CHAPTER 1

Facial trauma: incidence, aetiology and principles of treatment

Facial trauma is a challenging area of clinical practice. By its very nature, the highly visible effects it can have on both the function and aesthetics of the face means that any repair that is less than perfect will be all too apparent. Injuries to the nasoethmoid region are especially noticeable – the medial canthus needs only to drift a millimetre or so to become obvious. However, fractures are just one component of the spectrum of 'maxillofacial injuries'. They are variably associated with injuries to the overlying soft tissues and neighbouring structures such as the eyes, lacrimal apparatus, nasal airways, paranasal sinuses, tongue and various sensory and motor nerves.

The bones and tissues of the face support and maintain a number of key functions, including those relating to the oral cavity, nasal cavity and orbits. Not surprisingly, injuries to the face can have a major cosmetic impact and even so-called 'minor' injuries if poorly treated can result in significant disability and an unsightly appearance. When fractures extend into the skull base and involve the intracranial contents they are usually referred to as 'craniofacial' injuries. These will often require combined management with a neurosurgeon. Facial trauma can vary in severity therefore from a simple crack in a bone to major disruption of the entire facial skeleton with associated severe soft tissue injury.

Most facial injuries occur following relatively low energy impacts and require relatively straightforward treatment. However, despite high patient satisfaction rates, less than perfect results are still common. Clinicians treating these injuries should strive for the ideal goal of returning the patient to their pre-injury form and function. Unfortunately in many cases, especially when high energy injuries have resulted in both comminution of the facial skeleton and significant soft tissue damage, this cannot always be achieved. Despite major developments in the fields of tissue healing, biomaterials and surgical technology, there is still room for improvement.

Although fractures of the facial skeleton are common, they can easily be overlooked when accompanied by soft tissue swelling or lacerations. Delay in diagnosis can contribute to the likelihood of residual deformity and all doctors working in emergency departments should therefore be able to recognize these injuries, understand their significance and be familiar with basic management. Fractures of the lower jaw or alveolus may also present to a dental surgeon in general practice, or very rarely be a complication of a difficult tooth extraction. An understanding of facial fractures, as well as other facial injuries, has a practical application for many specialists therefore, and is not just of relevance to those studying for higher qualifications or those pursuing a career in specialist surgery.

When considering the topic of facial fractures parallels can be drawn with orthopaedic surgery. In a sense, management of facial trauma can be regarded as 'facial orthopaedics' and as such requires the same core knowledge of fracture management and application of similar treatment principles. These include an understanding of fracture healing, principles of fixation and an appreciation of the importance of the 'soft tissue envelope'. However, facial surgeons will also need to draw on their specialist aesthetic skills to ensure the best possible results, facilitating this by being as anatomically precise as possible.

Incidence

When considering trauma in all its forms maxillofacial injuries are not particularly common, although it is difficult to arrive at any accurate estimate of their global

Fractures of the Facial Skeleton, Second Edition. Michael Perry, Andrew Brown and Peter Banks.

incidence. Estimates vary considerably both within and between countries. Reported incidences may also be skewed, depending on local referral pathways. Nasal fractures, for instance, are commonly treated by plastic surgeons and otorhinolaryngologists as well as oral and maxillofacial surgeons. As a result they may not be fully captured by any single database. There will also be a variation in the number of fractures treated by any particular specialist unit depending on geographical location, the demographics of the catchment population and seasonal factors. Generally speaking, the most common facial fractures are nasal and mandibular fractures, followed by injuries to the zygoma, maxilla and orbit. Dentoalveolar fractures are also common but may not present to specialist centres, so accurate figures are not widely available. Finally, the terminology used for recording injuries may add to the confusion about fracture incidence. For example, the term 'middle third fracture' is not anatomically precise and may be used to include fractures of the midface, orbito-zygomatic complex and fractures of the nose.

In one large study of patients sustaining injuries as a result of personal assault approximately 80% of all fractures and 66% of all lacerations were facial. Other prospective studies of severely injured patients have shown that a significant number of maxillofacial injuries may also be associated with life-threatening injuries elsewhere. Of these patients, approximately one fifth subsequently died while in hospital. This frequency of coexisting injuries may have major implications when considering transfer to specialist centres.

