports on prognosis (122). Similarly, the reported outcomes of apical surgery differ among the many studies due mainly to inconsistencies in composition, treatment procedures, and methodology, as highlighted above (see the section Why are the reported outcomes diverse?). This diversity obscures the evidence necessary to estimate the prognosis and thus to support clinical decision-making regarding apical surgery. Strategies are required, therefore, that would allow the clinician to 'navigate' the wealth of available literature, and to glean valid and relevant evidence from selected studies. The basis of these strategies is the recognition that *clinical*

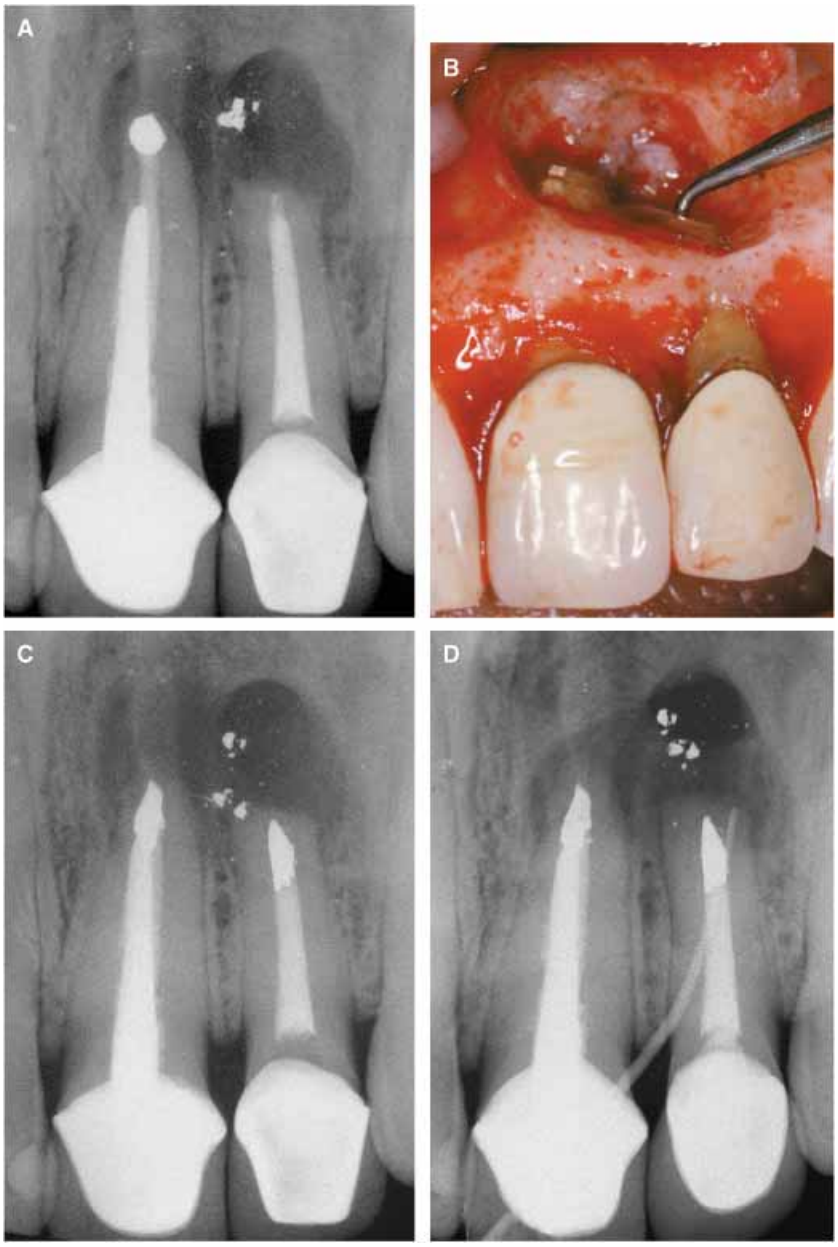


**Fig. 9. Outcome classified as 'persistent disease' based on radiographic and clinical measures. (A) Root-filled, previously surgically treated maxillary incisors with persistent apical periodontitis. (B) Clinical view during repeat surgery, showing minimal bevelling of the cut root surfaces and preparation of root-end cavities with an ultrasonic tip. (C) Completed surgery, including root-end fillings with amalgam and varnish. (D) After 2.5 years, the lesion is not healed and a sinus tract is present, indicating persistence of the disease.**

*studies vary in the level of evidence they provide*, and the necessity to differentiate clinical studies according to the level of evidence. For the purpose of this review, it is necessary to apply an appraisal strategy to identify the studies that provide the best evidence, so as to focus the review mainly on these studies.

## Definition of terms

A brief review of the terms used in the appraisal of studies for levels of evidence is appropriate as a basis for the section below. These definitions also differ somewhat from one authority to another. One example is the recent series of review articles on evidence-based endodontics (1, 123–125), in which the authors define the 'cohort study' as a follow-up of an exposed cohort compared with an unexposed cohort, in contrast to the definition suggested below.

For the purpose of this review, the author used the terms as defined by the Cochrane Collaboration (*http://www.informedhealthonline.org/item.aspx?tabid=15*), as follows:

- *Prospective study*: 'In a prospective study, the study is designed ahead of time, and people are then recruited and studied according to the study's criteria.'

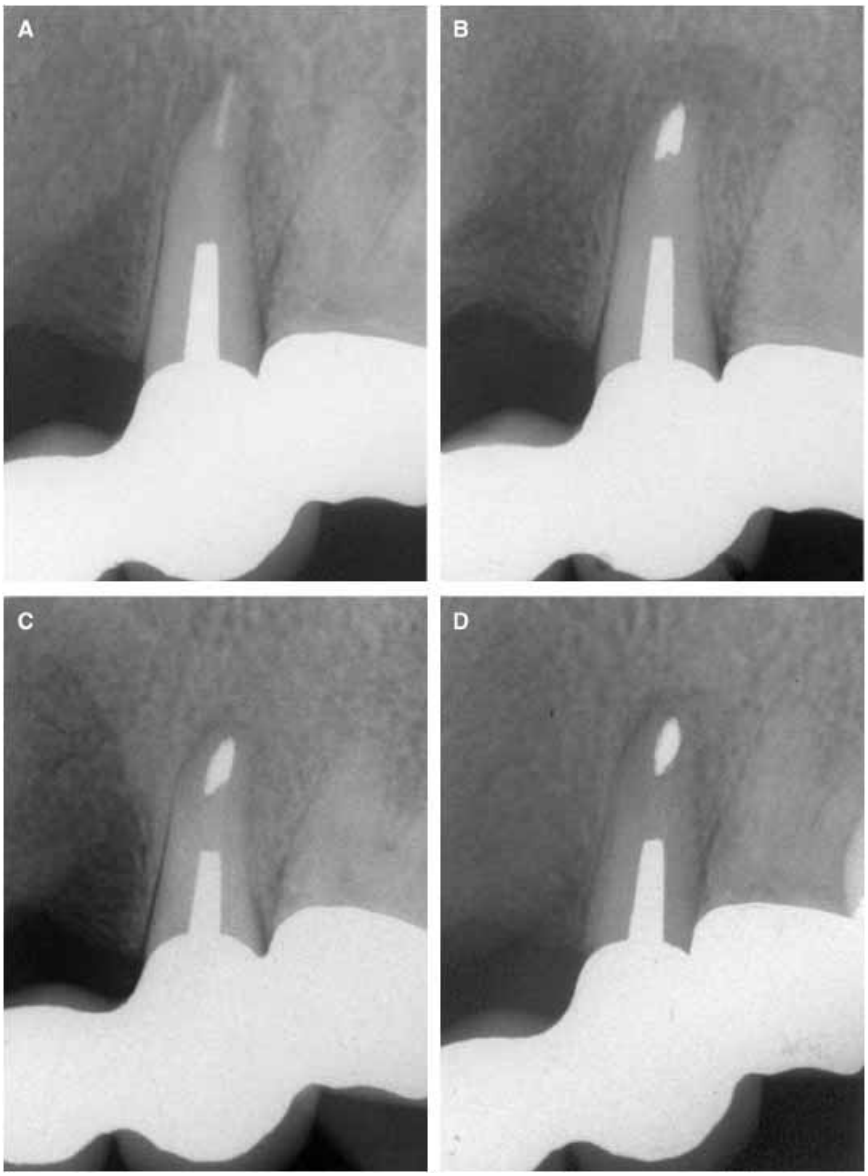


**Fig. 10. Outcome classified as 'persistent disease' based on clinical measures. (A) A root-filled maxillary canine with persistent apical periodontitis characterized by a subtle radiolucency and pronounced pain to apical palpation. (B) Completed surgery, including root-end filling with amalgam and varnish. (C and D) After 6 and 9 months, respectively, the lesion appears to have decreased, but continued pain to palpation suggests persistence of the disease.**

- *Retrospective study*: 'In a retrospective study, the outcomes of a group of people are examined in hindsight ('after the event'). Retrospective studies are generally more limited in the data available for analysis, as the data have rarely been collected with the needs of that particular study in mind. This kind of limitation means that a retrospective study is usually less reliable than a prospective study.'
- *Clinical trial*: 'A clinical trial involves administering a treatment to test it. It is an experiment. Clinical trial is an umbrella term for a variety of health care trials ... Types include uncontrolled trials, controlled clinical trials (CCT), community trials, and randomized controlled trials (RCT). A randomized controlled trial is always prospective.'
- *Observational study*: 'A survey or non-experimental study. The researchers are examining and reporting on what is happening, without deliberately intervening in the course of events.'
- *Cohort study*: 'A 'cohort' is a group of people clearly identified; a cohort study follows that group over time, and reports on what happens to them. A cohort study is an observational study, and it can be prospective or retrospective.' [A prospective study is also named 'concurrent cohort study,' while the retrospective study is named 'historical cohort study' (75)].


**Fig. 11. Outcome classification as 'functional.' (A) A root-filled maxillary lateral incisor with persistent apical periodontitis. (B) Completed surgery, including root-end filling with amalgam and varnish. The root-end cavity and cut root surface were irradiated with Nd : YAG laser. (C) After 6 months, the lesion is considerably decreased, and appears to be healing. (D) After 1 year, the lesion is enlarged relative to (C), and external resorption of the root-end suggests persistence of the disease. Orthograde retreatment, possibly combined with repeat surgery, was recommended to the patient; however, in the absence of clinical signs and symptoms, the patient considered the tooth to be functional and declined the proposed treatment.**

- *Case–control study*: 'Compares people with a disease or condition ('cases') to another group of people from the same population who do not have that disease or condition ('controls'). A case–control study can identify risks and trends, and suggest some possible causes for disease, or for particular outcomes. A case–control study is retrospective.'
- *Cross-sectional study*: 'Also called a prevalence study. It is an observational study. It is like taking a snapshot of a group of people at one point in time and seeing the prevalence of diseases or actions in that population.'
- *Case series*: 'A case study is a report of a single experience. A case series is a description of a number of 'cases'.'

## Appraisal strategy

The design of clinical studies may differ depending on their aim – comparison of the effectiveness of different interventions, assessment of prognosis, or assessment of risk associated with the intervention. Accordingly, there are several strategies for appraising clinical studies to determine their level of evidence and clinical relevance. An important consideration in this process is to differentiate studies designed to assess prognosis or risk; the prognostic factors identified by the former can be different from the risk factors identified by the latter (75).

