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Article in *Oral and Maxillofacial Surgery Clinics of North America* · September 2005

DOI: 10.1016/j.coms.2005.05.003 · Source: PubMed

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## Maxillofacial Trauma Treatment Protocol

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In the early days of World War I, a young surgeon from New Zealand stationed in Aldershot, England was inundated by horrendous wounds to the head and neck of soldiers returning from the front lines. Because of advances in ballistics and weaponry, coupled with the fact that trench warfare necessitated the soldiers to place their maxillofacial region at great risk to monitor the status of the enemy, this surgeon was faced with injuries never before encountered. His name was Harold Delf Gillies, and his contributions to the medical community are universally accepted as the initiation of the discipline of plastic and reconstructive surgery [1,2]. Hippocrates once famously told his students, “War is the only proper school for surgeons.” Unfortunately, the experiences undergone since September 11, 2001 have provided a whole generation of military surgeons the opportunity to treat a new type of injury pattern never before seen [3]. Improved body armor, which allows soldiers to survive wounds that would have been fatal 2 to 3 years earlier, and the catastrophic and new injury patterns sustained by improvised explosive devices (IEDs)

have forced military surgeons to reinvent how we treat maxillofacial trauma patients, much like the experiences that faced Sir Harold Gillies. Unfortunately, the Israeli experience shows us that terrorists possibly could use the same tactics as the Iraqi insurgents and expose the American populace to IEDs.

Before September 11, 2001, the protocol designed by Robertson and Manson served as an excellent framework for the management of high-energy ballistic injuries to the maxillofacial region [4]. The complex nature of the wounds caused by IEDs and newer ballistics has rendered some portions of their treatment plan ineffective and prone to secondary infection. IEDs are packed with dirt, glass, rocks, metal, bones from dead humans or animals, and other body parts if detonated by suicide bombers. If this technique of terrorism is used in the United States, civilian providers will be faced with the same difficulties previously faced by the military. The challenge was to develop a system that could be used for conventional ballistic injuries and injuries that result from IEDs. A new protocol has been developed that serves as the current treatment regimen used by the oral and maxillofacial surgery departments at Wilford Hall USAF Medical Center, the National Naval Medical Center–Bethesda, Walter Reed Army Medical Center, and the National Naval Medical Center–San Diego. In this article we present our treatment algorithm for ballistic maxillofacial trauma based on the surgical experiences gained by performing 329 procedures on 109 patients since September 2001 (Box 1).

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The views presented in this article reflect those of the authors and do not represent the official policies of the United States Air Force, the United States Army, the United States Navy, the Department of Defense, or any branches of the United States government.

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### Box 1. Treatment protocol for maxillofacial injuries

1. Stabilize patient
2. Identify injuries
3. Obtain radiographic studies and stereolithographic models
4. Initiate consultations (eg, psychiatry, physical therapy, speech therapy)
5. Initiate cultures/sensitivities (infectious disease consultations)
6. Undertake serial débridement (days 3–10) to remove necrotic tissues
7. Stabilize hard tissue base to support soft tissue envelope and prevent scar contracture before primary reconstruction
8. Conduct comprehensive review of stereolithographic models and radiographs and determination of treatment goals
9. Replace missing soft tissue component (if necessary)
10. Perform primary reconstruction and fracture management
11. Incorporate aggressive physical/occupational therapy
12. Perform secondary reconstruction (eg, implants, vestibuloplasty)
13. Perform tertiary reconstruction (eg, cosmetic issues, scar revisions)

### Stabilization of the patient

Although this should be intuitive, in a mass casualty or acute trauma situation the basics of medical care should be emphasized, because these actions undoubtedly will save lives. Securing the airway by whatever means necessary, including endotracheal intubation or surgical airway, should be performed immediately if there is any doubt about future stability of the patient. A true disaster scenario easily could overwhelm the ability of a medical care facility to monitor the condition of victims with possible or suspected future airway compromise. Bleeding should be controlled and volume expansion should be accomplished to maintain perfusion of the vital organs by blood transfusion, blood substitutes,

colloids, or crystalloids as indicated. Identification of potentially fatal situations, such as tension pneumothorax, cardiac tamponade, intraperitoneal hemorrhage, or intracranial hemorrhage, should be accomplished as soon as possible.

### Identification of injuries

After initial stabilization of a patient, a thorough examination should be performed to document all injuries. If a patient is comatose or intubated or the evaluation is otherwise compromised, care should be taken to note clearly the limitations of the examination and the reasons for the difficulty. Detailed documentation of all injuries is necessary to coordinate the sequence of treatment with all respective surgical services (Figs. 1 and 2). Any opportunity to limit exposure to general anesthesia should be taken, as long as combined procedures do not affect the outcome of planned surgical interventions. Physical examination, radiographic studies, and laboratory tests are necessary components to identify correctly all potential injuries.

### Obtaining radiographic studies and stereolithographic models

Adequate radiographs are essential for diagnosis of and treatment planning for complex maxillofacial



Fig. 1. Drainage of left facial swelling. After fluid was sent to laboratory for evaluation, amylase level was noted to be in excess of 3000, which is consistent with obstructed parotid gland secondary to transection of Stenson's duct from shrapnel.



Fig. 2. Shrapnel injury to right upper extremity.

trauma. Modern radiographic techniques allow for three-dimensional visualization of the skeleton, help identify foreign bodies, and evaluate displaced fracture segments. CT scans should be the minimum information obtained before surgery (Fig. 3). The current CT scanner at Wilford Hall Medical Center is the GE Lightspeed 16 (GE Health Care, Chalfont St. Giles, United Kingdom), which allows rapid assimilation of data and manipulation of conventional coronal and axial cuts to three-dimensional images via use of the GE Advantage Workstation AW 4.1 (GE Health Care; Chalfont St. Giles, United Kingdom) (Fig. 4).

It is our opinion that complex panfacial trauma, such as the injuries seen during Operations Iraqi Freedom (OIF) and Enduring Freedom (OEF), absolutely require the fabrication of stereolithographic (SL) models to plan treatment adequately and determine sequencing of fracture repair. The use of SL models allows preadaptation of surgical plates to obtain proper soft tissue projection and support that otherwise would not be possible to the degree of accuracy obtained by this technique (Fig. 5). SL modeling has the advantage of allowing custom implant fabrication to support the soft tissue envelope when the bony architecture is lost or irreversibly misshapen. This has the advantage of reproducing a patient's preoperative soft tissue profile as close as possible to the preinjured state. Currently, Wilford Hall Medical Center transfers conventional CT data via the Materialise Mimics software program (Materialise, Leuven, Belgium) for model fabrication by the Viper SLA (3D Systems, Valencia, California). Depending on the size of the image being manufactured, most SL models can be completed by the Viper SLA within 6 to 24 hours. This relatively rapid turnaround time does not impact patient care and is essential in our experience for obtaining the best

possible result while actually decreasing surgical time [5].

