Chapter 46

ADVANCES IN SURGICAL TECHNIQUES, PROCEDURES, AND WOUND CARE

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INTRODUCTION

Since ancient times, war has provided a fertile ground for innovation in medicine and surgery. Novel therapies are introduced or hastened to maturity, unanticipated crises drive creative responses, and thoughtful review of the lessons learned ultimately drives the evolution of both civilian and military medicine. Moreover, as noted by Hippocrates in his advice to young surgeons to ply their craft by following an army, physicians, particularly surgeons, expand their personal capabilities and that of the profession by meeting the unique challenges presented by the injured patient in the crucible of combat. The Global War on Terror (GWOT), with focal conflicts in Iraq and Afghanistan, upholds this legacy of medical and surgical innovations, particularly with regard to injuries of the head and neck.

Surgeons of the head and neck have always been integral to the care of patients in wartime, but increasing specialization and an arguable decrease in the scope of "general" surgery led to a surge in the roles played by surgical specialists in Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (OEF). Otolaryngologists, oral-maxillofacial surgeons, vascular surgeons, neurosurgeons, and ophthalmologists comprise core elements of the dedicated head and neck teams providing care at Role 3 facilities in combat zones.[1,2] These various specialties have unique skill sets that complement each other and promote quality and comprehensive care for these complicated injuries. The successes of these teams underscore the need for multidisciplinary, in-theater representation that includes otolaryngologists in ongoing and future conflicts.

Beyond the personnel involved, these wars capitalized on burgeoning technical developments in healthcare and witnessed unprecedented extension of many of these technologies to comparatively austere environments. Advances in medical imaging and modeling, surgical techniques, endoscopic and endovascular therapies, and communication that developed seemingly independent of military intentions were rapidly adapted to the combat environment. Other innovations, such as composite tissue transplantation, emerged during the wars and may serve to change the lives of injured soldiers, marines, and airmen well after the drawdown of formal hostilities. Furthermore, the compilation of extensive databases of injured patients—including traumatic brain injury (TBI)—and progressive, collaborative medical research efforts stand to significantly impact civilian healthcare and the approach of the military medical community to future conflicts.

By leveraging air supremacy (efficient patient transport that could deliver patients to the United States within 3 days), medical-technological advances, and appropriate personnel, the military medical system achieved survival rates of >90% for combat-wounded troops, an unprecedented number in modern warfare.[3,4] The Multidisciplinary Head and Neck Teams (MHNTs) were integral to these survival rates. Moreover, forward-deployed specialist capability enabled less severely injured troops to return to their duties safely and quickly, without the need for aeromedical evacuation to Role 4 or even stateside facilities.[1] Advances in communication, including teleconferencing and even video capabilities, promoted a climate of continuous process improvement, as providers at Role 2 and Role 3 facilities were supplied follow-up information in near real time by teams in Europe or the United States on patients whom they treated at the time of, or shortly after, injury. The ease of communication even allowed consultation between deployed and stateside (even civilian) experts to determine the appropriate management of patients with nonlife-threatening or chronic medical problems

ADVANCES IN HEAD AND NECK SURGERY IN OPERATION IRAQI FREEDOM AND OPERATION ENDURING FREEDOM

Evolution of Head and Neck Teams in Operation Iraqi Freedom and Operation Enduring Freedom

At the onset of hostilities in the GWOT, the military medical service relied heavily on Forward Surgical Teams and established overseas facilities such as Landstuhl Regional Medical Center (Landstuhl, Germany) as the Role 2 and Role 3 facilities rapidly evolved in-theater. Although some surgical specialists, including otolaryngologists, deployed during these early days, they were not serving in their primary specialty.

By prospectively evaluating the diagnoses and treatment of patients evacuated from Iraq and Afghanistan between January 2003 and March 2004, Xydakis and colleagues[5] were able to determine that 16% of all evacuated patients required treatment by the otolaryngology service at Landstuhl Regional Medical Center, and 21% of combat injuries involved the head and neck. Other reports noted that up to 25% of patients evacuated to Walter Reed Army Medical Center in the early days of the Iraq War sustained combat injuries to the head and neck.[6] As areas that remain exposed even

in the presence of contemporary body armor, facial and neck injuries were quickly noted to occur with increased frequency over prior conflicts—whether this reflects the predominant mechanism of injury by improvised explosive devices, the exposed nature of the face and neck, or the avoidance of less survivable torso wounds due to body armor—and remain a matter of debate.[2,7,8] Regardless, with this revelation, otolaryngology was added to the earlier triad of neurosurgery, ophthalmology, and oral-maxillofacial surgery to create a true MHNT, often along with plastic surgery.[1,5] Colonel Joseph Brennan (Medical Corps, US Air Force) spearheaded this effort, and his early reports cemented the importance of ear-nose-throat (ENT) surgeons to comprehensive care of the combat injured. In a 4-month period, the ENT team performed 257 operative procedures on 159 patients, making ENT the busiest of the head and neck team services. Facial soft-tissue repair, tracheotomy, airway management, and neck exploration for penetrating neck trauma constituted the most frequent indications for ENT involvement and made the ENT surgeon the busiest member of the head and neck team.[1]

The impact of deployed ENT in Iraq soon led to extension of the MHNT to Afghanistan in 2007, with similar results.[9] Once the right personnel were emplaced to comprehensively manage head and neck trauma in OEF and OIF, treatment philosophies and techniques evolved over time, based on the type and severity of injury. Overall estimates of the incidence of combat-related head and neck injury range from 29% to 52%, compared with about 16% based on estimates from prior conflicts.[2,7,10] Between 2001 and 2011, >42% of patients evacuated to Role 4 facilities out of theater were noted to have craniomaxillofacial injuries, with a significant number of other patients successfully and safely treated in theater, and providing further justification to the creation of highly functional head and neck trauma teams.[11,12] This evolution of personnel, technique, and technology directly contributed to the >96% survival rate for head and neck injury, and the pearls acquired over the years by a number of providers from the specialties represented on the head and neck team merit enumeration and discussion.[6]