The most commonly applied criteria are those developed for inclusion/exclusion of studies for systematic reviews of the literature (126). Taking into account the *research design* and *methodological rigor*, the following hierarchy of evidence has been established, from top to bottom:

- Rigorous randomized-controlled trial (RCT); systematic review (SR), or meta-analysis of the same.
- Rigorous cohort study; SR of the same; compromised RCT.
- Rigorous case–control study; SR of the same.
- Compromised cohort or case–control study; cross-sectional study; case series.
- Expert opinion; case report; narrative literature review.

The review process described below was based on two premises:

- The research design of reviewed studies should be matched to the questions asked (75). For questions regarding the prognosis *the suggested design is a cohort study*, while for questions regarding the benefits of different treatments the suggested design is an RCT (75, 127).
- Evidence-based practice is defined as ' . . . the conscientious, explicit and judicious use of *current best evidence* in making decisions about the care of individual patients' (122). Thus, reviews should focus on the best evidence available, even if it does not comply with the highest level.

Arguably, the conclusions from structured reviews of *well-designed* observational studies can be consistent with those of systematic reviews or meta-analyses of RCTs (128, 129). Although controversial, this opinion highlights the methodological rigor of a clinical study as a crucial consideration (130) – rigorous cohort studies can outweigh compromised RCTs. Because the primary focus of this review is the prognosis after apical surgery, and not a comparison of the benefits of apical surgery and alternative treatments (e.g. orthograde retreatment or extraction and replacement), the appraisal process described below also includes cohort studies that appear to be methodologically adequate.

### *Concerns of bias*

Appraisal strategies of clinical studies are primarily concerned with validity and relevance (126). Cohort studies, in particular, are subject to different forms of bias that may distort their conclusions. Because of bias, differences between groups may be demonstrated that do not really exist, while existing differences may be obscured (75). Bias can potentially occur at the stage when the study cohort is assembled (sampling, selection, confounding, or assembly bias). Groups of subjects may differ with regard to prognostic factors other than the studied ones, and these extraneous factors may influence or even determine the outcome of the study (75). Thus, differences observed in the conclusion of the study may result from inherent differences at the beginning of the study, rather than from the assessed variables. In studies on apical surgery, assembly bias may occur if subjects differ in prior treatment, i.e. only initial treatment (Figs 1, 7–11) or also retreatment performed before surgery (Figs 3 and 6). Similarly, bias occurs if subjects are assembled who have a preferential capacity to benefit from treatment, or are not equally susceptible to the outcome studied. In studies on apical surgery, the majority of teeth have apical periodontitis, but occasionally teeth are included that do not have apical periodontitis (63), and these will have a far greater capacity to heal after surgery. Furthermore, bias can occur at the stage when outcomes are assessed (measurement bias) (75). Subjects may differ in the chance of having a specific outcome detected. For example, in studies on apical surgery, the clinical signs and symptoms may go undetected. Likewise, if the examiners are the same as the providers of treatment, their interpretation of follow-up radiographs may be biased toward a more favorable assessment (94).

For studies on prognosis, such that concern this review, the main check list includes the following questions (75, 91–93, 122):

- Was the study cohort defined, assembled at the inception of the study, described in detail, and

entered at a similar point in the course of the disease?
- Was the referral pattern described?
- Were baseline features measured reproducibly?
- Was the follow-up achieved in at least 80% of the inception cohort, the follow-up period described, and long enough for the outcome to occur?
- Were the criteria used for outcome assessment described, objective, clinically important, and reproducibly measured?
- Was the outcome assessment blind?
- Was adjustment for extraneous prognostic factors performed?

The appraisal criteria can be grouped into four general categories, used below as the basis for appraisal of the studies on apical surgery.

### *Cohort, at inception, and end-point of the study*

The best evidence is derived from a *prospective* design, with the *inception cohort* defined before the study is initiated, and then observed over time. The cohort should be *clearly characterized* to ascertain unbiased interpretations. The *pattern of referral* of the treated cohort should be described, including the type of patients treated and the case selection criteria used, to determine the external validity (applicability to the population at large) of the reported results (75). At the end-point of the study, at least 80% of the treated subjects should be examined. Importantly, the *entire inception cohort must be accounted for* to allow identification of 'dropouts' (subjects who do not present for follow-up at their own volition; their absence may be related to the outcome of interest) and 'discontinuers' (subjects who are excluded from the study by the investigator for accountable reasons, e.g. death or relocation; their absence is not related to the outcome of interest), to allow accurate calculation of the recall rate. Finally, the *sample size*, or size of the inception cohort, may be required to exceed a certain threshold as determined by the reviewer. For the purpose of this review, a minimum sample size of 45 teeth was required.

### *Exposure (treatment, intervention)*

The *treatment procedures* should be clearly described, to avoid the need for interpretation. The *treatment providers* (students, general dentists, specialists) should be characterized to establish the external validity of the results (75). The reviewer may choose to exclude studies if the treatment procedures described are considered irrelevant to the review, or otherwise unacceptable. For example, a specific technique of apical surgery comprising a 'bony lid approach' has been described (39); if the review is concerned with the typical forms of apical surgery, the 'bony lid' study may be excluded.

### *Outcome assessment*

The assessment of outcomes in a study should follow strict rules in order to minimize measurement bias (75). Outcome dimensions and measures should be *clearly defined*. Bader & Shugars (131) define four dimensions of dental outcomes:
- physical/physiological – pathosis, pain, and function;
- psychological – perceived esthetics, level of oral health, and satisfaction with oral health status;
- economic – direct and indirect cost; and
- longevity/survival – tooth loss and time until repeat treatment for same or new condition.

The apical surgery studies of interest usually assess the first, the last, or both of the dimensions listed above, leaving out the second and third dimensions. The outcome measures used to assess these dimensions should be as *objective* as possible. To ascertain *consistent assessment* throughout the study, examiners should be *properly calibrated* and their *reliability established*. Outcome assessment should be *blinded or masked*; therefore, the examiner(s) measuring the outcome should be different from the provider(s) of the treatment, and direct comparisons of radiographs, e.g. pre-operative and at follow-up, must be avoided.

The follow-up period should be *long enough* to capture the conclusion of the healing processes in the majority of the study sample. Although 1 year has been suggested as an adequate follow-up period (37, 41, 103), the risk of recurrence of disease in the longer term after apical surgery (17, 23, 46, 49, 58, 66, 103) suggests that the follow-up period should be at least 4 years. For the purpose of this review, a minimum follow-up of 1 year was required.

### *Reporting of data and analysis*

The reporting of a study should be detailed to the extent that will allow skilled readers to identify potential

biases and assess the validity of the study. Thus, all data pertaining to the study cohort, the exposure, outcome assessment, and analysis should be provided clearly in the report. The statistical analysis should be designed so as to minimize potential bias. The analysis should take into account extraneous factors, and the potential confounding effects of different prognostic factors. In many observational studies, the investigators do not control the prognostic factors; at the least the uncontrolled factors should be observed and recorded, to allow judicious analysis of the outcomes.

### Selected studies

Studies pertaining to the outcome of apical surgery published in the past 40 years are listed in Table 1 with data related to this review. The outcome in all the listed studies is interpreted from that reported by the original authors, as follows:

- Combined clinical, and radiographic normalcy is classified as 'healed.'
- Whenever the rate of reduced radiolucency combined with clinical normalcy is given, this is classified as 'healing.'
- The rate of teeth without signs and symptoms is classified as 'functional' – for several studies, this is simply the sum of 'healed' and 'healing' (when both are available), while for others it also includes teeth where the radiolucency persisted.

True 'survival' is not used as an outcome category, because in the majority of studies the outcome is calculated after extracted teeth are excluded from the sample. The long-term survival of teeth treated by apical surgery is available from one study (132). Typically, the survival rates are lower than the healing and functional rates reported in cohort studies.

The listed studies are related to the general categories of appraisal criteria outlined above, and notation is made of their compliance with those criteria. Insistence on strict compliance with all four criteria would result in a very narrow evidence base. To broaden the evidence base, studies that satisfy any three of the four categories have been selected. These seven studies (58, 62, 63, 67, 68, 71, 72) form the *best evidence* for estimating the prognosis after apical surgery, and serve as the reference for defining the expected outcome and its predictors.

The selected studies are listed in Table 2 with highlights of their methodology. Notably, they are rather uniform in methodology, but still represent considerable differences in case selection and the composition of study materials. For example, all the teeth included in the study by Zuolo et al. (62) had received orthograde retreatment at least once before surgery. Chong et al. (68) imply that many teeth included in their study were previously retreated, but the proportion of these teeth is not specified. Two other studies (63, 71) included 37–39% of previously retreated teeth, while the other studies (58, 67, 72) do not mention the previous treatment history of their sample. As highlighted above and reiterated in the sections below, the outcome of apical surgery after previous orthograde retreatment (Figs 3 and 6) is expected to be better. Similarly, in Rahbaran et al. (63), Gagliani et al. (72), and Wang et al. (71), teeth with a previous history of apical surgery comprise 44%, 33%, and 10% of their samples, respectively. In contrast, Jensen et al. (67) included only teeth that required first-time surgery, while the other studies (58, 68) do not characterize their cohorts with regard to previous surgery. As highlighted below, the outcome of repeat surgery is expected to be poorer than that of first-time surgery (Fig. 12).

## What is the expected outcome of apical surgery?

Apical periodontitis affecting root-filled teeth ('post-treatment disease,' or 'non-healing') is caused primarily by residual or subsequent infection after previous treatment. It can be treated by orthograde retreatment, apical surgery, intentional replantation, or a combination thereof. This article reviews only the prognosis and expected outcome after treatment by apical surgery.

### Reported proportions of different outcome categories

Although the seven studies (58, 62, 63, 67, 68, 71, 72) selected from all those listed in Table 1 were all assessed as methodologically adequate, there is still considerable inconsistency in their reported outcomes.

