Reducing Risks for Midface and Mandible Fracture Repair

Néha Datta, MD[a,b], Sherard A. Tatum, MD[a,*]

KEYWORDS

• Midface • Maxillofacial • Craniomaxillofacial • Mandible fracture • Maxillary fracture • Safety • Facial trauma • Fracture repair

KEY POINTS

- Hemorrhage may occur in the acute, intraoperative or postoperative period, requiring constant vigilance; therapeutic agents such as tranexamic acid and 4-factor prothrombin complex concentrate can aid in managing critical bleeding.
- Adequate exposure and precise fracture reduction are essential to help prevent postoperative complications.
- Staged reconstruction for critically ill patients involving initial fracture stabilization followed by definitive repair can reduce technical difficulty, and complications associated with prolonged operations.
- Early restoration/stabilization of the premorbid occlusal relationship can help prevent malreduction and malocclusion and aid in pain control.
- Attention must be paid to associated injuries and preexisting comorbidities to reduce complications associated with maxillofacial trauma.

INTRODUCTION

Traumatic fractures of the midface and mandible may result from motor vehicle collisions, interpersonal conflict including blunt or penetrating trauma, sports injuries, or falls. Midface and mandible fractures are often associated with other injuries; the maxillofacial surgeon must maintain a high degree of suspicion for ocular, intracranial, and/or spinal injuries.[1] In one series of 3950 patients with craniofacial fractures, 4.4% of patients with mandibular fractures had associated cervical spine injury (CSI), and this rate was higher for mandibular fractures with any midface fracture.[2]

The midface is composed of several structural subunits including the maxilla, lower orbit, zygomaticomaxillary complex (ZMC), nasal and nasolacrimal structures, palate, and upper dentition as well as their associated soft tissue components. The skull base unites with the midface through the pterygoid plates, medial and lateral orbital walls, and nasal septum; trauma in this region can result in life-threatening airway compromise and hemorrhage. The mandible is a single arch structural unit that may be subdivided into zones: symphysis, parasymphysis, body, angle, ramus, coronoid, condyle neck and head, and alveolar process. Mandibular fractures can result in debilitating trismus, malocclusion, malunion, or infection if not identified and treated in a timely manner. A thorough understanding of midface and mandible anatomy, fracture patterns, and a systematic approach to treating fractures in this region is essential to help reduce risks and complications of fracture repair.

[a] Department of Otolaryngology–Head and Neck Surgery, Upstate Medical University, State University of New York, 750 East Adams Street, Syracuse, NY 13210, USA; [b] Department of Plastic and Reconstructive Surgery, Johns Hopkins University School of Medicine, Baltimore, MD, USA
* Corresponding author.
E-mail address: tatums@upstate.edu

Facial Plast Surg Clin N Am 31 (2023) 307–314
https://doi.org/10.1016/j.fsc.2023.01.014
1064-7406/23/

A detailed review of the technical aspects of facial fracture repair has been addressed in prior articles.[3,4] The following describes the major complications and unfavorable outcomes associated with these fractures, how to prevent their occurrence and how to manage them if they arise. Complications unique to each fracture region are also highlighted for consideration.

Complications Common to all Midface and Mandibular Fractures

Infection/osteomyelitis

Open fractures, where gingival, oral mucosal, or dentoalveolar disruption is present, should be treated with preoperative antibiotics to reduce the risk of infection. Postoperative antibiotic administration for patients with midface or mandible fractures is not supported by the literature[5] unless risk factors are present. It is important to note that although definitive fracture fixation may not be feasible in critically ill patients, every effort should be made to debride wounds and establish temporary occlusal reduction and stabilization. This can be accomplished at bedside in the critical care unit for patients who are sedated and may include bridle wires and maxillomandibular fixation (MMF). Teeth with significant caries near the fracture line should be considered for removal. Removal of healthy, stable teeth in the fracture is controversial. They can either aid or hinder reduction. They can either facilitate the seal of torn gingiva or, when pulled, provide an empty socket pathway for infection. Wounds and lacerations should be debrided and closed to help prevent the loss of tissue domain, improve long-term cosmesis, and help prevent infection. Fracture mobility from unstable fixation is an important risk factor for infection. Blood glucose control, tobacco cessation, and adequate nutrition also help mitigate infection risks. Management of acute wound/hardware infection includes cultures, antibiotics, wound washouts, possible hardware exchange, and/or bone debridement. Chronic infection with osteomyelitis requires hardware exchange (potentially more rigidity) bone grafting and cancellous bone grafting.