ADVANCES IN SURGICAL TECHNIQUE AND MEDICAL MANAGEMENT

Immediate Surgical Care

Initial surgical efforts in the acutely injured combatant adhere to contemporary general trauma principles of damage control surgery—*control and repair of life-threatening injuries intending to stabilize patients for transport to higher levels of care or delayed definitive care once patients have been adequately resuscitated*. Airway control, assessment and repair of vascular injury, and identification of pharyngoesophageal injuries constitute the primary acute surgical goals. Deployed otolaryngologists are frequently called on to secure difficult airways, often in emergent settings, via intubation or tracheotomy, and tracheotomy constitutes one of the most common procedures performed by ENT surgeons.[1] In one report, 10% of patients with maxillofacial injuries required some form of emergent airway control after initial management failed, and the availability of personnel with advanced airway management experience has been credited with achieving >94% survival in patients presenting with airway obstruction.[13]

Once the airway is secure, resuscitation proceeds according to the principles of damage control resuscitation. The hallmarks of damage control resuscitation include *permissive hypotension* to prevent excessive bleeding and *hemostatic resuscitation*, which is based on the administration of blood products in a 1:1:1 ratio of fresh frozen plasma, packed red blood cells, and platelets, in addition to reversing hypothermia, acidosis, anemia, hypocalcemia, and coagulopathy.[14,15]

Penetrating Neck Trauma

Penetrating neck trauma occurred in 5% of US servicemen injured in combat operations, compared with 10% in British combat-wounded personnel.[16] Based on available data, the majority of neck injuries occurred in troops who were not wearing the cervical protective adjunct to body armor, and the compliance of US service personnel who were wearing the neck protection has been attributed to the lower rates of neck injury reported in American troops.[16] A detailed analysis of British combat fatalities revealed that, when present, a neck wound directly contributed to death in 73% of patients who died of battlefield wounds, with vascular injury most commonly occurring after explosions and cervical spine injury resulting from gunshot wounds. Survivors of penetrating neck trauma were noted to suffer from

- ischemic strokes,
- cranial neuropathies,
- Horner's syndrome, and
- brachial plexopathy

with permanent neurological complications noted in 14% of survivors.[16]

Despite the destructive power of the mechanisms of penetrating neck trauma (improvised explosive devices and indirect fire), in most cases the survival rate has been reported to be >96%.[13] This success rate has been achieved by following a protocol of selective exploration based on clinical and radiographic findings, particularly computed tomography (CT) angiography, rather than mandatory exploration, as well as having surgeons available in theater who are familiar with the regional anatomy and the various approaches required for access, particularly in Role 3. Although the external carotid artery, external jugular vein, and internal jugular vein may be readily ligated if severely injured, vascular shunts have proven advantageous in the acute management of internal or common carotid injury, and advances in endovascular therapy have demonstrated efficacy in the management of pseudoaneurysms and arteriovenous fistulae, thus decreasing the risk of rebleeding.[17–19]

Management of penetrating neck trauma is discussed elsewhere in this text, but the value of experienced personnel may be readily seen in the overall outcomes (as illustrated in Case Study 46-1). Even when the initial neck exploration is performed at a lower level of care, a comprehensive evaluation of the upper aerodigestive tract is still required, employing CT scanning and endoscopy to detect potential occult pharyngoesophageal injury as noted in Case Study 46-2 to rapidly detect and correct these injuries.

Craniomaxillofacial Trauma

The nature of asymmetric warfare in these conflicts has lead to a high rate of craniomaxillofacial injury, with >33% of patients treated at in-theater Role 3 facilities and 42% of patients evacuated to a Role 4 facility suffering from

- soft-tissue wounds,
- fractures,
- nerve injuries,
- burns, and
- vessel injuries of the head and neck.[11]

These wounds are typically extensive, with soft-tissue injuries to multiple anatomical regions, complicated open fractures (most involving the midface), and concomitant burns. Nerve injuries are also common, accounting for 6% of the aeromedical evacuations and most frequently involving the facial nerve, followed by the auditory nerve, and then the optic nerves.[11] Although this proliferation of head and neck injuries has been attributed to the wearing of combat body armor, the exact relationship has not been elucidated, but the frequency of fragmentation injuries, avoidance or increased survivability of torso injuries, and lack of facial protection have emerged as the main reasons for this surge in head and neck injuries.[20]

As in the evaluation of patients with penetrating neck trauma, multislice helical CT scanning is integral to the management of patients with soft-tissue and/or bony maxillofacial trauma.[21] Images cannot replace a thorough physical examination by experts in head and neck anatomy in the initial evaluation of patients with maxillofacial trauma because the facial nerve and parotid duct are often injured, but overlooked by less experienced personnel.[11]

Once the extent of injury has been determined and patients stabilized, soft-tissue repair—as well as open reduction and internal fixation of facial fractures—may be safely and successfully performed in theater, provided that

- the fracture could be accessed through an existing soft-tissue laceration or as part of an approach for another operative purpose,
- the patient requires general anesthesia for another injury, and
- definitive treatment would not delay aeromedical evacuation, or definitive treatment may allow a service member to remain in theater.[9,12,22]

For those inevitable garrison-related or noncombat-related maxillofacial injuries, in-theater repair of facial injuries may successfully facilitate the efficient return of service members to duty.

However, Brennan[9] has adroitly highlighted that deployed surgeons must resist the temptation to immediately perform "home-run" surgeries, with comprehensive repair and reconstruction performed shortly after injury due to the devascularization that arises from cavitation around the point of injury. Once the tissues have been allowed to recover, definitive reconstruction is certainly possible, even with free tissue transfer, based on an aggregate experience of microvascular reconstruction performed on injured coalition partners who lacked the capacity for aeromedical evacuation out of theater.[23]

With the technical challenges of significant devitalized or compromised tissue in wounds that are often heavily contaminated and prone to infection with atypical pathogens (compared with civilian practice), such as *Acinetobacter baumannii*, a critical appraisal of practice patterns and outcomes data has led to several recommendations on wound care and management,

as well as antibiotic prophylaxis. Despite the natural inclination to use long-term prophylactic antibiotics after craniomaxillofacial injury, such perioperative prophylaxis beyond 24 hours has not demonstrated a reduction in infection rates and is therefore not recommended. Similarly, liberal use of negative pressure wound therapy has been advocated to promote granulation tissue formation and potentially simplify the closure of complex wounds.[24]

Otological and Vestibular Injuries

The nature of modern combat operations places great stress on hearing and balance function, and complaints—such as hearing loss, tympanic membrane perforation, and dizziness from vestibular injury—were increasingly common in OIF and OEF. Traumatic hearing loss constituted the most frequent presenting complaint at a deployed outpatient ENT clinic, with 20% of visits related to acute hearing loss and 10% of visits attributed to tympanic membrane perforation.[1] With an initial management paradigm centered on cleaning the ear canals to achieve a thorough examination and obtaining an audiogram, these patients require the services of otolaryngology. If a significant threshold shift is noted, these injured service members need to be removed from combat. However, in the absence of a significant threshold shift, some tympanic membrane perforations may be managed in theater with ototopical agents, with the expectation that the majority of traumatic perforations will heal spontaneously. By providing otolaryngology services in theater, select troops may be spared aeromedical evacuation and returned to their duties expeditiously.