#### *Proportion of healed teeth*

The most pronounced variation among the studies selected for the review exists in the 'healed' rate, ranging from 37% (63) to 91% (62). This range is

**Table 2. Methodological characteristics of follow-up studies selected for review**

| Methodological considerations | | Kvist & Reit (1999) | Zuolo et al. (2000) | Rahbaran et al. (2001) | Jensen et al. (2002) | Chong et al. (2003) | Wang et al. (2004) | Gagliani et al. (2005) |
|---|---|---|---|---|---|---|---|---|
| Type of study | Direction | Prospective | Prospective? | Retrospective | Prospective | Prospective | Prospective | Prospective? |
| | Design | RCT | Cohort | Cohort | RCT | RCT | Cohort | Cohort |
| Cohort | Tooth type | Anteriors | Anteriors 38%<br>Premolars 24%<br>Molars 38% | Anteriors 73%<br>Premolars 19%<br>Molars 8% | Anteriors 25%<br>Premolars 33%<br>Molars 42% | Single-rooted<br>Molars (M roots) | Anteriors 39%<br>Posterior 61% | Anteriors 17%<br>Premolars 33%<br>Molars 50% |
| | Inclusion criteria | AP present | AP present<br>1 tooth/subject<br>At least 1 retreat<br>Good restoration | 20% w/o AP<br>No probing<br>Good root filling<br>Good restoration | 1 tooth/subject | AP present<br>1 tooth/subject<br>No probing<br>Good root filling<br>Good restoration | All included | No probing<br>Good root filling<br>Lesion <10 mm |
| | Exclusion criteria | Recent retreatment<br>Probing to apex | Fracture<br>Perforation<br>Resorption<br>Trauma<br>Probing >7 mm<br>Loss of bone plate | | Previous surgery | | None | |
| | Previous retreatment | | 100% | 39% | | Yes; ?% | 37% | |
| | Previous surgery | | None | 44% | None | | 10% | 32% |
| Intervention | Operators | Endodontist | Endodontist | Endodontics residents | 4 oral surgery residents | Endodontist | Endodontics residents | Endodontist |
| | Resection level | 1–2 mm | 2–4 mm<br>Bevel | | 2–3 mm | No bevel | | 3 mm<br>Little bevel |
| | Hemostasis | | | | Epinephrin | | Epinephrin<br>Ferric sulfate | Ferric sulfate |
| | Cavity preparation | Bur<br>34% R-rtx | Ultrasonic | Bur or ultrasonic | Scooped | Ultrasonic | Ultrasonic<br>7% R-rtx | Ultrasonic |
| | Root-end filling material | GP softened with chloroform or heat | IRM | S-EBA, amalgam, IRM, GP, none | Retroplast<br>GIC | IRM<br>MTA | Amalgam, IRM<br>s-EBA, CR, MTA, none | ZOE with EBA |

**Table 2. Continued**

| Methodological considerations | | Kvist & Reit (1999) | Zuolo et al. (2000) | Rahbaran et al. (2001) | Jensen et al. (2002) | Chong et al. (2003) | Wang et al. (2004) | Gagliani et al. (2005) |
|---|---|---|---|---|---|---|---|---|
| | Magnification | | | | | Microscope | Loops | Loops × 4.5 |
| | Sutures | | Monofilament 5×0<br>3–4 days | 4–7 days | Vicryl 4×0 | 4–7 days | | Silk |
| | Antibiotics<br>Anti-inflammatories | | 7 days<br>Steroid | 45% of teeth | Only when sinus invaded | | 44% of teeth | |
| | Antiseptic rinse | | 4 days | 7 days | | Used | 7 days | |
| Assessment | Radiographic aids | Stents | | | None used | Stents | Parallel device | Parallel device |
| | Radiographic criteria | 'Strict definition of healing/disease' | CH = success<br>IH = success<br>UH = failure<br>>4 years<br>US = failure | CH = success<br>UH = uncertain<br>Failure | CH = success<br>IH = success<br>UH = doubtful<br>US = failure | CH = success<br>IH = success<br>UH = failure<br>US = failure | PAI 1,2 = healed<br>PAI ⩾ 3 = disease | CH = success<br>IH = improvement<br>Failure |
| | Calibration | | Yes | Yes | No | Yes | Yes | Yes |
| | Blinding | | | Yes | No | Yes | Yes | Yes |
| | Observers | 2 | 2 | 3 | 3 | 2 | 1 | 2 |
| | Conflicts resolved | Joint assessment | Joint assessment | Joint assessment | Consensus or majority | Joint assessment | NA | Worst accepted |
| Analysis | Follow-up | 6, 12, 24, 48 months | 1–4 years<br>Successful not followed further | 1, 2, 4 years | 1 year | 1, 2 years | 4–8 years | 5 years |
| | Evaluated unit | Tooth | Tooth | Tooth | Tooth | Root and tooth | Tooth | Root |
| | Bivariate tests | Used | Used | Not used | Used | Used | Used | Used |
| | Multivariate tests | NA | Not used | Used | Used | NA | Used | NA |

AP, apical periodontitis; R-rtx, retrograde retreatment; GP, gutta-percha; GIC, glass-ionomer cement; CR, composite resin; ZOE, zinc oxide eugenol; CH, complete healing; IH, incomplete healing; UH, uncertain healing; US, unsatisfactory healing; NA, not applicable; IRM, intermediate restorative material; EBA, ethoxy benzoic acid; MTA, mineral trioxide aggregate.

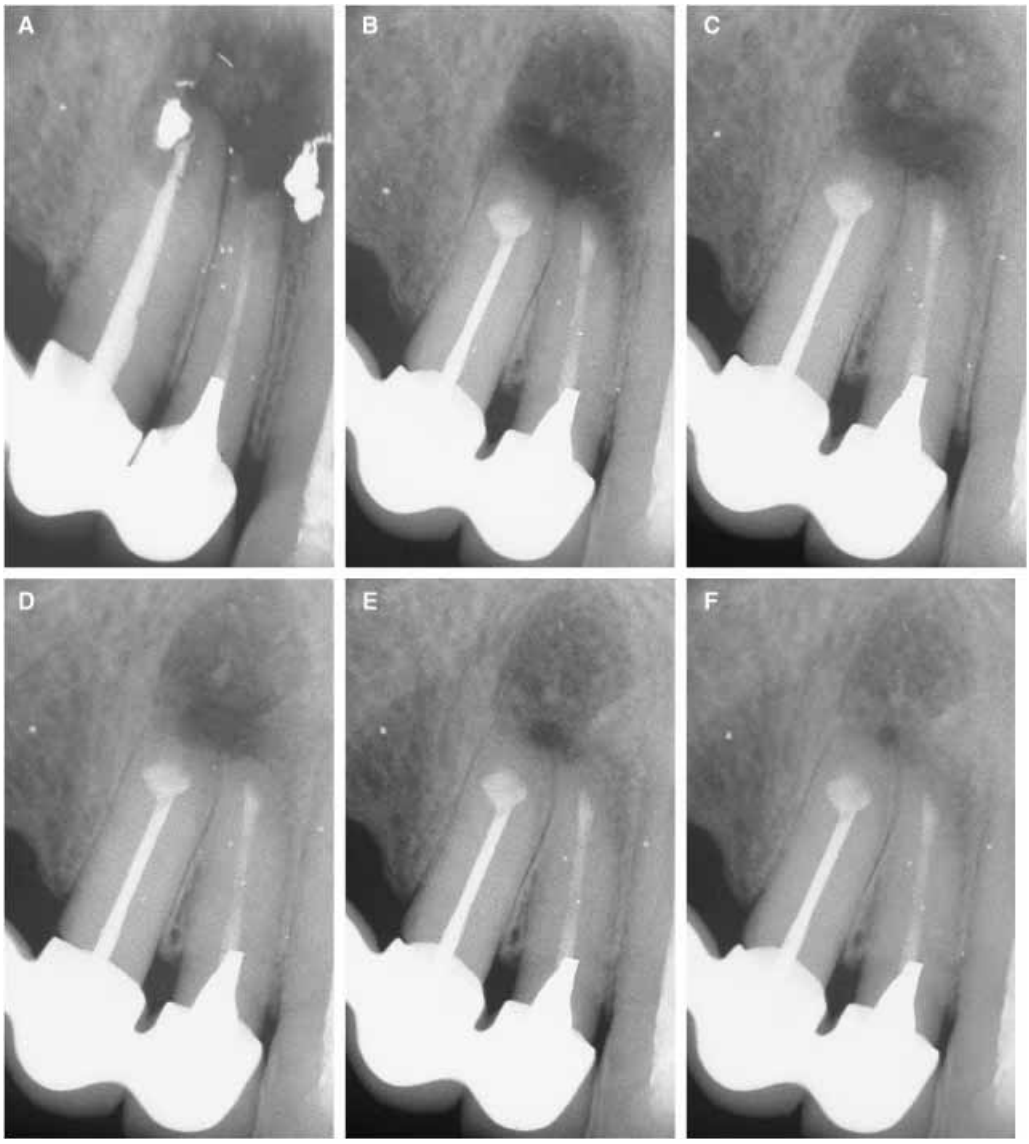


**Fig. 12. Repeat (second-time) surgery. (A) Root-filled and previously surgically treated maxillary lateral incisor and canine, with poorly placed root-end fillings and persistent apical periodontitis. (B) Completed repeat surgery, including root-end filling with MTA. (C-E) After 4, 7, and 13 months, respectively, the lesion is becoming gradually smaller. (F) After 1.5 year, the lesion is healed; a small scar is present between the two treated roots. See also Fig. 9.**

almost as large as that observed across all studies (Table 1), in contrast to the expected uniformity of studies that satisfy the appraisal criteria. Because in these studies the outcome criteria are well defined and rather consistent, the variation in reported outcomes must be related to other factors (see the section Why are the reported outcomes diverse?).

- The variation may have resulted from assembly bias, particularly from inclusion of teeth with persistent disease after previous orthograde retreatment (Figs 3, 6), as opposed to previous initial treatment (Figs 1, 7, 8, 10, 11). These two scenarios may differ with regard to the site where the persistent bacteria are located (12, 71, 77). Persistence of disease after previous retreatment suggests that 'intracanal irritants and contamination' were reduced (62), and infection is sustained by bacteria situated beyond reach, in the apical ramifications of the canal (133), the outer surface of the root tip (134), or the periapical tissue (135). In all these sites, the infection would be eradicated by the surgical removal of the root tip and periapical tissue; indeed, the reported healed rate in teeth that have been retreated at least once before the surgical treatment

is 84% (71) to 91% (62). Persistence of disease after initial treatment is more likely to be sustained by bacteria situated within the root canal (136, 137). Rather than eradicating these bacteria, an attempt is made during surgery to enclose them by placement of a root-end filling. The proportion of teeth where apical surgery was performed because of persisting disease after retreatment has been specified in only three of the studies (62, 63, 71).

- The variation may have resulted from differences in treatment procedures. The techniques and materials used in one of the selected studies (58) differ from the current ones used in the more recent studies (62, 63, 67, 68, 71, 72). These current procedures included use of ultrasonic tips to prepare deeper, cleaner, and better-aligned root-end cavities, with a lesser risk of lingual perforation than with the round burs used in the past (78, 80, 81, 83, 138). Magnification and micro-instruments were used (68, 71, 72), which facilitated identification and treatment of accessory canals and isthmuses, as well as detection of root cracks (81, 138–140). These modern tools are amenable to work in smaller bony crypts and with lesser apical bevel, so that fewer dentinal tubules become exposed (78, 80, 81, 83, 141). Instead of using amalgam for root-end filling, IRM, Super-EBA cement, MTA, or a dentin-bonded composite resin was used, with the expectation of improved clinical performance based on favorable outcomes in animal studies (84–89). Collectively, these current procedures may have improved the outcome of treatment in some of the more recent studies when compared with the study where these techniques were not used (58).

### *Proportion of healing teeth*

When reported, the 'healing' rates varied between 6% (68) and 33% (63). A high proportion of teeth demonstrating progressive healing usually indicates a short follow-up period that is insufficient for capturing the completion of the healing process (12, 13). Therefore, it is atypical that the highest proportion of 'healing' was reported after a follow-up of 4 years or longer (63). Possibly, the cohort in this particular study included many large lesions that healed by formation of a scar (Figs 6 and 7) and were included in the 'uncertain' category (consistent with the definition of 'healing'), whereas in the other selected studies, scars were included in the 'incomplete healing' category (consistent with the definition of 'healed'). Thus, the proportion of cases classified as 'healing' in the different studies may have resulted from the specific case selection or outcome classification used in each study.