Soft tissue ptosis

Most maxillomandibular fractures are accessed via limited, hidden incisions. There is frequently significant subperiosteal elevation performed to provide adequate exposure for reduction and rigid internal fixation. Retraction, edema, and gravity can cause the soft tissue to redrape and distort the face even if the bony reduction is excellent. It is important to support the soft tissue at least with periosteal closure if not additional skeletally anchored sutures, particularly for the midface.

Malunion/nonunion

Improper technique, including inadequate fracture exposure, imprecise reduction and fixation, and not adhering to load-bearing/load-sharing principles can result in fixation failure with malunion or nonunion. Missed injuries can also lead to these complications, for example, in multiple-segment mandible fractures where one or more fractures is missed and loading forces are not appropriately addressed. Bone gaps more than a few millimeters should be addressed by early bone grafting, with autogenous bone preferred.

Hardware failure

Poor technique can contribute to interfragmentary instability, infection, and hardware failure, particularly in mandible fractures where continuous movement and devitalized bone can provide a substrate for pathogenic organisms.[6] Load-sharing fixation can only be used on simple fractures. Drilling must not be allowed to overheat or chatter away screw hole bone. The amount of bone holding the screw threads is a fraction of a millimeter. Stripped screw holes must have larger screws placed. Bending a plate too many times can weaken the metal to failure. Comminuted or defect fractures, and edentulous, atrophic mandibles should be treated with a heavy load-bearing reconstruction plate. Patients with partial dental arches can be treated with customized dental splints and MMF. Radiographic or clinical evidence of hardware failure should be addressed with revision including more rigid hardware.

Missed injuries

Missed injuries can include subtle craniofacial fractures or vascular injury not apparent on standard CT imaging. Ancillary physical examination findings such as Battle sign or periorbital ecchymosis may not be apparent in the acute setting and can take 24 to 48 hours to appear.[7] Patients with maxillofacial fractures have a 2% to 10% incidence of concurrent CSI especially in the setting of lower two-thirds facial fractures.[1–3] Missed injuries can have devastating consequences. Therefore, a high degree of suspicion must be maintained and cervical-spine precautions kept in place until CSI is definitively ruled out. In addition, blunt cerebrovascular injury (BCVI) can have serious complications such as stroke and may not manifest initial presentation. Dedicated multislice, multidetector CT angiography has been established as an equivalent gold standard for rapid diagnosis of BCVI compared with 4-vessel cerebral angiography and should be considered for any patient with

significant facial fractures and/or spinal injury.[8] High-resolution, thin slice (1 mm or thinner) CT and 3 dimensional imaging can help resolve subtle fractures.

SYSTEMATIC APPROACH TO MIDFACE AND MANDIBLE FRACTURES

Trauma Assessment and Resuscitation

An organized, systematic approach to assessment and management of the patient with midface and mandible fractures is essential for reducing risks associated with repair. This begins with initial assessment and resuscitation following Acute Trauma Life Support (ATLS) guidelines. The ATLS program was developed by the American College of Surgeons Committee on Trauma and has been validated as a safe, reliable system to stabilize, resuscitate, and minimize risks of morbidity and mortality for the trauma patient. Following these established principles will reduce the risk of missed injuries.

Life-threatening injuries to the airway, central nervous system, and viscera are prioritized, and the patient is stabilized. Ancillary teams including Neurosurgery, Ophthalmology, and Orthopedic surgery are activated early, in addition to Otolaryngology, Plastic Surgery, and/or Oral Maxillofacial trauma surgeons managing the facial fractures. In facilities where advanced Interventional Radiology (IR) or Neurointerventional Radiology is available, it is essential to activate this team early in cases where intracranial and/or skull base hemorrhage is suspected. Preoperative history and physical examination is important but may not always be possible, such as the critically ill patient who cannot participate with examination. After the patient has been stabilized and resuscitated, a more thorough physical examination is performed. This includes comprehensive cranial nerve, sensory, motor, and dental examination.

