Introduction
Modern techniques of fracture management allow easy access to the whole craniofacial skeleton, accurate fracture reduction, internal fixation with mini and microplating systems and primary bone grafting where necessary to replace missing bone. The goal of primary treatment is to restore normal anatomy and therefore normal form and function of the craniofacial complex. However, patients may present with posttraumatic deformity for a variety of reasons. They may fail to present in the acute phase or injuries may go undiagnosed if specialist expertise is not available. Other serious injury or medical conditions may preclude or compromise immediate treatment of facial injuries and the results of primary treatment may be unsatisfactory if the extent of the injury is underestimated or in the more severe comminuted panfacial fractures (Fig. 24.1).1

Classification
There is no entirely satisfactory system for classification of posttraumatic facial deformity which incorporates the necessary mix of hard and soft tissue deficits or takes account of resultant esthetic or functional difficulties. Tessier2 proposed a system based on the major esthetic aspects of the disfigurement and included an orbital syndrome with enophthalmos (Fig. 24.1), a craniofacial syndrome including stigmata of residual frontal and nasoethmoidal fractures, a maxillary syndrome with occlusal abnormalities, and a nasal syndrome characterized by naso-orbital dislocation. Other workers such as Manson3 and Gruss4 have devised systems related to the previous location of bone fractures, comprising frontobasilar, Le Fort I, II and III fractures of the maxilla, naso-orbitoethmoid, zygomatic, nasal, mandibular, complex and panfacial deformities.

Principles of Management
The principles underlying management of secondary posttraumatic skeletal deformity include:
■ accurate assessment by history, clinical examination and special investigations
■ treatment planning
■ surgery, utilizing a variety of techniques for management of soft and hard tissue deficits or deformities, including osteotomies and bone grafting.

Assessment
Assessment of any deformity requires a detailed history, examination and special investigations.

Fig. 24.1: Residual nasal and zygomatic deformity with enophthalmos and restricted ocular motility following untreated midfacial injury. (a) Facial appearance. (b) Restricted eye movement.
History

A full history is essential in diagnosis of secondary post-traumatic deformity. Of particular importance is documentation of the patient’s complaints or concerns. A number of potentially correctable deformities may be present, but it is important to assess which of these require correction in order to address the concerns of the patient. A brief assessment of the psychosocial effect of the deformity may help to highlight important areas, since relatively minor physical abnormalities may give rise to significant psychological, social or occupational problems. The history of the original injury, whether any primary surgery was carried out and if so what this involved are important in order to plan secondary surgery and anticipate potential difficulties or complications (e.g. previous craniotomy with or without dural repair will make subsequent craniotomy more difficult due to dural adhesions, thus predisposing to increased risk of dural tear and subsequent CSF leak. Eye injury or visual loss will increase the significance of the risk to vision in operating on the contralateral orbit). Time elapsed between the original injury or its primary management and presentation of secondary deformity may be significant because timing of secondary surgery may be important. Some problems are better corrected early, whilst in others the timing may be less critical (e.g. correction of enophthalmos and orbital and nasal reconstruction).

Examination

A comprehensive clinical examination of the craniofacial complex is mandatory and should include assessment of both hard and soft tissues.

Soft tissues

Whilst not directly the subject of this chapter, mention must be made of the soft tissues. The presence of cutaneous scars, soft tissue deficiency and distortions or subcutaneous fat atrophy may limit the extent of bony movement and/or the degree of soft tissue response to the underlying bony movement and leave a persisting esthetic or functional deficit even if a perfect underlying skeletal position can be achieved. This should be appreciated in the planning phase so that soft tissue adjustment can be carried out at the appropriate time, usually subsequent to the skeletal reconstruction. In addition, what may seem to be a bony asymmetry may be solely due to soft tissue problems and surgical technique for correction is likely to be different from that chosen where the underlying problem is truly skeletal in nature. When considering complaints of orbitozygomatic deformity, soft tissues of the bony orbit are of paramount importance. Globe displacement in the vertical or anteroposterior plane needs to be accurately assessed and the presence of characteristic stigmata of enophthalmos, such as pseudoptosis, implies a degree of displacement of the orbital tissues (Fig. 24.1).

Examination of eye movement and forced duction test will allow assessment of tethering of the extraocular muscles (Fig. 24.2) and traction on the insertions of the medial and lateral recti (usually under general anesthetic prior to surgery) will give an indication of the potential for improvement in anteroposterior eye position following enophthalmos correction. On occasion, intraorbital fibrosis may preclude anterior eye repositioning despite good orbital volume correction. The position of the lateral and medial canthi should be assessed, intercanthal distances measured and note made of any abnormality of eyelid position such as retraction or ectropion.

Hard tissues

A thorough assessment of any bony distortion, deficiencies or asymmetry must be carried out by inspection and palpation. Techniques used for assessing the bony (and cartilaginous) craniofacial skeleton are well documented in the craniofacial, rhinoplasty and orthognathic literature. Assessment should be applied in a logical way and must include all areas of the craniofacial skeleton, including the calvarium and forehead, frontal sinus, orbits, zygomas, external and internal nose, temporomandibular joints, mandible, upper and lower dental

(a) (b)

Fig. 24.2: Forced duction test. (a) Tethering of inferior rectus. (b) Normal contralateral eye.
arches and dental occlusion. Assessment should be made of displacements in each area examined in the three planes of space, anteroposterior, vertical and transverse, and should include assessment of asymmetries in each of these three planes.

Special investigations

These may include plain films, dental study models, photographs and CT or MR scanning, with three-dimensional stereolithographic modeling where appropriate.

Plain films

Plain films will demonstrate the site and extent of the original injuries, the presence of bone plates and grafts used in primary treatment. Detailed measurements to assess malposition and asymmetries, including AP and lateral cephalometry, may be useful both in delineating the underlying problem and in planning surgical correction. This particularly applies to fractures of the mandible where plain films will demonstrate a fibrous or non-union, the direction and extent of displacements and major occlusal abnormalities such as anterior open bite or mandibular asymmetry.

Dental study models

Dental study models are mandatory for assessment of posttraumatic deformity involving the tooth-bearing segments of the maxilla or the mandible. Where a posttraumatic malocclusion exists, an assessment can be made of the achievable occlusion and whether any secondary dentoalveolar compensatory changes have occurred, which may result in a need for orthodontic or restorative correction or segmental surgery. Facebow recording and anatomical articulation may be useful particularly in cases of bilateral condylar malunion, where vertical face height changes are planned and mandibular autorotation is anticipated.