### *Proportion of asymptomatic functional teeth*

Four of the selected studies (62, 63, 71, 72) suggest that 80–94% of the teeth are 'asymptomatic and functional' at the follow-up examination (Fig. 11). This rate of 'asymptomatic function' is not synonymous with the lower 'survival' rate reported in another study (132) because the former does not take into account all lost teeth. Thus, the reported rate of 'asymptomatic function' overestimates the probability of teeth to be retained after apical surgery. Importantly, however, a survival analysis may underestimate the chance of teeth to be retained, if the reported tooth loss includes functional teeth without disease that are extracted as part of a comprehensive treatment plan or to avoid costly restorative or periodontal treatment. The good potential for maintained asymptomatic function suggests that for root-filled teeth with apical periodontitis and with a reasonable periodontal prognosis, *apical surgery is a conservative treatment option that should be attempted* rather than having the tooth extracted and replaced.

## Dynamics of healing

Healing progresses quickly after apical surgery, peaking within the first year after treatment (58, 103). Approximately 60% of the teeth that heal eventually, and almost all those that heal by scar, are already healed by 1 year (25, 26, 37, 69, 103, 111). From those that appear as healing at 1 year, over one-half are healed by 3 years, totalling approximately 85% of the teeth that heal eventually, while about one-quarter revert to disease (17, 37, 103). The majority of teeth that appear either healed or diseased at 1 year demonstrate the same outcome also at 3–5 years (17, 23, 25, 66, 103). Thus, apparently, the 1-year follow-up may be considered conclusive for the majority of cases, while a longer follow-up is required only for those cases that appear as still healing (103, 111). However, recurrence of disease in the long-term (Fig. 13) has been reported in 5% to over 40% of healed cases (17, 23, 46, 49, 58, 66, 103). It is advisable, therefore, to perform follow-up

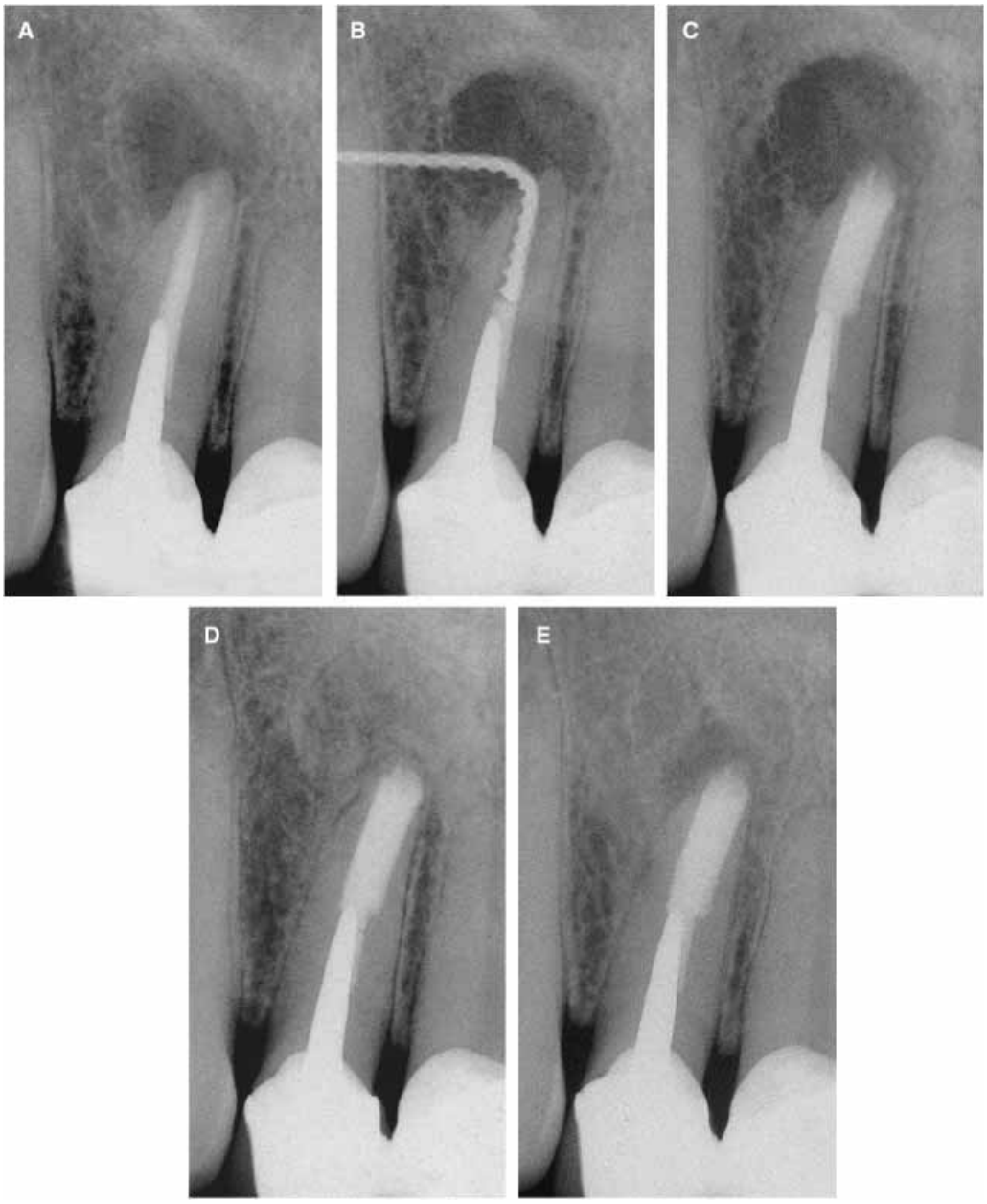


**Fig. 13. Recurrence of disease after confirmed healing. (A) A root-filled maxillary lateral incisor with persistent apical periodontitis. (B) Measurement of the extent of retrograde retreatment performed. (C) Completed surgery, including a root filling with sealer and injectable gutta-percha. (D) After 6 months, the lesion is healed. (E) After 2.5 years, renewed radiolucency demonstrates recurrence of the disease.**

examinations on the teeth periodically even if they appear healed at the 1-year examination.

Healing after apical surgery can be in the form of fibrous periapical tissue (scar) (Figs 6, 7, 12) rather than deposition of bone at the surgery site (102, 104, 109–111). This form of healing occurs particularly when a cavity is formed in the bone through both the buccal and the lingual plates (37, 41). Because the scar remains stable over time (111), the area is considered healed (102, 104, 111).

## Persistence of disease

Persistent disease after apical surgery (Figs 1, 4, 9, 10, 11, 13) usually occurs when the attempt to seal the bacteria within the root canal system is ineffective (12).

The root canal bacteria may interact with the periapical tissues by means of different pathways:

- Accessory canals or isthmuses between canals may not be sealed by the root-end filling (81, 142).
- Exposed dentinal tubules cut open after apical resection may communicate between the root canal space and periapical tissues (143–145) (Fig. 14). The number of exposed tubules corresponds to the degree of bevelling of the cut root surface (145).
- The root-end filling fails to seal the canal effectively, either because of poor placement and adaptation, or poor sealing ability (12, 90).

**Fig. 14. Patent dentinal tubules at the cut root surface. A root specimen, taken out of a dog 6 months after apical surgery, subjected to dye leakage and then sectioned vertically. The root-end filling was dislodged to allow assessment of dye penetration. Note the bevelled cut surface and dye penetration through the dentinal tubules, demonstrating the communication between the root canal and periapical environment. The dentinal tubules can provide a pathway for intra-canal bacteria to bypass the root-end filling and sustain the disease process.**

## Which factors influence the outcome of apical surgery?

In a comprehensive review of the studies on apical surgery, Friedman (12) has listed several factors that appear to influence the outcome of treatment to some extent. In this narrative review, no attempt was made to differentiate studies according to the level of evidence. Consequently, contradictory results were rather frequent. The present review focuses primarily on the studies selected in accordance with the level of evidence (58, 62, 63, 67, 68, 71, 72), as described above. For easy identification in the following section, the citation numbers referring to these studies are highlighted by **bold font type**. The non-selected studies (identified by regular font type) are cited only where selected studies are not available as reference. As in the earlier review (12), the prognostic factors are divided into pre-, intra-, and post-operative.

### Pre-operative factors

The pre-operative prognostic factors form the basis for estimating the outcome after apical surgery, and thus the expected benefit that the patient can weigh against those of alternative treatments. Therefore, it is important to recognize the pre-operative factors and to take them into account at the stage when treatment decisions are formulated.

#### *Patient's age, gender, and systemic health*

In the studies that examined the patients' age **(62, 63, 71)** and gender **(62, 63, 71)**, these factors have not significantly influenced the outcome of treatment. Systemic health has not been assessed as a prognostic factor in any of the studies. Thus, none of these factors should be considered to influence the outcome of apical surgery.

#### *Tooth location*

In several studies **(62, 63, 71, 72)**, comparable outcomes have been reported for different tooth types, in both the maxilla and mandible. The only outcome feature related to tooth location is the frequent healing by scar tissue observed in maxillary lateral incisors (37, 41). Apparently, when apical surgery is performed on any tooth, anterior or posterior, the specific convenience of access and root anatomy influences the outcome to a greater extent than the location of the tooth *per se* (12).

### *Clinical signs and symptoms*

A comparable treatment outcome has been reported for asymptomatic teeth and for teeth presenting with pre-operative symptoms **(63, 71)**. Therefore, the presence or absence of symptoms should not be considered to influence the outcome of apical surgery, even though in one study (32) a poorer outcome was reported in teeth with a sinus tract present (Fig. 15).

### *Lesion size*

One study **(63)** suggests that the lesion size has no significant influence on the outcome of treatment. However, in another study **(71)** a better outcome is reported in teeth with small lesions, up to 5 mm in diameter, than in teeth with larger lesions (Fig. 1). The authors hypothesize that when the lesion is small, surgical enlargement of the crypt is required to gain adequate access, resulting in eradication of the pathological lesion and creation of an excisional wound in the surrounding bone (146). When the lesion is large, the access is adequate and the crypt is not enlarged to avoid injury to adjacent anatomic structures; therefore, curettage of the pathological lesion may be incomplete and an excisional wound is not created. Thus, a better outcome may be expected when the lesion diameter does not exceed 5 mm. When the lesion is very large, exceeding 10 mm in diameter, more healing by scar tissue occurs (37, 41).

### *Supporting bone loss*

The treatment of teeth where the entire buccal bone plate is missing (Fig. 2) has not been assessed in any of the selected studies. However, several other studies (11, 23, 25, 30, 32) have suggested a poor prognosis for teeth with considerable bone loss, either vertical or marginal. Such bone loss can compromise periodontal reattachment by apical migration of gingival epithelium. Consequently, bacteria present in the periodontal sulcus may invade the periapical site and prevent healing (12).

### *Restoration of the tooth*

Apical surgery is frequently performed on teeth that are already restored; in these teeth, the restorative status is a pre-operative consideration. In one study **(63)**, a poorer treatment outcome is reported in teeth with a faulty coronal seal or with a post; however, this finding is not corroborated by another study **(71)**. Although there is insufficient data to assess the prognostic significance of the restoration, it is clear that a defective restoration can impair the survival of endodontically treated teeth (147) (Fig. 4). Indeed, Wang et al. **(71)** report that of 10 teeth lost after apical surgery, seven teeth (70%) were extracted because of restorative considerations, while two teeth were extracted because of fracture and one tooth because of persistent apical periodontitis.

### *The existing root filling*

The root filling with which the tooth presents for surgery can be characterized by its material, density, and length. The type of filling material does not influence the outcome of apical surgery **(63, 71)**. The filling density – absence (Fig. 3) or presence (Fig. 8) of voids – also does not appear to influence the outcome **(63, 71)**. With regard to the filling length, a significantly better outcome is reported when the filling is too short ( $\geq 2$ mm from the root end) or too long (extruded beyond the root end) (Fig. 7) than when its length is adequate **(71)**; however, this finding is not supported by another study **(63)**.