Initial management

1. The cervical spine is stabilized while the airway is assessed and secured. Midface fractures are associated with skull-base injuries and present a relative contraindication to nasogastric tube placement and nasopharyngeal intubation; inadvertent intracranial placement is a well-documented complication and has resulted in mortalities. Advanced airway techniques are often required for patients with facial trauma and unstable airways; fiberoptic-guided orotracheal intubation or tracheostomy may be necessary to avoid manipulation of the cervical spine. Emergency tracheostomy indications include acute upper airway obstruction/hemorrhage with failed endotracheal intubation, penetrating laryngeal trauma, and severe subcutaneous facial/neck emphysema. Elective tracheostomy is recommended for patients who are postcricothyrotomy, have panfacial fractures, and/or are expected to require mechanical ventilation longer than 7 days.
2. Breathing and ventilation are assessed and secured. Lower airway obstruction can result from inhalation of blood, teeth, or other debris. It is essential to carefully and thoroughly examine the nasal and oral airways to clear this material from the airway early and to obtain airway imaging.
3. Circulation is assessed and stabilized. Patients may have comorbid conditions predisposing them to uncontrolled bleeding after facial trauma. These can include coagulopathies, alcoholism, or hypertension. Trauma-induced coagulopathy is a known entity that can further worsen hemorrhage. Patients may be taking medications or supplements that impair normal coagulation. Consideration should be given to restoring blood volume and coagulation components with whole blood transfusion and clotting factors (such as 4-factor prothrombin complex concentrate [4F-PCC]), where available.[9–12] Patients with craniomaxillofacial trauma are more likely to have associated intracranial trauma and hemorrhage, constituting an emergency. Any delay in treatment can increase risk of major disability and death. Tranexamic acid (TXA) can reduce bleeding in trauma patients used systemically or topically. Several studies have demonstrated efficacy in reducing intraoperative blood loss[13–16] although its use in this setting remains off-label.
4. Causes of hemorrhage associated with facial trauma are essential for the craniomaxillofacial (CMF) surgeon to be aware of. These may develop in the acute or subacute setting, and vigilance is paramount. The vascular network of the head and face is robust, with multiple anastomoses and redundancies, making hemorrhage a significant concern. Midface fractures can be associated with disruption to the internal maxillary artery and its branches including the descending palatine arteries. Nasal septal hematoma may be present. Persistent, brisk epistaxis from both nares and/or the oropharynx may indicate either a posterior nasopharyngeal vascular disruption or an internal maxillary artery or ethmoidal artery laceration. Direct pressure with packing, cauterization, and ligation in areas with easy access can help abate hemorrhage. Hemorrhage from midface structures presents a unique challenge because direct pressure or suturing is often not

possible. Unstable patients with severe uncontrolled hemorrhage may require external carotid artery ligation. Attempting to control hemorrhage without adequate light and suction can lead to iatrogenic injury to adjacent structures. Intracranial and/or skull base hemorrhage is often best controlled by IR-access.

5. Definitive fracture repair is delayed until the patient has been resuscitated and stabilized. Patients should further undergo more refined physical examination and history collection. This includes sensory-motor examination, assessment of occlusion, and any relevant medical history. Injury-induced dysfunction must be documented before repair measures. Serial physical examination to assess for the evolution of trauma injuries must be performed consistently. Any changes should be documented and investigated; for example, carotid-cavernous sinus fistula can occur in patients with midface and skull base fractures and may not be readily apparent on an initial presentation.[17,18]

Imaging

The advent of high-resolution, thin slice computed tomography (CT) imaging has revolutionized the care of patients with facial fractures. Newer acquisition protocols reduce radiation exposure and contrast loads necessary for imaging. For patients suspected of having facial fractures based on physical examination and injury mechanism, CT imaging guides management and assists in surgical planning and has become the gold standard. Many centers have CT scanners within the trauma suite or ED to facilitate rapid, safe, early scanning. Subtle injuries may not be readily apparent on all views but could have significant influence on the management and risk reduction. Three-dimensional imaging adds improved visualization and perspective, although care should be taken to review the primary images for fidelity because small fragments may be erroneously fused to larger fragments in the 3D reconstruction. CT-guided intraoperative navigation has become more prevalent and may allow for more precise reconstruction in cases where severe comminution or tissue destruction is present.[19–21]