### Early initiation of consultations

Returning casualties from a war zone have many needs that must be addressed in concert to treat the entire patient. Not only is the treatment of a patient's wounds of paramount importance but also are the treatment of a patient's psychological status, facilitation of speech and nutrition in maxillofacial injuries, management of centrally mediated pain syndromes, and identification, evaluation, and involvement of a patient's family or peer support system. This section attempts to identify consultants who may be deemed integral in the treatment of returning casualties with war injuries.

### Infectious disease

The importance of this consultation cannot be overemphasized. Patients returning from OIF/OEF are well documented to be colonized by *Acinetobacter baumannii* [6]. The nature of war injuries also provides an environment for the gross contamination of wounds by staphylococci, enterococci, *Klebsiella*, and *Clostridium perfringens* and *Clostridium tetani*. Further discussions of the infectious disease consultation and the use of culture and sensitivity testing to facilitate treatment are presented in the following section.



Fig. 3. Conventional CT scan indicates loss of soft tissue and anterior mandible extending bilaterally from the angle to angle.

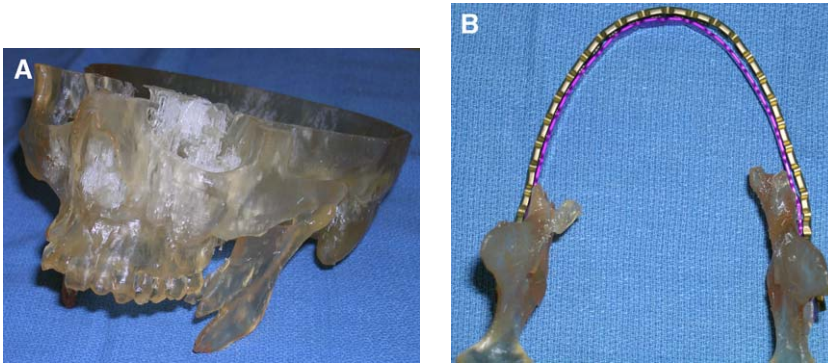


Fig. 4. (A) Stereolithography model of case presented in Fig. 3. (B) Model used as template for prebending of reconstruction bar.

*Psychiatry consultations*

Injured patients who return from a war zone may present with a host of psychiatric challenges, all of which must be addressed for appropriate treatment of the patient. These stressors include unrecognized combat stress, depression related to an injury, and guilt related to leaving fellow unit members or surviving. Facial appearance has been found to be an important variable in how patients are perceived by others, and maxillofacial injury patients must develop the additional coping skills throughout their treatment to improve their self-esteem and ability to continue with reconstructive surgery.

*Nutrition and speech therapy consultations*

Avulsive injuries to the maxillofacial region remove vital structures for phonation, mastication,

and deglutition, and even if many of these structures are salvaged or reconstructed, injury to cranial nerves may make performing these functions next to impossible. The ability to provide nutrition to a healing surgical patient is of primary concern in healing and maintenance of a patient's immune system. Early consultation may lead to early placement of percutaneous endoscopic gastrostomy feeding tubes, central catheters, and evaluation of the digestive and respiratory tracts.

*Physical therapy*

The physical therapy consultation is important in the management of not only maxillofacial injuries but also any orthopedic injuries. Maxillofacial physical therapy addresses the movement of the temporomandibular joint and should address electrical stimulation of facial musculature, which has been effected by

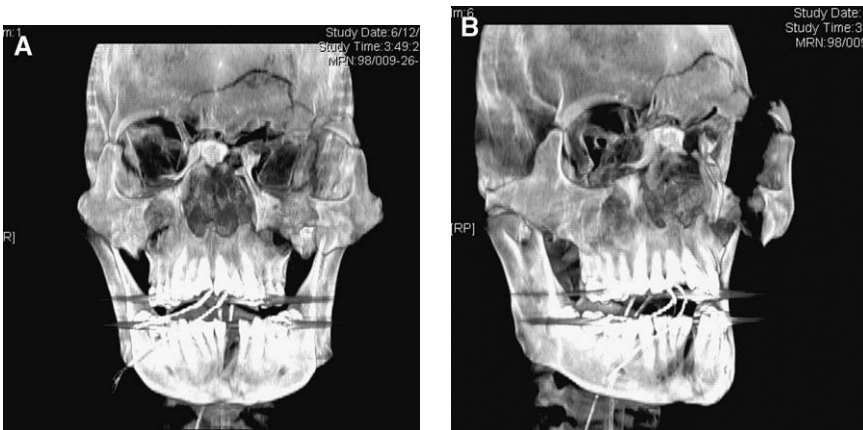


Fig. 5. (A, B) Examples of three-dimensional CT scans.

facial nerve injury. This stimulation prevents facial muscle atrophy and encourages facial nerve regrowth in the area of deficit.

#### *Pain management services*

Many patients who have returned from theater with severe injuries manage their pain with large amounts of opiate analgesics. Centrally mediated pain syndrome has been identified in a small number of patients whose pain issues have been addressed inadequately. For both of these subgroups of patients, consulting the pain management service assists in facilitating the comfort of patients and supports in the withdrawal from opiate analgesics to an appropriate level of pain medications.

#### **Cultures and sensitivities (infectious disease)**

Casualties from OEF/OIF who have been treated in multiple health care settings, including austere combat situations, bring with them complex infectious disease issues related to multiple resistant organisms. Patients with open wounds automatically should be started on prophylactic antibiotics for 24 hours, with the cornerstone of treatment being surgical serial débridement. The decision regarding antibiotic use should be based on the area of injury and degree of wound contamination.

Should a battlefield wound become infected, treatment should be definitive, with removal of foreign bodies and necrotic and infected tissue. Empiric broad-spectrum antibiotics are initiated against likely pathogens for 7 to 10 days. Table 1 provides an overview of the various antibiotics and spectrum of coverage [7,8]. Gram stains, cultures, and sensitivities are obtained to direct antibiotic therapy. Because *Clostridium* and *Bacteroides* species are difficult to culture, antibiotic therapy should be directed to cover these organisms.