CT scanning

CT scanning in the axial and coronal planes yields very useful information, particularly in complex midface and orbitozygomatic deformity and calvarial defects. Two-dimensional imaging is useful in delineating areas of deformity or deficiency and, as with plain films, accurate measurements taken from stable and unaffected portions of the craniofacial skeleton can give an assessment of degree of displacement or deformity. However, an additional benefit of CT scanning is its ability to generate three-dimensional images which allow the surgeon to visualize all aspects of the deformity at the same time and can sometimes reveal the underlying cause of a deformity or discrepancy, which is difficult to assess by two-dimensional scans (Fig. 24.3). In addition, the recent introduction of stereolithographic modeling allows direct visualization of the defect. Direct measurement of required bony movements or augmentation is possible and if necessary, surgical simulation may be carried out. It also facilitates prefabrication of alloplastic implants and production of templates as a guide for size and shape of bone grafts, as well as prebending of plates or mesh for graft fixation. Stereolithographic modeling has been a major advance in the management of patients with complex posttraumatic bony deformity.

Treatment planning

Having identified the concerns of the patient, established treatment goals and documented all areas of anatomical and functional abnormality, detailed operative planning is required. If a portion of a craniofacial skeleton is malpositioned or deficient and is giving rise to patient concerns or complaints, it should be restored to its normal anatomical position, shape or volume. However, in planning treatment, it must be borne in mind that correction of one deformity may result in accentuation of another, which may not have been previously noticed by the patient, e.g. malar osteotomy may make a previously mild enophthalmos more obvious or correction of mandibular asymmetry may exaggerate an ipsilateral mild nasal deviation. In this situation, the milder unnoticed defects may require simultaneous or subsequent correction even though they may not be of direct concern to the patient initially.

Detailed planning of surgical interventions and movements depends on the information gathered from the history and examination, but in particular the special investigations. When planning bony surgery, it is essential that an accurate plan of surgery and movements is established prior to operation. This entails a detailed assessment of the extent of movement required in the three planes of space, i.e. anteroposterior, vertical and transverse. If onlay grafts are to be used, the site and extent of augmentation should be similarly established preoperatively. Intraoperative judgment of the extent of necessary bone movement or augmentation to achieve symmetry is extremely difficult, due to distortion of overlying soft tissues as a result of the surgical access, edema, presence of an endotracheal tube and inaccessibility of normal reference points beneath sterile drapes. Where three-dimensional modeling is available, prebending of plates, preforming of implants or production of bone graft templates helps to facilitate accurate correction of the deformity and may reduce operating time.
It is important to insure a co-ordinated approach to the correction of both bony and soft tissue abnormalities. This usually means correcting the bony abnormality first and then carrying out any necessary soft tissue revision subsequently. It is essential to discuss with the patient the proposed correction and insure a realistic expectation of outcome, including both the positive and negative effects of any proposed surgery.

**Treatment Techniques**

**Surgical access**

Surgical access to the entire craniofacial skeleton is afforded by bicoronal flap, lower eyelid or transconjunctival and intraoral buccal sulcus incisions. In addition, a variety of intra- and extraoral incisions are available for access to the mandible, in particular the vertical ramus and condyle.

**Bicoronal flap**

A bicoronal flap gives excellent surgical exposure of the upper craniofacial skeleton. Pre-auricular extension of the incision and dissection in the temporal region immediately adjacent to the deep temporal fascia allow excellent exposure down to and including the zygomatic arches. If the dissection is kept on the surface of the deep temporal fascia, there is no need to pass deep to the superficial layer of the deep temporal fascia and the frontal branch of the facial nerve is elevated with the flap, resulting in little risk of nerve injury and easy dissection in a single surgical plane (subgaleal), leaving pericranium attached to the outer table of the skull. Once the flap is raised to within a centimeter of the supraorbital margins the pericranium can be incised along the temporal crest each side and across the vertex of the skull posteriorly. The pericranial flap pedicled anteriorly can be raised to expose the underlying skull and is available as vascularized tissue for dural repair if needed. Freeing the supraorbital nerves from their foramina can be carried out using small osteotomies medial and lateral to the nerves. The calvarium, forehead, supraorbital rim, orbital roof and lateral orbital rim are exposed and after mobilization and reflection of the temporalis muscle, access is gained to the lateral wall of the orbit and the temporal fossa.

At the end of the operation, the temporalis muscle must be anchored to the lateral orbital rim with sutures, if necessary following anterior mobilization of the muscle, to prevent postoperative retraction and temporal hollowing (Fig. 24.4). Access to the infraorbital margin and orbital floor is possible through a bicoronal flap but is limited and fixation of osteotomy cuts or grafts can be difficult from this approach without a lower eyelid incision. In addition, if at the start of the operation the medial canthal ligament is intact and attached to the anterior lacrimal crest, it should never be detached during elevation of the flap, since this requires the use of a transnasal canthopexy on closure, the results of which are often disappointing. The attachment of the medial canthal ligament can therefore limit access to the medial orbital wall. If full access to the medial orbital wall is necessary, a lower eyelid incision is required in addition to access gained via the orbital roof exposure of the bicoronal flap.

**Lower eyelid incision**

Transconjunctival, subciliary or midtarsal incisions, with retro-orbicular preseptal dissection, all give excellent access to the infraorbital rim, orbital floor, infraorbital foramen and anterior surface of the maxilla. We avoid the infraorbital incision for cosmetic reasons. Occasionally, postoperative lower eyelid retraction and increased scleral show may occur but this is unusual and amenable to correction if it fails to resolve spontaneously (Fig. 24.5).

**Intraoral buccal sulcus incisions**

A horseshoe incision in the upper buccal sulcus gives excellent access to the lower half of the maxilla and zygomatic arches.

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Fig. 24.4: Postoperative retraction of temporalis muscle. (a) Before treatment. (b) After treatment by onlay augmentation of temporal fossa and correction of lower eyelid tethering.
buttress, and limited access to the infraorbital rim. It should be placed at the height of the sulcus, extending from first molar to first molar, and be directed out into the cheek posteriorly to avoid tearing and insure maintenance of a good vascular pedicle to the maxilla. Repair of the paranasal muscles at the end of the procedure may reduce the risk of alar flaring postoperatively.5

Extraoral approach to the mandible

While lower buccal sulcus incisions give good intraoral access to the horizontal ramus and angle of the mandible, on some occasions avoidance of the transoral route is necessary. In addition, intraoral access to the vertical ramus and mandibular condyle is poor and surgical procedures on these areas of the lower jaw often require an extraoral approach.