Recent publications have described a potential association between TBI and tympanic membrane perforation, but other reports call this link into question.[25,26] Regardless of the final verdict on this question, tympanic membrane perforations constitute the most common manifestation of primary blast injury, which in turn is frequently associated with TBI. Because of the impact of TBI on postdeployment function, early and accurate identification of patients with tympanic membrane perforation and hearing-related complaints is imperative in the long-term health management of deployed personnel.[27,28] Although questions persist about the strength of the association between tympanic membrane perforation and TBI, the relationship between vestibular injury and TBI is more clear. Again, subtle clinical findings may be elucidated by an otolaryngologist performing a comprehensive ENT examination that may identify patients with vestibular neuropathy who merit close follow-up for development of TBI.

Humanitarian Efforts

Although the primary mission for a deployed head and neck team is to provide care for injured US service members and allies, followed by local national civilians injured in the course of military operations, there is often some capacity to provide humanitarian assistance on a case-by-case basis. The conflicts in Iraq and Afghanistan devastated the host nation's ability to provide healthcare for its citizens. In Afghanistan, generations of war have severely limited the growth of an indigenous healthcare system. Thus, patients are left to the mercy of volunteer organizations and military medicine.

The variety of skills offered by members of a multidisciplinary head and neck team is invaluable in a humanitarian context. Facial deformities such as cleft lips and palates, chronic otitis media with hearing loss and infection, and even disfiguring tumors may all be addressed by particular surgeons as the operations tempo, command directives, and hospital capacity for high acuity care allow (such as that which occurred in Case Study 46-3).[29] Many times, these operations can be performed with minimal impact on the hospital census because patients may be discharged following short hospital stays.[30] Not only is this morally right, but also such acts have significant symbolic and even practical benefit to the United States, the US military, and even security operations.[30]

Outcomes Measurement and Research Endeavors

Although the meticulous recordings of wartime physicians comprise the foundation of historical advances in healthcare achieved through conflict, OIF and OEF ushered in a new era of medical research in war. With the establishment of a military Human Research Protection Plan in 2005, prospective noninterventional protocols were devised and implemented that drove data collection, tissue analysis, and control subject assessment in accordance with the principle of ethical research.[31] An entire apparatus evolved to facilitate research, including forward deployed elements as part of the Joint Combat Casualty Research Team, and this complemented the rigorous data collection of the Joint Theater Trauma Registry.

In addition to meticulous documentation of demographics, injury data, interventions, and sequential care, the cornerstone of the Joint Theater Trauma Registry is the regular participation in teleconferences or video teleconferences by surgical personnel at Role 2 to Role 4 facilities. These conferences constitute an internal quality and process improvement tool, while

EXHIBIT 46-1

PRINCIPLES OF TACTICAL COMBAT CASUALTY CARE APPLICABLE TO THE HEAD AND NECK

- Use of nasopharyngeal airways
- Have patients (when possible) who have suffered maxillofacial trauma sit up and lean forward to keep airway clear of blood
- Secure (early) surgical airways for patients who cannot sit up and lean forward after maxillofacial trauma
- Use a modified approach to spinal precautions in penetrating trauma, as suggested previously
- Use aggressive fluid resuscitation and administration of supplemental oxygen in patients suspected of suffering traumatic brain injury
- Prevent hypothermia and secondary coagulopathy
- Use fluoroquinolones and ertapenam or cefotetan as battlefield antibiotics
- Utilize 1:1 plasma and packed red blood cells for patients who are in shock
- Use tranexamic acid to help prevent death from noncompressible hemorrhage

Data source: Modified from Blackbourne LH, Baer DG, Eastridge BJ, et al. Military medical revolution: deployed hospital and en route care. *J Trauma Acute Care Surg*. 2012;73(6 suppl 5):S378–S387.

providing meaningful follow-up information to treating physicians at all echelons. The database and conferences create the potential for early identification of trends that can lead to changes in management, care, or even transport.

Education and Training

Improved outcomes in maxillofacial or head and neck injuries are in part attributable to the personnel and techniques outlined throughout this chapter, but a significant contribution also arises from improved prehospital care and resuscitation principles. Standardization of battlefield trauma techniques via adoption, implementation, and dissemination of principles of Tactical Combat Casualty Care (TCCC) across services and allied nations has improved outcomes and decreased the number of "preventable" combat deaths. Several key principles of Tactical Combat Casualty Care relate to the head and neck, and are summarized in Exhibit 46-1.[32]

Similarly, a focus on training and readiness for deployed otolaryngologists has evolved over the course of these conflicts. Not all oral surgeons, otolaryngologists, and plastic surgeons possess the same skills that are applicable to the deployed environment, nor do the demands of garrison medicine typically match those of a deployed environment. As such, core competencies have been proposed, and arrangements, both formal and informal, have been developed with civilian institutions to prepare surgeons for the rigors of deployment. Even with a defined curriculum, gaps do exist in an individual surgeon's training, experience, and comfort level. Although certain skills constitute a core for a board-certified member of the head and neck team, other valued skills such as familiarity with advanced reconstructive techniques (including microvascular reconstruction and bony maxillofacial trauma) demonstrate broad variability. Figure 46-1 depicts the ideal skills represented within a MHNT, and it must be recognized that there is some flex within these parameters. Future military medical leaders should keep the fluid, but complementary, skills of individual otolaryngologists, oral surgeons, and plastic surgeons in mind when assigning personnel to deployment teams.

