Abstract

Trauma is the leading cause of morbidity and mortality in the pediatric population worldwide with a large proportion of death-related trauma related to head injury. Injury mechanisms are particular to this age group and include the full spectrum of sporting events, falls, motor vehicle collisions, interpersonal assaults, and intentional injuries. Although safety measures have decreased the incidence of fatal head injuries, there has been a concomitant increase in nonfatal injuries. Some studies suggest that during the past years, there has been an increase in the number of children that require emergency and inpatient...
management for these injuries. The popularity of manual high-speed wheeled devices, such as bicycles, skateboards, and scooters, among the pediatric population has also contributed to the increased rate of injury. Additionally, the use of motorized vehicles is implicated in high-velocity injuries, resulting in amplified peripheral damage. Engaging in sporting activities, whether on a playground or in a supervised environment, is also a common cause of pediatric injuries. Prevention is key. The use of helmets, protective gear, and restraints reduces but does not eliminate the occurrence of facial injury in users.

Keywords
Trauma · Morbidity and mortality · Pediatric population · Prevention · Facial injury

Introduction

Children present unique features that make them particularly prone to sustain head and facial trauma. Craniofacial injuries account for approximately 80–90% of all traumatic injuries (Gassner et al. 2004; Haug and Foss 2000; Imahara et al. 2008; Muniz 2008; Atabaki 2007). The increased ratio of cranial relative to body mass leaves younger patients more vulnerable to craniofacial trauma with higher energy impacts to this region. At birth, the ratio between cranial volume and facial volume is approximately 8:1, which becomes close to 2.5:1 in adults. The retruded position of the face compared to the skull is an important feature that explains the lower incidence of midfacial and mandibular fractures and the higher incidence of cranial injuries in children younger than 5 years of age. The elastic nature of the also contributes to this fact (Gassner et al. 2004; Haug and Foss 2000; Imahara et al. 2008; Ferreira et al. 2005, 2015a; Alcalá-Galiano et al. 2008). Although children are prone to suffer head and facial trauma, international studies reveal that facial trauma has a higher incidence in children compared to the adult population (Andrew et al. 2019).

Evaluation of facial injuries presents a unique diagnostic challenge in this population, as differences from adult anatomy and physiology can result in vastly different injury profiles. It’s essential that the treating physician be aware of these variations. Injured children require very expeditious, careful, and thorough evaluation and prompt management to achieve good outcomes. For instance, the low overall body mass and surface area of children result in an increased amount of force per unit area during a motor vehicle collision and leave them susceptible to rapid heat and fluid loss. The cartilaginous, elastic skeleton of a child results in greater transmission of force to the internal organs. The elevated metabolic rate of children can result in a lower overall physiologic reserve and can lead to a rapid deterioration if resuscitation is delayed (Gassner et al. 2004; Ryan et al. 2011). The potential psychological effect of the trauma must also be taken into account.

The face, more than any other part of the body, plays a major role in establishing identity and self-esteem. An unfavorable result from an injury or an attempted treatment can lead to devastating results in both aesthetic and functional outcomes. In this chapter, the management of pediatric facial injuries is reviewed, including soft tissue and facial skeleton injuries. Assessment of these injuries, cleansing, surgical technique, anesthesia, and considerations for special wounds are discussed. The secondary management of pediatric facial injury is also discussed, including scar revision, management of scar hypertrophy/keloids, and staged surgical correction.

History

During the initial assessment of any facial injury, it is important to review the mechanism and time of injury and to determine whether it was witnessed. The history of injury is often taken from a witness or caregiver who should be queried not only on the time and mechanism but also on other details of the injury (e.g., striking objects, trees, or pavement; sharp or blunt injury; loss of
consciousness) (Ryan et al. 2011; Vasconez et al. 2011; Hogg 2012). This information helps give an indication of the type, extent, and severity of soft and hard tissue injuries that may be encountered. The history may also help predict wound progression and guide management, particularly in delayed and contaminated wounds. For open wounds, the tetanus status of the child should be determined, and early treatment should be initiated (Vasconez et al. 2011). Any suspicion for nonaccidental causes of injury must be pursued to determine possible abuse (Ryan et al. 2011).

Use of the AMPLE acronym (allergies, medications, past history, last meal, events surrounding the accident) facilitates a complete trauma history.

Physical Evaluation

Pediatric facial trauma can present a challenge to even the most experienced surgeons. Injuries to the head and neck may involve bone and soft tissues with an assortment of specialized organs and tissue elements involved. Extensive swelling, distracting injuries, and the psychological impact of the craniomaxillofacial trauma may occasionally render the physical examination difficult or even impossible in the initial setting. Local anesthesia and nerve blocks may be used to alleviate patient discomfort (Hogg 2012; Horsewell and Meara 2012; Mueller 2013).

Assessment of severe trauma in children must take into account anatomic and physiologic differences from those in the adult. The disproportion between the head, midface, and neck may result in more airway collapse or compromise in the supine child, and precautionary steps should be taken to address this potential issue. Airway compromise may further lead to worsening of hypoxia in children due to increased respiratory rate and oxygen consumption and decreased residual volume (Ryan et al. 2011; Vasconez et al. 2011; Hogg 2012; Horsewell and Meara 2012).

Initial evaluation can begin once a patient has been stabilized and a complete injury list has been determined. Pediatric patients with facial injuries often have concomitant injuries that require a multidisciplinary approach to management (Gassner et al. 2004; Imahara et al. 2008; Ferreira et al. 2015a; Ryan et al. 2011).

A thorough head and neck examination is performed in a logical and consistent manner to avoid missed injuries. It should proceed from top to bottom, from outside in, and from superficial to deep. The examination includes the skin, soft tissue, neurovascular structures, and bone (Ryan et al. 2011; Vasconez et al. 2011; Hogg 2012; Horsewell and Meara 2012; Mueller 2013; Hollier Jr et al. 2014; Fonseca et al. 2013).

Ecchymoses and soft tissue swelling serve as red flags for potential underlying injury and are used with the information regarding the mechanism of injury to develop a level of suspicion of possible underlying injuries (Hogg 2012). Bony structures should be palpated in a systematic fashion to identify tenderness, deformity, step-offs, or relative mobility. Imaging studies may be indicated (Haug and Foss 2000; Ferreira et al. 2005; Alcalá-Galiano et al. 2008; Fonseca et al. 2013). Additionally, it may be difficult to elicit tenderness because of simultaneous distracting injuries, as previously mentioned. The examiner must not be misled by more impressive injuries and overlook less obvious but potentially significant problems (Imahara et al. 2008; Ferreira et al. 2015a; Hollier Jr et al. 2014).

The examiner should then carefully assess the patient for neurologic deficits, including trigeminal and facial nerve lesions. Sensory disturbances in the forehead, cheek, and lower lip should be well documented, as should any deficits in facial nerve function. Lacerations, contusions, and abrasions of the skin may focus the exam by indicating which nerves are at risk.

The mouth should be inspected for the presence of loose or missing dentition (Horsewell and Meara 2012). They may have been lost in the wound or even aspirated. If this is suspected, a radiograph will be necessary (Ryan et al. 2011; Hogg 2012). Brief examinations of special structures, such as the eyes, are important. A simple check of vision and extraocular muscle movement can suggest a more serious injury. The condition and position of the globes may also warrant further inspection of the orbit and surrounding
skeletal structures. Signs of globe injury, such as asymmetric pupils, hyphema, torn bulbar conjunctiva, corneal damage, and so forth, should prompt an immediate evaluation by an ophthalmologist (Hogg 2012; Horsewell and Meara 2012; Mueller 2013; Hollier Jr et al. 2014; Fonseca et al. 2013).

Careful attention should be given to the soft tissue coverage and integrity of the cartilage of the nose and ear. Cerebrospinal fluid (CSF) leaks should be inspected (Ryan et al. 2011).

The neck should be evaluated for tracheal deviation, discoloration (expanding hematoma), or tenderness (Mueller 2013).

For more severe injuries, emergent evaluation must follow the established routines as outlined in Advanced Trauma Life Support (ATLS) – A = airway; B = breathing; C = circulation; D = disability; and E = exposure. This is a dynamic process of continual evaluation, intervention, and reevaluation. The initial survey often indicates or determines whether the child will survive.

**Imaging Studies**

Several diagnostic studies may already have been done before examination of the patient’s facial injuries. A computed tomographic scan of the craniofacial skeleton, if indicated, will provide clear definition and extent of the fractures and information on the alignment of the various structures such as the globe, nasal septum, the sinuses, and muscle layers (Alcalá-Galiano et al. 2008; Ryan et al. 2011). Additionally, in cases of complex facial trauma, it is helpful to have a three-dimensional (3D) reconstruction of the facial skeleton formatted so as to provide for a better overall orientation. A panoramic radiograph is extremely beneficial for mandibular evaluation. These radiographs evaluate the entire mandible, from condyle to condyle, in a single image and provide excellent detail of the condyles and dentition (Haug and Foss 2000; Alcalá-Galiano et al. 2008; Ryan et al. 2011; Chapman et al. 2009; Neinstein et al. 2012; Brisco et al. 2014). Magnetic resonance imaging is valuable for the assessment of intracranial structures and can be useful to evaluate the soft tissue layers and structures of the face (Kolk et al. 2009). While these imaging studies are easily obtained in many trauma centers today and add valuable information for diagnosis as well as treatment planning, they should be viewed as a supplement to the primary physical examination and not a substitute for it.

