Chapter 21

THERMAL INJURIES

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INTRODUCTION

Throughout history, military forces have utilized various substances and tactics in thermal warfare. Although gunpowder greatly increased the incidence of burn wounds sustained during conflicts, the historical incidence of combat-related burns was only approximately 3% prior to the advent of motorized warfare.[1] The introduction of vehicles, designed to move or simply protect service members, had the unintended consequence of placing them at significantly higher risk of being burned with fuel, often in a confined area.[1] The importance of burns and inhalational injuries was thus firmly established during World War I and World War II.[1] Burn casualties hold a unique place within the pantheon of military medicine because they frequently survive the initial trauma, in contrast to penetrating head or chest trauma, and can be salvaged with appropriate resuscitation and subsequent reconstruction.

The first comprehensive reviews evaluating the incidence of head and neck (H&N) trauma in Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (OEF) revealed an incidence of 26% and 29%, respectively.[2,3] This is an increase in H&N trauma relative to historical rates (World War II = 21%, the Korean War = 21%, and the Vietnam War = 16%), whereas other locations of injury were either stable or decreasing in comparison with historical rates.[2,3] These changes in injury patterns are thought to be due to improvements in body armor and forward surgical capabilities.[4] A retrospective review that evaluated the complete data set contained in the Joint Theater Trauma Registry (JTTR) for OIF (October 19, 2001 to March 27, 2011) completed after the conclusion of combat operations in Iraq demonstrated that 42% of patients evacuated out of theater had H&N battle injuries.[3] Of these casualties, 10% (419 of 4,036) had H&N burns. The vast majority of H&N burns involved multiple facial subunits.[3] Interestingly, these thermal injuries were predominantly caused by fire and flame related to explosives.[5] Thermal injuries that have been encountered in OIF and OEF are disproportionately distributed in terms of location. The hands and face account for 80% and 77% of cases seen in OIF and OEF respectively, because of the increased exposure of these areas during the performance of combat-related tasks.[6] Facial and upper extremity burns accounted for 70% of the reconstructive burden at the US Army Institute of Surgical Research (Fort Sam Houston, TX), the location performing the vast majority of reconstructive surgery on severe burn injuries among injured service members.[5] Anecdotally, the rate of burn injury was greater in OIF than what has been seen thus far in OEF, likely because of the increased use of vehicle-borne operations conducted in Iraq compared with Afghanistan, where the majority of ground combat operations consists of dismounted foot patrols.

It is significant that the aforementioned reviews deal only with US and coalition SMs, yet the majority of the patients who have been treated in deployed US combat hospitals are not United States and coalition service members. Within the aggregate patient population treated in US combat hospitals during both OIF and OEF, the pediatric subpopulation deserves special attention. Pediatric admissions account for more than 10% of the workload in deployed US combat hospitals, with burns as the underlying etiology for a significant proportion.[7] Several clear and significant trends concerning pediatric burns have been identified in the combat hospitals deployed in support of OIF and OEF:

- Pediatric burns were more common in OIF than OEF.
- Girls were more often affected than boys.
- Most of the children treated were under 8 years of age.[7]

Independent risk factors for mortality in the pediatric subpopulation included thermal injury, age less than 8 years, and female gender.[7]

Although several retrospectives have been published by otolaryngologists detailing the injuries they encountered during deployment, these articles have predominantly dealt with maxillofacial trauma, penetrating neck trauma, and airway management, with none referencing H&N burns.[4,8–13] H&N burns may present an immediate threat to the patient's life because of airway compromise and may result in disfiguring deformities.[14] H&N deformities pose a unique reconstructive challenge because of the omnipresent visibility of the face and subsequent importance to personal identity, coupled with the critical functions and special senses located in H&N respiration, vision, hearing, and smell.[15] All burns result from the interaction between the burning agent and the involved tissue, with temperature and the time of exposure being inversely proportional.[14] The exception to the preceding generality is a thermal injury resulting from a high-voltage electric current in which the underlying tissue destruction is often considerably more extensive than the skin injury, fortunately a rare event in the deployed setting.[14] The varied thickness of the skin and underlying tissue within the many distinct subunits of the H&N directly influences the outcome of H&N burns because areas of thin skin and underlying tissue are obviously more susceptible to full-thickness dermal injury.[14,16] Recent data from civilian burn centers demonstrate that although full-thickness burns of the face are rare, partial thickness burns to the H&N region are relatively common, occurring in one-fourth to just more than one-half of all cases—a range that has been stable over the last several decades.[16,17]