TECHNICAL INNOVATION

Virtual Surgical Planning

The complexity of traumatic maxillofacial injuries creates significant challenges for the reconstructive surgeon, whether stateside or in a deployed environment. The development of three-dimensional CT reconstruction technology, followed by advances in medical modeling and virtual surgical planning, has revolutionized maxillofacial reconstruction. Whether relying on embedded software within the

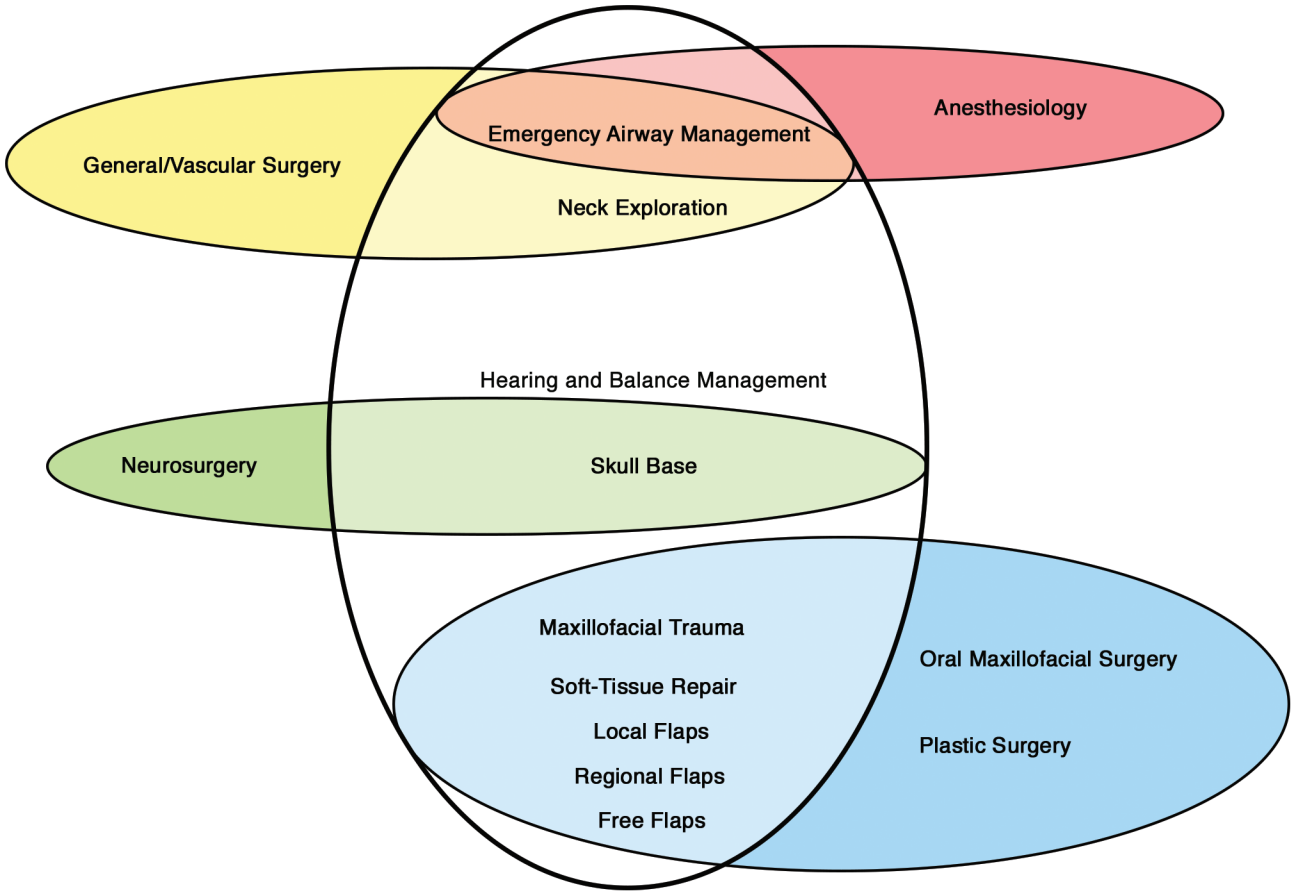

Figure 46-1. Schematic of the responsibilities of the Multidisciplinary Head and Neck Trauma Team. Based on the potential breadth of skill and training, otolaryngology comprises the central component, with important contributions from the other listed disciplines. These lines may flex somewhat based on individual skills and experience.

CT scan or by exporting thin-slice images to a third party viewer, three-dimensional reconstruction allows an improved appreciation of the complexities of the injury.[33] A number of third-party programs are available, and some are even considered "freeware," thus enabling the deployed surgeon to download the software to a personal computer for surgical planning in preparation for definitive reconstruction.

Extrapolating from the early results of employing three-dimensional reconstructions to fully assess postmorbid anatomy, computer-aided design and manufacturing have progressed to the point that reconstructions may be made of not only the injury, but also an idyllic "normal" based on a mirror image of the contralateral side or a proposed image from available tissue. Models can then be made, and reconstructive plates or implants contoured to fit the proposed "end"-state, with the fracture segments, flaps, or implants designed accordingly, thus recognizing that the craniofacial skeleton is often slightly asymmetric.[34] Early reports in mandibular and midface reconstruction suggest that such virtual surgical planning and intraoperative navigation may lead to improved, accurate surgical results.[34–36]

Hemostatic Agents

From time immemorial, exsanguination has constituted one of the more frequent reasons for death on the battlefield and remains the number one preventable cause of death in our current military operations.[37] The body's natural response to blood loss is often insufficient to deal with severe hemorrhage and volume depletion, especially in the setting of acute coagulopathy that follows tissue trauma and hypovolemic shock. Additionally, transit time

from the point of injury to a facility equipped for surgical correction of hemorrhage is often prolonged. Therefore, agents that can rapidly and effectively control hemorrhage in the field have the potential to save many lives. The experience in Vietnam and the First Gulf War drove a rediscovery of the benefits of tourniquet application to quell extremity hemorrhage, and the Combat Application Tourniquet (North American Rescue, LLC, Greer, SC) is now routinely distributed to combat troops as a first-line intervention in combat casualty care.[15,38] However, many wounds, particularly those in the head and neck, are not amenable to tourniquet application, and technology has rapidly evolved to deliver products that have achieved widespread use on the battlefield, some of which are migrating to the civilian sector for both traumatic and elective purposes.