**Consultation to Other Services**

Usually, a proper evaluation of all systems will be done with the multiply injured patient by the trauma service. However, the examination of the craniofacial structures may warrant further consultation by ophthalmology, neurosurgery, dentistry, and other services after evaluation from a plastic or a maxillofacial surgeon.

**Neck Injuries**

Blunt and penetrating trauma to the neck account for approximately 7% of head and neck injuries in children (Ferreira et al. 2004, 2015a). Penetrating injuries of the neck are a complex type of trauma which can be life-threatening and are usually managed by a number of specialists. A number of important structures are at risk, especially when the injury is at the root of the neck.

Impalement injuries combine aspects of blunt and penetrating trauma and usually result from penetration by a large, rigid, blunt-tipped object that traverses with great force a certain body area in a through-and-through fashion and often remains in situ at the time of presentation (Ferreira et al. 2004). These uncommon injuries usually result from accidents like motor vehicle accidents or falls or from falling objects. Sometimes the head and neck are involved in this type of injury (Fig. 1). General principles of management include minimal manipulation before and during transport, a multidisciplinary approach, careful preoperative planning, and meticulous wound care. Removing an object from the patient’s body at the accident site may result in massive bleeding, and it is generally advised that the object should remain in situ until arrival at the hospital.
is important to know the route of the impaled object and its relation to adjacent structures. Whenever possible, antegrade removal of the object should be performed.

Associated vascular, neurological, and skeletal injuries can be present in neck injuries and can be a serious problem. Further investigations, such as radiography, computerized tomography, magnetic resonance imaging, and angiography, are useful in assessing injuries; however, the patient’s clinical state determines the balance between preoperative investigations and delivery to the operating room (Gassner et al. 2004; Haug and Foss 2000; Imahara et al. 2008; Muniz 2008; Atabaki 2007; Ferreira et al. 2004).

**Sedation and Anesthesia**

Although general anesthesia may be necessary for some wounds and for facial fractures treatment, many facial wounds can be repaired under a regional nerve block. If regional blockade is impractical, a field block may be necessary to avoid direct infiltration of excessive amounts of local anesthetic (Ryan et al. 2011; Vasconez et al.)
An excess of local anesthetic may cause distortion of anatomic landmarks that are useful in restoring the tissues to their anatomic positions. Only 1–2 mL of anesthetic at the site of the nerve trunk is needed to provide complete anesthesia for the respective region. Often multiple regions require blockade.

**Soft Tissue Injuries**

Soft tissue trauma constitutes the majority of the injuries of the craniomaxillofacial region that present for urgent management (Gassner et al. 2004; Haug and Foss 2000; Ryan et al. 2011; Vasconez et al. 2011). In adults, motor vehicle collisions and interpersonal violence are the most frequent causes of injury, whereas in children and the elderly, slips and falls are more common (Gassner et al. 2004; Haug and Foss 2000; Imahara et al. 2008; Ferreira et al. 2005, 2015a; Mueller 2013; Hollier Jr et al. 2014; Fonseca et al. 2013). Trauma forces to the facial region typically result in soft tissue avulsion injuries, lacerations, and contusions; however, the facial skeleton will often be spared owing to its elasticity (Gassner et al. 2004; Haug and Foss 2000; Imahara et al. 2008; Ferreira et al. 2005; Alcalá-Galiano et al. 2008; Horsewell and Meara 2012). Abrasions and retained foreign bodies are other frequent soft tissue injuries (Ryan et al. 2011; Vasconez et al. 2011; Hogg 2012).

Management of craniomaxillofacial soft tissue injuries varies widely depending on the region involved. The extent of injury is another significant factor and often delineates simple closure of wounds in the emergency department from more complex, multistage reconstructive procedures in the operating room (Vasconez et al. 2011; Chen et al. 2013). The wound configuration, whether linear or stellate, is less important, for the final result, than the degree of crush, contusion, and vascular compromise of the tissues. Freshening the wound margins contributes to rapid healing and improves the final result (Mueller 2013; Fonseca et al. 2013).

Principles of soft tissue repair in children must take into account the differences in the wound healing response of children, which is intense, more accelerated, and more prone to produce exuberant hypertrophic scars (Ryan et al. 2011; Vasconez et al. 2011; Hogg 2012; Horsewell and Meara 2012; Mueller 2013; Hollier Jr et al. 2014; Fonseca et al. 2013). Parents should be counseled regarding the inevitability of a scar despite a meticulous procedure of soft tissue repair and should be informed that they tend to fade and flatten over time. If not managed properly, this type of scar is more often seen.

The main goals of the management of facial injuries and wounds are similar to those of the other parts of the body. One wants to obtain rapid and uninterrupted wound healing and also achieve optimal functional as well as aesthetic results. Normal anatomic alignment of the various injured and disrupted soft tissues and gentle handling of these tissues are key elements for good results (Fig. 2) (Vasconez et al. 2011). When suturing an irregular wound, one should look carefully for recognizable landmarks because these will greatly facilitate accurate apposition of the remainder of the wound. The face has a very rich blood supply, so the chances of infection are less likely, and it is very rare that delayed primary closure will be necessary. What may appear to be nonviable tissue in a severely avulsed or macerated wound may survive with good initial care (Hollier Jr et al. 2014). For these reasons, the surgeon should attempt to preserve tissue as much as possible within the frame of inherent tissue and patient health, particularly in regionally specific tissue zones like the eyelid and nose (Fonseca et al. 2013). However, clearly devitalized tissue should be excised.

Most of the time, an adequate cleansing and debridement will be sufficient to allow primary closure. Better results are obtained with earlier repair. The ideal time window for closure of simple soft tissue wounds has been noted to be 8–12 h from the time of injury (Ryan et al. 2011; Vasconez et al. 2011; Hogg 2012; Horsewell and Meara 2012). Wounds with a high level of contamination (e.g., bites) and those open for greater than 24 h may not be appropriate for immediate closure and may be better approached with a strategy of delayed primary repair (Vasconez et al. 2011; Chen et al. 2013). Older wounds
should be thoroughly cleansed and their margins freshened before closure. Jagged irregular edges should be converted into sharper and better aligned margins, and there should be no tension across the wound. In cases where tension is a problem or there are tissue deficits, undermining of the skin, local or regional flaps, or skin grafts may be used (Hollier Jr et al. 2014; Fonseca et al. 2013). In very few cases, free tissue transfer or subsequent tissue expansion may be needed to obtain a satisfactory result (Fonseca et al. 2013). Avulsed or widely undermined soft tissue flaps require proper suction drainage to prevent hematoma formation and pressure or support dressings to allow both arterial inflow and venous outflow (Horsewell and Meara 2012). Some avulsions of large facial segments are best repaired by replantation. These include, but are not limited to, the scalp, nose, lip, ear, and cheek (Vasconez et al. 2011; Mueller 2013; Hollier Jr et al. 2014).

Skin closure should be performed in such a manner as to obtain the best possible outcome. A variety of recommendations have been made regarding the selection of suture technique and

Fig. 2 (a) Severe laceration and partial avulsed injuries, and non-displaced right zygomatic and nasal bones fractures in a 15-year-old girl, resulting from a car accident. (b) Final result after proper wound closure. Adequate cleansing, minimal debridement, and meticulous closure by layers were performed in the operating room. Zygomatic and nasal fractures were managed with closed reduction. (c), (d), and (e) Six months postoperative repair.
material for the closure of facial soft tissue lacerations. Staples are quick and effective methods of closure on the scalp and can be easily removed (Vasconez et al. 2011; Horsewell and Meara 2012). They have, however, no place in the closure of most wounds on the face. While it is often believed that fine, nonabsorbable suture material such as 5–0 or 6–0 polypropylene or nylon will yield the least amount of inflammation and therefore the most optimal scar when used for skin approximation, this must be evaluated in light of potentially longer closure times and the need for subsequent suture removal. Suture removal may be difficult or impossible with young children in the office setting (Vasconez et al. 2011; Hogg 2012). Although absorbable sutures tend to increase the tissue inflammatory response via enzymatic degradation in natural materials and by hydrolysis in synthetic materials, their use in the pediatric population is advantageous. Studies have demonstrated minimal to no significant changes in cosmesis compared with closure of wounds with nonabsorbable sutures (Vasconez et al. 2011; Hogg 2012; Horsewell and Meara 2012).

Suturing is the most common method of wound closure, especially with full-thickness or deep lacerations. These are usually closed “by layers.” Absorbable sutures are used to close deeper structures such as muscle, fascia, and subcutaneous tissue. Tissue dead space should be obliterated. Perhaps the most important step in the repair of skin lacerations is optimal approximation of the deep dermal layer. By placing closure tension deep to the skin, the resulting scar is improved.