### *Repeat (second-time) surgery*

Two studies focusing on repeat surgery (**72**, 112), and a systematic review of several non-selected studies (148) have concluded that the prognosis after repeat surgery is poorer than after first-time surgery (Figs 9 and 12). This finding is contradicted by two other studies **(63, 71)**. Wang et al. **(71)** report a non-significant difference in outcome between first-time (79% healed) and second-time (62% healed) surgery. As only eight teeth received repeat surgery, this analysis may be underpowered. Nevertheless, the authors speculate that in the other studies, surgery was frequently repeated using the same case selection criteria and techniques as in the first surgery, whereas in their study orthograde retreatment was preferred over repeat surgery (Fig. 16). In the few cases of second-time surgery, the technique differed from that of the first-time surgery. The authors suggest that the modified case selection and techniques may

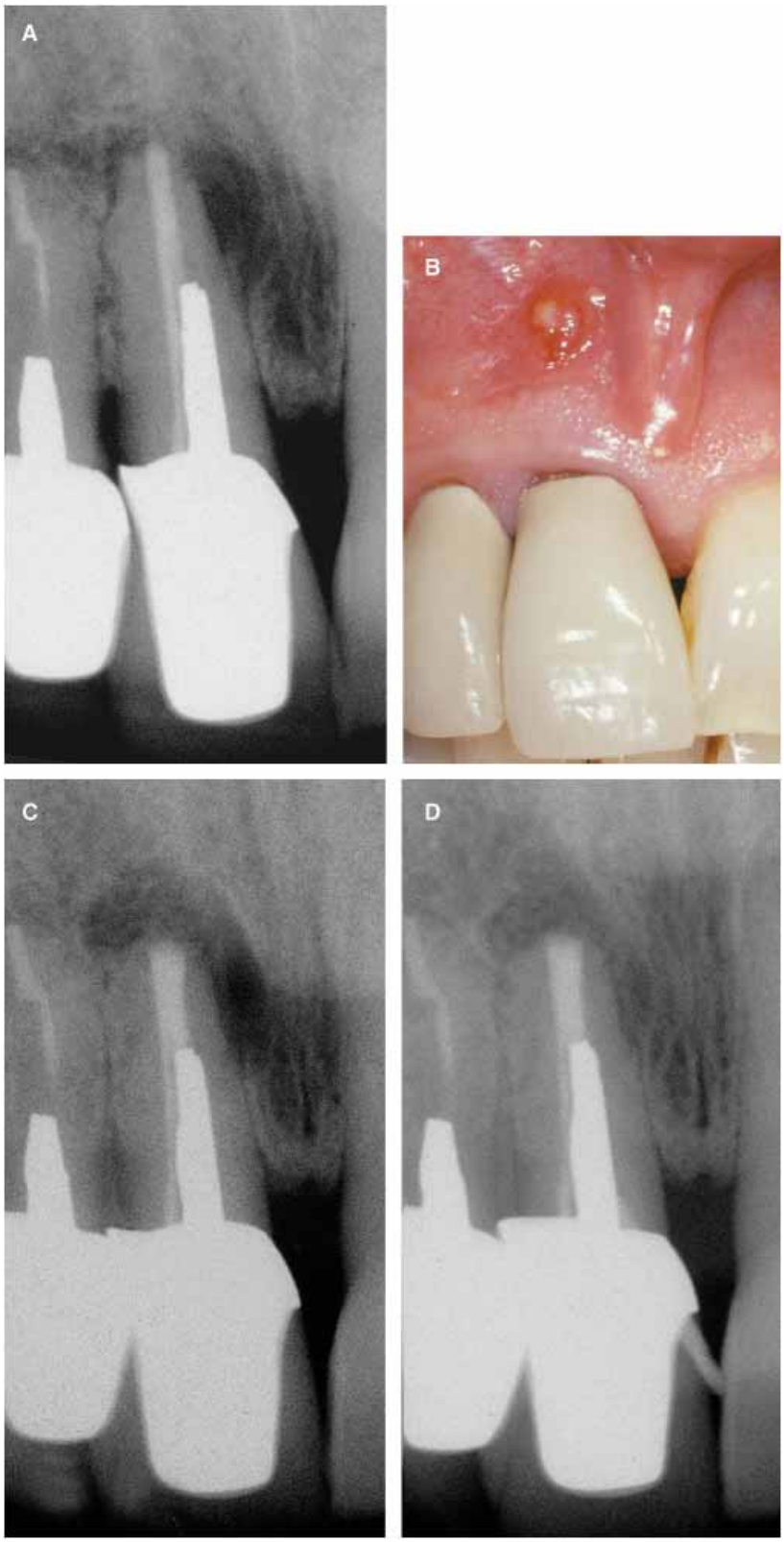


**Fig. 15. Pre-operative presence of a sinus tract – a poor prognosis? (A and B) A root-filled maxillary central incisor with persistent apical periodontitis associated with a sinus tract. (C) Completed surgery, including root-end filling with Super-EBA. (D) After 6 months, the lesion is not healed and a sinus tract is present (traced with a gutta-percha cone), indicating persistence of the disease.**

have resulted in a higher healing rate after repeat surgery in their study than in previous studies **(71)**. Thus, the outcome of repeat surgery may be poorer than that of first-time surgery, unless the repeat procedure is performed with an improved approach (Fig. 12).

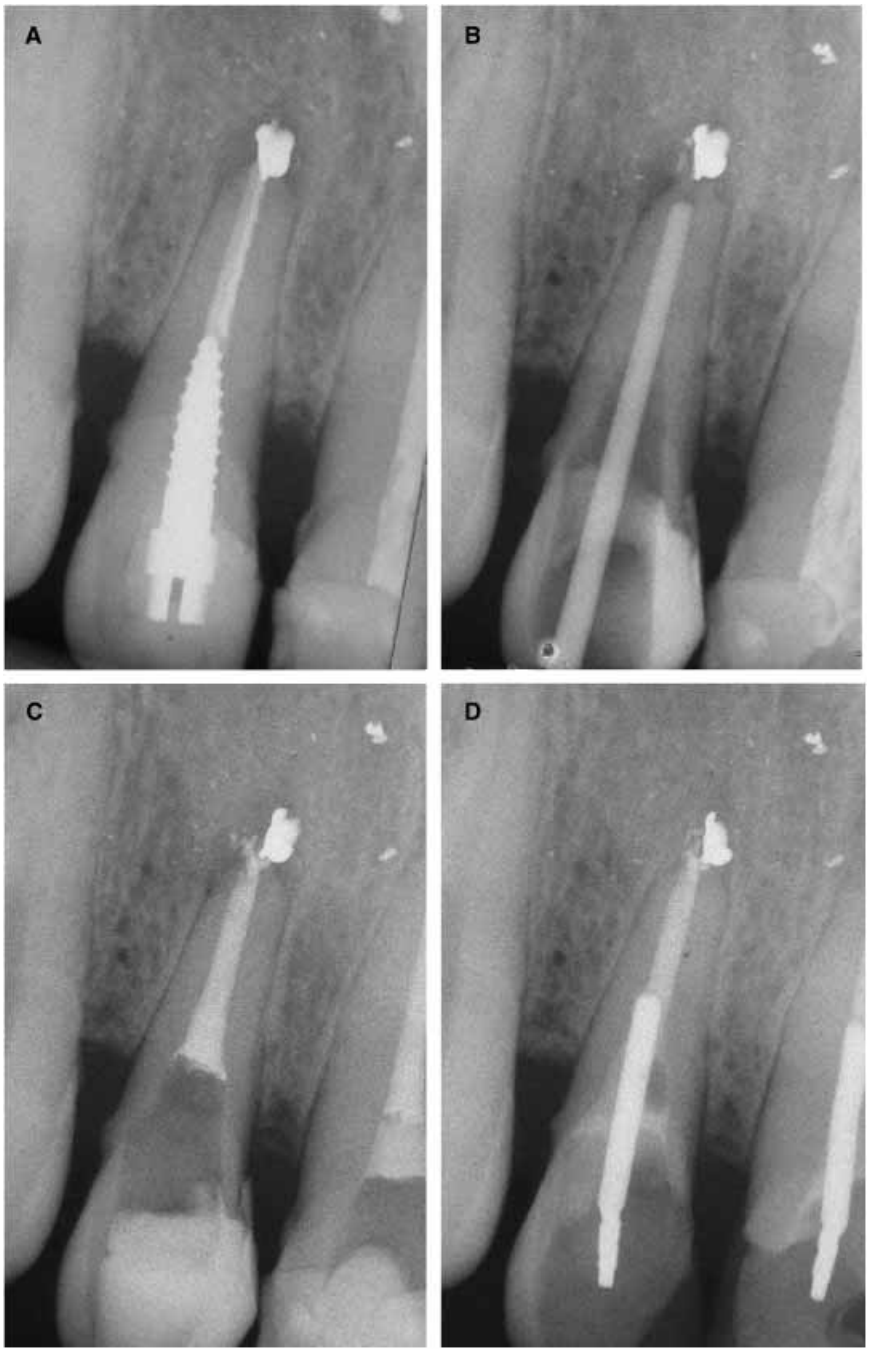


**Fig. 16. Persistent disease after apical surgery – treated by orthograde retreatment. (A) A root-filled and previously surgically treated maxillary lateral incisor, with a broken file, poorly placed root-end filling, and persistent apical periodontitis. (B) The fit of the master cone during orthograde retreatment. All the restorative material was removed from the coronal portion of the tooth, revealing an extensive cavity. (C) Completed retreatment. The root-end amalgam was displaced outside the canal. (D) After 2 years, the lesion is healed.**

## Intra-operative factors

The intra-operative prognostic factors can be instrumental in maximizing the patient's benefit by improving the outcome of the apical surgery procedure. Therefore, it is important to recognize the intra-operative factors and to take them into account at the stage when treatment strategies and techniques are selected.

### *Level of apical resection and degree of bevelling*

In one study (22), a better outcome is reported after resection at the mid-root level, than at a more apical level. Resection close to the apex may expose many ramifications of the canal system that, if not sealed by the root-end filling, can comprise pathways for intra-canal bacteria to sustain disease after surgery (81). Therefore, the resection should be performed approxi-

mately 3 mm from the apex, where ramifications are fewer (149). Furthermore, resection at a more coronal level facilitates preparation of the root-end cavity and filling. Thus, a better outcome may be expected after a more radical resection of the root than after a very conservative resection. The degree of bevelling has not been assessed in relation to treatment outcome. Nevertheless, the bevel should be minimal to avoid the risk of missing canals emerging at the lingual aspect of the root (81), and to reduce the number of exposed dentinal tubules on the cut root surface, that comprise a bacterial pathway for persistence of disease (65, 144, 145) (Fig. 14).

### *Presence/absence of a root-end filling*

Placement of a root-end filling is consistent with the rationale of apical surgery – to establish an effective barrier that will prevent interaction of intra-canal bacteria with the periapical tissues (90). This rationale applies in all teeth where it is assumed that apical periodontitis is sustained by persistent *intra-canal bacteria* (90). However, a root-end filling may be superfluous when the disease is assumed to be sustained by *extra-radicular bacteria* (**71**, 90) (Figs 17 and 18). Indeed, in one study **(71)** seven out of eight teeth (88%) suspected for extra-radicular infection healed without receiving a root-end filling.