Aetiology

In many countries the common causes of fractures of the facial bones are interpersonal violence, sporting injuries, falls, motor vehicle collisions (road traffic accidents) and industrial or agricultural trauma. For the first 30 years after the World War II, motor vehicle collisions (MVC) were the major cause of maxillofacial injuries, accounting for between 35 and 60% of fractures of the facial bones. Following the introduction of alcohol, seat belt and crash helmet legislation, these patterns dramatically changed. Many longitudinal studies from countries such as the Netherlands, Germany and the UK have reported that economically prosperous countries have shown a striking reduction in motor vehicle collisions as a specific cause of facial injuries, while at the same time there has been an increase in interpersonal violence and sports related injuries.

The incidences and causes of facial bone fractures are mostly influenced by:

1 Geography.
2 Social trends.
3 Alcohol and drug abuse.
4 Road traffic legislation.
5 Seasons.

Geography

Numerous studies have now shown clear relationships between urban living and facial injuries, possibly linked to alcohol consumption and social deprivation. Not surprisingly agricultural-type injuries are more commonly seen in rural communities. In developing countries where there is a rapid increase in road traffic, motor vehicle related trauma is still a major cause of fractures. In some countries, notably in some states in the USA, gunshot trauma now exceeds road traffic accidents as a cause of facial injuries.

Social trends

In more recent years in urban areas, interpersonal violence has accounted for an increasing proportion of facial bone fractures. This includes domestic abuse. Data from a number of centres around the world suggests that interpersonal violence now accounts for more than half of all facial injuries seen in emergency departments. In the United Kingdom between 1977 and 1987 there was a 47% increase in maxillofacial injuries caused by assault, while simultaneously there was a 34% decrease in road accident victims with facial bone fractures. The relative incidence of other facial injuries, such as lacerations, has also been influenced by these trends.

Alcohol and drug abuse

In many countries alcohol and drug abuse are now major factors in the aetiology of traumatic injuries. Maxillofacial injuries are commoner in young men than any other group and to a large extent this is a reflection of the increased alcohol consumption by this section of society and the violence that may ensue. Indeed it has been said that 'the combination of alcohol and testosterone is a potent mix'. Alcohol and drugs may also be a significant factor in maxillofacial injuries sustained by road users. The influence of alcohol on maxillofacial trauma was clearly demonstrated in a large prospective study of 6114 facial injuries presenting over a period of one week to 163 UK emergency departments. Of these, 40% of facial injuries were caused by falls, a large proportion of which were in children under five years and occurred within the home. However, 24% of the injuries were caused by interpersonal violence, mainly in young adults. In this group alcohol consumption was implicated in some way in 55%. Only 5% of facial injuries were caused by road traffic accidents (RTA) with 15% of victims having consumed alcohol. The 15–25 age group suffered the greatest number of facial injuries due to either assault or RTA and had the highest number of injuries associated with alcohol consumption. Overall at least 22% of all facial injuries in all age groups were related to alcohol consumption within 4 hours of the injury.

Road traffic legislation

Vehicle safety design has been influenced both by research and legislation, and in many countries the use of seat belt restraint has now been made compulsory in law. Seat belts have resulted in a dramatic decrease in injuries overall and severe injury in particular and that general trend has been reflected in the incidence of facial injury. The beneficial effects of improved car design and the use of seat belts are now well accepted, although there is some evidence that seat belts are not entirely effective in reducing the incidence of mandibular fractures. Air bags have also been associated with particular injury patterns to the orbit and globe. Interestingly, enforced low speed limits do not appear to carry the same benefit for facial fractures compared with other types of injury. Presumably, as a result of these changes, many patients who would have otherwise died are now surviving. Helmets are also mandatory for cyclists and motorcyclists alike in many countries, although most cycle helmets are primarily designed for brain protection and offer little effective protection to the face.