Wound support tapes (e.g., Steri-Strips®, 3 M, St Paul, MN) are valuable aids in the closure of well-aligned lacerations. Steri-Strips® are best utilized in conjunction with suture closure as an additional bolster and pressure dressing. A critical point to have in mind with Steri-Strips® application, as the primary closure modality, is that the area must be kept dry and that the strips should be reinforced if any laxity or loosening is noted in order to prevent increased tension across the wound and more resultant scarring (Vasconez et al. 2011; Hogg 2012).

Cyanoacrylate glues (e.g., Dermabond®, Ethicon, Somerville, NJ) or skin tapes, which are better tolerated by young patients, are commonly used in many emergency departments. Cyanoacrylate glue use in children has proven very popular because of their faster application and reduced pain associated with the administration. Another advantage is that they provide a waterproof dressing and can aid in the bacteriostatic protection of the incision. If a wound is leaky or moist, however, these glues may not adhere adequately to the skin. Skin glue should not be relied on to approximate wounds that are under tension, and some form of subcuticular closure should be used to diminish the risk of wound dehiscence. Petroleum ointment, such as antibiotic ointment, should not be used on the site closed with cyanoacrylate adhesives because they will degrade the product and increase the probability of dehiscence (Vasconez et al. 2011; Mueller 2013; Hollier Jr et al. 2014; Fonseca et al. 2013).

Although few prospective reports have been published, recent data suggest that no appreciable cosmetic difference between lacerations closed at the skin level with fast-absorbing catgut, removable nylon, or cyanoacrylate glue 9–12 months post-repair (Vasconez et al. 2011; Fonseca et al. 2013).

Postoperative Care

Permanent sutures on the face should be removed early enough to prevent track marks. As a general rule, they can be removed 5–7 days after suture when they are load-bearing. When a layer of reliable deep dermal sutures is in place, superficial skin sutures can be removed as soon as 3 days after suturing to avoid suture marks (Hogg 2012). Steri-Strips® or adhesives should remain until they fall off spontaneously or until the surgeon indicates that they can be removed with soap, water, or ointment. Prophylactic systemic antibiotics for facial soft tissue trauma are generally not required, with the exception of wounds at high risk of contamination such as bites (Ridgway et al. 2010). Topical antimicrobial agents, on the contrary, have been shown to decrease the rate of
infections of traumatic lacerations (Hollier Jr et al. 2014; Fonseca et al. 2013). They provide a moist environment that will promote healing and decrease the risk of infection. After wound healing is complete, the patient should be advised to massage scars regularly and to apply facial moisturizer and sunblock judiciously. Pressure therapy or silicone gel sheeting may have some efficacy in minimizing scar pending the acceptability of cost of these materials (Hogg 2012; Fonseca et al. 2013). Treatment of a reddened scar with a pulsed dye vascular laser has been shown to be effective. Topical corticosteroid-containing ointments may be utilized for short periods of time to decrease an exaggerated hemorrhagic and inflammatory response that may be observed in some children during wound healing (Hogg 2012). Dermabrasion can also provide some smoothing of the scar. Patients should be informed of the 6–12-month duration of full scar maturation before consideration of any surgical revision.

**Regional Soft Tissue Wounds**

**Ear**
The ear is a prominent and protrusive facial structure that has limited protection from injury secondary to its functional purpose of hearing. As a result, the ear is prone to a spectrum of traumatic injuries ranging from abrasion, simple laceration, complex laceration, partial avulsion, to complete avulsion. A complete ear evaluation should include an otoscopic examination of the external auditory canal and the tympanic membrane, so as to address potential canal stenosis and diminished acuity of hearing from tympanic membrane rupture (Hogg 2012; Horsewell and Meara 2012; Mueller 2013; Hollier Jr et al. 2014; Fonseca et al. 2013).

The excellent vascularity of the ear allows it to sustain severe trauma and if adequately approached can result in little residual injuries or noticeable effects even when it is hanging from a small pedicle. Large portions of tissue may rely on very small pedicles (Fig. 3) (Hollier Jr et al. 2014). Debridement should be kept to a minimum, with no more than 1 mm of tissue removed from wound edges (Hogg 2012). Once the wounds have been cleansed, meticulous closure of the skin and cartilage is required. Suture fixation with either non-absorbable or absorbable suture, depending on the situation, can be used. Large segments of cartilage that are not able to be covered with skin due to tissue loss can be banked in a subcutaneous pocket near the ear region for future surgical reconstruction. Significant avulsive injuries may require grafts and flaps for reconstruction, and these are best managed in the operating room (Hogg 2012). A total or subtotal avulsion of the ear should be considered for microsurgical replantation if the circumstances permit. If this is not possible, a staged ear reconstruction with costal cartilage may be required.

Consideration for the use of tissue support, including the use of acrylic supports or bolster dressing, should be made. Cartilage requires less oxygen than bone, but it needs complete soft tissue coverage. In fact, the two most prominent concerns in ear injuries are hematoma and chondritis (Hogg 2012; Fonseca et al. 2013). Collections of blood in proximity to the cartilage can result in cartilage resorption or a reactive chondrogenesis, which ultimately leads to cauliflower ear deformity. Once identified, hematomas need to be evacuated immediately with an incision and some type of bolster dressing placed that can be anchored with a nonabsorbable suture (Mueller 2013). These dressings can usually be made to contour the natural area of the ear affected and allow for excellent healing. Bolster dressings can be removed in 5–7 days. The use of a supportive bandage may be recommended for 2 or 3 days. Chondritis that is overlooked or not treated promptly may result in loss of a significant portion of the auricular cartilage. These patients typically require admission for intravenous antibiotic administration and possibly debridement (Fig. 4).

Patients and parents should be informed of the possibility of growth disturbances or deformity as a result of cartilaginous disruption.

**Eyebrows**
Reconstruction of the eyebrow is extremely difficult, and every effort to repair eyebrows without
Fig. 3  (a) Right ear complex wound in an 8-year-old girl resulting from a dog bite. (b) Minimal cartilage and skin debridement was performed. (c) and (d) Ear repositioning was achieved with skin closure with absorbable and non-absorbable sutures. (e) and (f) 45 days after ear repair
distortion or defect is important. In most injuries involving the eyebrow, the most critical aspect of repair is proper alignment of the margins. The eyebrow should not be shaved because of its unpredictable ability and speed to grow back. If nonvital tissue must be removed, incisions should be made parallel to hair follicles as to injure as few as possible. Special care should also be taken to avoid tight constricting sutures in the area, because hair follicles are sensitive to decreases in blood flow (Hollier Jr et al. 2014).

### Eyelid and Lacrimal Duct Injuries

Familiarity with eyelid anatomy is key to wound repair (Fig. 10). Patients with eyelid injuries and lacerations should be carefully evaluated for globe injury prior to repair. Direct injuries to the globe warrant urgent ophthalmologic consultation. Eyelid wound evaluation includes examination for foreign bodies and tissue loss. Wound irrigation is then completed with sterile saline.

As the eyelid is very vascular, even quite necrotic-looking ischemic tissue can often survive, and therefore no tissue should be excised (Vasconez et al. 2011; Hollier Jr et al. 2014; Fonseca et al. 2013). Good aesthetic and functional results can usually be achieved but may require several procedures. The eyelids are composed of anatomic layers called lamellae: the anterior lamella, the skin and muscle layer; the middle lamella, the tarsal plate and either the levator (upper lid) or depressor (lower lid) aponeurosis; and the posterior lamella, conjunctiva (Fonseca et al. 2013). All lacerations should be closed in multiple layers, from the deepest layer first, with more superficial layers closed subsequently. Anatomic landmarks for closure are crucial, with careful reapproximation of the muscles, conjunctiva, or tarsus, when necessary. The most critical step in eyelid repair is placement of an everting suture along the lid margin and the gray line (junction between the conjunctival mucosa and skin) (Fig. 5) (Vasconez et al. 2011; Mueller 2013). This facilitates proper alignment and curvature of the upper eyelid and makes notching of the lid margin less likely. In the lower eyelid, the suture in the lid margin can be left long and taped down to the cheek to prevent the suture ends from irritating the eye. In both eyelids, suture can be accomplished with 7–0 or 8–0 Vicryl. Although the conjunctiva will usually heal well without sutures, injuries associated with a significant deformity should be approximated with a fine, absorbable suture, with the knots facing away from the cornea to prevent any irritation or further injury (Vasconez et al. 2011; Fonseca et al. 2013). Next, the tarsal plate, which is the supportive structure of the eyelids, is repaired with a fine resorbable suture. If the septum has been violated, the periorbital fat may be seen protruding. The septum must be reapproximated to prevent orbital fat herniation, which can result in deformity, dysfunction, and possibly diplopia. Meticulous hemostasis is mandatory before closure of the septum in order to reduce the risk of retrobulbar hematoma, which may place excessive pressure on the globe and optic nerve and potentially cause blindness. If injury has occurred to any of the

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**Fig. 4** Diagram of basic eyelid anatomy. **CON** conjunctiva, **DEPR** depressors, **GL** gray line, **MG** meibomian gland, **OOM** orbicularis oculi muscle, **TP** tarsal plate
upper lid elevators, such as Muller’s muscle or levator palpebrae aponeurosis, it is necessary to reattach it to the tarsal plate in order to prevent any ptosis or long-term sequela from the injury. Finally, a fine, absorbable suture is used to approximate the final skin layer. At times, a pull-out polypropylene suture can be used to lessen inflammation (Mueller 2013; Hollier Jr et al. 2014).