It is also important for clinicians to realize that battlefield wounds are prone to tetanus because of high levels of contamination with *C tetani*. Every effort should be made to investigate a patient's current tetanus immunization status and initiate appropriate treatment or immunization. Necrotizing soft tissue infections from clostridial myonecrosis or polymicrobial infections can be the most dangerous and lethal infections that are encountered. All layers of tissue may be involved, and the treatment involves aggressive surgical débridement combined with antibiotic therapy.

Finally, clinicians must remember that patients may present with a confusing picture because of infection of various other wounds or a progression to sepsis. Following the previously mentioned principles and maintaining vigilant monitoring during medical evacuation should allow a patient to arrive at a large tertiary care facility for more definitive treatment and reconstruction.

Table 1  
Spectrum of selected antibiotic agents [16,17]

Agent	Antibacterial spectrum
Penicillin G	<i>Streptococcus pyogenes</i> , penicillin-sensitive <i>Streptococcus pneumoniae</i> , <i>Clostridium</i> sp
Ampicillin	Enterococcal sp, streptococcal sp, <i>Proteus</i> , some <i>Escherichia coli</i> , <i>Klebsiella</i>
Ampicillin/sulbactam	Enterococcal sp, streptococcal sp, <i>Staphylococcus</i> (not MRSA), <i>Escherichia coli</i> , <i>Proteus</i> , <i>Klebsiella</i> , <i>Clostridium</i> sp, <i>Bacteroides/Prevotella</i> sp
Nafcillin	<i>Staphylococcal</i> sp (not MRSA), streptococcal sp
Piperacillin/tazobactam	Enterococcal sp, streptococcal sp, <i>Staphylococcus</i> (not MRSA), <i>Escherichia coli</i> , <i>Pseudomonas</i> and other enterobacteriaceae, <i>Clostridium</i> sp, <i>Bacteroides/Prevotella</i> sp
Imipenem	Enterococcal sp, streptococcal sp, <i>Staphylococcus</i> (not MRSA), <i>Escherichia coli</i> , <i>Pseudomonas</i> and other enterobacteriaceae, <i>Clostridium</i> sp, <i>Bacteroides/Prevotella</i> sp
Cefazolin	<i>Staphylococcal</i> sp(not MRSA), streptococcal sp, <i>Escherichia coli</i> , <i>Klebsiella</i> , <i>Proteus</i>
Ciprofloxacin	<i>E coli</i> , <i>Pseudomonas</i> and other enterobacteriaceae
Gentamycin	<i>E coli</i> , <i>Pseudomonas</i> and other enterobacteriaceae
Vancomycin	Streptococcal, enterococcal, and staphylococcal species (incl MRSA); not VRE
Clindamycin	<i>Streptococcus</i> sp, <i>Staphylococcus</i> sp, <i>Clostridium</i> sp, <i>Bacteroides/Prevotella</i> sp
Metronidazole	<i>Clostridium</i> sp, <i>Bacteroides/Prevotella</i> sp

*Abbreviations:* MRSA, methicillin resistant *Staphylococcus aureus*; VRE, vancomycin resistant *Enterococcus*.

*Data from* Schuster GS. The microbiology of oral and maxillofacial infections. In: Topazian RG, Goldberg MH, editors. Oral and maxillofacial infections. 3<sup>rd</sup> edition. Philadelphia: WB Saunders; 1994. p. 39–78; and Gilbert DN, Moellering Jr RC, Sande MA. The Sanford guide to antimicrobial therapy. 34<sup>th</sup> edition. Hyde Park (VT): Antimicrobial Therapy, Inc.; 2004.

Upon receipt of casualties in our facilities, culture and sensitivity for *A baumannii* automatically are initiated. A patient usually is placed in contact and airborne isolation pending results, a process that can take up to 48 hours. If this resistant organism has been cultured in patients who have returned from OIF, aggressive antibiotic therapy is initiated to include coverage with ticarcillin and an aminoglycoside. In general, comprehensive wound care management coupled with appropriate antibiotic coverage and consultation with infectious disease specialists for challenging cases can prevent life-threatening sepsis.

### Serial débridement

The role of serial débridement cannot be overstated in dealing with patients injured in combat or terrorist activities. The injury patterns seen differ in several ways from those seen in a civilian trauma setting: (1) the devastating destruction of soft and hard tissues caused by high velocity, fragmentation-type injury patterns leads to compromised tissue beyond the visibly damaged tissue; (2) the battlefield environment in which patients are injured is grossly contaminated; (3) wound care on the battlefield and while in transport is less than ideal; and (4) evacuation off the battlefield is not always expeditious, which leads to increased wound contamination. Initial wound management involves hemostasis, dressing, awaiting evacuation to an aid station, and ultimately, a higher level facility in the combat theater.

Upon presentation at a higher echelon facility, aggressive irrigation and foreign body removal and limited soft tissue débridement are completed; the wounds should be left open or packed for hemostatic



Fig. 6. Initial presentation with irrigation and débridement; tacking sutures placed. (Courtesy of D. Clifford, DMD, MD; Bethesda, MD)



Fig. 7. Following pulsatile irrigation. (Courtesy of D. Clifford, DMD, MD; Bethesda, MD)

purposes. Tacking sutures may aid in securing gauze packing, but they should not be placed for reapproximation of wound margins. After evacuation to a higher echelon treatment facility out of theater (eg, Europe, United States), the entire wound is re-explored and débridement of grossly necrotic tissue is completed. Unless contraindicated because of concomitant injuries, aggressive irrigation with copious saline and antibiotic solution (eg, clindamycin) is performed with a pulsatile irrigation system (Pulsavac, Zimmer, Warsaw, Indiana). After the first pulsatile irrigation, superficial wet-to-dry dressing changes are performed three times per day. After 48 to 72 hours, the procedure is repeated. At that point, the surgeon is faced with the decision of when to perform the primary closure [9,10]. It has been our experience that definitive closure should not be performed if any sign of nonviable tissue is present upon exploration of the wound (Figs. 6 and 7). Delayed primary closure of the wound is generally performed after the second washout, although the threshold for continuing the débridement is low



Fig. 8. Healthy appearance of tissue at time of primary closure. (Courtesy of D. Clifford, DMD, MD; Bethesda, MD)

(Fig. 8). Generally the hard tissue base is stabilized at the time of primary closure.