From a historic perspective, many studies indicate that the presence of a root-end filling impairs the prognosis (14, 17, 19, 22, 26, 28, 32, 37, 41). For example, Grung et al. (37) conclude that 'retrofills have a strong negative effect on the end results,' In these studies, root-end fillings were placed in the teeth *treated exclusively by apical surgery*, but not in the teeth *treated concurrently by surgery and orthograde treatment*; therefore, comparison of teeth without and with root-end fillings was confounded by orthograde treatment, performed in the former but not in the latter (12, 90). However, limiting the analysis in the same studies and others to teeth treated only surgically reveals better outcomes with than without root-end fillings (14, 22, 25, 38, 42).

### *Root-end management*

In the past two decades, the classical root-end cavity drilled with a small round bur gave way to two main modifications. Rud and co-workers (43, 89, 150), developed the method of bonding a 'cap' of Retroplast (a composite resin) over the cut root surface, to seal all of the main canal, accessory canals, isthmuses, and exposed dentinal tubules (Fig. 19). Retroplast is not placed into a root-end cavity to avoid adverse effects of shrinkage. Instead, it is placed as a thin layer into a concavity created in the resected surface with a large

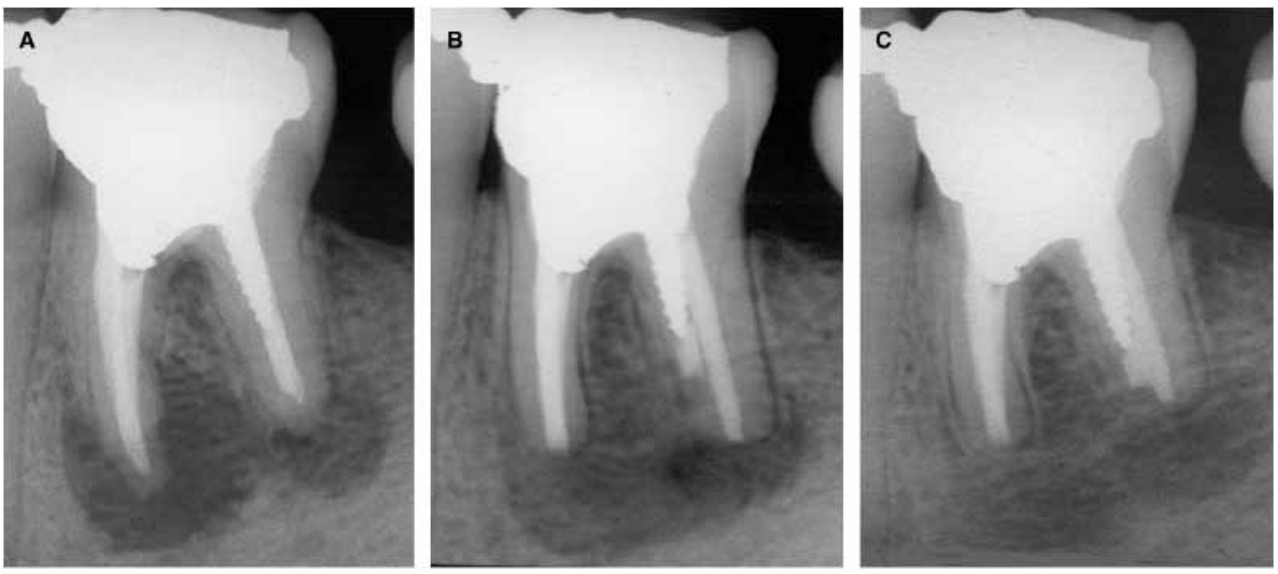


**Fig. 17. Suspected extra-radicular infection – placement of root-end fillings may be superfluous. (A) A root-filled mandibular first molar with persistent apical periodontitis associated with two sinus tracts, one lingual and one buccal, suggestive of periapical actinomycosis. (B) Completed surgery, including curettage and apical resection without placement of root-end fillings. (C) After 6 months, the lesions are healed.**

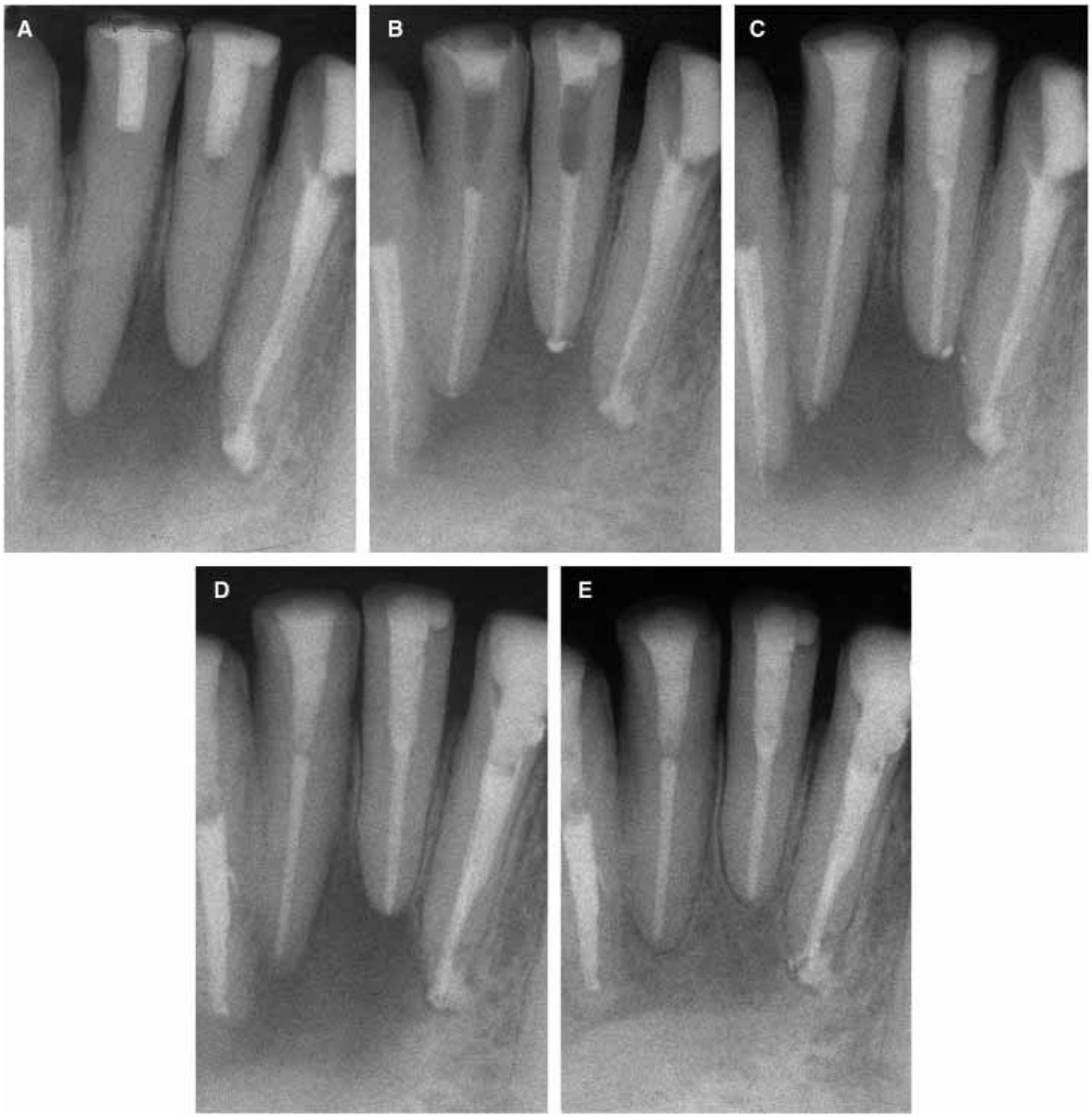


**Fig. 18. Suspected extra-radicular infection – placement of root-end fillings may be superfluous. (A) Mandibular central incisors with extensive apical periodontitis. (B) Completed root canal treatment. (C) After 2 years, the lesion is enlarged suggesting persistence of the disease, possibly because of an extra-radicular infection. (D) Completed surgery, including only periapical curettage. (E) One year after surgery, the lesion is healed.**

round bur. One of the selected studies **(67)** reports a 'healed' rate of 73% and a 'healing' rate of 17% 1 year after treatment with Retroplast. The outcomes in this study and several others where Retroplast was used (43, 52, 55, 64, 73, 89) appear to surpass the outcomes reported in studies where root-end cavities have been prepared and filled with a variety of materials (Table 1). Conceivably, Geristore (151, 152) and OptiBond can be used as alternatives to Retroplast for establishing the apical 'cap' (81); however, their clinical effectiveness in this capacity has not been reported.

To modify the form of the root-end cavity, Carr (81, 138) developed special angled tips for ultrasonic cavity preparation (Fig. 20). The use of these tips requires less bevelling of the cut root surface and a smaller bony crypt preparation than the use of burs (65, 80, 81, 83). More importantly, the resulting cavities are deeper, allowing the root-end filling to seal exposed dentinal

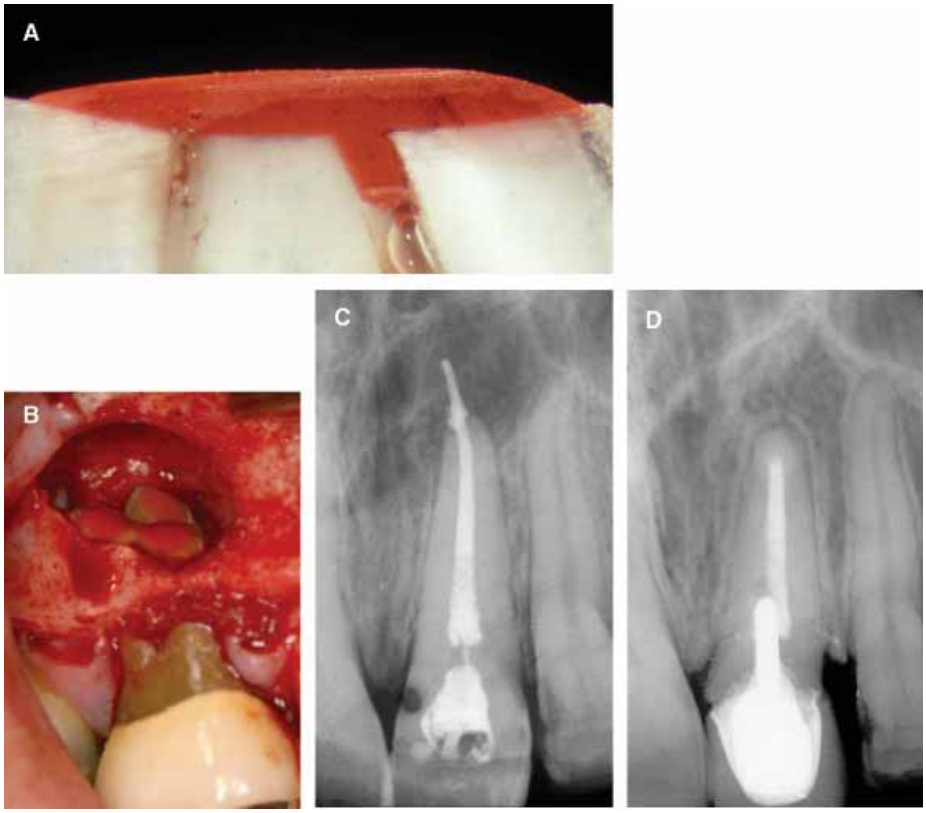


**Fig. 19. Root-end management with Retroplast. (A) A vertical section through a root end with a bonded Retroplast 'cap.' The cut root surface was scooped out with a round bur to accommodate the resin. The bonded 'cap' is sealing the main canal and an accessory one. (B) Clinical view of a maxillary first molar with Retroplast bonded to the three roots. (C) A root-filled maxillary central incisor with extruded root filling and persistent apical periodontitis. (D) Nine years after surgery, including the bonding of Retroplast at the root end, the lesion is healed. Originally, Retroplast was only slightly radiopaque; the current generation is fully radiopaque. (Courtesy of Dr Vibe Rud, Copenhagen, Denmark.)**

tubules from within the canal (78, 80, 83). The cavities are also cleaner and aligned better with the long axis of the canal, so that the risk of perforation of the lingual wall of the root is reduced (79, 82, 83). Two studies (56, 60) have reported a better outcome in teeth where root-end cavities were prepared with ultrasonic tips than when cavities were prepared with burs; however, the analyses in both studies were confounded by extraneous factors, undermining their conclusions. Importantly, the 'healed' rates (37–91%) reported in the selected studies in which root-end cavities were prepared with ultrasonic tips **(62, 63, 68, 71, 72)** are not different from those in other studies where root-end cavities were drilled with burs.