In cases of avulsive tissue loss to the lids, partial-thickness versus full-thickness and small versus large defect size are critical elements to carefully determine before surgical repair. Partial-thickness defects (<25%) may heal by secondary intention, but owing to eyelid skin laxity, primary closure can usually be achieved after undermining of native lid skin (Mueller 2013). Larger partial-thickness defects and total avulsion of tissues require tissue grafts or local flaps to achieve closure and avoid healing-induced ectropion or lagophthalmos. Full-thickness skin grafts harvested from the contralateral eyelid and preauricular, precervical, or lateral cervical regions will provide the best color match for eyelid skin (Mueller 2013).

Liberally apply chloramphenicol or lubricant (ointment is better than drops), and cover the entire area with a damp gauze swab to provide corneal protection.

The lacrimal duct apparatus is a complex system that merits a high degree of suspicion of injury whenever there is trauma involving the medial canthal region. Two methods may be used to help rule out injury: (Gassner et al. 2004) a Jones test with fluorescein dye and (Haug and Foss 2000) direct probing and irrigation (Vasconez et al. 2011; Hogg 2012; Horsewell and Meara 2012; Mueller 2013; Hollier Jr et al. 2014). Most children do not tolerate a thorough lacrimal and canalicular evaluation, so a detailed evaluation is often completed under general anesthesia in the operating room, preferably within 48–72 h of the initial trauma. If injured, obstruction, stasis, and infection may follow (Hogg 2012; Horsewell and Meara 2012). The severed ends need to be identified and realigned. Repair is then done over a Silastic catheter or Crawford tube to prevent epiphora (Fig. 6). The catheter is left in place until the lacrimal system has redeveloped and reepithelialized, usually during 6–8 weeks. These structures require an attention to detail and meticulous dissection to prevent further injury to the surrounding structures (Vasconez et al. 2011).

Scalp
Because the pediatric patient has a disproportionate skull-to-face ratio, the scalp is more exposed to traumatic injury (Gassner et al. 2004; Haug and Foss 2000; Hogg 2012; Horsewell and Meara 2012). The scalp is distinguished from

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**Fig. 5** (a) Eyelid laceration and anatomic repair. Note alignment of the capsulopalpebral fascia (1), gray line (2), and orbicularis oculi muscle (OOM). (b) Eyelid skin and gray line (GL) alignment. Note that the sutures are left long, retracted, and taped inferiorly away from the lashes and conjunctiva.
other tissues by its hair-bearing nature, inelasticity, relative thickness, and unique layers. These unique five layers consist of the skin (S), connective tissue (C), galea aponeurotica (A), loose areolar tissue (L), and pericranium (P). The thick connective tissue of the galea, in combination with the convexity of the underlying cranium, often makes primary closure difficult and necessitates scoring and/or wide undermining. These characteristics increase with increasing age of the patient, with substantial differences between the hypermobile scalp of the infant relative to the much stiffer, tethered scalp of the mature adult (Vasconez et al. 2011; Mueller 2013). Scalp injuries have the potential for substantial blood loss.

The management of traumatic scalp loss depends on the size, location, and depth of the defect and may incorporate all aspects of the reconstructive ladder (Vasconez et al. 2011; Fonseca et al. 2013). Attempts should be made to close the scalp injury in layers. Generally feasible for defects measuring less than 3–4 cm in diameter, primary closure is the simplest option for reconstruction. Because excessive tension may also damage hair follicles, primary closure should be avoided if significant tension is present despite attempts at galeal scoring and undermining in the loose areolar plane. For significant areas of tissue loss, split-thickness skin or acellular dermis grafts may be employed, for temporary coverage, if the pericranium is intact. If significant avulsive injury occurs with cranial bone exposure, reconstruction can be achieved with local rotational flaps. Grafts often yield a poor cosmetic outcome due to lack of hair, color mismatch, and lack of tissue height and contour restoration. However, grafted areas can then be excised secondarily, either with small serial excisions or with tissue expansion. Tissue expansion, although not generally an option in acute traumatic defects, may be of utility in secondary scalp reconstruction (Mueller 2013; Hollier Jr et al. 2014; Fonseca et al. 2013). Despite a complication rate of up to 25%, it is generally accepted that tissue expansion can allow reconstruction of up to 50% of the scalp without distorting the hair growth pattern or creating a new donor defect (Fig. 7) (Ridgway et al. 2010). Additionally, it provides donor tissue of the same color, texture, thickness, innervation, and blood supply with minimal scar formation and minor donor site morbidity, avoiding distant tissue transfers (Mueller 2013; Fonseca et al. 2013).

**Fig. 6** (a) Eyelid and canicular injury. LS lacrimal sac; LD lacrimal duct. (A), Silicone lacrimal tube wedged onto pigtail probe and placed through the canalicular and collecting duct system. (b) Eyelid and canicular injury. LS lacrimal sac; LD lacrimal duct. (B), Silicone lacrimal tubes placed through the canaliculi and into the lacrimal system (2) exiting the nasolacrimal duct in the inferior meatus. Note the sutures are secured intranasally high (3) in the vestibule with two nonabsorbable sutures. Closure of the wound (1) is commenced once the tubes are in place and secured.
Near-total defects of the scalp are best managed with free tissue transfer. In the case of near-total scalp avulsion, consideration should be given to scalp replantation (Mueller 2013).

As a final point of emphasis, when managing soft tissue injuries of the scalp or forehead, efforts should be made to preserve the contour of the patient’s natural anterior hairline.

**Nasal Injuries**

Although the pediatric nasal complex is less pronounced and more pliable than the adult nose, its position and projection makes it a commonly injured structure (Haug and Foss 2000). Any injury to the nasal region can result in a substantial functional as well as cosmetic defect. Tangential forces and dog bites can lead to significant nasal soft tissue injuries (Vasconez et al. 2011; Chen et al. 2013).

Nasal bleeding from trauma usually stops spontaneously without therapeutic intervention, but in children, with a smaller blood volume, epistaxis can be life-threatening (Hogg 2012). On rare occasions, treatment may be necessary. Anterior epistaxis is more common than posterior nosebleed and usually involves hemorrhage from Kiesselbach’s plexus, also referred to as Little’s...
area. Packing this area with cotton soaked in phenylephrine and 4% lidocaine will usually provide hemostasis and some topical anesthesia and often will be effective. If the patient has a posterior nosebleed, these efforts will be useless. The most practical definition of a posterior nosebleed is epistaxis that cannot be treated with an anterior nasal pack. Rhinorrhea or nasal discharge should be evaluated to rule out cerebrospinal fluid (CSF) leakage. If present, a CSF leak should prompt immediate neurosurgical consultation (Ryan et al. 2011; Horsewell and Meara 2012).

Anesthesia with a 4% or 10% cocaine solution or lidocaine with epinephrine may be necessary for an adequate evaluation of nasal injuries, which includes a careful speculum examination to diagnose mucosal lacerations and septal hematoma. If seen, this can be evacuated through a small incision in the septal mucosa. A running absorbable suture (4–0) is placed through and through the septum, and polyvinyl acetyl sponges or silicone splints may be placed into the nasal passage to prevent reaccumulation (Mueller 2013; Hollier Jr et al. 2014; Fonseca et al. 2013). Failure to diagnose septal hematoma can result in erosion and loss of septal cartilage and consequent “saddle-nose” deformity as a result of septal collapse (Vasconez et al. 2011; Mueller 2013). Any intranasal mucosal laceration should be repaired, and the nasal cavity packed to assist in preventing any post-traumatic nasal adhesions.

The concept of aesthetic units plays an important role in all facial reconstruction, but a special note should be emphasized for the nose. Principles of aesthetic reconstruction include minimal debridement when possible and anatomic realignment of the soft tissues, especially the nasal rim. Lacerations of the nose may involve the skin, nasal cartilages, and mucosa. Repair of injuries involving all three layers should proceed from deep to superficial with repair of the mucosa, followed by cartilage and then the skin (Hollier Jr et al. 2014; Fonseca et al. 2013). Cartilaginous disruption, particularly of the nasoseptal cartilaginous skeleton, may induce growth disturbances. In order to avoid this, a limited number of cartilage sutures are desirable. Avulsive wounds of the nose may require skin grafts. Skin grafts are ideally done with full-thickness postauricular grafts, which give the best match of color and texture.

**Lip Injuries**

Lacerations to the lip may occur as a result of foreign body trauma but often are secondary to dental trauma (Hogg 2012; Hollier Jr et al. 2014).