### Stabilization of hard tissue base to support soft tissue envelope and prevent scar contracture before primary reconstruction

Because of the high risk of infection and extensive soft tissue injury in these patients, definitive reconstruction is often deferred to a secondary phase. Our experience has demonstrated that with a lack of bony support, fibrous tissue and scar contracture compromise the eventual functional and aesthetic result of any reconstruction. In the routine trauma setting, bone grafting or alloplastic implants may be placed at the initial surgery with immediate soft tissue coverage. We have opted to use standard rigid fixation systems to span bony gaps and give support to overlying soft tissue with only limited bone grafting or other alloplast use (eg, Medpor Porex, Newnan, Georgia) as necessary to reduce scar contracture. Complete reconstruction is often deferred to a secondary phase. The placement of rigid fixation follows standard trauma protocol to provide support of the facial pillars. One of the risks of using titanium plates in this manner is that of plate exposure. Although it occurred in some patients, the associated morbidity was low, the area was excised, and primary closure was performed with minimal cosmetic defect. Another option for supporting the soft tissue is the application of an external fixator, which has proved successful in projecting the mandible and zygomaticomaxillary complexes until the primary reconstruction

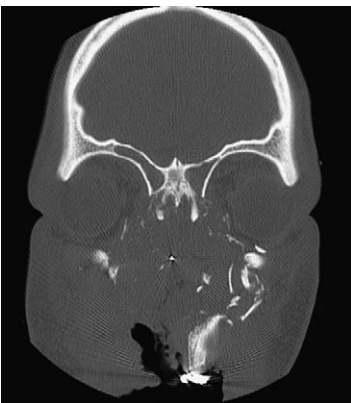


Fig. 9. CT scan demonstrates avulsive defect of midface region. (Courtesy of D. Clifford, DMD, MD; Bethesda, MD)

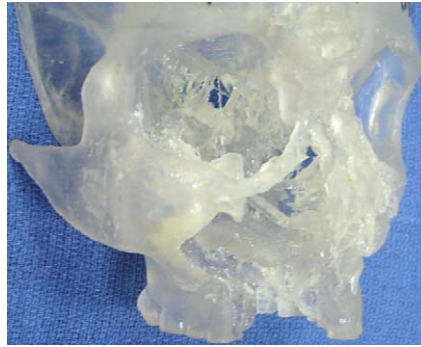


Fig. 10. Stereolithographic model demonstrates avulsive defect of midface region seen in Fig. 9. (Courtesy of D. Clifford, DMD, MD; Bethesda, MD)

can be undertaken. Such support also maintains a tissue plane, which provides easier dissection upon secondary reconstruction with either autogenous or alloplastic materials.

### Comprehensive review of stereolithography models and radiographs and determination of treatment goals

The ultimate treatment goal for our combat casualties with facial injuries is the restoration of function and cosmesis. Most injured patients have significant avulsive defects of facial structures. CT scans are the gold standard for imaging of facial fractures (Fig. 9). Three-dimensional reconstructed CT scans and stereolithographic models are essential adjunctive elements in preparing a treatment plan for avulsive-type defects (Fig. 10). The most important aspect of treating avulsive defects is using appropriate imaging to develop a staged reconstruction plan with the final endpoint in mind before any reconstruction begins. Items for consideration in viewing the studies and models are (1) which structures are missing, (2) which structures remain, (3) the effect of each on the reconstruction goals, (4) which structures require replacement, (5) how those structures will be replaced (nonvascularized versus vascularized tissue), (6) identifying stabilization points for replacement structures, (7) soft tissue considerations, (8) choice of grafting material, and (9) the effect of grafting plan on future implant reconstruction or dental rehabilitation. The choice of grafting or replacement material includes (1) bone (eg, cranial, iliac crest [block versus particulate], osteomyocutaneous vascularized flaps), (2) myocutaneous



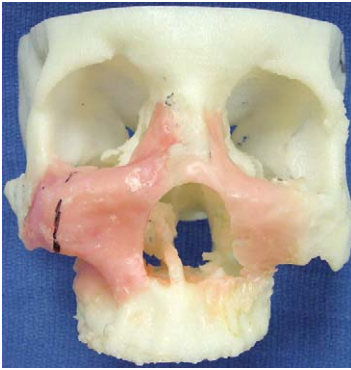


Fig. 11. Replacement of avulsed tissue with wax for template formation. (Courtesy of J. Solomon, DMD and G. Waskewicz, DDS; Bethesda, MD)

vascularized flaps, and (3) alloplast. Stereolithographic models allow for wax replacement of avulsed structures (Fig. 11) or generation of mirror-image structures, prebending of plates (Fig. 12), fabrication of templates for contouring of bone grafts, fabrication of custom implants (Fig. 13) (Medpor Porex, Newnan, Georgia, titanium, or polymethylmethacrylate), or use of stock alloplasts (eg, Medpor) [5].

### Replacement of missing soft tissue component

If soft tissue has been avulsed or is lost over the course of serial débridement, it is absolutely critical to replace this tissue with some form of vascularized flap—either rotational flap or free flap—before the development of scar contractures or colonization with

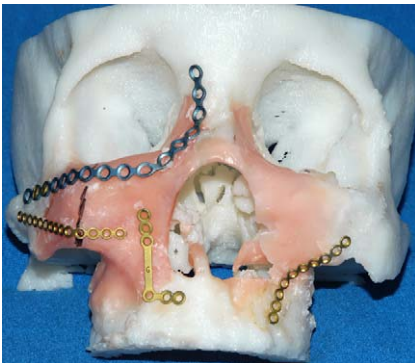


Fig. 12. Plates prebent to wax template replacing avulsed tissue. (Courtesy of J. Solomon, DMD and G. Waskewicz, DDS; Bethesda, MD)

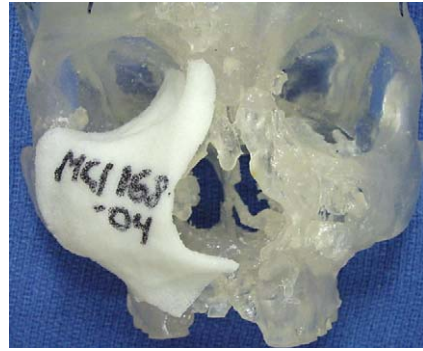


Fig. 13. Custom Medpor implant for avulsive midface defect seen in Figs. 9 and 10. (Courtesy of D. Clifford, DMD, MD; Bethesda, MD)

bacteria from the oral cavity or external environment (Fig. 14). Once scar contractures develop, it is essentially impossible to recover from this and create a normal soft tissue appearance. In our experience, vascularized tissue is more resistant to secondary infection and scar contracture and gives the most ideal result. Patients who present with injuries sustained by IED blasts usually are already contaminated with multiple bacterial species and are highly susceptible to recurrent infections and secondary scarring. The use of vascularized tissue has helped minimize complications in these cases. When faced with the dilemma of using a local rotational flap versus free flap, the reconstructive surgeon should determine whether a satisfactory result can be obtained in one surgical procedure or if several revision surgeries are necessary (Fig. 15). If a single surgery is planned, rotation of a local flap may be indicated because of the similarities in tissue coloration, consistency, and appearance. If the need for future surgical intervention is necessary, consideration should be given to using the free tissue transfer initially to inhibit scar contracture and finalize treatment at the secondary and tertiary surgeries with the local flap (Fig. 16). We recommend waiting a minimum of 8 to 12 weeks after placement of a graft to allow for maturation before the next surgical procedure at that site (Fig. 17).