INITIAL MANAGEMENT—AIRWAY

The deployed otolaryngologist's primary role as part of the team managing the initial resuscitation of a burn casualty often involves assisting in the detection and management of respiratory insufficiency and airway management.[14] The most severe initial manifestation of respiratory insufficiency is asphyxia, with an estimated prehospital mortality of more than 50%.[14] Asphyxia may result from one or a combination of several factors:

- low oxygen concentration coupled with a high concentration of carbon monoxide in the inspired air at the burn site,
- chemical injury resulting from the byproducts of combustion, or
- thermal injury to the upper respiratory tree.[18]

Direct thermal injury to the orofacial region can result in severe edema that may then obstruct the external nares and mouth. Edema in the supraglottic airway usually develops 8 to 24 hours after a burn injury.[14] This relatively predictable timeline is the basis for recommending early intubation in casualties with facial burns. Thermal injury to the lower airway, trachea, and lungs is relatively rare because of the protective reflex of the larynx and the fact that air is a poor conductor of heat.[14] Most tracheobronchial injuries result from the products of incomplete combustion and noxious fumes that create a chemical tracheobronchitis.[18] The timeline for presentation of signs and symptoms of a lower airway injury lags behind that seen in the upper airway and may not manifest until 24 to 72 hours after injury.[18] Certain conditions make inhalational injuries (INHIs) more likely: burns sustained within a confined space, severe facial burns, and loss of consciousness. Unfortunately, these conditions are often present when burns are sustained during combat. *Clinical signs* of an inhalational injury include

- dysphonia,
- stridor,
- cough,
- carbonaceous sputum, and
- hypoxemia causing restlessness or diminished mentation.[18]

Physical examination findings include

- singed vibrissae,
- perioral and/or perinasal burns,
- oral or pharyngeal burns,
- rales,
- wheezes, or
- diminished breath sounds.[18]

These clinical findings are important clues to the possibility of injury, but are not pathognomonic, thus necessitating a high index of clinical suspicion. Bronchoscopic abnormalities consistent with inhalation injury include the presence of extramucosal carbonaceous material, bronchorrhea, and blistered or edematous mucosa.[14]

Initial treatment of an INHI includes administration of humidified oxygen and bronchodilators. If there is suspicion of carbon monoxide poisoning, 100% oxygen delivered via a nonrebreathing mask should be implemented because this will dramatically decrease the disassociation time of carboxyhemoglobin from 250 minutes to 50 minutes.[18] Pulse oximeters cannot distinguish carboxyhemoglobin from oxyhemoglobin. In terms of airway obstruction, the pulse oximeter may be normal right up to the point of obstruction and thus is never reassuring. A patient with an INHI will require serial direct laryngoscopy and bronchoscopy to remove debris from the airway and document injury progression and subsequent resolution. Heat-induced airway edema usually peaks within 5 to 6 days and then improves during the diuretic phase. Burn casualties with INHI will require up to 30% more fluid during initial resuscitation and will be more difficult to manage on the ventilator because of both the injury itself and the additional fluid.[19] This increased fluid requirement in patients with INHI is simply the result of an increase in the total burn surface area (TBSA) of the burn, but not all body surface area is external. The combined presence of an INHI with an external thermal injury has been shown to increase the mortality by up to 20% over external burns alone.[19] INHI complicated by pneumonia can increase mortality by up to 60% over an isolated external burn.[19] For casualties with a burn greater than 60% TBSA, INHI, and acute respiratory distress syndrome, the estimated mortality rate is 100%. Children younger than 3 years of age are especially susceptible to an INHI with a subsequent expected increase in mortality.[19] A child with a 50% TBSA burn and an INHI has an estimated mortality rate of 10%. In comparison, a child would need a 73% TBSA burn without an INHI to have an estimated mortality rate of 10%.[19]