Injury to the lip may involve the underlying orbicularis oris muscle, as well as the mucosa. The most important consideration in repairing soft tissue injuries involving the lips involves accurate reapproximation of the injured structures in a layered fashion from an “inside-out” ordination beginning first with the mucosal layer closure. Special attention should be given to the vermilion border. A discrepancy in alignment of the vermilion border as little as 1 mm is noticeable at a conversational distance (Fig. 8) (Hogg 2012; Mueller 2013; Fonseca et al. 2013). As such, prior to infiltration of any local anesthetic, the location of the vermilion border on either side of a laceration should be tattooed using a needle with methylene blue.

For full-thickness injuries, absorbable sutures should be used to reapproximate the orbicularis oris muscle. Failure to do so will result in bunching of the muscle on either side of the laceration with attempted animation, which typically results in a shortened scar with an exaggerated notching of the lip. Scars or defects that affect the sphincter activity of the orbicularis oris muscle produce drooling, functional difficulties in eating, and alterations of speech (Mueller 2013; Hollier Jr et al. 2014). Any intraoral mucosal defect should be closed using a fast-absorbing suture. Scarring of the oral commissure may cause microstomia.

Although healing by secondary intention may result in good functional and aesthetic outcomes in the pediatric population, most defects involving less than one-third of the lip should undergo direct primary closure by layer. Partial-thickness defects of less than one-third of the lip should generally be converted to full-thickness defects by excision and then closed primarily. Moderate to large lip defects involving up to two-thirds of the lip length typically require more complex reconstructions with flaps (Fig. 9) (Mueller 2013; Hollier Jr et al.
Near-total lip loss may require free tissue transfer. The radial forearm free flap has been used most often for this application, often together with the palmaris longus tendon to serve as a sling for lip support (Mueller 2013). In cases of traumatic amputation of lips where tissue has been well preserved, microsurgical replantation is an option.

Cheek

The cheek tissue is usually thick and muscular and includes numerous other anatomic structures. It is bordered by the infraorbital region superiorly, the lateral nose and nasolabial fold medially, and the preauricular region laterally (Fonseca et al. 2013).

Injury to the cheeks may involve two critical structures: the facial nerve and the parotid gland/duct. Soft tissue injuries to the face involving the facial nerve are particularly devastating (Mueller 2013; Hollier Jr et al. 2014; Fonseca et al. 2013). Significant crossover between the buccal and zygomatic branches confers a certain degree of protection from injury sequela (Horsewell and Meara 2012; Mueller 2013). The clinical presentation of facial nerve injury most often consists of functional and aesthetic deficits of the ocular and oral musculature. The attending physician should specifically test elevation of brow, forced closure of the eyes, voluntary smile, and eversion of the lower lip. However, preoperative clinical assessment in a young or disconsolate and uncooperative child may be unreliable (Vasconez et al. 2011; Hogg 2012; Horsewell and Meara 2012). Grossly, wounds may evidence depth of injury if the fat is exposed in young children, indicating high likelihood of facial nerve injury. As a general rule, all such injuries should be explored operatively.

A line drawn from the lateral canthus to the midbody of the mandible gives an indication of the potential for nerve regeneration after injury (Fig. 10) (Horsewell and Meara 2012; Hollier Jr et al. 2014). Generally, wounds distal to this line will not require facial nerve exploration or repair, because these wounds usually do not result in permanent loss of muscle function due to the extensive arborization of the nerve at this level. Most of these injuries will undergo a spontaneous reinnervation over a 3- to 6-month period (Fonseca et al. 2013). Wounds proximal to this line should be explored under magnification for possible nerve injury and the need for repair. The time of recovery for a repaired nerve can be approximated by measuring the distance between the site of injury and the target muscle. Nerve regeneration typically occurs at a rate of 1 mm/d after a 1-month lag (Mueller 2013; Hollier Jr et al. 2014; Fonseca et al. 2013).

A parotid gland injury does not require any special intervention unless the underlying parotid duct is involved. The duct is located in a line parallel with a line drawn from the tragus to the midpoint of the upper lip. Involvement of the Stensen’s duct may result in a parotid fistula unless corrected (Mueller 2013; Hollier Jr et al. 2014). These injuries may be difficult to identify and may only be seen following repair of skin lacerations with subsequent accumulation of saliva. Since the major buccal branch of the facial nerve tends to run with the parotid duct, motor
deficits in the muscles innervated by the buccal branches (e.g., weakness of the upper lip on facial animation) should raise the suspicion of injury to both structures (Hogg 2012; Hollier Jr et al. 2014).

The Stensen’s duct orifice (parotid papilla), which communicates the parotid duct with the oral cavity, lies adjacent to the second molar. If injury is suspected, the duct should be probed.

**Fig. 9** 11-year-old girl with an electrical burn of 2/3 of lower lip from biting an electrical cord. (a) Acute setting. (b) 3 days after. (c) and (d) A schematic drawing of the two-stage Abbe flap demonstrates the cross-lip transfer that is divided at approximately 3 weeks postoperatively. (e) Reconstruction was performed with an Abbe flap from the upper lip. (f) Preoperative photograph of flap division. Ten years after injury, (g) frontal view and (h) lateral view.
Frequently, the needleless portion of an angiocatheter is attached to a saline-filled syringe and Stensen’s duct is cannulated. Repair is completed in the theater under microscopic magnification. Primary anastomotic repair using 8–0 or 9–0 nylon sutures is advocated, and this is often performed over a silicone stent (Horsewell and Meara 2012; Mueller 2013; Hollier Jr et al. 2014; Fonseca et al. 2013). The Silastic stent is left within the duct, and the proximal end is sutured to Stensen’s duct orifice or to the buccal mucosa, to avoid displacement, and maintained up to 2–4 weeks until ductal continuity and integrity have been restored. When ducts are stented, the patient should be prescribed antibiotics for 7–10 days (such as penicillin or cephalothin), as the gland may develop stasis and become prone to obstructive sialadenitis (Hollier Jr et al. 2014).

**Bites**

The likelihood of a child sustaining a dog bite during his or her lifetime is reported to be almost 50%, and half of all bites are to the head and neck region (Vasconez et al. 2011; Hogg 2012; Horsewell and Meara 2012; Chen et al. 2013). The prevalence of facial dog bites in children predominantly reflects their stature, since their faces are often at eye level with the dog and easily accessible upon provocation (Chen et al. 2013). Bites are most common in the periorbital region and in a “central target area” that includes the nose, cheeks, and lips (Hogg 2012; Chen et al. 2013; Hurst et al. 2020). In more rare situations, bony involvement may be present. Biting dogs are typically family pets or neighborhood pets known to the victims. Pit bulls, Rottweilers, German shepherds, Dobermans, and mixed breeds are the breeds responsible for the majority of documented bites (Vasconez et al. 2011; Hogg 2012; Horsewell and Meara 2012; Chen et al. 2013). Rabies is a serious consideration with any animal bite. Immediate and thorough washing of the wound with a soap or scrub solution is probably the best prevention against rabies. Postexposure rabies prophylaxis is

![Fig. 10 Zone of arborization of the facial nerve](image-url)
recommended for patients attacked by suspected animals or in geographic locations in which the incidence of rabies is particularly high. Domesticated dogs with a known vaccination status should be quarantined for 10 days, and postexposure prophylaxis can be withheld unless signs of rabies develop in the quarantined dog. An assessment of the patient’s tetanus immunization status is required (Chen et al. 2013).

In addition to dog bites, which are responsible for most bite wounds, cat bites and human bites may result in soft tissue trauma to the head and neck. Cat bites are the second most common and account for approximately 5–15% of animal bite wounds. Compared to dog bites, cat bites are believed to carry a higher risk of wound infection, of about 30–50% (Vasconez et al. 2011) This may be because of the long slender teeth of cats, allowing deep inoculation into the tissues, or from the unique oral flora of cats (Vasconez et al. 2011; Hogg 2012; Fonseca et al. 2013). Human bites are clearly less common than animal bites, but may have the highest rate of infection of all bite wounds (Mueller 2013; Hollier Jr et al. 2014).

Although prospective data are lacking, general consensus suggests that bite wounds to the head and neck are appropriately managed with primary closure within 24 h of injury, provided there are no signs of acute infection such as cellulitis, purulence, or fever (Vasconez et al. 2011; Hogg 2012; Fonseca et al. 2013; Chen et al. 2013). Exceptions are puncture types of wounds that should not be closed primarily because they are difficult to adequately clean, bite wounds with extensive crush injury and wounds requiring a considerable amount of debridement, which are best treated with delayed primary closure (Vasconez et al. 2011; Mueller 2013). Repair should be done with as few deep sutures as necessary in order to reduce tension, followed by fine simple interrupted sutures of the skin to allow for potential drainage.

The use of prophylactic antibiotics is advisable for animal bites. This is especially true for deep tissue injuries with exposed structures such as cartilage, wounds closed after 6–12 h, and in patients with immunosuppressive comorbidities (Vasconez et al. 2011; Horsewell and Meara 2012). Prophylactic antibiotics or empiric antibiotics in the case of wound infection should be directed at the common causative organisms, which include Pasteurella, Streptococcus, Staphylococcus, and anaerobes for cat and dog bites and Eikenella, Streptococcus, Staphylococcus, and anaerobes for human bites. Amoxicillin-clavulanate is widely regarded as the gold standard in the treatment of animal bites.