Developed in 2006, QuikClot Combat Gauze (ZMedica, LLC, Wallingford, CT) belongs to a class of hemostatic agents known as procoagulant supplementers, and the kaolin, which impregnates the gauze, activates the intrinsic clotting pathway (ie, the gauze may be stuffed into a bleeding wound). Unfortunately, Combat Gauze does not tightly seal the wound, allowing ongoing blood loss following application until clot forms. Because it depends on the presence of natural clotting factors, it is less effective in the setting of coagulopathy. Nevertheless, it is now commonly used in the field, and Combat Gauze has been shown to be safe and effective although hemostatic agents remain an area of ongoing research.[39] Other hemostatic products have been developed, including factor concentrators like QuikClot, that rapidly absorb the aqueous component of blood and lead to an increase in the local concentration of clotting factors, as well as mucoadhesive agents such as HemCon (HemCon Medical Technologies, Inc, Portland, OR), a chitosan-based product that anneals to the wound and thereby promotes cessation of bleeding.[40]

Tranexamic acid is an antifibrinolytic agent that inhibits the activation of plasminogen to plasmin, thereby preventing fibrin breakdown. First noted in the 1960s, it has gained increasing acceptance in traumatic bleeding and has been recently associated with a significant reduction in all-cause mortality as well as deaths from bleeding in a multiinstitutional randomized controlled trial.[41] The use of tranexamic acid in combat has been demonstrated to be advantageous, and it is now recommended for routine administration for self-care or buddy care by American and British military medical experts.[38,42]

Reflecting on the historical progression of medical innovation from the battlefield to the civilian arena, a number of these agents are gaining increasing attention in hemorrhage prevention following septorhinoplasty or sinus surgery, as well as epistaxis control in patients with inherited coagulopathies.[43–45] This remains a popular area of investigation, and the long-term impact and applications of these newer agents will likely evolve rapidly, as deployed surgeons transition back to stateside and civilian practice.

Medical Devices

Just as combat medicine triggers innovation in technique, logistics, and personal skill, it also provides a fertile ground for technological breakthroughs, often through civilian–military partnerships. Although most of the research is in the realm of personal protection and injury prevention, particularly with regard to the head and neck, a few products have demonstrated applicability and have garnered attention in the medical literature.[46] Building on the common practice of videoendoscopy for airway control, Nicholas and colleagues[47] created a videolaryngoscope with an incorporated suction channel for use in difficult airways that are compromised by significant hemorrhage or secretions. Early reviews of this device have been favorable, and it holds promise for future use on the battlefield. Similarly, the same group has developed a pharyngeal forceps that is compatible with the view provided by the videolaryngoscope for both foreign body removal and intubation purposes.[48]

HORIZONS

The rapid expansion of medical and technological capabilities continues apace, often distinct from those developments driven by wartime concerns. The past 10 years have witnessed an extraordinary explosion in the technical foundations for allograft tissue transplantation, and facial transplantation has successfully been performed for a variety of traumatic and congenital defects.[49] Although facial transplantation is in its practical infancy, the ability to provide functional neuromuscular reconstruction of facial defects, particularly those of the midface, holds tremendous promise in the event our service members continue in harm's way across the globe, as part of the GWOT or some heretofore unknown conflict.

SUMMARY

Head and neck trauma occurred at an unprecedented rate during OIF and OEF. Whether manifesting as penetrating neck trauma, maxillofacial injury or fracture, airway compromise, or acoustic injury, members of the MHNT distinguished themselves and their specialties by the sheer numbers of patients they helped and the tremendous outcomes they achieved. With the increase in clinical specialization in American medicine, it is foolhardy to think that such disparate injuries can be managed by a general surgeon or oral surgeon. Although oral surgeons, vascular surgeons, neurosurgeons, and plastic surgeons are highly valuable members of the MHNT, the otolaryngologist emerged from these conflicts as the central component to comprehensive care of the combat injured head and neck/ENT patient.

Knowledge is not proprietary, and it is not the specialties themselves as much as the skill sets represented by individuals on a given rotation that are the hallmark of the MHNT. Various specialties often have significant overlap in their skills, and these skills are often complementary. This is most evident in head and neck trauma (as depicted in Figure 46-1). The complexity of the cases performed in forward environments often demands that two surgeons work in concert. In cases of penetrating neck trauma, an otolaryngologist and a trauma or vascular surgeon collectively can address the vessel, soft-tissue, and potential upper aerodigestive tract injuries.[4] Neurosurgery and ENT are complementary with many skull base injuries, but the primacy of the former in intracranial injuries and of the latter in otological issues, such as tympanic membrane perforation and hearing loss, cannot be overstated. Craniomaxillofacial trauma demands familiarity with fracture fixation, as well as soft-tissue repair and reconstruction. The head and neck team construct builds on the paradigm at major teaching facilities in which facial trauma responsibilities are shared by oral surgery, ENT, and plastic surgery.

Otolaryngologists–head and neck surgeons are integral to the head and neck team, based on their unique knowledge and training regarding otological issues, such as:

- hearing loss and tympanic membrane perforation,
- advanced airway assessment and management skills,
- complementary abilities in soft-tissue and maxillofacial trauma, and
- penetrating neck injury.

Combat injuries related to improvised explosive devices, the most common instrument of asymmetric warfare, result in significant tissue damage from laceration, fracture, destruction, and burns. Once stabilized, these wounds often require complex reconstruction, and deployed otolaryngologists and plastic surgeons trained in microvascular techniques have demonstrated that free tissue transfer can be safely and effectively executed in a forward environment on local national combatants and civilians alike. These complementary and often interdependent skills in managing the soft tissues of the face and neck, the upper aerodigestive tract, the craniomaxillofacial skeleton, and the cervical vasculature, whether in the trauma or humanitarian setting, underscore the importance of the MHNT and role of ENT on this team.

In addition to the development and maturation of the head and neck trauma teams, OIF and OEF witnessed tremendous progress in initial stabilization and surgical care of injured combatants, with the development of protocols on the management of penetrating neck trauma, in-theater repair of facial fractures and soft-tissue injuries, and evaluation of patients with otological manifestations of primary blast injury. These advances would not have been disseminated as widely or as quickly without the creation of accurate patient databases and an ethical, meticulous research apparatus. Demonstrating a degree of flexibility, the US military medical establishment was able to identify knowledge or training gaps in deployed personnel, formulate core competencies, and aggressively create training opportunities (either internally or in collaboration with civilian institutions) to ameliorate these deficiencies and adequately prepare surgeons for deployment. Ideally, these relationships and training programs will remain in place even as combat operations draw to a close in these theaters, in preparation for the next conflict or disaster. Finally, medical innovation serves to benefit both the military and civilian arenas, as advances in resuscitation, endoscopy, and hemostasis—driven by battlefield situations—find applicability in civilian medicine and new horizons in virtual surgical planning and even facial transplantation offer new hope for injured servicemen and women.