High-quality imaging is helpful to diagnose subtle but clinically significant findings; 1-mm or thinner CT tomographic images can identify fine fractures that may otherwise be missed. It is also important to consider associated cerebrovascular injury, which requires dedicated angiography of the vessels of the neck and skull base, as mentioned previously. Critically ill patients who are not suitable candidates for acute definitive operative fracture repair but are stable for CT scanning can benefit from 3D modeling, virtual surgical planning, and creation of customized dental splints, which can aid in achieving temporary reduction of midface and/or mandible fractures with MMF.[22] This reduces the risk of malunion or nonunion and allows for minimal or simplified osteotomies during delayed fracture repair.

Intraoperative Considerations

Airway

Airway management of patients with facial trauma requires planning and sustained vigilance. In patients with midface fractures, nasotracheal intubation should be avoided if advanced airway skills are not present. The size, length, and geometry of the intubation tubing should be chosen carefully. Nasal or oral Ring-Adair-Elwyn (RAE) tubes are designed with a preformed bend that can facilitate facial surgery but they may make rescue maneuvers to resecure the dislodged airway difficult. Another disadvantage of RAE tubes is a predetermined depth of intubation based on the location of the bend, which may not be suitable for certain patients. Steel-reinforced tubing (anode or armored) can be more difficult to maneuver around; however, it is more resilient to collapse or inadvertent puncture.

Where possible, the airway circuit FiO_2 should be reduced to less than 35% when electrocautery is used, to reduce the risk of airway fires. Submental intubation should be considered when tube interference with occlusion is a concern. Sometimes, the tube can pass through dental defects or behind the posterior molars. Tracheostomy should be considered for patients meeting criteria as discussed above. Surgical airways established emergently should be inspected for collateral damage.

Blood loss management

Controlled hypotensive anesthesia has been studied in orthognathic surgery and found to be a safe and reliable method to reduce hemorrhage during dissection and exposure.[23,24] When this is combined with administration of a single preoperative dose of 10-20 mg/kg TXA in adults, blood loss can be significantly reduced.[13,16,25,26] Positioning the patient in reverse Trendelenburg, with the angle of the mandible above the level of the sternal angle helps prevent venous pooling in the operative field. The risk of air embolism must be considered if the skull is open, particularly in the presence of hypovolemia.

Special Considerations

Orbital complications potentially common to all midface fractures

- Telecanthus

- Nasolacrimal duct disruption
- Pulsatile ophthalmopathy
- Globe injury
- Retrobulbar hematoma
- Complete or partial vision loss
- Diplopia/periorbital/orbital entrapment
- Ectropion, entropion
- Enophthalmos, vertical dystopia, and diplopia
- Optic nerve/retinal ischemia

Nasomaxillary region

The blood supply to this region derives from a rich, interconnected network. Injury to the ethmoidal, sphenopalatine, and greater palatine arteries can be difficult to control locally; stable patients warrant urgent angiography and embolization. Unstable patients may require operative ligation of the external carotid artery.[27] The maxilla is a central keystone of the face, connecting the skull base with the orbit and occlusal plane. Orbital floor fractures, composed of the roof of the maxillary sinus, can lead to periorbital soft tissue entrapment. This can result in extraocular muscle dysfunction and/or volume loss. True muscle entrapment should be released urgently to avoid muscle fibrosis. A forced duction test must be performed at the beginning and conclusion of the procedure on all patients who undergo orbital floor repair to confirm the orbital soft tissue is freely mobile.[28]