The guiding principles of airway management in burn patients and nonburn patients are similar. The preferred initial intubation technique—whether traditional, video-assisted, or awake transnasal fiberoptic—is always one that will allow optimum visualization of the larynx.[20] Equipment required for multiple modalities should be immediately available. If possible, prior to initiating attempts at intubation, the proposed algorithm for each patient should be discussed by the airway team. However, several points deserve additional emphasis. Distorted anatomy secondary to either edema (*early*) or scar (*late)* tissue can significantly impair the ability to mask ventilate and intubate the patient. Traditional rescue methods (eg, laryngeal mask airway or emergent cricothyroidotomy) may also be difficult or impossible, thus necessitating that the airway team thinks two or three steps ahead.[21,22] A very low threshold for intubation should be maintained in young, healthy service members with suspected INHI because they may demonstrate relatively normal respiration with few, if any, signs of compromise until just prior to upper airway obstruction and cardiopulmonary collapse. If intubation is unsuccessful, the otolaryngologist or trauma surgeon should expediously perform either an emergent cricothyroidotomy or an urgent tracheostomy. In keeping with standard teaching from the American College of Surgeons Committee on Trauma (Chicago, IL), the only type of airway that is appropriate in a trauma scenario involves a tube (endotracheal or tracheotomy) with a cuff inflated below the glottis.

There is debate about the necessity and timing of tracheotomy in burn patients after initial stabilization, particularly in pediatric patients.[23–25] Historically, concern was raised because of high complication rates and increased mortality in burn patients who underwent tracheotomies. However, more recent analyses have shown these concerns to be unfounded, with the possible exception of tracheotomy-induced pneumonia.[26] Although pneumonia occurred more often in tracheotomized burn patients versus orally intubated burn patients in one study, this increased infection rate did not result in increased mortality.[26] Other studies, however, have not demonstrated increased rates of pneumonia in tracheotomized burn patients.[23,27] The decision to perform a tracheotomy should always be made in close consultation with the team managing the patient's overall care. Several commonly accepted conditions requiring tracheotomy exist among trauma surgeons:

- if the patient is expected to be on a ventilator for more than a week,
- an agitated patient (despite adequate medication) at risk of accidental extubation,
- a patient with significant INHI,
- extremes of age,
- extensive facial burns, and
- patients with >60% TBSA burns.

Tracheotomy will simplify and improve the safety of patient care, facilitate the weaning of patients off the ventilator, and often improve patient comfort. The use of low pressure cuffs, reflux prophylaxis, and early tracheotomy improves results in patients with INHIs.[28] If tracheotomy appears likely and the anterior neck is involved with a full-thickness burn, the eschar should be excised and a split-thickness skin graft (STSG) placed 4 to 5 days prior to the tracheotomy.[18] Securing endotracheal tubes can also become a practical problem in casualties with H&N burns, potentially requiring that endotracheal tubes be rigidly fixated to the maxillary incisors.

INITIAL MANAGEMENT—SOFT TISSUE

H&N thermal injuries are classified and treated according to depth and which facial subunit(s) is involved. Partial-thickness burns extend through the dermis to varying degrees, allowing some of the adnexal structures to be preserved. Fortunately, the adnexal structures serve as a cellular reservoir, allowing for spontaneous reepithelialization and healing of the injury. Partial-thickness burns should be managed conservatively.[29] Wounds should be thoroughly cleaned. This is mandatory in the case of flash burns, which result from a blast injury in which additional debris is universally implanted in the skin. Failure to adequately cleanse the wound may result in long-term traumatic tattooing. Blisters that break should be debrided, and the exposed surfaces covered with ointment. However, intact blisters should be allowed to remain undisturbed. Cold compresses may help significantly to lessen pain and discomfort. Healing typically takes place uneventfully within 1 to 3 weeks.