The submandibular approach gives good access to the horizontal ramus and angle and allows limited access to the vertical ramus of the mandible. The marginal mandibular branch of the facial nerve must be protected, either by dissection deeply on the cervical fascia or by dissection on the deep surface of platysma and formal identification of the nerve in the subplatysma fascial layer. Excessive traction may result in temporary paralysis of the lower lip due to stretching of the marginal mandibular branch of the facial nerve but permanent weakness should be uncommon through this approach. However, nerve injury is more likely if the submandibular approach has been used previously, with fibrosis, loss of surgical planes and distortion of the local anatomy.

Retromandibular incision with blunt dissection between the buccal and marginal mandibular branches of the facial nerve can give excellent access to the vertical ramus and condylar neck and a pre-auricular incision with temporal extension allows access to the condylar head and temporomandibular joint. As with the bicoronal flap, dissection on the surface of the temporals fascia will avoid injury to the frontal branch of the facial nerve.

Other incisions

Other local incisions such as the upper eyelid blepharoplasty incision, lateral eyebrow incision or use of existing scars may be indicated in selected cases, where more extensive exposure is not necessary.

Correction of deformity

Correction of bony deformity may be carried out by using osteotomy, onlay grafting or a combination of both techniques. If an individual component of the facial skeleton is of normal morphology but in abnormal position (displacement), osteotomy is usually the technique of choice. If the bulk of the bone is in normal position but there is abnormal morphology, e.g. localized contour deficit (deficiency) then onlay grafting may be appropriate.6 If both displacement and deficiency exist, then both techniques may be required. However, the choice of technique must take account of the concerns of the patient, as well as the nature and degree of

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Fig. 24.5: Postoperative lid retraction. (a) Before treatment. (b) Following correction by placement of auricular cartilage graft.
deformity, the extent of surgery required, potential complications and a realistic assessment of the likely outcome. These considerations may necessitate a departure from or modification of the basic principles outlined above.

Osteotomy

A variety of osteotomies are available and are well documented. These effectively recreate the original fracture pattern in the area of concern. Secondary osteotomies for trauma patients are usually carried using conventional surgical techniques with use of interpositional bone grafting if required to fill gaps created by the bony movements, to insure primary bone healing, stability of the bony movement and support for overlying soft tissues. Osteogenic distraction of the craniofacial skeleton is becoming more widespread and may offer another treatment option in selected cases. However, its role in the correction of posttraumatic deformity has yet to be established.

Onlay grafting

Onlay grafting to correct bone deficiencies may be carried out using a number of materials. Autografts, homografts, heterografts and alloplastic materials have been described and each has its advantages and disadvantages. The ‘ideal’ characteristics of onlay grafts have been outlined by a number of authors but include the following: biocompatible, no risk of disease transmission, resistant to infection, dimensionally stable, easy to shape or mold, amenable to skeletal fixation, long shelf life, cheap.

Autogenous materials

Bone

Autogenous bone may be used as an interpositional graft or for onlay augmentation. It has several advantages over other materials, including its biocompatibility and lack of risk of disease transmission. Resistance to infection is good, particularly if the bone is vascularized. Dimensional stability is variable and depends on the vascularity (vascularized being better than non-vascularized), embryological origin (membranous bone being better than cartilaginous bone), fixation (rigid fixation better than non-rigid fixation), graft site (interpositional graft better than onlay) and functional loading (functional loading is better than no functional loading). A number of donor sites including tibia, iliac crest, mandible and calvarium are available. The author’s preferred donor site is iliac crest for cancellous or corticocancellous bone grafting to mandibular non-union and calvarial bone grafting for almost all other situations where osteotomy gaps or bony deficiency exist, where masticatory loading is expected and where dimensional stability is important.

The use of non-vascularized grafts requires a healthy, well-vascularized graft bed. This is usually present in secondary posttraumatic deformity patients, but occasionally the graft bed may be of sufficiently poor quality to require vascularized bone grafts. Vascularized calvarial bone pedicled on temporoparietal fascia provide an excellent source of vascularized bone for midface and mandibular reconstruction. A disadvantage in mandibular reconstruction is the possibility of postoperative restriction in mouth opening. In cases where a large bulk of vascularized bone is required, microvascular free flap transfer is the treatment of choice, with a variety of potential donor sites, including iliac crest (deep circumflex iliac artery) and fibula. In selected cases, bone regeneration by distraction osteogenesis may be an option but has currently not been widely applied to treatment of posttraumatic deformity.

The disadvantages of autogenous bone grafting include prolongation of operating time and the creation of a graft donor site, with its potential associated morbidity. Variability of calvarial thickness may result in inadvertently cutting into the intracranial space during graft harvesting, but complications are rare.

Cartilage

Autogenous cartilage is an excellent material for reconstruction in some situations. It is biocompatible, maintains its viability, is dimensionally stable and easy to carve and shape. It can be fixed with wires or sutures. Although its resistance to infection is limited, it has been proved to be a reliable material when implanted into a vascular bed, especially when used in the orbit and nose. It is an excellent space filler but not rigid and therefore unsuitable for load bearing. Potential donor sites are auricular concha and nasal septum, which give a relatively thin sheet with limited area and volume, or costal cartilage, which has an abundant supply and can provide large volume. As with autogenous bone, prolongation of operating time and donor site morbidity, particularly if costal cartilage is used, are relative disadvantages.

Other materials

A variety of homografts, heterografts and alloplastic materials are available and the reader is referred to Chapters 8 and 31 for discussion of these. In principle, we prefer to use autogenous materials in most situations to minimize the risk of disease transmission, peri-implant infection or late extrusion. Exceptions to this are large calvarial defects, where sufficient autogenous bone may not be available, temporal or forehead contour defects, where bone graft substitutes (e.g. tricalcium phosphate) may be used, and minor malar deficiencies where alloplastic onlay grafts are an option.