Seasons

Facial fractures show a seasonal variation in most temperate zones, which reflects the increased traffic and increased urban violence during summer months and the adverse road conditions in the presence of snow and ice in mid-winter. Sporting injuries also show a marked seasonal variation. Seasonal affective disorders and failed attempts at suicide may make a very small contribution in some countries.

Principles of treatment

Surgical anatomy

The facial skeleton

Understanding the applied surgical anatomy of the facial skeleton and its associated structures is extremely important in the assessment and management of facial fractures. Specific fracture patterns are well known to commonly occur and the effects of displaced bone fragments, notably at the skull base and orbital apex, can dramatically affect risks and outcomes. Traditionally the facial skeleton has been divided into an upper, middle and lower third. The lower third is the mandible. The upper third is formed by the frontal bone. The middle third is the region extending downwards from the frontal bone to the level of the upper teeth, or if the patient is edentulous the upper alveolus. However, this arbitrary division now has much less role to play in modern management. The terminology used can also sometimes be a little confusing. Fractures of the middle third of the face are often referred to as 'upper jaw fractures' or 'fractures of the maxilla'. However, in view of the fact that the adjacent bones are almost invariably involved, these terms are not strictly accurate. It is perhaps better to use the terms 'midfacial' and 'fractures of the midface' (Fig. 1.1).

From a functional point of view, an interesting and teleological question is, 'Why do some animals have sinuses?' A number of theories exist, but the answer is still unclear. One suggestion is that the skeleton of the midface has evolved into a protective 'crumple zone', functioning much like the chassis of a modern car. As such it acts as a cushion, absorbing the energy of any cranially directed impacts coming from an anterior or anterolateral direction. The midface can be considered as a fragile 'matchbox' sitting below and in front of a hard shell containing the brain. In this respect it differs markedly from the rigid projection of the mandible below (Fig. 1.2). The midfacial bones have the capacity to absorb impact energy, thereby protecting the brain and conferring a survival advantage. Any impact directly applied to the cranium may be sufficient to cause severe brain injury. However, the same force applied to the

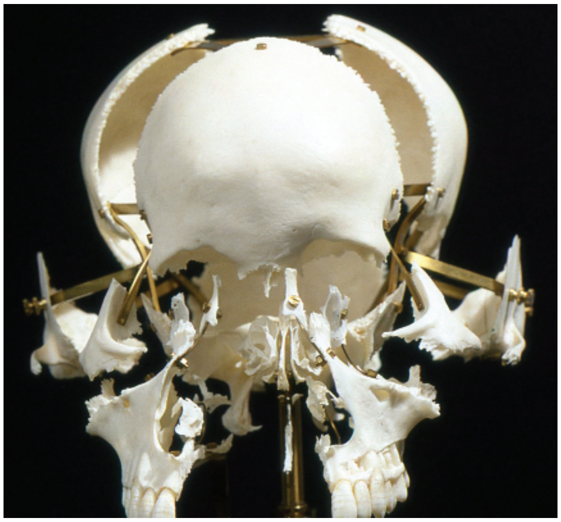

Figure 1.1 Anatomical specimen showing the bones of the mid and upper face separated and mounted to show their complex inter-relationship. Note that the bones of the midfacial skeleton are all relatively fragile. From above downwards they are the perpendicular plate of the ethmoid, with paired lacrimal bones, nasal bones, palatine bones, maxillae and inferior conchae. The zygomatic bones are shown laterally. The midline vomer is missing. (Courtesy of the Wellcome Museum of Anatomy and Pathology, Royal College of Surgeons of England.)

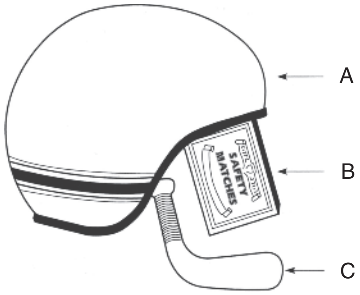

Figure 1.2 Diagrammatic representation of the relative strength of the skull and facial bones. The 'matchbox' like structure of the midface cushions the force of impact (B), whereas a blow to the skull is transmitted directly to the intracranial contents (A). An impact to the mandible (C) is transmitted indirectly to the cranial base. Damage to the brain may be prevented by protective fracture of the condylar neck, which is represented here as the handle of a bent baseball bat.

midface is cushioned as the bones collapse. In many cases the force is absorbed to such an extent that it may not even lead to loss of consciousness. Of course the price of surviving such an impact may be considerable damage to the bones and soft tissues of the face. In those cases where the mandible absorbs the entire impact the cushioning effect is reduced and brain injury can result, as with a boxer's knockout punch. However, occasionally one or both condyles fracture following a blow to the chin. This mechanism may afford some degree of protection to the brain stem and upper cervical cord passing through the rigid foramen magnum.