Full-thickness burns appear pale to reddish-brown, have a leathery texture, are avascular, and are nontender because of the destruction of nerve endings.[18]

Management of full-thickness burns on coalition members being evacuated out of theater should be limited to covering the wound with either a silver preparation, such as silver sulfadiazine (Silvadene, Monarch Pharmaceuticals, Inc, Bristol, TN), or a sulfonamide, such as mafenide acetate (Sulfamylon, UDL Laboratories, Rockford, IL).[30] Silver sulfadiazine cream is applied to facial burns to create a layer at least 3 to 5 mm thick and is replaced every 24 hours. The timing and ease of reapplication make daily Silvadene soaks preferred to daily Sulfamylon soaks, which may have to be replaced as often as every 2 hours for casualties being evacuated out of theater.[30] However, the rapid, deep penetration of mafenide acetate—coupled with its broad antibiotic profile—may make it preferred for the management of casualties who cannot be evacuated out of theater.[30] A recent Cochrane review evaluating the effects of topical treatments on wound healing in facial burns was unable to draw any specific conclusions because of a dearth of high-quality studies.[16] The burned auricle and nasal alae deserve heightened attention to prevent injury progression and iatrogenic injury. It is incumbent on the otolaryngologist to stress the importance of preventing pressure necrosis from tubes and bandaging to all medical personnel involved in the patient's care during evacuation out of theater.

DEFINITIVE RECONSTRUCTION

The need may arise to provide definitive burn care for casualties who cannot be evacuated out of theater. Considerable experience in both OIF and OEF demonstrates that casualties with 50% or greater TBSA full-thickness burns who cannot be evacuated out of theater should be considered expectant. Early excision and grafting stop the progression of bacterial colonization from gram-positive organisms to gram-negative organisms, and subsequently decrease wound infection and sepsis (Figure 21-1).[31] However, whether this is as important in a patient with burns of the H&N is uncertain, given the exceptionally high vascularity of the H&N and the fact that wounds subsequently heal better and become infected less frequently, relative to the rest of the body.[16,32] Therefore, the main goal of facial burn reconstruction should be thought of in terms of optimum aesthetic and functional outcome instead of infection prevention. Full-thickness H&N burns and deep partial-thickness burns that progress or show no evidence of healing after 8 to 10 days should be excised and grafted, in keeping with the subunit principle, even if small areas of uninvolved skin must be sacrificed.[29,33] Unfortunately, the need for definitive reconstruction may extend to children, and the reconstructive surgeon should remember that the H&N region of neonates comprises a significantly greater relative TBSA (19%) compared with adults. This relatively greater TBSA decreases 1% per year until adult proportions are reached at 10 years of age, with 7% body surface area for the head and 2% for the neck.[18]

Eyelids

Most eyelid burns are partial thickness and heal spontaneously without significant scarring, but deep partial-thickness or full-thickness injuries to the eyelid require early skin grafting to protect the cornea and prevent ectropion.[15] Ophthalmological consultation, with inspection and evaluation of the cornea and globe, is mandatory in every patient with lid burns. The upper lid is more dynamic than the lower lid and should be resurfaced with a thin (0.005–0.012 inch)- or medium (0.012–0.018 inch)-thickness skin graft from the postauricular or supraclavicular fossa to provide a good color match.[14,34] The inner surface of the upper arm serves as a backup harvest site if the first two preferred H&N harvest sites are unavailable. An STSG will be thin enough to preserve function and allow for the eventual formation of a supratarsal fold. If a single upper lid is injured, the contralateral lid may serve as a donor using standard upper lid blepharoplasty techniques. For lower lid reconstruction, a full-thickness skin graft (FTSG) from the postauricular or supraclavicular fossa should be utilized because these grafts provide an excellent color match, however with less contraction.[17] If all four eyelids must be grafted, preference is given to grafting both upper eyelids first because they are the

Figure 21-1. Split-thickness skin graft to forehead and face.

more dynamic structures. Despite the best attempts, subsequent contraction of the skin during healing can result in the characteristic periocular burn deformity of ectropion (intrinsic and extrinsic), epicanthal fold formation, forward displacement of the medial canthus, and elongation of the palpebral fissure.