Follow-up

Postoperative follow-up is essential, not only to monitor the results of treatment but to assess the need for further procedures. It is not uncommon for several reconstructive procedures to be necessary in order to achieve the best possible result. Cohen & Kawamoto presented a series of complex posttraumatic deformity cases, with an average of 3–4 procedures per patient in order to obtain optimal correction and a range of 1–15. It is also important to appreciate the limita-
tions of corrective surgery and to accept that some patients cannot be restored to complete normality. There is a danger that unrealistic expectations of outcome on the part of the patient or the surgeon may result in increasing numbers of surgical interventions yielding diminishing returns. If this point is reached, psychological counseling may be appropriate in order to help the patient accept and cope with any residual deformity.

The principles of secondary correction of posttraumatic deformity will be discussed in the following areas.

- Cranial vault deformity
- Orbitozygomatic injuries
- Nasoethmoidal injuries
- Posttraumatic malocclusion
- Complex cases involving bone deficiency

Defects and deformity of the skull

These will be discussed under the headings of calvarial defects, frontal sinus fractures and orbital roof fractures.

Full-thickness calvarial defects

Background

Full-thickness calvarial defects may be seen in a number of situations such as following gunshot wounds, after loss of osteoplastic craniotomy flaps or as a result of a growing skull fracture. Growing skull fracture is a specific and unusual variant on the full-thickness calvarial defect. These may be linear or non-linear skull fractures, which enlarge with time and are usually seen in children below the age of 3 (Fig. 24.6). Ninety percent occur under the age of 3 years but the process may be observed in older children and adults. The incidence of ‘growth’ as a delayed complication of skull fracture is rare and occurred in only 0.6% of the cases in one large series. They present with soft swelling in the region of a previous skull fracture with clinical and radiographic evidence of increased width and length of a previous fracture. The predominant factor responsible for increase in the size of the fracture seems to be a dural defect with abnormal growth of the underlying cerebral tissues, usually in the form of a leptomeningeal cyst but...
also from herniated cerebrum or dilated underlying ventricle with porencephalic cyst.

Full-thickness calvarial defects may require treatment for a number of reasons. The patient may be at risk from further trauma, either from blunt injury or penetrating objects, and a significant cosmetic defect may be apparent (Fig. 24.6). In addition, infections of the scalp present a significant risk of intracranial spread due to loss of the natural barrier of the calvarial bone, with potentially serious consequences.19

Reconstruction using alloplastic prostheses has historically been the most commonly used method for correction of the larger full-thickness calvarial defect. In the early 20th century active interest developed in autogenous cranioplasty from various donor sites, such as tibia, ilium, ribs or skull. More recently, however, the trend has been to use split-thickness calvarial bone grafting. Calvarial bone grafts have become more popular because of their greater dimensional stability and lower donor site morbidity compared with other bone graft donor sites. However, harvesting of these grafts still involves small risks of dural tears, meningitis, brain abscess, encephalitis and sagittal sinus tears. These risks depend upon the size of the graft harvested and whether full-thickness or split-thickness grafts are used,20 the location of the donor site and the skill and experience of the operator.

Assessment
A full history of the cranial defect should be established together with previous surgical details, including any prior attempts at reconstruction, in order to anticipate potential surgical complications such as dural tears or the need to remove plates or other implants placed previously. As always, a thorough clinical examination is required. Special attention should be given to the site and size of the skull defect. The position of previous surgical scars should be noted and the quality of the soft tissues overlying the bony defect assessed.

Plain X-rays show a characteristic irregular oval or elliptical skull defect which may be demonstrated on anteroposterior and lateral films. However, more detailed images are gained from CT scans, which in addition give useful information about the underlying brain. This is of special relevance where growing skull fractures are being managed and an MRI study is often used in addition because of its excellent soft tissue imaging characteristics. Reformating of axial and coronal CT images can be performed to create three-dimensional images which give excellent visualization of the cranial defect. Modern software allows the milling of an exact model of the skull and defect. This is particularly useful for very large defects as it allows the fabrication of a custom-made alloplastic cranioplasty implant (Fig. 24.7).

Treatment planning
The decision to reconstruct a full-thickness calvarial defect depends on a number of factors including age, risk of injury, size of defect, any underlying pathology and the cosmetic consequences of the defect. The decision to operate is taken on the merits of each individual case. Whether calvarial bone graft or alloplastic implant is used depends largely on the size of the defect and the availability of sufficient calvarial bone to cover the defect, without leaving a deficiency in the donor area. Large full-thickness calvarial defects therefore are usually reconstructed using acrylic or titanium implants, whilst smaller defects are amenable to the use of split calvarial bone grafts.

Operative technique
Surgery is performed using a standard coronal flap approach. Great care is needed when elevating the flap in the region of the bony defect in order that a dural tear is not produced. The margins of the defect are carefully exposed by subperi-cranial and extradural dissection and any soft tissues within the fracture line or defect are excised or replaced. Excision of non-viable cerebral tissue and dural repair is carried out where necessary.

If calvarial bone graft is to be used, a template of the defect is cut out using sterile paper to aid in accurate harvesting of the graft. The exact form of the calvarial bone graft depends on the size of the defect being reconstructed. Shave grafts consist of fine strips of bone harvested from the outer table with osteotomes. Their advantage is that multiple grafts can be harvested from a wide area without leaving a significant donor defect. However, their small size means that they cannot be rigidly fixed in their new position.

Sliding bone grafts are in many ways analogous to the advancement flaps used in skin surgery. An area of bone is exposed adjacent to the defect and a bone graft somewhat larger in size than the defect is marked out using saws or burrs. The outer table of the skull is then harvested through the dipoic layer as a partial-thickness graft. The bone graft is then slid across the defect in such a manner that it still partially lies across the inner table of the donor site. Such overlap allows increased primary stability and may possibly lead to earlier bony union.

Transposition calvarial bone grafts are now the most widely accepted method of reconstructing sizeable full-thickness skull defects.20 Following complete exposure of the edges of the bony defect, a temporary template is fashioned and a suitable area for the harvest of calvarial bone is identified.
This is most usually in the parietal region on the contralateral side to the pre-existing defect. A full-thickness piece of calvarial bone slightly larger in dimensions than the template is removed, taking great care not to damage the underlying dura. Once this has been achieved the bone graft is split using fine osteotomes and saws along the diploic layer, thus producing two similarly sized pieces of bone consisting of the inner and outer table respectively (Fig. 24.8). Once this has been done, the outer table bone graft can be returned to the donor site, leaving the inner table graft which can then be adapted to reconstruct the bony defect.