The midface is therefore so ordered that it can simultaneously withstand the forces of mastication and at the same time provide protection for vital structures, notably the brain and eye. This design has evolved as a result of Wolff's law, which states that healthy bone will remodel in response to the functional loads to which it is subjected. In the face most of this loading is related to biting and chewing forces. Where bone is not needed, it is resorbed. Thus, the midface contains the minimal amount of bone required to provide support and protection of several important organs, including the eyes and upper respiratory/olfactory tract.

The bones of the midface can therefore be thought of as a series of vertical and horizontal bony struts or 'buttresses' surrounding the sinuses, eyes and uppermost part of the respiratory tract. Joining these buttresses together is wafer-thin bone. The forces of mastication are thus distributed round the nasal airway, globes and paranasal sinuses as they pass upwards to the relatively rigid skull base (Fig. 1.3). Experiments have supported this theory. Fractures of the midface have been shown to occur with forces between one-fifth and one-third of those required to produce simple fractures of the mandible. Although this 'crumple zone' type arrangement may appear to have an obvious survival advantage collapse of the buttresses can result in significant displacement of the tissues. The midfacial bones as a whole have a very low tolerance to impact forces. The nasal bones are least resistant, followed by the zygomatic arch, while the maxilla itself is very sensitive to horizontal impacts.

The upper third of the facial skeleton is chiefly the frontal bone, which forms the superior orbital margin and orbital roof. From here, the base of the skull extends backwards and downwards at approximately 45° from the frontal bone. The midfacial complex articulates with this slope and is effectively suspended from the skull base. In the midline the cribriform plate of the ethmoid makes contact with the meninges of the brain and transmits the olfactory nerves (Fig. 1.4). High energy impacts

Figure 1.3 Transilluminated skull and facial bones demonstrating the thick buttresses of bone that distribute the forces of mastication within the skeleton of the midface. The much stronger bone of the mandible is also clearly evident. (Reproduced with kind permission of Springer Science+Business Media.)

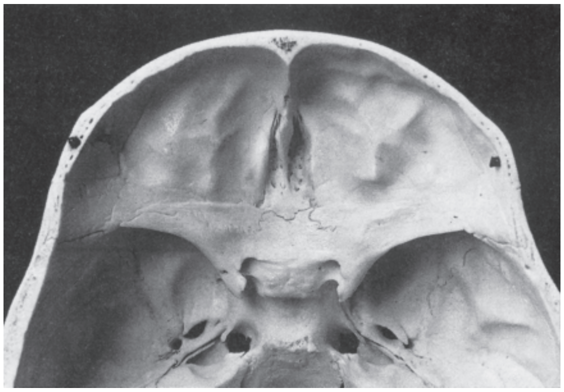

Figure 1.4 View of the anterior cranial base showing the cribriform plate of the ethmoid with the olfactory nerve foramina and midline crista galli. This fragile bone is fractured in high midface Le Fort type and severe naso-orbito-ethmoid injuries. Damage to the underlying dura may result in cerebrospinal fluid rhinorrhoea.

can result in the middle third of the face being sheared off the cranial base with displacement downwards and backwards along this plane. As a result, the upper posterior teeth impact on the lower ones and prop open the bite. Clinically, this results in an elongated face and an anterior open bite (see Fig. 3.12 in Chapter 3). In severe cases there may be significant swelling and severe bleeding. Airway compromise may occur, particularly in the supine patient.