Surgeons should be aware of the oculocardiac reflex, which can contribute to labile blood pressure due to bradycardia. The globe is vulnerable to direct and indirect injuries. A full ophthalmologic examination is indicated for fractures involving the orbit. Retrobulbar hematoma is a vision-threatening complication that should be recognized and intervened on emergently with lateral canthotomy/cantholysis. Blindness may be caused by direct optic nerve or optic canal injuries or by other causes including iatrogenic injury during facial fracture repair or retinal artery occlusion secondary to orbital compartment syndrome. Although rare, with postrepair blindness reported as low as 0.24% in a series of 1338 orbital fractures at one center,[29] the consequences are devastating for patients. Delayed vision loss may occur as late as a week after the initial injury; a Marcus-Gunn pupil at initial presentation is highly sensitive for vision tract injury and should be noted before fracture repair.[30] Patients with these findings, or other physical examination findings concerning for impending vision loss, should be considered corticosteroids and urgent optic nerve decompression.[31–33] Surgical repair of periorbital fractures around a damaged or only seeing eye should be carefully considered.

Complications associated with fractures of this region include the following:

- Septal hematoma
- Septal deviation
- Nasal deformity
- Nasal valve stenosis
- Synechiae between septum and turbinates
- Anosmia
- Cerebrospinal fluid (CSF) leak
- Maxillary sinusitis

Zygomaticomaxillary complex/orbital floor region

ZMC fractures can result in significant functional and esthetic derangement. The zygomatic nerve, cranial nerve V2, provides sensation to the midface via 3 main branches. The frontal branch of the facial nerve, cranial nerve VII, passes superficial to the zygomatic arch, deep to the superficial musculoaponeurotic system before transitioning deep to the temporoparietal fascia. Muscles of facial expression, zygomaticus major and minor, originate from the zygoma and can be disrupted by trauma or malpositioned with improper dissection during fracture repair. Finally, the lateral canthal tendon of the orbit inserts onto the lateral orbital tubercle (Whitnall's) on the orbital surface of the zygoma, below the ZF suture. Injury from trauma or improper dissection and malpositioning during fracture repair can result in abnormal palpebral fissure shape and orientation, possibly ectropion.[34] There is considerable discussion in the literature about delayed and nonoperative management of floor fractures. When they are deemed necessary, orbital floor implants must be carefully considered for necessity, material, size, and position. The most popular materials are titanium, porous polyethylene, and absorbable polymers. Their primary purpose is to restore orbital support returning orbital soft tissue back into the orbit. They must be large enough to cover the defect or strong enough to support by cantilever. If they are placed too low, they will not provide enough support. If placed too high, they can put pressure on the orbital contents leading to poor motility or even blindness. Postoperative CT verification of implant placement and eye examination are recommended. Navigation or intraoperative CT scanning is even better.

Complications associated with fractures of this region include the following:

- Cranial nerve V2 dysfunction, in particular infraorbital nerve dysfunction
- Facial nerve palsy/paralysis
- Poor malar projection with negative globe vector

- Facial asymmetry
- Trismus

Palate/alveolus/dentition region

The palate serves as a major horizontal buttress of the face and defines the occlusal plane, in conjunction with dentition. Thorough physical examination and review of imaging findings are essential to restoring premorbid occlusion and decreasing the risk of malocclusion, asymmetry, and dental disruption. It is important to recognize dental trauma to avoid the risk of aspiration and to determine acuity. Patients who have sustained isolated injury or are otherwise stable without the risk of aspiration can be considered for reimplantation of avulsed teeth, although this is typically successful only within the first hour from injury, with an intact periodontal ligament.

Examples of complications associated with fractures of this region include the following:

- Malocclusion
- Temporomandibular joint (TMJ) dysfunction
- Oronasal/oroantral fistula
- Dental trauma
  - Partially or completely avulsed teeth
  - Tooth fractures
  - Luxation

Mandible

The mandible is an arch osseous unit that articulates with the skull base at the glenoid fossae. In conjunction with the maxilla, it contributes to the occlusal plane via the lower dentition. The buccal surface of the mandible features the anterior and posterior ramus, the sigmoid notch, the condylar process and the coronoid. The lingual surface includes the medial sigmoid notch, lingula, and mandibular foramen. The inferior alveolar nerve (IAN) enters the foramen and traverses the lower ramus and body of the mandible, providing sensation to the dentition, lower lip, and chin. Isolated, single-segment mandible fractures commonly include the body, condyle, or angle. The lingual nerve is a branch of cranial nerve V3, often sharing a common tract with the IAN until it dives into the oral cavity at the medial ramus, near the third molar. The marginal mandibular nerve is typically 2 fingerbreadths below the mandibular border in the skeletally mature patient, as it descends from near the mandibular border in children. It is important to understand this anatomy to avoid inadvertent injury to these nerves when performing mandibular fracture repair. It is also important to document any preoperative dysfunction of these nerves.