Fixation is achieved for the bone at the donor and the grafted sites using micro or miniplates (Fig. 24.9). In growing skull fractures in pediatric patients, consideration should be given to use of resorbable plates to avoid drift of the plate from the outer to the inner aspect of the calvarium with continued skull growth. The donor site should be covered with a layer of Surgicel, the pericranial layer closed and the scalp repaired over a suction drain if necessary.

Outcome of calvarial defect reconstruction

The outcome of reconstruction of simple calvarial defects using split calvarial bone grafts is excellent. In a follow-up study of 27 patients, Posnik et al found minimal complications with no infections, graft exposures or intracranial injuries. However, a growing skull fracture is a different clinical entity. In a study of 41 patients with growing skull fractures Gupta et al reported a death rate of 7%, postoperative CSF leaks in 7% and local wound infection in 14%. In a review of 132 cases reported in the literature, Pezzota et al found a high incidence of seizures and focal neurological deficit, with functional recovery being linked to the clinical presentation and early diagnosis. Reconstruction of simple calvarial defects is therefore associated with a better outcome than growing skull fractures, in which the postoperative morbidity is largely related to abnormalities of the underlying brain.

Frontal sinus fractures

Background

Frontal sinus fractures are most commonly managed in the acute setting where open reduction and internal fixation of the disrupted bone is performed together with any necessary maxillofacial or neurological surgery. Where the posterior wall of the frontal sinus is fractured, cranialization of the sinus and stripping of the lining mucosa together with obliteration of the frontonasal duct with muscle, fat or cancellous bone chips are necessary to prevent late complications of CSF leakage, mucopyoceles, osteomyelitis and meningoencephaloceles. A dural repair is generally required where the posterior wall is fractured. On occasion, however, patients may present for late correction of a deformed fracture of the frontal bone, usually for reasons of cosmesis.

Assessment

A thorough history of the injury and its subsequent management should be taken. If the posterior table was involved in
the original fracture it is important to know if a cranialization procedure was performed as this will have important consequences for the reconstruction of the bony defect. In this situation, fibrosis and adhesions will increase risk of further dural tear and avoidance of extradural dissection is desirable. Onlay bone graft or use of an alloplastic filler material may be more appropriate than osteotomy in order to reduce risk of complications.

Examination of the frontal bone contour together with the condition of the overlying skin is performed. The sensation subserved by the supraorbital and supratrochlear nerves should be assessed prior to raising the coronal flap.

Plain films can give useful information especially with regard to the presence and location of metalwork from previous surgical procedures. CT scans are required to show greater detail of the anatomy of the anterior and posterior walls of the frontal sinus. The presence or otherwise of active frontal sinus disease can also be assessed and if present, should be treated prior to reconstruction.

Treatment planning
There are two principal methods of management, both usually through a coronal approach. First, the bone may be re-osteotomized along the previous fracture lines and the bone fragment(s) fixed in their original position with miniplates or microplates. If the posterior table has been involved this is likely to involve a formal craniotomy. Alternatively the defect can be masked with an onlay bone graft or, if the contour defect is minor, it may be corrected more simply using a calcium triphosphate bone replacement material keyed to the bone with microscrews or fine titanium mesh.

Operative technique
Figure 24.10 illustrates the operative technique.

Outcome
Outcome of secondary osteotomy or bone grafting for displaced anterior wall fractures is excellent. Most complications are associated with the original injury and are depend-
ent on whether the posterior wall is involved with dural tear, CSF leaks, involvement of the nasofrontal duct and whether adequate treatment including, where necessary, dural repair, cranialization or obliteration of the sinus and nasofrontal duct were carried out. In a series of 33 patients with frontal sinus fracture, \textsuperscript{25} long-term complications occurred in four patients, with only two being cosmetic. The requirement for secondary surgery is therefore small in well-managed frontal sinus fractures.

Orbital roof fractures

Background

Orbital roof fractures are a consequence of severe trauma and are associated with a considerable likelihood of neurological and ophthalmological injury. In general such injuries are managed in the acute phase but where they are not treated or where treatment is inadequate, the patient may present with a significant secondary deformity. Below the age of 3, the orbital roof may be the site of a growing skull fracture.\textsuperscript{15}

Assessment

A full history of the original injury is taken together with a history of previous treatment. Original notes, X-rays and scans are of great help in shedding light on previous treatment and planning surgery.

A full assessment of the external bony contour should be made. Irregularity or asymmetry of the supraorbital rims should be noted. An assessment of enophthalmos or exophthalmos (including pulsating exophthalmos indicative of orbital roof defects) should be made. Sensory function of the supraorbital and supratrochlear nerves should be assessed. As with any orbital reconstruction, an ophthalmological opinion should be sought before any surgery is performed to document vision and ocular motility preoperatively to identify problems and to act as a baseline for postoperative follow-up.

Where the orbital roof itself has been depressed, ocular dystopia with inferior displacement of the globe is a common finding (Fig. 24.11). Larger defects of the orbital roof put the patient at risk of dural herniation which may result in pulsating exophthalmos and disturbance of ocular function.

Special investigations

Fine cut axial and coronal CT scans should be obtained to give detailed images of the orbital roofs of both orbits (Fig. 24.12). This allows accurate surgical planning and measurements can be made of bony displacement, deficiency or asymmetry.

Operative technique

In the great majority of cases a coronal flap will be the most appropriate approach. Occasionally it may be possible to access the surgical area via an existing scar and for small defects confined to the supraorbital rim, this approach may be adequate. However, more major deformities and any significant displacement or deficiency of the orbital roof will require a transcranial approach with unilateral frontal

![Fig. 24.11: Orbital roof fracture. (a) Inferior displacement of eye. (b) Proptosis.](image-url)
craniotomy, retraction of frontal lobe and on occasion may require removal of the supraorbital bar. This obviously requires joint neurosurgical/maxillofacial management. Where small depressions or contour irregularities exist they may be masked by bony recontouring with burrs and by the application of small onlay bone grafts or alternatively one of the proprietary bone cements now available. Large displacements or defects in the orbital roof require accurate reduction or reconstruction with split-thickness calvarial bone graft, if necessary following dural repair. Where a frontal craniotomy has been performed, the graft can be harvested from the inner table of the frontal bone flap, thus avoiding any visible or palpable donor site defect.26

Outcome
There is very little in the literature regarding secondary correction of orbital roof fractures.27 With accurate reconstitution of the anatomy, the outcome should be good in both pediatric and adult patients. However, some inaccuracy in vertical and AP globe partitioning may occur, as well as post-operative diplopia.