In most fractures of the facial skeleton the frontal and sphenoid bones, including the greater and lesser wings, are not usually fractured. In fact, they are protected to a considerable extent by the cushioning effect achieved by the midface already mentioned. Fractures of the cranial components tend to occur following direct blows to these bones.

The protective buttresses also define the three dimensional shape of the face. When it comes to planning the treatment of the injured facial skeleton attention to the buttresses is important. Anatomical reduction is essential if precise three-dimensional re-establishment of facial height, width and projection is to be achieved (Fig. 1.5). Attention to the nasal septum is also an important part of this and is often overlooked. Not only is the septum crucial in the development of the growing midface, but it is an important element in maintaining nasal projection and patency. A useful way to visualize the facial skeleton is to think of it like a framed picture when viewed from in front. The 'frame' is made up of the rigid frontal bone above, two vertical lateral struts made up by the lateral orbital margins and the zygomatic complex and a lower horizontal mandibular platform, which is hinged and mobile. This frame contains a complicated 'picture' made up of the multiple bones of the midface, the orbital contents, paranasal sinuses and teeth. The overlying soft tissues (the 'glass'), including the cartilaginous nasal skeleton, complete the composition. This analogy is useful. If a framed picture is damaged it is repaired in a logical order. The frame is first reconstructed followed by a detailed restoration of the contents and finally the protective glass is replaced. Although correct sequencing is important when repairing complex facial injuries, the precise order is somewhat controversial and opinions differ. One possible sequence can be represented diagrammatically using concentric circles as a guide (Fig. 1.6).

Figure 1.5 The importance of accurate anatomical reduction to restore all three dimensions of the facial skeleton. Representation of a three-dimensional CT scan of a complex facial fracture that has been reduced and treated with miniplate fixation of the main buttress areas. (Reproduced with kind permission of Springer Science+Business Media.)

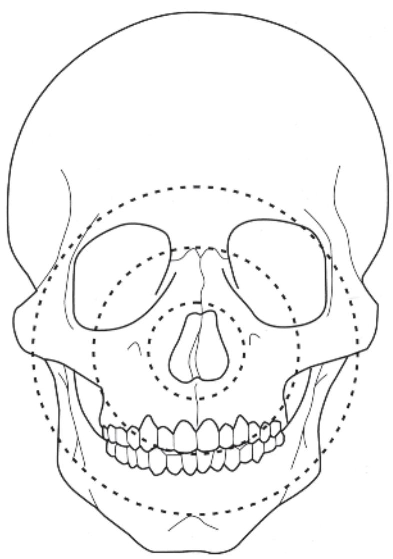

Figure 1.6 Diagram to illustrate sequencing of multiple facial fracture repair. The outer circle defines the 'frame' of stronger bones that are reduced and immobilized first (frontal bone, lateral orbital margins, zygomas and mandible). The middle circle contains the 'contents' of this 'frame' (essentially the maxillae) that are reduced and repaired next, and finally the nasal complex (inner circle) is restored.

The 'soft tissue envelope'

The healing process following a fracture can be considered under two aspects; healing of the soft tissues and healing of the bone. Correct management of the associated soft tissue injury is essential and often under-appreciated. It is not just a case of getting the bones back together. The entire healing process and subsequent rehabilitation relies heavily on the viability of the 'soft tissue envelope', more specifically its blood supply. As such it is important to be mindful that the energy force that resulted in the fracture also passed through the overlying soft tissues to get to the bone. The soft tissues are therefore injured to a varying extent, quite apart from the additional trauma of any surgical repair. Blast, crush and compound injuries are obvious examples of soft tissue injury, and lacerations do not necessarily need to be present to indicate extensive damage to the soft tissues. With most blunt trauma of course soft tissue loss and gross contamination is unusual, although the soft tissues may still be significantly damaged.