CASE PRESENTATIONS

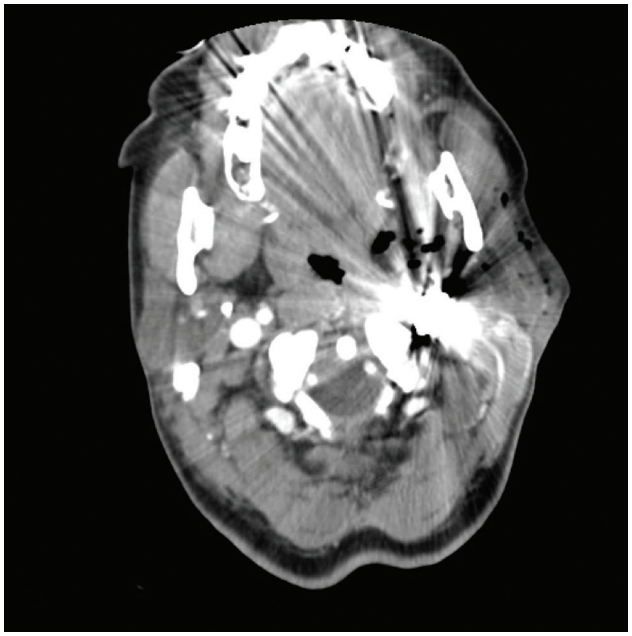

Figure 46-2. Contrasted CT (computed tomography) scan images of fragments at the left skull base following penetrating neck trauma.

Figure 46-3. Contrasted CT (computed tomography) scan images of fragments at the left skull base following penetrating neck trauma

Case Study 46-1

Presentation

A 24-year-old Army specialist was struck by indirect fire at a Forward Operating Base, sustaining extremity wounds and a penetrating injury to the left upper neck. She was CASEVACed (casualty evacuated) directly to a Role 3 facility, where a comprehensive evaluation—including CT angiography—was accomplished. There was modest bleeding from a 1-cm, irregular left neck wound that was predominately located superior to the angle of the mandible. The CT scan revealed fragments at the skull base with interrupted flow of the internal jugular vein and subtle irregularity of the internal carotid artery (Figure 46-2 and Figure 46-3). She was taken emergently to the operating room where a left neck exploration was accomplished through a broad apron incision from ongoing bleeding (Figure 46-4).

Multiple mortar fragments were removed from the wound (Figure 46-5), and the jugular vein was noted to be lacerated from the transverse process of the C1 vertebral body—immediately adjacent to the spinal accessory nerve—to the jugular foramen. The inferior aspect of the jugular vein was ligated, and the jugular foramen was packed extralumenally with Gelfoam (Pharmacia and Upjohn Company, Kalamazoo, MI) and Surgicel (Ethicon US, LLC, Somerville, NJ). The carotid artery was inspected and found to be uninjured. The patient was ultimately transported back to the United States. Follow-up through the

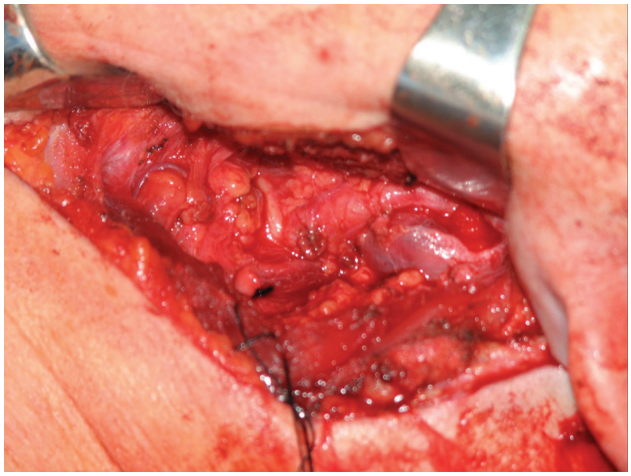

Figure 46-4. Apron incision used for Zone III neck exploration. Neither a mandibulotomy nor a parotidectomy was required for access to the jugular foramen, as in neck dissection.

Figure 46-5. Mortar fragments removed from the jugular vein at the skull base.

global electronic medical record revealed that her neck wound healed without additional surgery, and she had intact cranial nerve XI function.

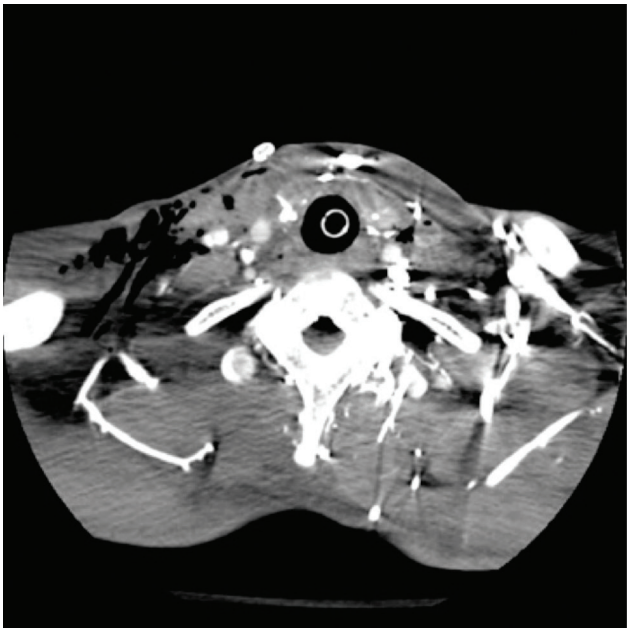

Figure 46-6. Axial contrasted CT (computed tomography) scan of the neck following penetrating neck trauma revealing significant and diffuse subcutaneous emphysema. The patient had undergone a limited neck exploration at a Role 2 facility without significant findings, but endoscopic assessment of the upper aerodigestive tract was required to complete the evaluation. There was some ecchymosis without laceration or perforation of the pharyngeal wall noted.

Case Study 46-2

Presentation

A 29-year-old Special Operations soldier was struck by an improvised explosive device while on a mission. He sustained a 2-cm wound to the neck, with notable bleeding. Taken to a Role 3 facility, he underwent neck exploration without identification of any vascular injury. He was then transported to a Role 3 facility where his physical examination was remarkable for a stapled incision, multiple contusions and abrasions, and massive subcutaneous emphysema. A CT scan was obtained (Figure 46-6), revealing a significant amount of free air in the neck. Because the forward facility performed the neck exploration without a thorough assessment of the upper aerodigestive tract, the patient underwent a direct laryngoscopy, bronchoscopy, and esophagoscopy while in the operating room for an orthopaedic procedure. The endoscopic examination revealed only some pharyngeal ecchymosis and no perforation, but it was indicated to complete a comprehensive assessment of the neck after the penetrating injury.