### Primary reconstruction and fracture management

The goal of primary reconstruction should be to obtain the best functional and cosmetic results possible, because the tissues injured by explosive projectiles may have significant scar contracture at

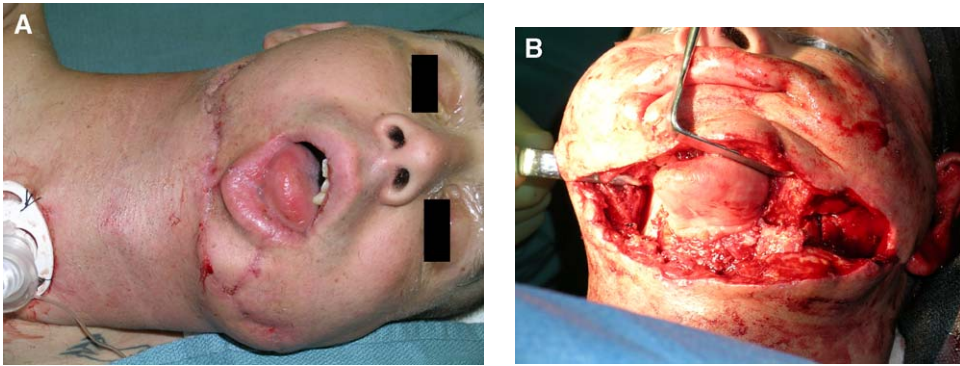


Fig. 14. (A) Presurgical appearance. Soft tissue closure accomplished at field hospital. (B) Avulsive injury with significant loss of soft tissue.

any future procedure and the opportunity to obtain a satisfactory result will be decreased. Preoperative planning is of paramount importance, with support of the soft tissue envelope being a priority for maintaining as normal a facial contour as possible.

Replacement of missing bone should be included in this treatment planning, because support of the soft tissue envelope is important. A strong recommendation is to consider exhausting native bone graft options before resorting to other choices. If the

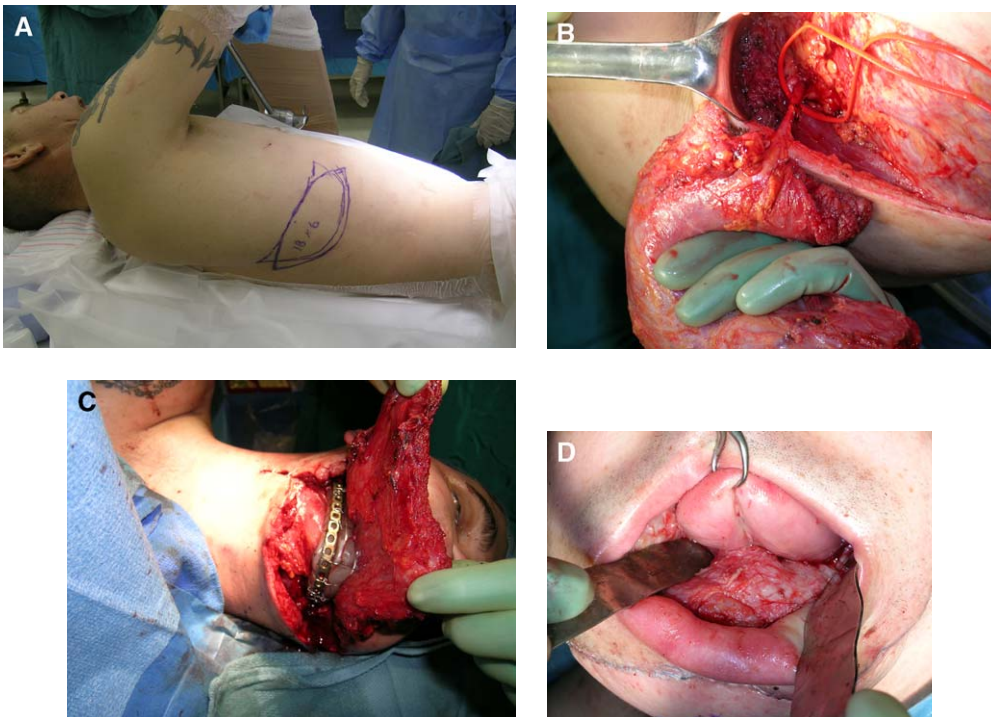


Fig. 15. (A) Location of latissimus dorsi free flap donor site. (B) Mobilization of the flap and preservation of vascular access. (C) Latissimus dorsi free tissue transfer to the mandibular region. The vascular supply is from the superior thyroid artery. Note presence of reconstruction bar to provide support to the free flap and assist with prevention of scar contracture. Osseous reconstruction is attempted at secondary surgery with corticocancellous bone graft. (D) Reconstruction of the floor of mouth with the muscular component of the latissimus dorsi flap.



Fig. 16. Appearance of flap immediately postoperatively.

recipient site is contaminated or infected, which is not unlikely in cases of IED blasts, our experiences have shown that allogeneic bone has a high propensity for resorption and chronic foreign body reaction. Native bone, particularly bone transferred with periosteal coverage, has been less likely to show evidence of late infection and better maintains the soft tissue projection obtained. In cases of significant panfacial trauma that involves the maxilla and mandible, we recommend sequencing of treatment as previously published by Wong and Johnson (Box 2) [11].

Our clinical experience has been to secure the airway and reconstruct the mandible as a first stage in surgery. In most cases of panfacial fractures, accomplishing these procedures takes several hours at a minimum, and proceeding immediately to a lengthy reconstruction of the midface and orbital fractures may not be advised because of potential fatigue of the surgical team. Breaking after the mandibular proce-



Fig. 17. Appearance of patient 4 months after free flap.

dures also allows for dental impressions and splint fabrication to occur to a known reference point, the newly reconstructed mandible.