In orthopaedic surgery it is often taught that the success of fracture management depends not only on the condition of the bones and how well they are repaired, but also to a large extent on the condition of the overlying soft tissues. Consider for example two identical fractures, one of which is covered by healthy, well vascularized soft tissues, while the other is exposed through a heavily contaminated, open wound following a crush injury. Whether the fracture is in the leg, arm, mandible or midface, intuitively outcomes will be better in the first fracture than in the second. This comparison highlights the importance of the soft tissues, and in particular the blood supply, in the healing process. In this regard the mechanism of injury gives useful clues as to the likelihood of injury to the soft tissues. Take for example fractures following a single punch, being kicked by a horse, a blast injury and being shot. Each mechanism carries with it increasing amounts of kinetic energy, potentially compromising the vascularity of the tissues. The more the blood supply is compromised, the greater the chances of infection, non-healing and bone loss. Comminution in a fracture implies high energy transfer and more energy is therefore transferred to the surrounding soft tissues during the injury. Excessive movement across the fracture also has an adverse effect in healing by preventing vascularization of the bone fragments. These factors have major implications for the choice of repair.

Gunshot or missile injuries also transfer a considerable amount of energy and blast effects deep into the tissues. Ballistic injuries of this type differ from most other facial injuries. They are often heavily contaminated with extensive soft tissue disruption and tissue loss. They may also be associated with thermal injury, and the transmission of the blast effect through the tissues may result in damage at sites relatively remote from the injury. Contaminated wounds may therefore require several operations with serial debridement and packing. However, in the maxillofacial region, because of the excellent blood supply, this is only required in really heavily contaminated wounds. Management of this type of injury requires experience and judgement. If there is any doubt about tissue viability it is better to adopt a 'watch and wait policy' and delay intervention for 48 hours or so in order that non-vital tissue can declare itself.

Fracture classification

The basic orthopaedic classification of fractures as simple, open, comminuted and pathological can equally be applied to the facial skeleton.

Simple (closed)

These include fractures of the condylar process, coronoid process and ramus of the mandible, and fractures of the body of the edentulous mandible. The 'greenstick' fracture is a rare variant of the simple fracture and is found exclusively in children.

Open (compound)

Fractures of the tooth-bearing portions of the mandible and midface are nearly always open into the mouth via the periodontal membrane. More rarely, fractures may be compound through the overlying skin. Nasal and zygomatic fractures are technically 'open' into the sinonasal airway tract, but usually heal without infective complications probably due to their extensive blood supply.

Comminuted

A comminuted fracture is one where the bone is fragmented into multiple pieces. This usually requires considerably more energy than does a simple fracture. Direct violence to the mandible from penetrating sharp objects and missiles may cause limited or extensive comminution. Such fractures are usually compound and may be further complicated by bone and soft tissue loss.

Pathological

Fractures are termed pathological when they result from minimal trauma to a bone already weakened by a pre-existing pathological condition (such as osteomyelitis, neoplasms or generalized skeletal disease). In the face this is most commonly seen in the mandible.

Whilst this orthopaedic classification is applicable to the facial skeleton a more practical approach is to consider maxillofacial fractures as falling into one of two main groups:

1. Fractures without gross comminution of the bone and without significant loss of hard or soft tissue.
2. Fractures with gross comminution of the bone and with extensive loss of both hard and soft tissue.

The majority of fractures fall into the first category. Those in the second group either result from missile injuries, industrial injuries involving machinery or major road accidents, where there is direct injury from sharp objects moving at relatively high velocity. Although somewhat arbitrary, this broad division is useful because the management of the second group is entirely different from the first, both in terms of the primary assessment and repair.

Fracture healing

Fracture healing is often referred to as 'direct' or 'indirect'. These are two entirely different processes and have major implications in management. Direct healing (or primary bone healing) can only occur when there is absolute rigidity across a fracture and sufficient bone to bone contact. Growth of bone occurs across the gap and there is no callus formation. Compression across a fracture is believed to facilitate this and healing is usually rapid. Although plating techniques in orthopaedic surgery are designed to encourage direct healing, in the face this is only practically possible in the mandible. This is because direct healing requires heavy plates and large screws to achieve the necessary degree of rigidity and compression. Indirect healing is a different process and occurs across a fracture where some degree of mobility persists. This is seen in limbs treated with orthopaedic casts and is the natural healing process seen in land mammals. Initial hematoma formation is followed by the ingrowth of delicate fibrovascular tissue. Gradual ossification then occurs and the fracture is encased by 'immature bone' or callus. This is more prominent in load bearing situations and provides early stability. Once fully healed, remodelling of the callus occurs, resulting in the final trabecular or 'mature' bone. Callus formation therefore implies some degree of mobility across a fracture during healing. This type of healing is more commonly seen following repair of facial fractures, although with the newer materials fixation hardware is achieving increasingly greater degrees of rigidity.