Facial Fractures

Introduction

Although fractures of the facial skeleton are less common in children than in adults, an important part of pediatric morbidity is related to craniofacial fractures (Gassner et al. 2004; Haug and Foss 2000; Imahara et al. 2008; Ferreira et al. 2005; Alcalá-Galiano et al. 2008; Ryan et al. 2011). Patterns of facial injury in children also differ from those of adults. Because of the differences between adult and children anatomic, physiologic, and psychologic development, not only do the consequences of trauma differ, but the management techniques should be modified to address these differences (Haug and Foss 2000; Alcalá-Galiano et al. 2008; Hatef et al. 2009; Wheeler and Phillips 2011). Maxillofacial injuries in children always present a challenge in diagnosis and management.

Despite the attention that facial fractures have received in the literature, the epidemiology of these injuries is not well characterized in children. There is a wide variation in the estimates of injury incidence, mechanism, pattern, and associated injury.

Preventive legislation (speed limits, alcohol restriction, use of helmets, shoulder, and seat restraints), improved road construction measures, and vehicle safety modifications (safety glass, padded dashboards, stronger frames, collapsible steering columns, airbags) have led to a significant decrease in the incidence and severity of motor vehicle accidents (MVA) in some countries (Ferreira et al. 2015b; Arbogast et al. 2002). There has also been a corresponding decrease in
the incidence and severity of facial fractures, particularly in children below the age of 10 years (Ferreira et al. 2015b).

**Unique Features of the Pediatric Facial Skeleton**

Many of the unique features of pediatric facial trauma are directly related to the underdevelopment and continued growth of the facial skeleton (Haug and Foss 2000; Ferreira et al. 2005; Alcalá-Galiano et al. 2008). Pediatric maxillofacial fractures are different from adult fractures, and they are more often non- or minimally displaced and isolated, mainly in children below age 3. During the first years of development, the bone has a high osteogenic potential and is characterized by a thick medullary space and thin bony cortice. Consequently, children have a greater susceptibility of greenstick fractures than adults (Haug and Foss 2000; Hatef et al. 2009; Wheeler and Phillips 2011). A child’s face has certain characteristics that makes fractures in this region less likely to occur. Most of the growth of the pediatric cranium occurs during the first year of life (Hatef et al. 2009; Wheeler and Phillips 2011). The retruded position of the face relative to the “protecting” skull is an important reason for the lower incidence of midfacial and mandibular fractures and the higher incidence of cranial injuries in young children (less than 5 years of age) (Fig. 1) (Gassner et al. 2004; Haug and Foss 2000; Ferreira et al. 2005). With increasing age and facial growth (in a downward and forward direction), the midface and mandible become more prominent, and the incidence of facial fractures increases, while cranial injuries decrease (Hatef et al. 2009; Wheeler and Phillips 2011). Therefore, by teen years, the patterns of injury are very similar to those of adult patients. In addition, the bony framework of the face is protected by thicker tissues and more buccal fat (Ferreira et al. 2005). The presence of unerupted teeth in the maxilla and mandible also makes the pediatric facial skeleton more resistant to fractures (Haug and Foss 2000; Alcalá-Galiano et al. 2008; Hatef et al. 2009). The gradual pneumatization of the paranasal sinuses is also thought to contribute to the decreased frequency of facial fractures, because of the solidity of the bone. Furthermore, young children are less often involved in occupational or violence-related accidents that are typical features of adult facial fractures (Ferreira et al. 2005).

Since children are in a growing phase, care should be taken so that the overall growth pattern of the facial skeleton is not jeopardized. With the future morphological and anatomical changes in mind, the management of these facial injury victims becomes a more complex and arduous task for the surgeon (Haug and Foss 2000; Hatef et al. 2009; Wheeler and Phillips 2011).

The possibility of adverse post-injury growth disturbances, particularly after severe nasal septal and condylar injuries, should be considered when planning treatment (Chao and Losee 2009; Chrcanovic 2012). Growth potential, on the other hand, may serve to improve long-term results as with compensatory condylar growth after condylar fractures. In addition, children in the deciduous and mixed dentition stages demonstrate some capacity for spontaneous occlusal readjustment, after injury and treatment, as deciduous teeth are shed and permanent teeth erupt (Haug and Foss 2000; Hatef et al. 2009; Wheeler and Phillips 2011; Chao and Losee 2009).

As paranasal sinuses continue to pneumatize and expand and the permanent dentition erupt at about 12 years of age and continue to grow into adolescence, the craniofacial skeleton becomes more adultlike, and adultlike surgical management becomes increasingly more appropriate (Haug and Foss 2000; Ferreira et al. 2005; Alcalá-Galiano et al. 2008).

**Epidemiology of Facial Fractures in Children**

**Incidence**

Social, cultural, and environmental factors vary from one country to another and influence the incidence and etiology of facial fractures (Gassner et al. 2004; Haug and Foss 2000; Imahara et al. 2008; Ferreira et al. 2005; Alcalá-Galiano et al. 2008; Ryan et al. 2011). Although the frequency of facial fractures in children is much lower than that of adults, these patients tend to have higher injury severity scores with prolonged hospital
admissions and higher associated morbidity and mortality (Imahara et al. 2008). Approximately 5–15% of all facial fractures occur in children (Ferreira et al. 2005). The incidence and etiology of facial trauma are also affected by age-related activities (Haug and Foss 2000; Ferreira et al. 2005). The incidence of pediatric facial fractures is lowest in infants and increases progressively with increasing age (Table 1). A large number of these patients are teenagers. It has been reported that the risk of a child with facial trauma to sustain a fracture of the facial skeleton increases by 14% with every year of age (Gassner et al. 2004; Haug and Foss 2000; Alcalá-Galiano et al. 2008). Facial fractures are rare below 5 years of age (0.87–1%), and their incidence rises as children begin school. Another peak in incidence occurs during puberty and adolescence with increased unsupervised physical activity and sports. Seasonal variations are reported with peak frequencies during summer months (except for skiing injuries) when outdoor activity is greatest (Ferreira et al. 2005).

**Gender**

There is a marked preponderance of boys in the worldwide pediatric population affected by facial fractures, with the male-to-female ratio ranging from 1.1:1 to 8.5:1 (Haug and Foss 2000; Imahara et al. 2008; Ferreira et al. 2005), with this ratio differing between age groups and depending on the series (Table 1). The preponderance of boys is attributed mainly to the greater and more dangerous physical activities among boys like the increased participation in sporting activities (Haug and Foss 2000; Ferreira et al. 2005, 2015a; Horsewell and Meara 2012; EggenspergerWymann et al. 2008). In younger age groups, gender differences are less significant, and the etiologies are similar in both genders (Haug and Foss 2000; Horsewell and Meara 2012).

**Etiology**

The main causes of pediatric facial fractures vary, depending on the data source (Haug and Foss 2000; Ferreira et al. 2005; Qing-Bin et al. 2013; Bamjee et al. 1996; Glazer et al. 2011). Causes of fracture are closely linked with age-related levels of activity. While young children, who are constantly supervised and have a protected environment, usually sustain injuries from low-velocity forces (e.g., falls), older children are more likely to be exposed to high-velocity forces (e.g., in MVA and sports-related trauma). The frequency of severe fractures increases with age (Wang et al. 2018). Involvement in a MVA as a pedestrian is also a common cause of facial fractures in children 6 years of age and above. Involvement in a MVA as motorcyclist is common in patients older than 14 years of age. In contrast to adults, interpersonal violence is a rare cause of facial fractures in children. These injuries occur more commonly in adolescents (Gassner et al. 2004; Haug and Foss 2000; Imahara et al. 2008).

MVA have been well documented in the surgical literature as the most common cause of maxillofacial fractures in children in developing countries (Ferreira et al. 2005; Hatef et al. 2009; Wheeler and Phillips 2011; Ferreira et al. 2015b). Imahara et al. (2008) found that motor vehicle collisions double one’s risk for facial fractures compared with other mechanisms, and lack of appropriate restraints (either seat belts or child safety seats) also increases facial fracture risk by 16%. However, falls are reported to be the most common etiologic factor of pediatric maxillofacial fractures in Switzerland (EggenspergerWymann et al. 2008) and China (Li and Li 2008). A study from South Africa indicated that violence was the leading cause of pediatric facial fractures (Bamjee et al. 1996). Glazer et al. (2011), from Israel, reported a relatively high incidence of mandibular fractures due to horse kicks, probably because the study was performed in an hospital located in a huge agricultural region, where the outdoor activity of the children is mainly on farms, unsupervised and adjacent to animals. These differences provide evidence that the etiology of facial fractures varies from one country to another, depending on social, cultural, and environmental factors.