The correction of burn-induced lid ectropion hinges on an accurate diagnosis of whether the cause is *intrinsic* (primarily from scar contracture in the lid) or *extrinsic* (caused by contracture in the periocular region).[14] When required, ectropion correction should be staged, with extrinsic issues addressed prior to intrinsic repair. Repair of ectropion may necessitate either medial or lateral canthoplasty, lateral tarsal strip, and replacement or addition of tissue to the anterior lamella after releasing scarred tissues. Replacement of anterior lamellar tissue should be completed using an overlapping technique.[17] A subciliary incision is made, and the contracted tissue is excised (allowing the lid margin to be released into a natural position). The graft is then harvested; it should be slightly larger than what is anticipated to fill the defect. The graft is first secured to the subciliary incision, draped over the defect, tailored, and then secured. Epicanthal folds can be corrected with utilization of a double-opposing Z-plasty.[14]

Brow

Because the forehead is a relatively large and flat aesthetic unit, attempts should be made to hide scars or transitions at the periphery. The brow, conceptualized as a hairless frontal extension of the scalp, is well suited to reconstruction using tissue expansion and can be treated easily with postoperative pressure dressings to prevent hypertrophic scars.[15,35] Reconstruction of burn alopecia involving the eyebrow may be accomplished using a free graft of the temporal scalp with a width of 3 to 5 mm.[17] Care should be taken during harvest and inset to prevent unnecessary follicular trauma and to ensure proper follicular orientation, both superiorly and laterally.[14] The contralateral eyebrow should be used as a template, if present. If neither eyebrow is present, the objective of surgery should be to create symmetry and harmony with the remaining facial features. The patient should be warned that the hair will inevitably undergo telogen effluvium and subsequent regrowth. Alternatively, axial pattern flaps from the temporal scalp based on the superficial temporal artery will provide a wider and more reliable graft.[15] A Juri flap may also be used to reestablish a frontal hairline. Follicular unit transplantation has been utilized to recreate the eyebrow with excellent results.[36,37]

Mouth

When revising burn scars involving the philtrum and mentum regions, the epidermis should be removed, but the underlying scar should be preserved to give fullness to the region.[14] The philtrum may require additional grafting, potentially even with cartilage, to allow for adequate contouring and the re-creation of a normal appearance.[15] Extrinsic lower lip retraction as a result of cervical contracture should not be overlooked. The cervical contracture should be corrected either simultaneously or prior to addressing the lower lip retraction.

Auricle

Casualties with H&N burns have auricular involvement more than 90% of the time.[14] Although the ear has been given low priority for reconstruction in the past, full-thickness injury with exposed cartilage mandates prompt surgical intervention to cover the cartilage with the intent of preventing infectious complications and subsequent devastating cartilage loss.[15] Local advancement flaps from the postauricular skin and STSG can be utilized for injuries limited to the helix and antihelix with excellent results.[36] The temporoparietal flap is the workhorse for reconstruction of extensive auricular burns.[14,37–39] It brings in a thin, well-vascularized covering for the cartilage and facilitates the subsequent placement of an STSG. The development of suppurative chondritis usually occurs 3 to 5 weeks after full-thickness injury and is heralded by the development of dull, progressive pain resulting in exquisite tenderness to palpation, along with warmth and erythema.[17] Cultures have consistently shown *Pseudomonas aeruginosa* along with *Staphylococcus aureus* to be the most likely culprits.[14] Interventions have historically relied on "bivalving" and then packing the wound with antibiotic impregnated gauze or using frequent antibiotic irrigations followed by serial debridement as needed. Systemic antibiotics are likely to be ineffective given the relative poor vascularity of these wounds.

Nose

The nose is frequently involved in casualties with H&N burns, with estimates from civilian burn centers ranging as high as 70%.[14] The thickness of the skin in the tip and radix region, coupled with the excellent vascularity of the nasal skin in general, usually prevents full-thickness injury in these areas. When a full-thickness nasal burn is allowed to heal spontaneously, it results in a characteristic deformity in which skin contracture elevates and everts the alar rims, and the tip is rotated superiorly, resulting in nasal shortening. Nasal shortening and alar retraction can be prevented by releasing the columella and placing a "ram's horn" skin graft in the early postburn period.[40] If early skin grafting fails to prevent the characteristic aforementioned nasal deformity, the nasal alae can be reconstructed with composite grafts from a nonburned ear. If the area to be reconstructed involves adjacent subunits, a traditional trilayer reconstruction should be performed.[41,42] Trilayer reconstruction involves the creation of a cartilaginous scaffold covered internally by mucosal flaps (eg, the inferior turbinate flap or the septal hinge flap) and covered externally by either an FTSG or locoregional flaps.[43]