Principles of fracture repair

In both orthopaedic surgery and maxillofacial surgery there are a number of basic principles commonly shared in fracture management. Both specialties have now moved towards open repair of most fractures, in preference to the less precise methods of closed reduction. Open repair facilitates anatomical reduction and fixation, and subsequent restoration of function. The relationship between excessive movement, poor union and infection is also well understood in both specialties. However, unlike limb fractures the repair of maxillofacial injuries can generally wait longer if necessary. This is due to the presence of the excellent blood supply to the face and, where relevant, salivary growth factors. Facial fractures can also be more extensively exposed, with less risk of infection or necrosis. Complete detachment of bone from the soft tissues (extra corporeal repair) and non-vascularized bone grafting are also possible. However, the repair of facial fractures requires a higher level of precision than most orthopaedic injuries in order to achieve optimum function and aesthetics.

Fracture fixation may be either rigid or semi-rigid. In the strictest sense rigid fixation means that there will be no movement whatsoever across the fracture site. This produces such a level of stability that direct bone healing can take place, assuming there is sufficient bone-to-bone contact. Rigid fixation therefore requires strong 'load bearing' fixation devices, usually large plates and bicortical screws. As such, these devices tend to be bulky and can only be used in the mandible. The other bones of the face are too friable to support such plates. With semi-rigid fixation there is still adequate support, although a variable amount of 'micro movement' will still occur. Much smaller so-called 'miniplates' can therefore be used.

Currently opinions differ on the amount of stability that is required for optimal healing. Rigid fixation is not as critical in the face as it is in the limbs and therefore maxillofacial fractures can be managed in several ways. Intermaxillary fixation (IMF), semi-rigid fixation and rigid fixation can all result in satisfactory healing, yet the degree of stability that each produces clearly varies.

Further reading

American College of Surgeons Committee on Trauma. *ATLS Advanced Trauma Life Support for Doctors*. 9th edn. Chicago: American College of Surgeons; 2012.

Bhrany AD. Craniomaxillofacial buttresses: anatomy and repair. *Arch Facial Plast Surg*. 2012 Nov 1;14(6):469. doi: 10.1001/arch facial.2012.906.

Giannoudis PI, Tzioupis C, Almalki T, Buckley R. Fracture healing in osteoporotic fractures: is it really different? A basic science perspective. *Injury*. 2007 Mar;38 Suppl 1:S90–99.

Kambalimath HV, Agarwal SM, Kambalimath DH, Singh M, Jain N, Michael P. Maxillofacial injuries in children: A 10 year retrospective study. *J Maxillofac Oral Surg*. 2013 Jun;12(2):140–144. doi: 10.1007/s12663–012–0402–6. Epub 2012 Aug 26.

Kraft A, Abermann E, Stigler R, Zsifkovits C, Pedross F, Kloss F, Gassner R. Craniomaxillofacial trauma: synopsis of 14,654 cases with 35,129 injuries in 15 years. *Craniomaxillofac Trauma Reconstr*. 2012 Mar;5(1):41–50.

Lee K. Global trends in maxillofacial fractures. *Craniomaxillofac Trauma Reconstr*. 2012 Dec;5(4):213–222. doi: 10.1055/s-0032–1322535. Epub 2012 Oct 18.

McAllister P1, Jenner S, Laverick S. Toxicology screening in oral and maxillofacial trauma patients. *Br J Oral Maxillofac Surg*. 2013 Dec;51(8):773–778. doi: 10.1016/j.bjoms.2013.03.017. Epub 2013 Sep 9.

Sathyendra V, Darowish M. Basic science of bone healing. *Hand Clin*. 2013 Nov;29(4):473–481.