A common combination fracture pattern observed is a parasymphyseal fracture with contralateral angle or subcondylar fracture. The unique geometry of the masticatory muscles insertions and their associated vectors of pull influence whether mandible fractures are "favorable" or "unfavorable." These vectors act to reduce or distract the fracture fragments depending on fracture orientation. Load-sharing fixation can be considered in simple, typically favorable fractures with minimal associated injuries. Comminution, multiple fractures, osseous defects, and comorbidities call for more rigidity. The atrophic and/or edentulous mandible presents a special situation because the loss of vertical mandibular height can make open reduction and internal fixation plating challenging,[35,36] often requiring load-bearing, heavy plates.

Complications associated with mandible fractures.

- Injury to IAN or, rarely, the lingual nerve
- Malocclusion
- Trismus
- Dental injury
- TMJ ankylosis

Stable, rigid fixation with precise anatomic reduction has been shown consistently to reduce the risk of malunion or nonunion, infection, and implant extrusion.[37–39] Motion across the fracture line leads to instability, hardware loosening and ultimately infection, loss of reduction, and fixation failure.

Panfacial fractures

Panfacial fractures require special consideration for management and risk reduction; these patients often require prolonged mechanical ventilation and treatment of concurrent central nervous system or other systemic injury. Generally, these are classified by concurrent fractures of the upper, middle, and lower thirds of the face. Organized fracture repair from stable to unstable in a stepwise fashion, either a top down, bottom up, centripetal, or centrifugal approach can help reduce complications by addressing complexity systematically.

SUMMARY

Midface and mandible fracture repair can be achieved safely by adhering to a systematic approach for early recognition of debilitating injuries, using advanced pharmacologic and imaging strategies for hemorrhage control, thorough knowledge of facial anatomy and early precise anatomic reduction and stable fixation. A consistently applied, systematic approach to the facial trauma patient in the acute, intraoperative and

postoperative periods can reduce risks associated with midface and mandible fracture repair.

Surgeons must be aware of the intricate facial osseous and vascular anatomy and should familiarize themselves with maneuvers for rapid control of the airway and hemorrhage that may result from the inciting injury or during intraoperative repair.

FUNDING

Neha Datta is a fellow sponsored by the AO Foundation, specifically AO Craniomaxillofacial North America (AO CMF NA) which provides stipend support for fellow activities. For further information please visit https://www.aofoundation.org/aona/our-community/cmf/cmf-fellowships.

CLINICS CARE POINTS

- Use a systematic approach to initial patient stabilization and resuscitation, followed by thorough serial physical examinations to reduce the risk of missed injuries, evolving, or unexpected findings during operative repair of midface and mandibular fractures.
- Surgeons should maintain a high degree of suspicion for high-morbidity or mortality complications of facial trauma and sustained vigilance throughout the pre, intraoperative and postoperative period.
- Pharmacologic adjuncts such as TXA and 4F-PCC can significantly reduce hemorrhage and associated complications for patients with facial fractures, both in the acute and perioperative settings.
- High-resolution, multidetector CT imaging with 1-mm slices can assist with identifying subtle fractures and be used to create customized temporary dental splints and/or fixation plates. Intraoperative navigation can be used for precision fracture reduction and plate placement for complicated fractures, reducing the risk of malunion, malposition, or unsatisfactory outcomes.
- Early intervention with precise anatomic reduction is critical to minimizing the risk of acute and long-term complications. Guiding principles of rigid fixation, stabilizing unstable segments, immediate autogenous bone grafting, and early definitive soft tissue management all contribute to improved outcomes. For critically ill patients who are not stable for definitive repair, antibiotics, early soft tissue closure and temporary reduction, and fixation with MMF should be considered.