One of the more common errors associated with panfacial trauma reconstruction is inadequate reduction of the mandibular archform, which results in excessive facial width secondary to splaying of the mandibular angles [12]. Excessive width of the mandibular angles results in the appearance of retrognathia because of posterior positioning of the mandibular symphysis. If the mandible is plated in the wrong position, ultimately the maxilla and zygomaticomaxillary complex also are improperly positioned, which results in excessive width to the face and the appearance of midfacial deficiency. This complication can be prevented by using prebent surgical plates made from stereolithographic or cadaveric/anatomic models to ensure accurate gonial width and anterior projection of the mandibular symphysis (Fig. 18).

After proper fixation of the mandible, attention is directed to zygomaticomaxillary complex and arch projection. Our experience has been that accurate positioning of the malar prominence and zygomatic arch is best accomplished by direct visualization of the zygomaticomaxillary and zygomaticotemporal

#### Box 2. Sequencing of treatment for panfacial trauma

- Secure definitive airway
- Obtain reduction and fixation of mandibular fractures
- Obtain mandibular arch impressions for fabrication of occlusal/palatal splints as necessary using the fixed mandible as template
- Position LeFort fractures into occlusion with mandibular dentition using maxillomandibular fixation
- Obtain reproducible seating of mandibular condyles into fossa
- Repair frontal sinus fractures if present
- Reduce zygomatic complexes and reconstruct nasofrontal junction
- Reduce naso-orbital-ethmoid complex fractures and medial canthopexies
- Reduce infraorbital rims
- Reduce LeFort I level fractures
- Reduce orbital floor fractures
- Undertake nasal grafting

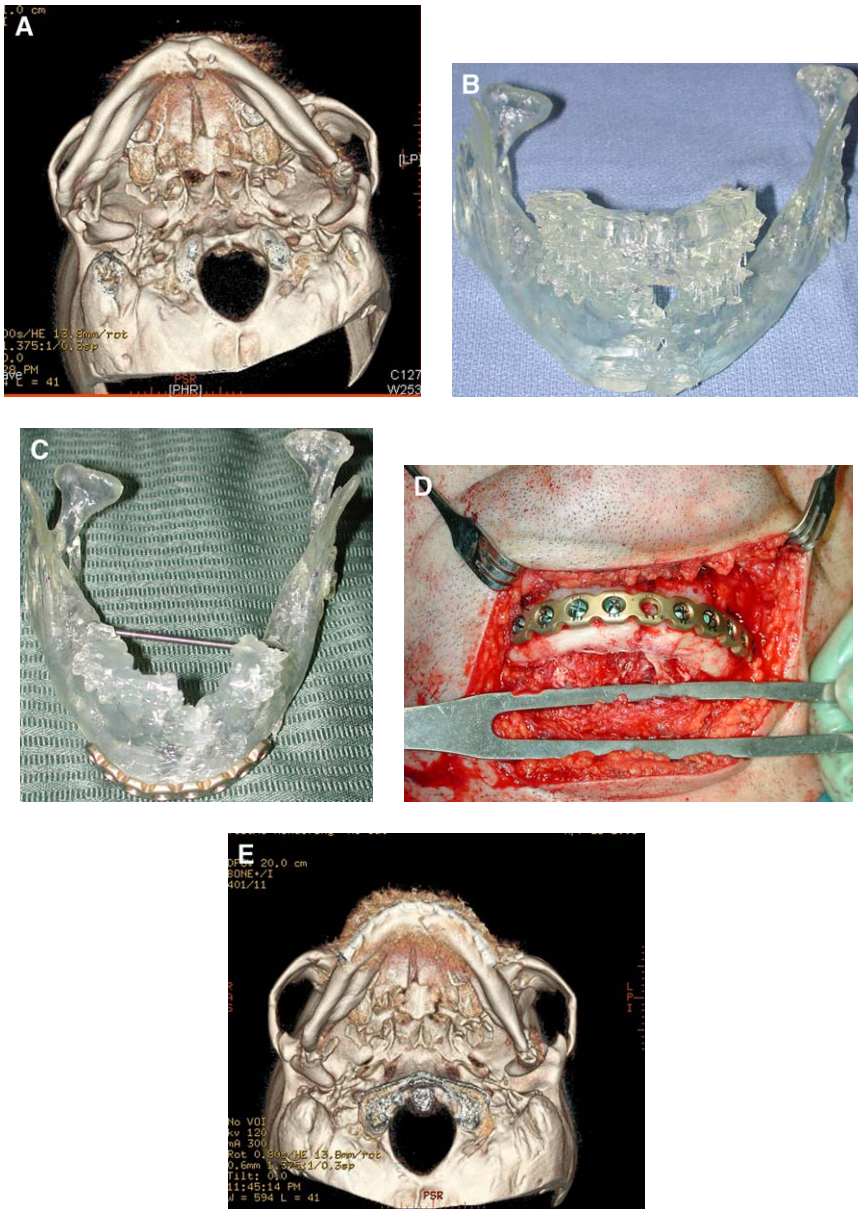


Fig. 18. (A) Three-dimensional CT scan shows excessive widening of the mandibular angles before definitive treatment of mandibular fractures. Anterior symphysis plate currently serves to stabilize fracture segments. Note open lingual cortical plate. (B) Stereolithography model of radiograph shown in (A). (C) Stereolithography model is sectioned and repositioned in accordance with accepted anatomic norms for gonial distance and ramus distance. Reconstruction bar is prebent to new dimensions to correctly position the segments intraoperatively. Condylar fracture reduction occurs during the same operation to correct vertical and anteroposterior position of the mandible before treatment of maxillary fractures. (D) Intraoperative view of mandibular fracture reduction and positioning of reconstruction bar. Proper positioning of mandibular angles is obtained by the surgical assistant, who places pressure in the region of the mandibular angles until fractured segments passively fit the reconstruction bar. The gonial distance was reduced 2.5 cm in this case from the presurgical dimensions. (E) Postoperative three-dimensional CT scan shows improved dimensions of gonial distance and mandibular contour and shape. Proper reduction of midfacial fractures can occur at this time to optimize aesthetic and functional result.

junctions by the use of the coronal flap (Fig. 19). Some surgeons may argue that the scar from the coronal flap is unsightly and an “acceptable” position of the zygomaticomaxillary complex can be obtained by other approaches. In cases of minimal or isolated fractures of the zygomaticomaxillary complex we would agree. Our bias in cases of significant midfacial destruction or gross comminution of the maxilla is that proper projection of the midface cannot occur without direct visualization, and ultimately secondary scar contracture continues to displace the segments and results in the previously “acceptable” appearance ultimately becoming unacceptable. Our technique is to use the stereolithographic model as a template for plate adaptation. If the contralateral side is unaffected, we bend surgical plates to that side of the model and place them on the affected side whenever possible to reproduce accurately a patient’s preinjury skeletal contours and maximize the potential for an accurate zygomatic width and good soft tissue projection after healing.