Deformity of the zygomatico-orbital region

Background
The treatment of fractures of the orbit and fractures of the zygoma will be dealt with together due to the great overlap of these topics. Injuries to this area can produce complex deformities and careful planning is required when secondary corrective surgery is contemplated. In general, deformity is due to inadequate primary surgery and is related in part to the underlying bony skeletal abnormality and in part to the soft tissue component including scarring, thickening and incorrect draping of the soft tissue envelope on the facial bones. Deformities of upper and lower eyelids may be seen, often as a result of the initial trauma but also occasionally resulting from a previous surgical approach. Patient complaints may be related to the cosmetic or functional deficit that they are experiencing or both. It is important to establish from the outset the specific concerns of the patient and his expectation of the outcome of treatment. This will allow surgery to be tailored to the patient’s concerns rather than the surgeon’s view of the deformity and will give the opportunity to dispel any unrealistic expectations that the patient may have.

Assessment
A full history should be taken including the mechanism of the original injury, the treatment previously received and the current concerns of the patient. A number of factors contribute to unsatisfactory appearance following orbitozygomatic injuries and give rise to cosmetic complaints. Enophthalmos is common due to increased orbital volume or herniation of orbital contents through defects in the orbital walls, usually inferior or medial (Fig. 24.13). Ocular dystopia may occur with inferior displacement of the globe when Whitnall’s tubercle is inferiorly displaced as a result of zygomatic malunion following an inferiorly displaced fracture. Loss of zygomatic prominence leading to cheekbone asymmetry is common and increased facial width due to bowing of the zygomatic arch may occur secondary to an inadequately reduced posteriorly displaced zygomatic fracture. Telecanthus may be present if the original fractures involved the portion of bone bearing the medial canthal ligament or if the ligament has been detached during surgical access for primary treatment. Esthetic concerns with regard to the peri-orbital soft tissues are frequently related to the position of the eyelids and canthi. Lid retraction and/or true ectropion may be seen, usually as a result of previous treatment (see Fig. 24.5).

Functional deficits following orbital trauma frequently relate to injury to the globe itself and are thus within the preserve of the ophthalmological surgeon. Tethering and scarring of the periorbita and extraocular muscles may cause diplopia which, if severe, can be disabling (see Fig. 24.1). Epiphora is a frequent complaint and may be due to damage to the bony or soft tissue component of the lacrimal drainage apparatus,
including abnormalities of lower lid and therefore lacrimal punctum position. Where epiphora persists, corrective surgery may be necessary.

Clinical examination should include assessment of the degree of enophthalmos, which should be assessed subjectively by clinical examination and objectively by exophthalmometry. The classic signs of enophthalmos, including obvious ocular retrusion, hypoglossus, deep supratarsal fold, pseudoptosis and narrowing of the palpebral fissure, may be apparent (Fig. 24.14). Normal anterior projection of the globe relative to the lateral orbit rim is between 12 and 16 mm. Whilst formal exophthalmometry would seem likely to give a more objective assessment than clinical examination, it should be remembered that it is comparing the position of the globe with that of the lateral orbital wall and if this bony landmark has been altered by the original trauma, the subsequent reading may be unreliable.

Any asymmetry of the malar prominences should be noted. The malar eminence on the injured side may be displaced medially, posteriorly or inferiorly or combinations of these. Rarely, if previous surgery has overreduced the zygomatic complex, it may be lateral to its normal position and therefore overprominent. Facial width should be assessed by comparing the relative prominence of the zygomatic arch on the injured and uninjured side. If the zygoma is displaced posteriorly, this results in a ‘bowing out’ of the zygomatic arch, thus increasing the facial width on the injured side.

An assessment of the overlying soft tissues should be made. The quality and thickness of the tissues should be noted. Scarred, contracted tissues may require correction either at
the time of osteotomy or subsequently. Loss of sensation in the distribution of the infraorbital nerve is common following orbital trauma, whilst loss of supraorbital and supratrochlear nerve sensation is less frequently seen. There is no evidence to suggest that secondary surgery will have a beneficial effect on compromised nerve function and indeed, the patient should be aware that surgery carries the risk of further nerve damage.

Special investigations

Plain X-rays have a limited role in surgical planning of midface deformity. They are useful in identifying the type and position of internal fixation used in previous operations, as this will almost certainly need to be removed if further surgery is performed. A submento-vertex radiograph will show the form of the zygomatic arches. Subtle variations in the shape of the zygomatic arches can have a profound effect on facial width and overall facial balance.

CT scans are invaluable in surgical planning. Images should be obtained in the coronal and axial planes and 3D images can be particularly useful in orbitozygomatic injuries. By taking measurements from unaffected fixed points such as the pterygoid plates or contralateral uninjured orbit, a quantitative measurement of the bony deformity can be established with respect to the contralateral uninjured side. These measurements should be established in three planes so that the necessary movements or augmentations of the zygomatico-maxillary complex can be predicted in the vertical, mediolateral and posteroanterior planes. These movements should be accurately established before surgery is undertaken (Fig. 24.15).

MR scans are little used in the planning of facial bone osteotomies at the present time but they do have a role in assessing the nature and quality of the overlying soft tissues and may be a useful investigation in difficult cases. The degree of herniation of tissues through the medial, inferior and to a lesser extent the lateral orbital walls may be assessed with MRI scanning. It may also be possible to image trapping or tethering of extraocular muscles.

Dental study casts have little role to play in the management of zygomatico-orbital deformity unless there is going to be a simultaneous osteotomy of the maxilla or mandible to correct a malocclusion. The advent of computer-generated

Fig. 24.15: Surgical planning on CT scans. (a) Anteroposterior measurement. (b) Vertical measurement.
3D models of the bony facial skeleton milled or cast using information derived from CT scans has been a major step forward in this regard. Exact measurements can be made on the models and the surgery accurately preplanned. If alloplastic materials are to be used they can be custom made on the 3D models. Recent advances in computer software are likely to allow much more specific surgical planning in relation to the hard or soft tissue movements.