REFERENCES

1. Feldman JS, Farnoosh S, Kellman RM, et al. Skull base trauma: clinical considerations in evaluation and diagnosis and review of management techniques and surgical approaches. Semin Plast Surg 2017;31(4):177–88.
2. Färkkilä EM, Peacock ZS, Tannyhill RJ, et al. Risk factors for cervical spine injury in patients with mandibular fractures. J Oral Maxillofac Surg 2019 Jan;77(1):109–17.
3. Thomas JR, Kriet JD, Humphrey CD, editors. Facial plastic surgery clinics of North America30. Philadelphia: Elsevier; 2022. p. i–124. Issue 1, 2022-2031-31.
4. Kellman RM, Tatum SA. Principles in rigid fixation of the facial skeleton (78. In: Rosen CA, editor. Bailey's head and neck surgery-otolaryngology. 6th edition. Philadelphia: Lippincott-Raven Publishers; 2022. p. 1195–212.
5. Mundinger GS, Borsuk DE, Okhah Z, et al. Antibiotics and facial fractures: evidence-based recommendations compared with experience-based practice. Craniomaxillofac Trauma Reconstr 2015; 8(1):64–78.
6. Alpert B, Kushner GM, Tiwana PS. Contemporary management of infected mandibular fractures. Craniomaxillofac Trauma Reconstr 2008;1(1):25–9.
7. Battle WH. Three Lectures on Some Points Relating to Injuries to the Head. Br Med J 1890;2(1542): 141–7.
8. Kim DY, Biffl W, Bokhari F, et al. Evaluation and management of blunt cerebrovascular injury: a practice management guideline from the eastern association for the surgery of trauma. J Trauma Acute Care Surg 2020 Jun;88(6):875–87.
9. Sellers W, Bendas C, Toy F, et al. Utility of 4-factor prothrombin complex concentrate in trauma and acute-care surgical patients. J Am Osteopath Assoc 2018;118(12):789–97.
10. Jehan F, Aziz H, O'Keeffe T, et al. The role of four-factor prothrombin complex concentrate in coagulopathy of trauma: a propensity matched analysis. J Trauma Acute Care Surg 2018;85(1):18–24.
11. Zeeshan M, Hamidi M, Feinstein AJ, et al. Four-factor prothrombin complex concentrate is associated with improved survival in trauma-related hemorrhage: a nationwide propensity-matched analysis. J Trauma Acute Care Surg 2019;87(2):274–81.
12. Tanaka KA, Shettar S, Vandyck K, et al. Roles of four-factor prothrombin complex concentrate in the management of critical bleeding. Transfus Med Rev 2021;35(4):96–103.
13. Choi WS, Irwin MG, Samman N. The effect of tranexamic acid on blood loss during orthognathic surgery: a randomized controlled trial. J Oral Maxillofac Surg 2009;67(1):125–33.