**Site and Pattern**

The most common site of injury varies according to the study population. Because most studies are conducted based on data from trauma databases or from patients seen at trauma centers, many minor,
isolated fractures are likely underreported, such as dentoalveolar and nasal bone fractures (Haug and Foss 2000; Ferreira et al. 2005, 2015a; Alcalá-Galiano et al. 2008; Ryan et al. 2011; Horsewell and Meara 2012; Chapman et al. 2009; Hatef et al. 2009; Wheeler and Phillips 2011; Ferreira et al. 2015b; Arbogast et al. 2002; Chao and Losee 2009; Chrcanovic 2012; Eggensperger-Wymann et al. 2008; Li and Li 2008; Qing-Bin et al. 2013; Bannjee et al. 1996; Glazer et al. 2011). The site and pattern of a fracture depends on the interrelationship between the etiology and force of the injury and the unique anatomic and physiologic features of the child’s stage of development. Young patients less than 5 years of age are more likely to have frontal trauma and nasal and superior orbital injuries. This is thought to be due to the high cranial/facial proportions. The cranium quadruples in size from birth to adulthood, while the face undergoes a 12-fold increase (Fig. 1). Therefore the frontal protrusion of the cranium absorbs the full force of the initial trauma, thus “protecting” the face (Hatef et al. 2009; Wheeler and Phillips 2011). Older pediatric patients are more prone to injuries of the chin/lip region and have a higher incidence of mandibular fractures, due to the relative prominence of the lower jaw, and of orbital floor injuries, due to the aeration of the maxillary sinus (Haug and Foss 2000; Alcalá-Galiano et al. 2008).

According to the available sources, nasal fractures are the most common, representing around 50% of the total, followed by mandibular fractures (15–86.7%) (Table 1) (Haug and Foss 2000; Alcalá-Galiano et al. 2008; Horsewell and Meara 2012; Hatef et al. 2009; Wheeler and Phillips 2011). The nasal bones are the least resistant of the facial skeleton. This, combined with the relative prominence of the nose, which increases with growth, makes it most vulnerable to injury in older children (Haug and Foss 2000). Nasal fractures are often treated in the outpatient setting, and because of this, the frequency of their occurrence is probably underestimated. Mandibular fractures are most often diagnosed in the hospital setting. Their incidence increases with age. The condylar region is the most frequently fractured site (Table 2) (Haug and Foss 2000; Ferreira et al. 2005; Chrcanovic 2012; Glazer et al. 2011).

Orbital (9.5–45%), frontal skull (5.1%) (Fig. 11), and midfacial (3.8%) fractures are next in frequency, and complex fractures (naso-orbito-ethmoidal, Le Fort) (Fig. 12) are the least common types (1.5%) (Table 3). Alveolar and dental

### Table 1

| Incidence among all facial fracture patients | <16 y of age | 1%–14.7% |
| Sex distribution | Boys | 53.7%–80% |
| Anatomic distribution | Mandible | 15%–86.7% |
| | Midface (maxilla, zygoma, nose) | 8%–54% |
| | Upper face (orbit, frontal bone) | 12%–45% |
| Concomitant injury | Overall incidence | 10.4%–88% |

### Table 2

| Anatomic distribution of mandibular injury | Condyle | 14.5%–60% |
| | Alveolus | 8.1%–50.6% |
| | Body | 5.6%–44% |
| | Symphysis | 1.8%–40.4% |
| | Parasympysis | 23.9%–33.7% |
| | Angle | 3%–27% |
| | Ramus | 0.75%–10% |
| | Coronoid | 0%–19% |
fractures are also very common, but they are not included in many series, because they are usually managed in the outpatient setting (Haug and Foss 2000; Imahara et al. 2008; Ferreira et al. 2005, 2015a, b; Alcalá-Galiano et al. 2008; Ryan et al. 2011; Horsewell and Meara 2012; Chapman et al. 2009; Hatef et al. 2009; Wheeler and Phillips 2011; Arbogast et al. 2002; Chao and Losee 2009; Chrcanovic 2012; Eggensperger-Wymann et al. 2008; Li and Li 2008; Qing-Bin et al. 2013; Bamjee et al. 1996; Glazer et al. 2011).

**Fig. 11** (a) and (b) Axial CT scans views of a 16-year-old girl with frontonasal-orbito-ethmoid fractures. (c) and (d) Preoperative views of depressed frontal region. (e) Intraoperative view of comminuted frontal sinus and orbital roof fracture before and (f) after reconstruction with titanium plates and screws. (g) and (h) Result 4 months after surgery. (e) Intraoperative view of comminuted frontal sinus and orbital roof fracture before and (f) after reconstruction with titanium plates and screws. (g) and (h) Four months after surgery.

**Diagnosis of Facial Fractures in Children**

Pediatric facial fractures are sometimes not suspected or are overlooked in the emergency room. The injuries are uncommon, so the index is generally low. Pre-injury photographs, as well as dental or orthodontic records, can be extremely helpful in determining the pre-injury appearance.
Any available information regarding pre-injury occlusion is important.

As in adults, clinical signs of facial fractures may include displacement of fragments, facial asymmetry, mobility, crepitus, hematoma, swelling, mucosal tears, limited mouth opening, malocclusion, monocular or binocular ecchymosis or hematoma, enophthalmus, decreased and painful ocular mobility, diplopia, pain, and sensory deficits in the distribution of the affected nerves.

The diagnosis of facial fractures should be confirmed with imaging. Because of the incompletely calcified areas of the developing skeleton, the small and minimally pneumatized paranasal sinuses, the presence of a developing dentition, and the importance of the cartilaginous and soft tissue structures, plane, or panoramic radiographs are not always effective in the diagnoses of these fractures in pediatric patients (Alcalá-Galiano et al. 2008; Horsewell and Meara 2012; Chapman et al. 2009; Hatef et al. 2009; Wheeler and Phillips 2011; Arboagast et al. 2002; Chao and Losee 2009; Chrcanovic 2012; EggenspergerWymann et al. 2008; Li and Li 2008; Qing-Bin et al. 2013; Bamjee et al. 1996; Glazer et al. 2011; Macmillan et al. 2018).

Computed tomography (CT) scans greatly increase diagnostic accuracy and have become the gold standard of imaging of pediatric maxillofacial trauma victims. For some authors, standard thin-slice CT scans of the facial skeleton, from the vertex of the skull to the bony menton, should be routinely performed (Alcalá-Galiano et al. 2008). These scans are also important for the evaluation of head associated injuries. In addition to sagittal and coronal views, reformating images into a 3D reconstruction provides an improved perspective.
in complex injuries. These reconstructions provide anatomic detail that may be necessary to guide surgeons in achieving accurate reduction of fractures, especially of midfacial, and upper facial injuries and of intracapsular (comminuted or medial pole) fractures of the developing condyle. Coronal and sagittal formatting of images is useful for depicting changes in facial volume and width and is essential for assessing orbital roof and floor fractures. A detailed assessment of pediatric mandibular fractures, especially those involving the temporomandibular joint or condyle, is also more frequently achieved with coronal images (Haug and Foss 2000; Alcalá-Galiano et al. 2008; Chapman et al. 2009; Hatef et al. 2009; Wheeler and Phillips 2011; Chrcanovic 2012).

Recently, there have been significant concerns regarding excess radiation exposure in children. In particular the eye may be damaged, with an increased risk of cataract development. The multiplanar techniques that allow for excellent, detailed images also incur a higher radiation dose. As a result, many institutions have been exploring protocols that lower the dose of radiation with a consequent reduction in image quality (Brisco et al. 2014).

Management of Facial Fractures in Children

Children are not “small adults,” and the management of facial fractures in this population is unique. The treatment of pediatric facial fractures is controversial, and the optimal method of fixation of these fractures is not consensual (Haug and Foss 2000; Hatef et al. 2009; Wheeler and Phillips 2011). When planning the treatment of a child’s fracture, the following factors should be taken into account: age of the patient (to maximize growth and development), anatomic site (to optimize form and function), complexity of the fracture (displacement, comminution, and the number of sites), time elapsed since injury (ideally treatment should be performed within 4 days), concomitant injuries (fitness for anesthesia and duration of surgery), and the surgical approach (closed versus open) (Hatef et al. 2009; Chao and Losee 2009; Chrcanovic 2012; Glazer et al. 2011).

The greatest concern when treating the pediatric patient is the effect of the injury or the treatment on growth and development of the facial skeleton (Chao and Losee 2009). The risk of a growth disturbance should be considered when planning treatment (Chao and Losee 2009). Traumatic stripping of the periosteal tissues either from direct trauma or surgical repair may potentially cause growth disturbances (Haug and Foss 2000; Hatef et al. 2009; Wheeler and Phillips 2011). The periosteum provides the bone with a blood supply; it is osteoinductive, and following elevation it can form a scar. The risk decreases with increasing age, as the facial skeleton develops and permanent dentition erupts. Treatment should be noninvasive whenever possible, and, when surgery is necessary, the least invasive procedure and least intrusive devices (e.g., the fewest and smallest plates) should be used (Haug and Foss 2000; Ferreira et al. 2005; Alcalá-Galiano et al. 2008; Hatef et al. 2009; Wheeler and Phillips 2011; Chao and Losee 2009). It is more common to treat pediatric facial fractures conservatively compared with adults as the capacity to of the pediatric facial skeleton to remodel is greater. As in adults, the pre-injury skeletal and dentoalveolar anatomy and function are reestablished by anatomic reduction of fractures based on occlusion. Accurate reduction with or without fixation should be achieved earlier than in adults as children’s bones heal much faster, and if immobilization is used, it should be for shorter periods of time (2 weeks vs. 4–6 weeks in adults) in order to avoid temporomandibular (TMJ) ankylosis (Horsewell and Meara 2012; Hatef et al. 2009; Wheeler and Phillips 2011; Chao and Losee 2009).