Case Study 46-3

Presentation

A 17-year-old Afghan girl was brought to the ENT clinic by Special Operations medics. She had developed a large right facial and neck mass several years ago (Figure 46-7). She reportedly had been evaluated

Figure 46-7. Massive right salivary gland neoplasm in a 17-year-old Afghan female. Preoperative view.

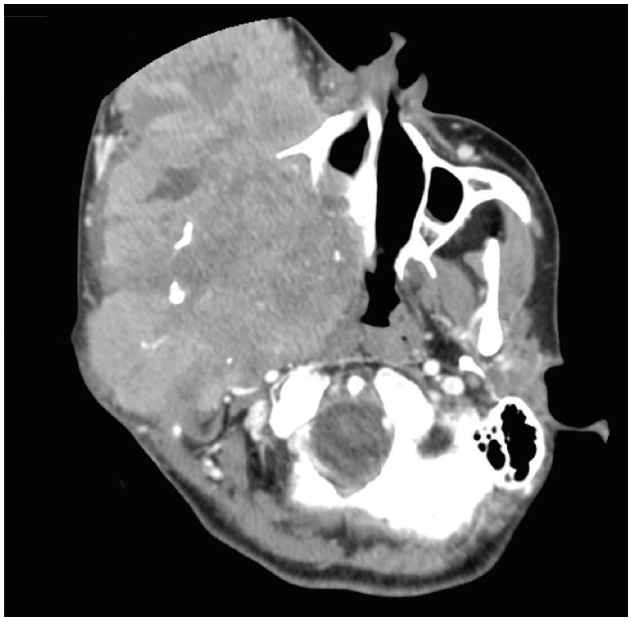

Figure 46-8. Axial contrasted CT (computed tomography) scan of patient from Case Study 46-3, revealing a large tumor involving the deep and lateral aspects of the parotid gland, the mandible, and the parapharyngeal space.

Figure 46-9. Postoperative images of patient from Case Study 46-3 following successful resection and combined serratus-latissimus dorsi free flap.

by surgeons in Pakistan, who deemed the tumor unresectable. As the tumor grew, she suffered worsening problems swallowing and was effectively banished from the family home and society because of her disfigurement. Once clearance was obtained from the hospital commander to proceed with her workup (with an eye toward resection and reconstruction if the operations tempo and hospital census permitted), a CT scan was accomplished that documented a massive tumor of the parapharyngeal space, mandible, and lateral lobe of the parotid, extending down into the neck and to the skull base in the infratemporal fossa (Figure 46-8). With approval from leadership and a lull in combat operations, a team consisting of three surgeons performed a transparotid, extracranial resection of a poorly differentiated salivary gland neoplasm, followed by reconstruction with a vertical rectus abdominis free flap. Unfortunately, the vertical rectus abdominis flap did not sufficiently fill the massive wound, and a serratus-latissimus free flap was used for salvage.

Ultimately, the patient did well in the short term, and was able to return to her village and resume normal activities. She stayed in the hospital for about 2 weeks as she recovered, and her early result was favorable (Figure 46-9).

REFERENCES

1. Brennan J. Experience of first deployed otolaryngology team in Operation Iraqi Freedom: the changing face of combat injuries. *Otolaryngol Head Neck Surg*. 2006;134:100–105.

2. Wade AL, Dye JL, Mohrle CR, Galarneau MR. Head, face, and neck injuries during Operation Iraqi Freedom II: results from the US Navy–Marine Corps Combat Trauma Registry. *J Trauma*. 2007;63:836–840.

3. Gawande A. Casualties of war—military care for the wounded from Iraq and Afghanistan. *N Engl J Med*. 2004;351:2471–2475.

4. Manring MM, Hawk A, Calhoun JH, Andersen RC. Treatment of war wounds: a historical review. *Clin Orthop Res*. 2009;467:2168–2191.

5. Xydakis MS, Fravell MD, Nasser KE, Casler JD. Analysis of battlefield head and neck injuries in Iraq and Afghanistan. *Otolaryngol Head Neck Surg*. 2005;133:497–504.

6. Montgomery SP, Swiecki CW, Shriver CD. The evaluation of casualties from Operation Iraqi Freedom on return to the continental United States from March to June 2003. *J Am Coll Surg*. 2005;201:7–13.

7. Breeze J, Gibbons AJ, Shieff C, et al. Combat-related craniofacial and cervical injuries: a 5-year review from the British military. *J Trauma*. 2011;71:108–113.

8. Rush RM, Stockmaster NR, Stinger HK, et al. Supporting the global war on terror: a tale of two campaigns featuring the 250th forward surgical team (airborne). *Am J Surg*. 2005;189:564–570.

9. Brennan J. Head and neck trauma in Iraq and Afghanistan: different war, different surgery, lessons learned. *Laryngoscope*. 2013;123:2411–2417.

10. Dobson JE, Newell MJ, Shepard JP. Trends in maxillofacial injuries in wartime (1914–1986). *Br J Oral Maxillofac Surg*. 1989;27:441–450.

11. Chan RK, Siller-Jackson A, Verrett AJ, et al. Ten years of war: a characterization of craniomaxillofacial injuries incurred during Operations Enduring Freedom and Iraqi Freedom. *J Trauma Acute Care Surg*. 2012;73:S453–S458.

12. Lopez MA, Arnholt JL. Safety of definitive in-theater repair of facial fractures. *Arch Facial Plast Surg*. 2007;9:400–405.

13. Brennan J, Gibbons M, Lopez M, et al. Traumatic airway management in Operation Iraqi Freedom. *Otolaryngol Head Neck Surg*. 2011;144:376–380.

14. Blackbourne LH, Baer DG, Eastridge BJ, et al. Military medical revolution: deployed hospital and en route care. *J Trauma Acute Care Surg*. 2012;73(6 suppl 5):S378–S387.

15. Schrager JJ, Branson RD, Johannigman JA. Lessons from the tip of the spear: medical advancements from Iraq and Afghanistan. *Respir Care*. 2012;57:1305–1313.

16. Breeze J, Allanson-Bailey LS, Hunt NC, et al. Mortality and morbidity from combat neck injury. *J Trauma*. 2012;72:969–974.

17. Fox CJ, Gillespie DL, O'Donnell SD, et al. Contemporary management of wartime vascular trauma. *J Vasc Surg*. 2005;41:638–644.