When properly designed and positioned, the coronal flap can be aesthetically pleasing. Our technique involves placing approximately 10 cc of 2% lidocaine with 1:100,000 epinephrine along the proposed incision site. We place the local anesthesia before performing the surgical scrub and address any obvious sources of vascular bleeding with cautious application of electrocautery. After reflection of the flap, a moist surgical sponge is placed over the cut edges to prevent desiccation at the incision edge and assist with control of bleeding. Blood loss in all cases has been minimal. This technique has been used in more than 20 cases by one of the authors and eliminates the need for scalp clips, which prevents

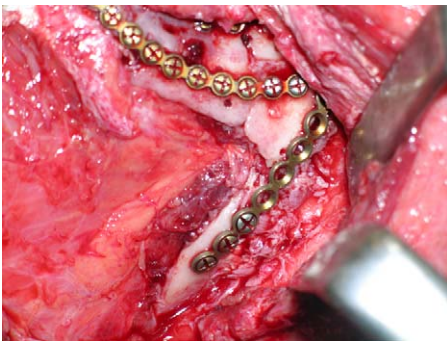


Fig. 19. Accurate reproduction of zygomaticomaxillary complex and zygomatic arch accomplished by prebending surgical plates on contralateral side of stereolithography model to reproduce preinjury facial projection and use of coronal flap for access.

possible formation of traumatic alopecia that can occur during prolonged reconstruction cases.

### Aggressive physical and occupational therapy

Oral and maxillofacial disability can result from scar contracture, soft or hard tissue fibrosis, and muscle atrophy caused by prolonged maxillomandibular fixation. Injured soldiers returning from OIF/OEF often present with some degree of maxillofacial disability. The injuries sustained typically involve soft tissue and hard tissue loss and comminution of the facial bony structure.

Soft tissue fibrosis and scar contracture are typically seen weeks to months after injury repair [13,14]. Initial management after adequate healing involves mandibular opening exercises with lateral excursive movements. The patients also perform manual massage of the injured area in an effort to soften fibrosis and contracture bands. The goal of this modality is to reduce the soft tissue tension and allow a full range of mandibular movement [15]. If this conservative therapy is not successful, a more aggressive regimen is followed to include a commercially available mandibular functional device. Our institutions use the Therabite device (Atos Medical AB, Hörby, Sweden) for cases that require further therapy. The protocol for this device is seven mandibular stretches held at maximum opening for 7 seconds. This routine is repeated seven times daily until a patient achieves a maximum incisal opening larger than 35 mm or improvement is no longer achieved. Another modality of therapy for soft tissue fibrosis involves injection of steroids into the fibrotic area. This approach promotes the reconfiguration of collagen fibrils and softening of the scar, which releases the tension of the soft tissue. Mandibular function is reassessed after 4 to 6 months of healing and therapy. For areas with high tension that have not responded to prior interventions, scar revision is considered with excision of fibrotic tissue and soft tissue release using rotational flaps or undermining procedures. Emphasis is placed on tension-free closure to allow optimal healing with minimal scarring.

Hard tissue fibrosis is seen in patients who sustain maxillofacial injuries caused by the degree of bone destruction and secondary blast effects. Patients with severe comminution of the mandible or maxilla typically undergo maxillomandibular fixation for 6 weeks. After the release of fixation, patients typically demonstrate a maximum incisal opening smaller than

15 mm [13,14]. Patients are instructed on active mandibular range-of-motion exercises and manual techniques to aid in opening. These exercises are performed with minimal pressure so as not to affect the healing fracture. For patients who do not respond to mandibular opening or manual manipulation, the Therabite device is introduced to their routine and the standard protocol is used. For patients with mandibular disability secondary to temporalis fibrosis who do not respond to conservative therapy, coronoidectomies may be considered. The goal of this intervention is to release the temporalis muscle attachment to the mandible and allow normal mandibular function.

Because of the destructive nature of the injuries sustained by soldiers in support of OIF/OEF, many casualties with oral and maxillofacial injuries present with mandibular disability secondary to either soft tissue or hard tissue fibrosis. The management approach to these patients—after all injuries are healed—follows a conservative algorithm with escalation as needed to achieve normal mandibular function. For this approach to be successful, patient compliance is necessary with diligence in following instructions as prescribed.

### **Secondary reconstruction**

The primary purposes of secondary reconstructive procedures should be to increase functional activity of the maxillofacial complex, correct obvious errors or bony relapses from the primary surgical intervention, and improve the cosmetic appearance of a patient. As with any trauma patient, a surgeon should begin to formulate the long-term reconstruction plans before any surgical treatment to avoid performing procedures that may limit definitive reconstruction. As many authors have expressed and we have emphasized repeatedly in this article, the success of long-term reconstruction depends greatly on initial wound management and the prevention of scar contracture. The ideal end result of the reconstructive process is to restore a patient to a functional dentition with optimal cosmesis. With avulsion of tissue associated with high-energy injury patterns, we have found that definitive reconstruction of the jaws is limited by the hard and soft tissue defect and the associated scarring, which often requires numerous secondary procedures. Common procedures performed during this phase from the maxillofacial surgery perspective include placement of ocular, auricular, or dental implants for prosthetic replacement or proprosthetic surgery wholly for dental

indications, such as vestibuloplasty, ridge augmentation, alveolar distraction, or orthognathic surgery to correct maxillary-mandibular arch discrepancies.

In dealing with soft tissue injuries as seen in terrorist attacks or warfare, a surgeon must show some creativity while maintaining basic surgical principles. Replacement of soft tissue can be as simple as skin grafting or local flap advancement, or it can be as advanced as tissue expansion or free flaps. Microstomia secondary to tissue loss or scarring may be addressed initially to give better access for intraoral procedures, which may be a necessity for dental impressions to be taken. Intraoral fibrous scar bands can be excised and grafts placed. In areas that have suffered from avulsive injuries, local recruitment of tissues should be the first option, with regional or free flaps used when the local tissues are inadequate. Free gingival grafts or connective tissue grafts are performed to restore an adequate amount of attached gingiva. After the primary bone grafting is complete, a prosthodontic consultation should be obtained for definitive treatment planning. A maxillofacial prosthodontist should be involved early in the treatment of large avulsive injuries, notably when an obturator for maxillary defects is proposed.