Sinus endoscopy is a relatively recent innovation and may be useful to assess the condition of the orbital floor. In the acute situation, some success with definitive fracture management has been achieved but whether endoscopically assisted surgery will have any role in the management of the secondary deformity is unclear. One case has been reported of correction of enophthalmos secondary to a medial wall defect using alloplastic material inserted via an endoscopic approach medial to the lacrimal caruncle.

Where surgery is being considered a full ophthalmic and orthoptic assessment is required as a baseline. This is especially important in those cases where the patient is experiencing diplopia.

Surgical technique

For successful correction of the zygomatico-orbital deformity, complete regional exposure is required although some authors advocate a more conservative approach. This is performed through a bicoronal flap, combined with a lower eyelid incision, and an upper buccal sulcus incision. The bicoronal flap gives excellent access to the orbit and zygomatic arch and body and permits harvesting of calvarial bone graft. Stripping of the temporalis muscle facilitates exposure of the lateral orbital wall. Lower eyelid approach gives access to the infraorbital rim and orbital floor and allows visualization and protection of the infraorbital nerve. It may be through a skin incision (blepharoplasty, midtarsal or infraorbital) or via a transconjunctival incision. The transconjunctival incision, which is usually combined with a lateral canthotomy, is technically more difficult to perform but has the advantage of leaving less facial scarring compared with the cutaneous approaches and may be associated with a lower incidence of lid retraction. The combination of bicoronal flap and lower lid approach allows circumferential subperiosteal dissection within the orbit. The lateral canthal ligament and should be tagged and reattached at the end of the procedure. Conversely, the medial canthal ligament, which is notoriously difficult to reattach, should have its origin carefully preserved.

The orbital floor must be dissected with great care as the infraorbital nerve is frequently embedded in dense scar tissue and may easily be damaged. A similar situation applies where gaps in the bony skeleton, for example in the lateral orbital wall, have led to fusion of the intra- and extraorbital soft tissues. The buccal sulcus incision gives access to the anterior surface of the maxilla, zygomatic buttress and, via the maxillary sinus, the inferior aspect of the orbital floor.

Correction of bony deformities in the zygomatico-orbital area is dependent upon the performance of several key maneuvers. Zygomatic osteotomy will reproduce the fracture lines of the original injury. Following exposure, bone cuts are made from the infraorbital rim just lateral to the nerve extending down the anterior maxillary wall, passing posteriorly, to the zygomatic buttress. The bone cut is continued around the lower extent of the buttress onto its posterior face. Within the orbit the cut passes from the infraorbital rim posteriorly to the anterior end of the inferior orbital fissure. The cuts are then continued superiorly through or just anterior to the greater wing of the sphenoid and continued to the zygomatico-frontal suture. Completion of the osteotomy at the posterior aspect of the buttress is best performed using a fine, curved osteotome, inserted via the coronal approach behind the lateral orbital rim within the temporal fossa, and extends from the anterior end of the inferior orbital fissure to join with the cut already made in the inferior part of the buttress. The root of the zygomatic arch is sectioned, resulting in complete freeing of the zygoma from its bony attachments. For the less experienced operator, appreciation of the exact three-dimensional anatomy is enhanced if a dry skull or a three-dimensional model is available in the operating theater.

Before the zygoma is mobilized, the bony movements should be marked at the infraorbital rim, the zygomatico-frontal suture and the zygomatic arch. The most common

Fig. 24.15: (c) Transverse measurement.
posttraumatic displacement of the zygoma involves impaction posteriorly, inferiorly and medially. Usually, bone removal is required at the zygomatico-frontal suture to permit superior repositioning of the zygoma, whereas advancement and lateral movement will create bony gaps. The zygoma is fixed into its new position with microplates. Repositioning of the body of the zygoma will often produce contour deformities and steps in the zygomatic arch and the arch itself may require local osteotomies to allow it to be recontoured.

Anterior, lateral and superior movement of the osteotomized zygoma will create bony gaps and step deformities at several sites and these require bone grafting in order to insure bony union, stability and soft tissue support and to avoid palpable irregularities and edges beneath the thin periorbital skin. Gaps occur at the infraorbital margin, orbital floor, the frontozygomatic cut, lateral orbital wall, zygomatic arch and zygomatic buttress. In addition, the zygomatic repositioning may have created an orbit larger in volume than before and allow herniation of periorbital tissues through bony defects of the orbital walls. Considerable widening of the inferior orbital fissure may occur as a result of repositioning. This increased orbital volume predisposes towards the development of enophthalmos. The inferior orbital fissure should be exposed and the soft tissues divided (no significant structures pass through it) and it should be obliterated with a graft. Bone grafting is essential to treat pre-existing enophthalmos and to prevent its occurrence following osteotomy. Contoured calvarial bone is used for this purpose. Calvarial bone graft exhibits considerably less tendency for resorption than the previously used rib or iliac crest grafts, particularly when rigid fixation techniques are utilized. Calvarial bone should now be considered as the ‘gold standard’ for grafting in and around the orbit. Contoured calvarial bone is readily available and does not require a separate incision for its harvest. Enough bone is available for the great majority of cases and the morbidity associated with its harvest has been shown to be very low. The technique has been described elsewhere but the bone is usually obtained as thin rectangular strips, which are ideally suited for grafting orbital defects.

For the correction of enophthalmos it is important that the bone graft is largely situated behind the equator of the globe.
in order that the eye is displaced forwards. Hypoglobus may be corrected if the bone graft is placed in the orbital floor beneath the globe, but care must be taken in placing orbital bone grafts not to produce unwanted elevation in globe position. Bone grafts placed posteriorly within the orbit do not generally require fixation although a number of specifically designed plates are available for this purpose. Where grafts are more anteriorly placed, fixation is recommended to minimize the amount of resorption and prevent migration. Where possible, the metalwork should be placed within the orbital margin so that it is not subsequently palpable through the thin infraorbital skin. A forced duction test is performed immediately before and after placement of bone graft to insure that ocular motility has not been jeopardized (see Fig. 24.2).

In cases where a bone graft is being placed to correct a pre-existing enophthalmos, overcorrection is advisable at the time of surgery in order to allow for swelling and a degree of bone graft resorption. Bone graft is carefully placed until a degree of exophthalmos has been achieved. Some authors have recommended incisions within the scarred periorbital tissues in order to allow the globe to take up a more anterior position. It is likely, however, that the scarring will recur and this maneuver is not recommended. Advancement of the displaced zygoma and orbital rim is dependent on the ability to simultaneously correct the enophthalmos as otherwise the appearance of the enophthalmos itself may be worsened (Fig. 24.16).