18. Cox MW, Whittaker DR, Martinez C, et al. Traumatic pseudoaneurysms of the head and neck: early endovascular intervention. *J Vasc Surg*. 2007;46:1227–1233.

19. Taller J, Kamdar JP, Greene JA, et al. Temporary vascular shunts as initial treatment of proximal extremity vascular injuries during combat operations: the new standard of care at echelon II facilities? *J Trauma*. 2008;65:595–603.

20. Tong D, Beirne R. Combat body armor and injuries to the head, face, and neck region: a systematic review. *Mil Med*. 2013;178:421–426.

21. Inaba K, Munera F, McKenney M, et al. Prospective evaluation of screening multislice helical computed tomography angiography in the initial evaluation of penetrating neck injuries. *J Trauma*. 2006;61:144–149.

22. Salinas NL, Faulkner JA. Facial trauma in Operation Iraqi Freedom casualties: an outcomes study of patients treated from April 2006 through October 2006. *J Craniofac Surg*. 2010;21:967–970.

23. Klem C, Sniezek JC, Moore B, et al. Microvascular reconstructive surgery in Operations Iraqi and Enduring Freedom: the US military experience performing free flaps in a combat zone. *J Trauma Acute Care Surg*. 2013;75:S228–S232.

24. Petersen K, Colyer MH, Hayes DK, Hale RG, Bell RB. Prevention of combat-related infections guidelines panel: prevention of infections associated with combat-related eye, maxillofacial, and neck injuries. *J Trauma*. 2011;71:S264–S269.

25. Harrison CD, Bebarta VS, Grant GA. Tympanic membrane perforation after combat blast exposure in Iraq: a poor biomarker of primary blast injury. *J Trauma*. 2009;67:210–211.

26. Xydakis MS, Bebarta VS, Harrison CD, Conner JC, Grant GA, Robbins AS. Tympanic-membrane perforation as a marker of concussive brain injury in Iraq. *N Engl J Med*. 2007;357:830–831.

27. Ritenour AE, Wickley A, Ritenour JS, et al. Tympanic membrane perforation and hearing loss from blast overpressure in Operation Enduring Freedom and Operation Iraqi Freedom wounded. *J Trauma*. 2008;64:S174–S178.

28. Breeze J, Pearson CR, Henney S, Reid A. Ear injuries sustained by British service personnel subjected to blast trauma. *J Laryngol Otol*. 2011;125:13–17.

29. Causey M, Rush RM Jr, Kjorstad RJ, Sebesta JA. Factors influencing humanitarian care and the treatment of local patients within the deployed military medical system: casualty referral limitations. *Am J Surg*. 2012;203:574–577.

30. Woll M, Brisson P. Humanitarian care by a forward surgical team in Afghanistan. *Mil Med*. 2013;178:385–388.

31. Hatzfield JJ, Childs JD, Dempsey MP, et al. Evolution of biomedical research during combat operations. *J Trauma Acute Care Surg*. 2013;75:S115–S119.

32. Butler FK, Blackbourne LH. Battlefield trauma care then and now: a decade of tactical combat casualty care. *J Trauma Acute Care Surg*. 2012;73:S395–S402.

33. Saigal K, Winokur RS, Finden S, et al. Use of three-dimensional computerized tomography reconstruction in complex facial trauma. *Facial Plast Surg*. 2005;21:214–220.

34. Beumer HW, Puscas L. Computer modeling and navigation in maxillofacial surgery. *Curr Opin Otolaryngol Head Neck Surg*. 2009;17:270–273.

35. Foley BD, Thayer WP, Honeybrook A, et al. Mandibular reconstruction using computer-aided design and computer-aided manufacturing: an analysis of surgical results. *J Oral Maxillofac Surg*. 2013;71:e111–e119.

36. Mustafa SF, Evans PL, Bocca A, et al. Customized titanium reconstruction of post-traumatic orbital wall defects: a review of 22 cases. *Int J Oral Maxillofac Surg*. 2011;40:1357–1362.

37. Kheirabadi B. Evaluation of topical hemostatic agents for combat wound treatment. *US Army Med Dept J*. 2011;Apr–Jun:25–37.

38. Butler FK, Hagmann J, Butler ED. Tactical combat casualty care in special operations. *Mil Med*. 1996;161(suppl):1–15.

39. Kheirabadi BS, Mace JE, Terrazas IB, Fedyk CG, Dubick MA, Blackbourne LH. Safety evaluation of new hemostatic agents, semctite granules, and kaolin-coated gauze in a vascular injury wound model in swine. *J Trauma*. 2010;68:269–278.

40. Granville-Chapman J, Jacobs N, Midwinter MJ. Pre-hospital haemostatic dressings: a systematic review. *Injury*. 2011;42:447–459.

41. Roberts I, Perel P, Prieto-Merino D, et al. Effect of tranexamic acid on mortality in patients with traumatic bleeding: prespecified analysis of data from randomised controlled clinical trial. *BMJ*. 2012;345:e5839.

42. Wright C. Battlefield administration of tranexamic acid by combat troops: a feasibility analysis. *J R Army Med Corps*. 2014;160:271–272.

43. Bartley J. Should chitosan and tranexamic acid be combined for improved hemostasis after sinus surgery? *Med Hypotheses*. 2013;81:1036–1038.

44. Eshghi P, Jenabzade A, Habibpanah B. A self-controlled comparative clinical trial to explore the effectiveness of three topical hemostatic agents for stopping severe epistaxis in pediatrics with inherited coagulopathies. *Hematology*. 2014;19:361–364.

45. Sakallioglu O, Polat C, Soylu E, et al. The efficacy of tranexamic acid and corticosteroid on edema and ecchymosis in septorhinoplasty. *Ann Plast Surg*. 2015;74:392–396.

46. Breeze J, Horsfall I, Hepper A, Clasper J. Face, neck, and eye protection: adapting body armour to counter the changing patterns of injuries on the battlefield. *Br J Oral Maxillofac Surg*. 2011;49:602–606.

47. Nicholas TA IVth, Barak-Bernhagen MA, Boedeker BH. Airway management in unusual environments. *Stud Health Technol Inform*. 2013;184:398–301.

48. Boedeker BH, Berhagen MA, Miller DJ, Doyle DJ. Comparison of the Magill forceps and the Boedeker (curved) intubation forceps for removal of a foreign body in a manikin. *J Clin Anesth*. 2012;24:25–27.

49. Alam DS, Chi JJ. Facial transplantation for massive traumatic injuries. *Otolaryngol Clin North Am*. 2013;46:883–901.