Maxillofacial surgical intervention is indicated usually for the repair of severely displaced and comminuted fractures that are likely to cause functional impairment, aesthetic deformity, or both. Nondisplaced, minimally displaced, and greenstick fractures are usually managed conservatively by observation, combined with a liquid to soft diet and analgesics as needed (Fig. 13). Conservative treatment is also preferred if there is reproducibility of adequate occlusion or minimal discrepancy in occlusion and no facial
Displaced fractures often require closed or open reduction and fixation (Haug and Foss 2000; Ferreira et al. 2005; Alcalá-Galiano et al. 2008; Hatef et al. 2009). Generally, the need for surgical intervention is more likely in older children where severe fractures are more common, the facial skeleton is almost fully developed, and permanent dentition is nearly complete. For these reasons the risk of growth disturbances with more invasive treatment is less likely (Fig. 14) (Haug and Foss 2000).

Fracture immobilization and fixation, when required, can be achieved with maxillomandibular fixation (MMF) or open reduction and internal fixation (ORIF), or a combination of these, depending on the type of fracture and the patient’s stage of development (Fig. 15). Intraosseous tooth buds and (erupting) teeth in the fracture line should not be traumatized during screw and plate placement (Haug and Foss 2000; Alcalá-Galiano et al. 2008; Horsewell and Meara 2012; Hatef et al. 2009; Wheeler and Phillips 2011). Oral hygiene is difficult to maintain with this technique which may exacerbate the prevalence of dental caries. Other methods, such as orthodontic brackets and vacuum-formed splints, also use the teeth as anchors to apply MMF. The orthodontic elastic traction applied to the teeth in some situations may also lead to teeth extrusion and occlusal disturbances (Haug and Foss 2000; Alcalá-Galiano et al. 2008; Horsewell and Meara 2012).

Although nutrition and airway compromise are concerns with any kind of MMF, child tolerance and subsequent compliance are the major drawbacks of this technique.
Fig. 14 Bilateral complex zygomatic, NOE, and bilateral blow-out fractures (arrows). Preoperative (a) coronal and (b) sagittal images. Preoperative (c) axial tomography image showing bilateral frontozygomatic fractures (arrows) and (d) 3D computed tomography image showing NOE fractures and zygomatic fractures (arrows). (e) Right and (f) left orbital floor reconstruction with titanium mesh through infraciliar approaches and rigid fixation of zygomatic fractures in infraorbital rims. (g) Left lateral upper eyelid approach of frontozygomatic suture fracture, and (h) rigid internal fixation with titanium plate and screws. (i) Postoperative coronal computed tomography, and (j) 3D images shows bilateral titanium mesh for orbital floor reconstruction and internal fixation of zygomatic fractures in both frontozygomatic sutures and infraorbital rims.
Internal Fixation

Open reduction and rigid internal fixation (ORIF) with titanium plates is controversial but has become the standard of care for the management of displaced fractures (Ferreira et al. 2005; Alcalá-Galiano et al. 2008; Hatef et al. 2009). A number of advantages are apparent when using this technique. Titanium’s unique properties of biocompatibility, strength, and ductility are well-known. ORIF provides precise reduction,
stabilization, and 3D restoration, promotes primary bone healing, shortens treatment time, and eliminates the need for or allows early release of MMF. Hygiene measures and nutrition are improved because ORIF permits a rapid return to a normal diet. Postoperative respiratory care, and tolerance and compliance of pediatric patients, is also less of a concern than with maxillomandibular fixation (Haug and Foss 2000; Horsewell and Meara 2012). However, internal fixation implies some form of open approach with subsequent subperiosteal dissection. This invasiveness has the potential to interrupt or limit the osteogenic potential of the periosteum, to create scars that may further restrict growth, or both (Haug and Foss 2000; Alcalá-Galiano et al. 2008; Horsewell and Meara 2012). Particularly in children, tooth buds or erupting teeth may be damaged by plate or screw placement. To prevent this, fixation is typically accomplished with 1.5 or 2.0 millimeter plates and monocortical screws (Hatef et al. 2009; Chao and Losee 2009). The potential for migration to occur as bones remodel is currently not completely understood, but migration into the cranium has been described. Moreover, depending on the patients age, a second surgical intervention may be required for removal of the fixation devices as early as 2–3 months after placement in order to prevent long-term growth disturbances and to facilitate removal before bone encasement has occurred (Horsewell and Meara 2012). Other limitations of this technique are the associated high costs, the potential artifacts on CT scans and magnetic resonance images, palpability or visibility of plates through the child’s thin skin, pain, early or late infection, and extrusion.

**Resorbable Plates and Screws**

Resorbable polylactic (PLLA) and polyglycolic acid (PGA) plates and screws may offer an alternative to metal devices in the growing skeleton (Ferreira et al. 2005; Horsewell and Meara 2012; Chao and Losee 2009; Eppley 2005; Gunarajah and Samman 2013). The combination of PLLA and PGA yields a copolymer which is used very successfully in maxillofacial trauma procedures, and these bioresorbable materials are also used in load-bearing areas. This combination in varying ratios has produced products that include the most favorable characteristics of both materials. PLLA is hydrophobic and resistant to degradation, whereas PGA is hydrophilic and not durable. The combination of 85% PLLA and 15% PGA results in a copolymer (PLLA/PGA) that has sufficient strength yet possesses a more rapid resorption rate of 9–15 months with minimal foreign body reaction compared with pure PLLA (Eppley 2005).

The resorbable devices may diminish the concern about the long-term effects of internal fixation, and they have the additional advantage of obviating a second surgical procedure for their removal (Fig. 17). Bioabsorbable plates and screws also are invisible on radiographs and are barely noticeable on CT images. The therapeutic results observed so far at follow-up CT are promising (Horsewell and Meara 2012; Eppley 2005). However when a fixation modality is required, many author’s still prefer small titanium plating systems, placed through limited incisions that adequately expose the fracture (Ferreira et al. 2005; Horsewell and Meara 2012). The downsides of resorbable hardware are that they have less inherent strength, and the plates are more bulky and oversized in relation to the bones of the pediatric facial skeleton in order to maintain some rigidity.

**Conclusion and Future Directions**

Soft tissue injuries of the face are very common. In children they are associated with high levels of anxiety and concern in the child but particularly in the family. It will also almost invariably present a lasting mark of the unpleasant event, especially if inadequate or delayed treatment is performed. Identification of the type and severity of the injury is important in developing a strategic approach to cleansing, debridement, and repair.

Careful and early assessment of the wound and use of appropriate surgical technique should be key elements to a successful outcome. Prevention of complications, including scars, infection, and long-term disfigurement, is of utmost importance.
While the incidence of general facial trauma in the pediatric population is higher than that in the adult population, the incidence of pediatric craniofacial fractures is much lower. Their presence should prompt the treating physician to aggressively look for other concomitant injuries, including injury to the cervical spine and cranial vault, and to treat these as well. CT should replace radiography as the initial diagnostic study because it provides the best depiction of facial fractures and because it is mandatory for the evaluation of patients with neurocranial trauma.

It’s important that clinicians involved in the care of these patients understand the differences between children and adult fracture patterns, the potential long-term effects on growth of the pediatric skeleton, and how to manage these problems when they occur. Fortunately, children heal well, and conservative techniques can frequently be used. Growth disturbances from the initial trauma and from the surgeon’s intervention are difficult to predict, but avoidance of aggressive dissection and extensive fixation is recommended. We believe that even after significant advancement in surgical technique and armamentarium, conservative treatment is still the most reliable approach in the management of the majority of maxillofacial injuries in children.

Long-term follow-up with a multidisciplinary team is often needed to adequately manage the future changes in facial development that may occur with these injuries. Large-scale, prospective, long-term studies are needed to fully understand and appreciate the complexity of treating children with facial fractures and determining the true incidence, subsequent growth, and nature of their complications.

Preventive measures are generated in order to reduce the number of accidents and/or minimize the severity of injuries. As previously noted, children are ensconced in a well-protected social environment with close adult supervision during their early years. However, as they begin to engage in social and athletic activity, their exposure to situations in which injury might occur increases. The use of personal protective equipment is critical for the reduction of the incidence of facial injuries in children. Specifically included under these measures is the use of helmets during noncontact activities, such as bicycling and skateboarding, and other protective equipment during other sports activities.

Perhaps the single most important factor necessary for the reduction of the incidence of pediatric trauma is the correct mandatory use of seat belts and safety seats in vehicles, for infants and children. The protective effect of seat belts and other devices, such as airbags and others, and their correct use has been demonstrated by many authors. However, compliance varies and is usually low, particularly among young males, who are in the population most at risk.

The importance of preventive measures should be emphasized. Supervising adults (coaches, administrators, teachers, and parents) should be educated, and children should be encouraged to develop appropriate habits at an early age.

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