Although there is no strong evidence to suggest that the apical 'cap' and the ultrasonic root-end cavity preparation offer a better prognosis, there is a sound clinical rationale for using both approaches. Both also offer greater ease and consistency of application than drilling the root-end cavity with small round burs, as in the past.

### *Root-end filling material*

Many restorative and endodontic materials used in dentistry over the years have also been considered as root-end filling materials, including amalgam with or without varnish, plain or reinforced zinc-oxide eugenol cement, EBA and Super-EBA cement, polycarboxylate cement, glass-ionomer cement, burnished or injectable gutta-percha, composite resin, cyanoacrylate glue, Teflon, gold foil, titanium screws, and Cavit. These materials have been comprehensively reviewed by Friedman (90). In the past decade, MTA, a material developed specifically for root-end filling, has also been used (87, 153). This plethora of materials has primarily been assessed by *in vitro* methods and characterized by inconsistency of the results (90, 154). To overcome the

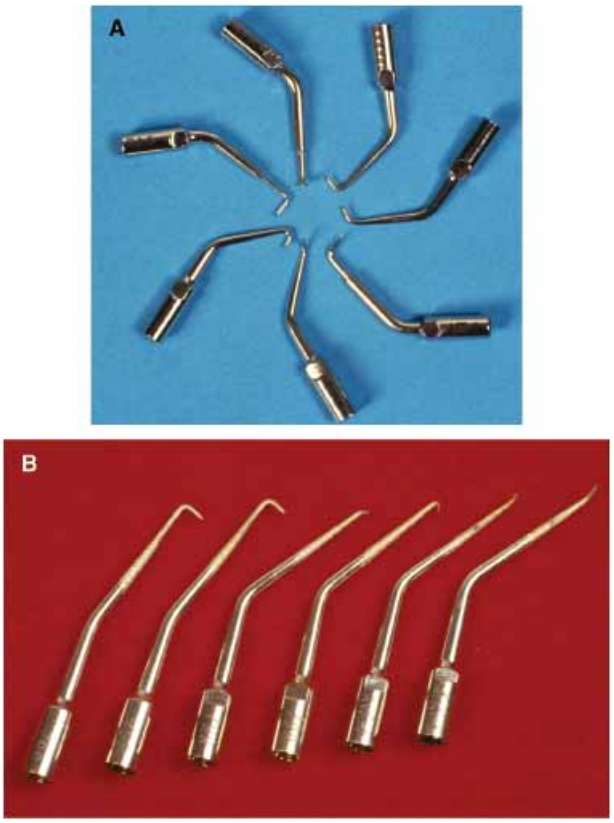


**Fig. 20. Ultrasonic tips designed for root-end cavity preparation. (A) The original CT design by Dr Gary Carr. (B) The recent Kis design by Dr Syngcuk Kim.**

limitations of *in vitro* studies, an *in vivo* simulation model was developed by Friedman et al. (155) (Fig. 21). Variations of this model have been used in several studies (84–88, 156) with better consistency of the results than in the *in vitro* studies. In these animal studies, IRM (84, 85), Super-EBA (86, 88), MTA (87), and Diaket (156) have performed better than other materials. Nevertheless, these *in vivo* studies do not provide the evidence base required for supporting the clinical effectiveness of these root-end filling materials.

Several non-randomized clinical trials have assessed different root-end filling materials, including Biobond (18), Cavit (21, 23), glass-ionomer cement (45, 49, 157), Retroplast (89), IRM (36, 42, 70), EBA (36, 42, 48), gold leaf (44), and titanium inlay (158). Amalgam has been frequently used as the control with which other materials are compared. The methodology in all these studies does not comply with an adequate level of evidence, negating their conclusions. For example, EBA cement is significantly superior to amalgam in one study (95% vs. 51% success, respectively) (36), marginally superior in another study (57% vs. 52%, respectively) (48), and marginally inferior in a third study (65% vs. 71%, respectively) (42). Better evidence can be derived from recent RCTs **(67, 68)**. For use as an apical 'cap,' Retroplast is significantly better than a glass-ionomer cement, which was observed to detach in several of the teeth **(67)**. For filling a root-end cavity, IRM and MTA are reported to be equally effective **(68)**; however, the validity of this finding can be disputed because the root canals sealed by these materials may not have been infected after a previous retreatment. A comparable outcome is also reported for root-end fillings with Super-EBA and 'other materials' (IRM, MTA, composite resin, amalgam) in a recent cohort study **(71)**. Thus, the outcome of apical surgery relying on a bonded 'cap' critically depends on the bonding properties of the material used. When an intra-canal root-end cavity is filled, a similar outcome may be expected if IRM, EBA cements, or MTA is used.

### *Method of hemostasis*

Different hemostatic agents, including epinephrine (adrenalin)-saturated (1 : 1000) pellets, ferric sulfate, bone wax, thrombin, calcium sulfate, Gelfoam, Surgicel, and collagen wound dressing, have been routinely used for crypt control by many clinicians (81, 159, 160). Good hemostasis is critically important for the quality of the root-end filling (81) and bonding of an apical 'cap' **(67)**. However, in a recent study **(71)** a comparable outcome has been reported with and without the use of hemostatic agents, suggesting that these agents do not influence the prognosis of apical surgery.

### *Combination with orthograde treatment*

Apical surgery performed concurrently with orthograde root canal treatment or retreatment addresses all possible sites where bacteria colonize – the root canal system including apical ramifications, the apical root surface, and the periapical tissue. Furthermore, according to Molven et al. (41), 'infection is eliminated and reinfection is prevented'. Consequently, studies in which both procedures were combined in the majority of the sample usually showed a better outcome than those in which only apical surgery was performed (12).

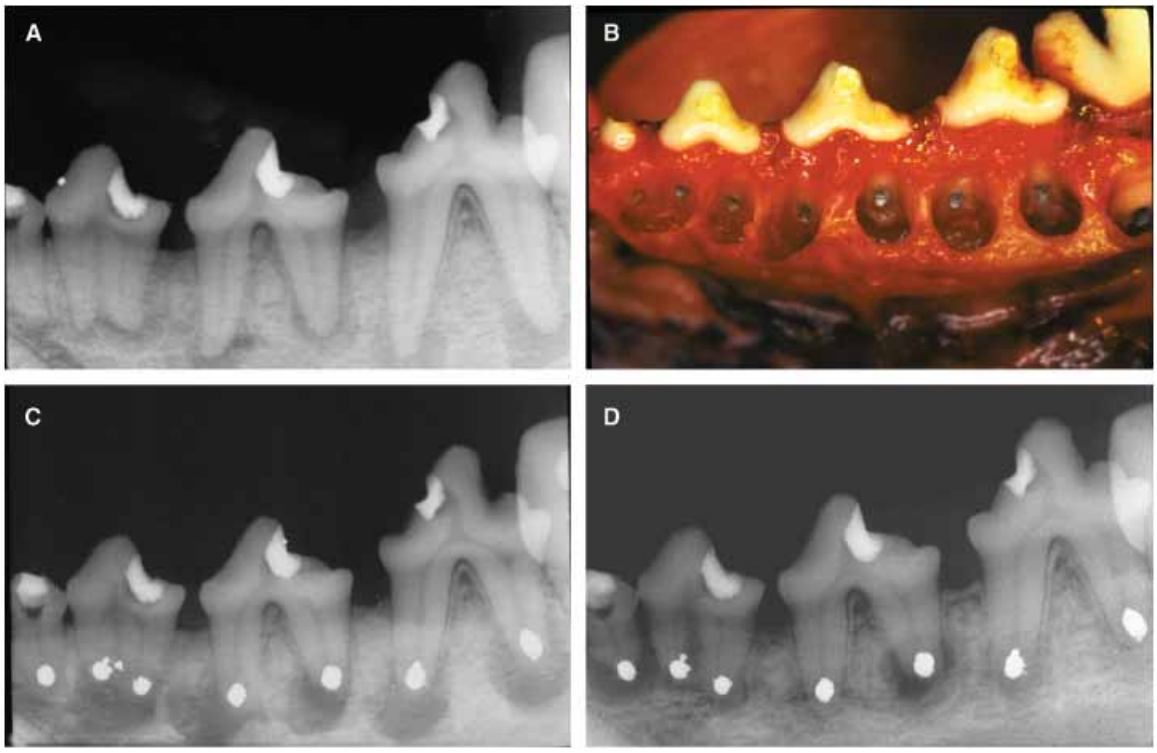


**Fig. 21. Animal model for assessing the efficacy of root-end filling materials. (A) A dog's mandibular premolars with apical periodontitis induced by inoculation of the canals with plaque. (B) Clinical view of the crypts and root-end fillings with amalgam and varnish in all the canals of the four premolars. (C) Completed surgery. (D) After 6 months, some of the lesions are healed and others are not. Healing is the measure of the sealing efficacy of the root-end fillings.**

The difference between the two approaches has also been demonstrated in specific studies (11, 14, 17, 19, 22, 26, 37, 90). Currently, however, apical surgery is not considered imminent when the root canal is accessible from the coronal pathway; rather, it is performed alone as an alternative to orthograde treatment. Therefore, the better prognosis offered by combining apical surgery with orthograde treatment is merely of academic interest. It confirms that root canal bacteria are the predominant cause of post-treatment apical periodontitis (136, 137), and that they may still sustain the disease process in spite of the root-end filling.

### *Retrograde root canal retreatment*

A modified approach to apical surgery, focusing on instrumentation, irrigation, and filling of the root canal as far coronally as can be reached from the apical end (Fig. 22), can be used as an alternative to the standard root-end filling (31, 34, 161–165). According to several clinical studies (31, 34, 71, 166), the 'healed' rate after such retrograde retreatment ranges from 71% to 100%, and the rate of persistent disease does not exceed 16%. Clearly, this procedure offers a better outcome than the standard root-end filling, as it places a deeper barrier between intra-canal bacteria and the periapical tissue. However, if bacterial ingress continues coronally under the restoration and along the post into the canal, with time, bacteria may overcome this barrier, resulting in recurrence of disease (Fig. 13).