14. Zahed R, Mousavi Jazayeri MH, Naderi A, et al. Topical tranexamic acid compared with anterior nasal packing for treatment of epistaxis in patients taking antiplatelet drugs: randomized controlled trial. Acad Emerg Med 2018;25(3):261–6.
15. Gharaibeh A, Savage HI, Scherer RW, et al. Medical interventions for traumatic hyphema. Cochrane Database Syst Rev 2013;12:CD005431.
16. Christabel A, Muthusekhar MR, Narayanan V, et al. Effectiveness of tranexamic acid on intraoperative blood loss in isolated Le Fort I osteotomies–a prospective, triple blinded randomized clinical trial. J Cranio-Maxillo-Fac Surg 2014;42(7):1221–4.
17. Zhang C, Tianjia Z, Lv H, et al. The possibility of internal carotid-cavernous fistula after maxillary fracture. J Craniofac Surg 2022;33(8):2586–8.
18. Hwang JH, Kim WH, Choi JH, et al. Delayed rupture of a posttraumatic retromaxillary pseudoaneurysm causing massive bleeding: a case report. Arch Craniofac Surg 2021;22(3):168–72.
19. DeLong MR, Gandolfi BM, Barr ML, et al. Intraoperative Image-Guided Navigation in Craniofacial Surgery: Review and Grading of the Current Literature. J Craniofac Surg 2019;30(2):465–72.
20. Ebker T, Korn P, Heiland M, et al. Comprehensive virtual orthognathic planning concept in surgery-first patients. Br J Oral Maxillofac Surg 2022;S0266-4356(22):00132–42.
21. Chin SJ, Wilde F, Neuhaus M, et al. Accuracy of virtual surgical planning of orthognathic surgery with aid of CAD/CAM fabricated surgical splint-A novel 3D analyzing algorithm. J Cranio-Maxillo-Fac Surg 2017 Dec;45(12):1962–70.
22. Marschall JS, Kushner GM. Point-of-care three-dimensional printing for craniomaxillofacial trauma. Plast Aesthet Res 2021;8:28.
23. Dolman RM, Bentley KC, Head TW, et al. The effect of hypotensive anesthesia on blood loss and operative time during Le Fort I osteotomies. J Oral Maxillofac Surg 2000 Aug;58(8):834–9. ; discussion 840.
24. Varol A, Basa S, Ozturk S. The role of controlled hypotension upon transfusion requirement during maxillary downfracture in double jaw surgery. J Cranio-Maxillo-Fac Surg 2010;38:345–9.
25. Zellin G, Rasmusson L, Palsson J, et al. Evaluation of haemorrhage depressors on blood loss during orthognathic surgery: a retrospective study. J Oral Maxillofac Surg 2004;62:662–6.
26. Chauncey J.M., Wieters J.S., Tranexamic Acid. [Updated 2022 Jul 25]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2022.
27. Nguyen M, Koshy JC, Hollier LH Jr. Pearls of nasoorbitoethmoid trauma management. Semin Plast Surg 2010 Nov;24(4):383–8.
28. Morris LM, Kellman RM. Complications in facial trauma. Facial Plast Surg Clin North Am 2013 Nov; 21(4):605–17.
29. Girotto JA, Gamble WB, Robertson B, et al. Blindness after reduction of facial fractures. Plastic and Reconstructive Surg 1998;102(6):1821–34.
30. Ord RA. Postoperative retrobulbar haemorrhage and blindness complicating trauma surgery. Br J Oral Surg 1981;19:202.
31. Levin LA, Joseph MP, Rizzo JF III, Lessell S. Optic canal decompression in Indirect optic nerve trauma. Opthalmology 1994;101:566.
32. Cook MW, Levin LA, Joseph MP, et al. Traumatic optic neuropathy: a meta-analysis. Arch Otolaryngol Head Neck Surg 1996;122:389.
33. Voss JO, Hartwig S, Doll C, et al. The "tight orbit": Incidence and management of the orbital compartment syndrome. J Cranio-Maxillo-Fac Surg 2016 Aug;44(8):1008–14.
34. Birgfeld CB, Mundinger GS, Gruss JS. Evidence-based medicine: evaluation and treatment of zygoma fractures. Plast Reconstr Surg 2017; 139(1):168e–80e.
35. Seu M, Jazayeri HE, Lopez J, et al. Comparing load-sharing miniplate and load-bearing plate fixation in atrophic edentulous mandibular fractures: a systematic review and meta-analysis. J Craniofac Surg 2021;32(7):2401–5.
36. Façanha de Carvalho E, Alkmin Paiva GL, Yonezaki F, et al. Computer-Aided Surgical Simulation in Severe Atrophic Mandibular Fractures: A New Method for Guided Reduction and Temporary Stabilization Before Fixation. J Oral Maxillofac Surg 2021;79(4):892.e1–7.
37. Chrcanovic BR. Open versus closed reduction: comminuted mandibular fractures. Oral Maxillofac Surg 2013;17(2):95–104.
38. Singh AK, Dahal S, Singh S, et al. Is manual reduction adequate for intraoperative control of occlusion during fixation of mandibular fractures? A systematic review and meta-analysis. Br J Oral Maxillofac Surg 2022;60(3):271–8.
39. Klatt J, Heiland M, Blessmann M, et al. Clinical indication for intraoperative 3D imaging during open reduction of fractures of the neck and head of the mandibular condyle. J Craniomaxillofac Surg 2011; 39(4):244–8.