Scalp

Large, full-thickness injuries of the scalp are best initially reconstructed with an STSG, whereas small areas (<5 cm^3) of full-thickness injury are amenable to reconstruction with local rotation or advancement flaps, dependent on location. Reconstruction with STSG will result in wound closure, albeit with alopecia, that will in turn require tissue expansion and excision of the grafted area to return a normal appearance to the hair-bearing scalp.[44–46] If a large portion of the outer layer of the calvarium has been destroyed, it should be removed or burr holes placed to facilitate the formulation of granulation tissue and subsequent placement of an STSG. Negative pressure wound therapy has a role to play in this scenario to both facilitate wound closure and simplify dressing changes.[46] Alternatively, if only a small segment of calvarium is necrotic, it can be successfully covered with locoregional flaps.[14] Rotation of hair-bearing flaps (eg, a delayed temporoparieto-occipital flap) can be used to restore the anterior hairline or sideburns. The scalp is an often overlooked, but excellent donor site for STSG.

Figure 21-2. Third-degree burn contracture requiring serial excisions.

Neck

The initial reconstruction of cervical burn scars centers on the placement of medium-thickness STSG and subsequent stabilization of the head in an extended position. Reconstruction of mature cervical burn scars can be divided into three groups, according to the extent of the involved surface area: (1) isolated linear scar contractures, (2) linear scar contractures coupled with scarring of the adjacent skin, and (3) essentially total loss of the anterior neck skin (Figure 21-2).[14] Isolated linear scar contractures are amenable to correction by either single or multiple Z-plasties. More involved cervical scar contractures—that may result in head flexion, chin fixation, and lower lip retraction—require excision of all the scarred tissue, with dissection in a subplatysmal plane to ensure adequate release. Dissection may potentially extend up onto the face or down onto the chest.[14] Once all of the contracted tissue has been removed, medium-thickness STSG and/or regional flaps should be placed (Figure 21-3). If skin grafts are placed, it is critical that the head is stabilized in an extended position after grafting, with consideration given to using a cervical collar. The patient should not be allowed to use pillows for several weeks after surgery. Alternatively, the cervical skin may be replaced using either a deltopectoral flap or pectoralis major flap.[47] If, however, the adjacent chest and shoulder skin were also burned and the deltopectoral and pectoralis major flaps are unavailable, a trapezius flap or variation thereof should be considered.[48–52] Finding adequate, healthy, regional skin may present a significant challenge; therefore, consideration should be given to utilizing either tissue expansion or delay to increase the surface area of the transferred skin paddle.[53]

Airway management for patients with significant cervical contracture is of the utmost importance, and difficulty during intubation should be anticipated

Figure 21-3. Split-thickness skin grafts placed after serial excisions of burn scar.

(Figure 21-4). Strong consideration should be given to utilizing awake fiberoptic intubation and/or relaxing incisions into the scar under local anesthesia.[20–22] Although cosmetic concerns have been raised about using regional flaps to resurface the anterior neck because of subsequent obfuscation of the prominent midline cervical anatomy, the primary concern should be restoration of neck movement and, in children, the prevention of mandibular growth retardation.[54,55]

Figure 21-4. Neck contracture.

SUMMARY

Approximately 10% of US service members evacuated from theater during OIF had thermal injuries involving the H&N. Burns of the H&N may present an immediate threat to the patient's life because of airway compromise and/or result in disfiguring deformities. The deployed otolaryngologist's primary role as part of the team managing the initial resuscitation of a burn casualty is to assist in the detection and management of respiratory insufficiency and to serve as the airway management expert. Management of US and coalition forces that are evacuated out of theater should be limited to cleaning the wounds and then covering the affected area with ointment. H&N burn deformities pose a unique reconstructive challenge because of the omnipresent visibility of the face and subsequent importance to personal identity, coupled with the critical functions and special senses located in the H&N. Definitive reconstruction of H&N burns will likely require the full complement of options on the reconstructive ladder.

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