### *Quality and depth of root-end filling*

Only one study **(63)** highlights the significance of the quality of the root-end filling, particularly its correct placement. In another study **(71)**, comparable outcomes are reported for root-end fillings extending up to 2 mm or deeper into the canal space. However, the depth of the root-end filling cannot be reliably assessed in radiographs because its apical surface is frequently bevelled **(63)**. Thus, the accurate placement of the root-end filling influences the prognosis of apical surgery, while the effect of the filling depth, ranging from 1 to 4 mm, can only be speculated.

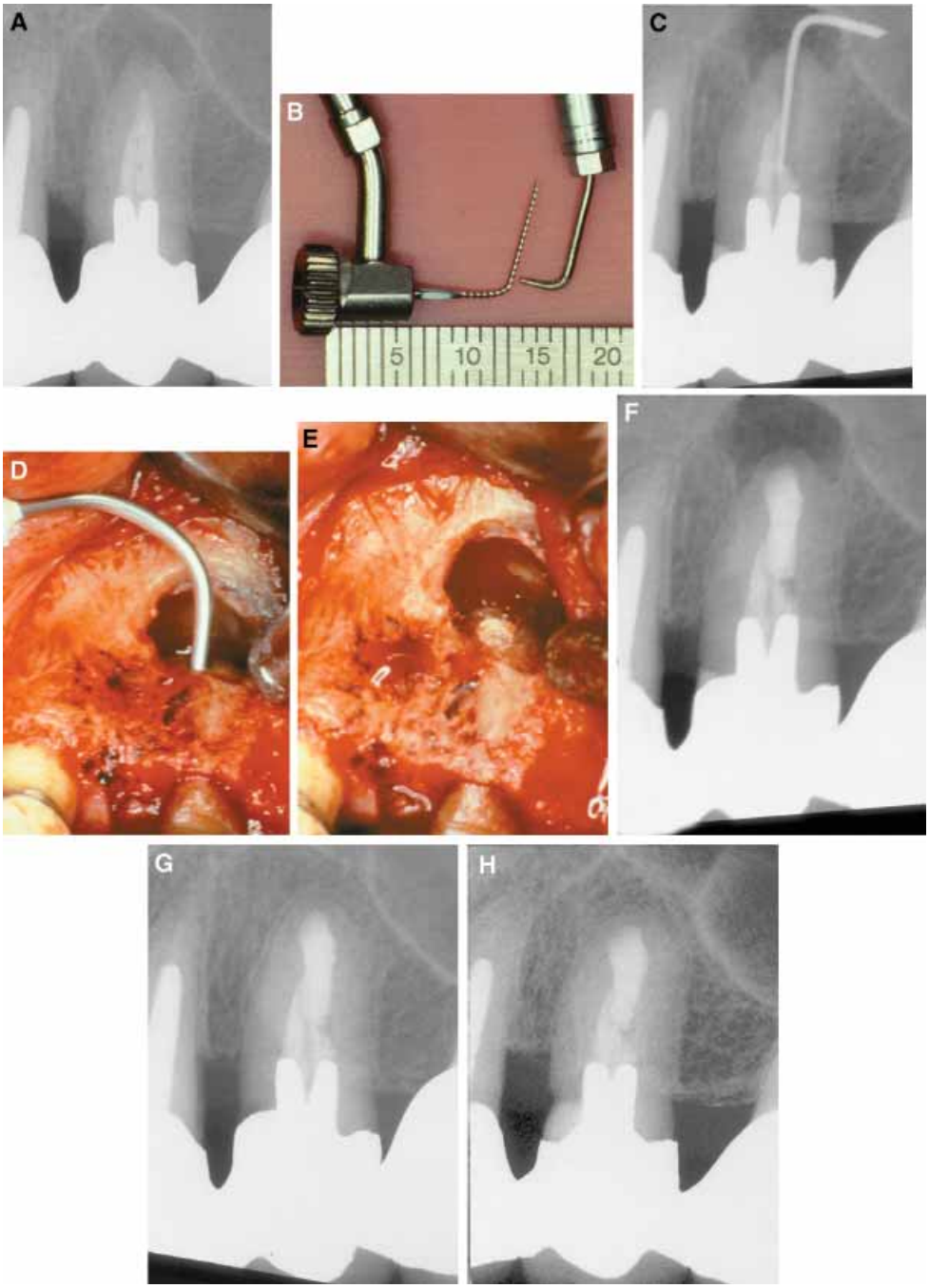


**Fig. 22. Retrograde retreatment. (A) A root-filled maxillary second premolar with persistent apical periodontitis. (B) A file mounted in an ultrasonic handpiece, bent to allow deep penetration into the canal, compared with a conventional ultrasonic tip with a 3 mm active point. (C) The measurement of the extent of retrograde retreatment carried out with ultrasonic files. (D and E) Clinical views showing irrigation and filling of the prepared canal space, respectively. (F) Completed surgery, including root filling with sealer and injectable gutta-percha. (G and H) After 1 and 7 years, respectively, the lesion is healed.**

### *Magnification and illumination*

In the past decade, the use of aids to enhance visualization during apical surgery has become increasingly popular among clinicians. Magnification aids include loops, operating microscopes (138, 167, 168), and endoscopes (169, 170). The latter two also greatly enhance illumination. Apart from considera-


**Fig. 23. Operating microscope – improved control of the apical surgery procedure. (A) Completed surgery in a mandibular second molar, including root-end filling with Super-EBA. The surgical procedure involved the exposure of the mandibular canal. (B) View of the inferior alveolar nerve through the microscope allows careful manipulation and retraction of the nerve to minimize injury; the patient experienced partial numbness in the lip. (C) After 6 years, the lesion is healed but the partial numbness in the lip persists. (Courtesy of Dr Richard Rubinstein, Farmington Hills, MI, USA)**

tions of convenience, use of these aids facilitates identification of intricate anatomic features and improves control of all aspects of the surgical procedure, from incision placement to suturing (81, 138–141, 169–171) (Fig. 23). Reporting 97% 'success,' one study (59) implies that the outcome of apical surgery can be improved by using the operating microscope and Super-EBA cement as the root-end filling. Among the selected studies, loops were used to enhance visualization **(71, 72)**, or the operating microscope was used to inspect the adaptation of the root-end filling (**68**). However, the true influence of magnification and illumination aids on the outcome of apical surgery has not been assessed at an adequate level of evidence.

### *Laser irradiation*

Laser irradiation of the resected root surface and crypt (Fig. 24) has been suggested as a means of sterilization and hemostasis (172–174), but also to render the dentin on the cut root surface impermeable to bacteria (175–179). Despite these theoretical benefits of laser irradiation, it has not been shown to influence the outcome of apical surgery when applied *in vivo,* in animal studies (155, 180) and in a clinical trial (56). Thus, use of laser irradiation in different steps of the apical surgery procedure does not influence the outcome of treatment.

### *Barriers and bone grafting substances*

The use of guided regeneration barriers in apical surgery has been advocated in case reports (181, 182). Similarly, the use of various bone-grafting substances in the crypt has been described (183–187). The handful of clinical studies and case reports published (182, 188–191) do not provide evidence to support the routine use of these procedures in apical surgery. Thus, use of barriers and bone grafting substances does not enhance the prognosis, while care must be taken to avoid infection of the foreign materials placed.

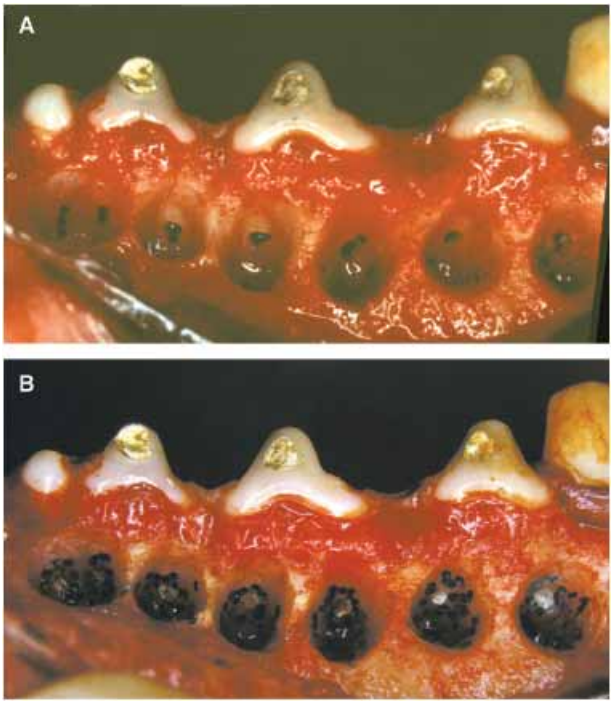


**Fig. 24. Laser application in apical surgery. (A) Clinical view of a dog's mandibular premolars after irradiation of the root-end cavities with $CO_2$ laser. (B) Similar view after root-end filling with amalgam, and irradiation of the cut root surfaces and the crypts. See also Fig. 11.**

### *Operator skill*

Resident students were the treatment providers in only a few of the studies **(63, 67, 71)**, while in the majority of studies treatment was performed by specialists, either oral and maxillofacial surgeons or endodontists. Therefore, reference to operator skill is scarce. Nevertheless, studies have suggested that the outcome of apical surgery may depend on the individual operator's skill (22, 40).

### *Complications*

Occasionally during apical surgery, a perforation can occur in the opposing (lingual or palatal) aspect of the root or cortical bone plate, or the maxillary sinus may be exposed. Perforation of the opposing bone plate does not appear to influence the outcome beyond an increased rate of healing by scar tissue (37, 41, **71**). Similarly, perforation into the sinus does not appear to influence the prognosis (20, 27, 74).

### *Antibiotics*

Antibiotics may be prescribed to prevent infection of a post-operative hematoma. However, a course of systemic antibiotics starting before and continuing after treatment does not influence the outcome of apical surgery **(63, 71)**.

## Post-operative factor

The only post-operative prognostic factor highlighted below may modify the prognosis estimated after completion of the apical surgery procedure. It may be considered when the follow-up schedule is devised.

### *Results of biopsy*

Periapical biopsies are frequently obtained during apical surgery. Theoretically, the biopsy results defining the pathological lesion – granuloma or cyst – might be used as indicators of the prognosis. Jensen et al. **(67)** report a significant association between the biopsy results and the outcome of apical surgery; however, no such association has been reported in 2 other studies **(62, 71)**. These conflicting reports may be a result of the differences in the processing of the biopsy specimens. Routine biopsies are seldom subjected to serial sections, and therefore may not accurately reflect the nature of the pathological lesion. Thus, a biopsy report on the nature of the lesion removed during apical surgery does not contribute to the estimation of the prognosis.

# Case selection considerations

Selection of cases for apical surgery takes into consideration the prognosis of the dental interventions – endodontic, restorative, and periodontal – and also health and socio-economic factors. Contraindications to treatment include periodontally hopeless teeth, patients with extensive dental problems and restricted resources (which should be selectively used to benefit as many teeth as possible), medically compromised patients at high risk for infection, or bleeding disorders.

Apical surgery is not truly contraindicated by any of the pre-operative clinical factors. The expected outcome is good – the probability of the site to be healed is reasonably high, and the probability of retaining a well-restored tooth in asymptomatic function over time is very good. Therefore, when other endodontic treatment alternatives offer a poorer benefit–risk balance, and whenever it is feasible, apical surgery should be attempted before considering tooth extraction and replacement.

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