### **Posttraumatic scarring and cosmetic management**

Complex maxillofacial penetrating trauma related to blast and ballistic injuries frequently results in aggressive, disfiguring scars. The combination of a high degree of wound contamination, wound avulsion, and loss of tissue vitality contributes to significant cicatrix formation and facial disfigurement. Our experiences managing these complex wounds sustained by servicemen and servicewomen in support of OIF and OEF have served as a basis for the following discussion according to the lessons learned by our surgeons.

The key to a successful cosmetic outcome after these devastating injuries is based on intervening procedures designed to prevent cicatrix formation rather than strictly addressing wound scarring as a secondary procedure. Initial management of these injuries must include early, extensive wound débridement of contamination through serial “wash outs” with copious antibiotic-containing irrigation solutions and obtaining wound cultures along the way to identify infective organisms and their appropriate sensitivities. Assessment of the degree of missing tissue present after these blast injuries is imperative. Patients who present with tissue loss or avulsion that is left to heal secondarily will develop severe

disfiguring scar formation. Early identification of tissue loss followed by procedures to bring vascularized tissue through local rotation flaps or distant free flaps is essential to minimize scarring and maximize form and function. Early reduction and fixation of underlying bony fractures and replacement of missing osseous structures with bone grafts or alloplastic augmentation also are essential for a favorable return of form and function and minimization of cicatrix formation. Early intervention regarding reconstruction of the underlying bony defects and overlying cutaneous defects should be accomplished within 10 to 14 days of injury to avoid extensive wound contracture and aggressive scarring. This is certainly a reasonable time period to initiate these surgical procedures once appropriate consultations have been accomplished and wound infection has been ruled out or appropriately treated. If this protocol is followed, the resultant scar formation should be minimized and amenable to the following treatment options to accomplish a cosmetically acceptable outcome.

Scarring associated with ballistic and blast injuries usually presents with tattooing of the penetrated tissues secondary to impregnation of the skin by metallic fragments. In addition to the tattoo effect, there is usually hypertrophic cicatrix formation. Early program dermabrasion of these scars 4 to 6 weeks after soft tissue closure or scar excision/revision has proved to be beneficial to leveling the skin and improving cosmesis. Injecting subcutaneous kenalog to reduce hypertrophic scarring is also beneficial as long as long as low doses are used so as not to cause significant dermal atrophy or liponecrosis. Topical application of silastic gel or sheets through a relatively unknown mechanism also improves wound levels and cosmesis. Topical application of imiquimod 5% cream also has been reported to reduce hypertrophic scar formation by activating cellular cytokines and alpha interferon. This agent is helpful if initiated by the second week after the wound repair [16].

Tattooing of the skin with gray-blue pigmentation after penetrating metallic injury can be reduced significantly or eliminated with treatments using the pulsed-dye laser. The pulsed dye laser (595 nm, yellow light laser) provides collagen rebuilding and reorganization while normalizing neovascularization. These treatments can be repeated on a monthly basis for eight to ten applications. The tattooing is secondary to implanted metallic fragments that consist of copper, zinc, graphite, and other metals. The metallic fragments can be disrupted through "photo acoustic shattering" of the pigmented particles using a "Q-switched" laser. Two other lasers have been effective in our experience in reducing

tattooing: the Nd Yag (1064 nm) infrared laser and the red Alexandrite laser (755 nm). We are convinced that persistence of these foreign particles within the soft tissues provides the impetus and etiology for significant hypertrophic scar formation. Prompt scar excision and revision coupled with laser-assisted phagocytosis and elimination of metallic particles provide the greatest likelihood of a favorable cosmetic soft tissue wound result [17].

Facial scarring secondary to ballistic and blast-related injuries is a significant cosmetic concern. The outcome can be made more predictable and cosmetically pleasing if certain treatment protocols and modalities are used. Essential considerations must include early fixation and reconstitution of the facial skeleton, followed by passive soft tissue wound closure through use of local rotational flaps or distant free flaps. In our experience, early scar excision and revision along with early program dermabrasion and use of laser technology to remove tattooing of soft tissue seem to provide the most favorable cosmetic outcome for these devastating facial injuries. Measures used to prevent or eliminate wound contamination and contraction provide the foundation for the most favorable cosmetic outcome. Preventive measures always outweigh the benefits of secondary management of posttraumatic scarring.

## Summary

The management of complex maxillofacial injuries sustained in modern warfare or terrorist attack has presented military surgeons with a new form of injury pattern previously not discussed in the medical literature. The unique wounding characteristics of the IED, the portability of the weapon platform, and the relative low cost of development make it an ideal weapon for potential terrorist attacks. If potential future terrorist attacks in the United States follow the same pattern as the incidents currently unfolding in the Middle East, civilian practitioners will be required to manage these wounds early for primary surgical intervention and late for secondary and tertiary reconstructive efforts.

The use of stereolithographic models in presurgical planning of complex maxillofacial injuries is critical and should be considered the standard of care. These models can be manufactured during the initial 48- to 72-hour period of serial débridement and surgical washouts. They are invaluable in visualizing the bony architecture of the skeletal framework. Our experiences with patients injured by IED blasts

indicate that they are highly likely to become infected by some type of organism, the only variable being when the infection will develop over the course of treatment. Scar contracture that occurs either secondary to infection or as a consequence of improper positioning of the bony substructure of the face is almost impossible to recover from if inadequate projection of the soft tissue envelope is not maintained. The treating surgeon should not fall victim to the mistake of rushing these patients to the operating room for definitive treatment before gathering the appropriate preoperative data. Projection and support of the soft tissue envelope is critical to the success of any surgical treatment initially performed. We also have used this treatment protocol on civilian pan-facial trauma casualties, such as victims of automobile accidents or isolated gunshot wounds, and have found it to be successful. Whereas our wish is that the information presented in this article never will be used in the United States for the treatment of patients injured in another terrorist attack, the lessons learned in the management of modern ballistic injuries and wounds sustained in warfare should be shared with the civilian community so that if that day ever comes, we shall all be prepared.

### Acknowledgments

The authors would like to acknowledge the chief residents of the National Capitol Consortium Oral and Maxillofacial Surgery Training Program, Michael J. Doherty, DDS, and Charles G. Stone, Jr, DDS, for their assistance with the research and preparation of this article.

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