Onlay grafting

Onlay grafting may be used in mild cases of malar asymmetry and can usually be carried out easily through a lower eyelid incision. Calvarial bone, bone substitutes or alloplastic implants may be used (Fig. 24.17).

Nasoethmoid fractures

Detachment of the medial canthal ligaments together with their bony insertion is relatively common following orbital and nasoethmoidal fractures. Inadequate primary management leads to telecanthus and blunting of the medial canthal angle. Osteotomy and repositioning of the nasoethmoidal segment may be required. Complete correction of the medial canthal position is notoriously difficult and overcorrection should be the aim. In those cases where the medial canthal ligament is not attached to an identifiable bone fragment, a transnasal canthopexy is required (Fig. 24.18). Where a nasoethmoidal fracture has been a significant part of the orbital injury a graft will almost invariably be needed to the dorsum of the nose to recreate the degree of nasal projection present before the injury. Calvarial bone has been widely used in the past but although it gives a satisfactory appearance, its 'feel', especially towards the nasal tip, is too solid to be natural and a nasal dorsal graft of carved costal cartilage may be preferred (Fig. 24.19).

Outcome

Long-term outcome depends on the extent of the secondary deformity, on detailed planning, choice of technique and meticulous surgery. In a series published by Freihofer & Borstlap, osteotomy was found to give superior results
Fig. 24.17: Onlay augmentation of left zygoma utilizing vascularized calvarial bone pedicled on temporalis muscle. (a) Preoperative. (b) Post operative.

Fig. 24.18: Secondary deformity following nasoethmoidal injury. (a) Medial canthal detachment. (b) Appearance following transnasal canthopexy.
compared with onlay techniques. In 16 posttraumatic cases, 14 were assessed as good or satisfactory, with only two being rated as unsatisfactory, due to undercorrection, overcorrection or persistence of enophthalmos. They found no decrease in visual acuity and in five cases with associated posttraumatic enophthalmos, two were corrected fully whilst three were only partially corrected. Infraorbital nerve sensory loss occurred in approximately half of the group. In a series of four cases, Perino et al reported good results and low complication rate. However, both these had a significant requirement for further
procedures to insure optimum outcome and in Cohen & Kawamoto’s series including 14 cases of orbitozygomatic deformity, the average number of operations required was 3.76. Further procedures may be required to reduce overcorrected malar position, to correct medial and lateral canthal dystopias, recurrence of enophthalmos and abnormalities of eyelid position.

Hammer reported good or satisfactory esthetic results following secondary zygomatico-orbital reconstruction in 20 out of 26 patients. Where diplopia was present prior to secondary correction, improvement occurred in just over half of the group. There was a complication rate of 15% including visual loss due to displacement and bone graft, endophthalmitis, orbital abscess and exposure of a nasal bone graft.

Freihofer reported a series of patients who underwent secondary correction of fractured zygomas, with a good result obtained in 80%. Medial canthopexy was carried out in 19 patients. Three required further procedures but all 19 achieved satisfactory or good final outcome.

**Posttraumatic malocclusion**

Background

Posttraumatic malocclusion may present following malunion of any fracture that directly or indirectly involves the alveolar segments of the maxilla or mandible. These include isolated dentoalveolar fractures of maxilla or mandible, maxillary fractures including Le Fort I, II or III with or without palatal split, and mandibular fractures.

Before the introduction of miniplating, stabilization of the occlusion by intermaxillary fixation (IMF) was the primary aim of treatment of facial fractures. The introduction of internal fixation makes direct anatomical segment reduction the primary aim. If this is achieved, a normal occlusion should automatically follow. This is indeed the case in the majority of cases. However, in some comminuted maxillary or mandibular fractures, a perfect occlusion may be difficult to achieve and most fractures of the mandibular condyle tend to be managed by closed techniques, with the potential for displacement following removal of the intermaxillary fixation. In addition, large muscle forces in the mandible may cause movement of the fracture site, resulting in fibrous or non-union. Infection of mandibular fractures, particularly those involving the tooth-bearing segment of the mandible or angle, may result in non-union and segment displacement with malocclusion.

**Diagnosis**

In the presence of small displacements of segments, patients usually complain of functional difficulties in biting and chewing and the inability to find a positive, comfortable intercuspal position. In large displacements, an effect on facial appearance may be added, particularly increases in mandibular angle causing anterior open bite, and mandibular asymmetry, both usually due to mandibular condylar fracture malunion. Complaints related to temporomandibular joint dysfunction may follow malunion of condylar fractures and mechanical joint derangement may result in severe deviation or limitation of mouth opening.

Assessment of temporomandibular joint function is mandatory, since restriction of mouth opening or severe deviation may necessitate surgery to the temporomandibular joint in addition to osteotomies or bone grafting. It is important to check for mandibular displacement and insure that when the malocclusion is assessed, the mandible is fully retruded. Occasionally, a patient will present with occlusal complaints but will apparently show a good occlusion. This may be due to a minor mandibular displacement, indicating a discrepancy between the retruded condylar position of the mandible and intercuspal position. In addition, fibrous union of a body fracture, allowing a very small degree of movement between segments, may allow good intercuspation but only at the expense of bone movement at the site of the fibrous union. It may be difficult to see obvious fracture mobility in this situation by standard clinical examination but careful inspection of the fracture site whilst occluding and disoccluding the teeth may demonstrate movement. The use of articulating paper may help assessment in cases where the discrepancy is small.

Investigation usually includes study models and plain radiographs. CT scans may occasionally help, particularly in assessment of condylar injuries.

Dental study models are necessary to assess whether segmental surgery or whole-jaw surgery should be undertaken. If the pretraumatic occlusion is obtainable with the existing arch form, then one-piece jaw surgery is indicated. If an acceptable occlusion is not obtainable, it may be indicative of a malunited segmental fracture or a degree of dentoalveolar compensatory change secondary to the altered occlusion and jaw position. In this situation, one-piece jaw surgery alone will not establish the pretraumatic occlusion and adjunctive treatment is necessary. If the occlusal discrepancy is slight, selective occlusal grinding may allow a reasonable seating of the occlusion. If this is considered undesirable or will not achieve a satisfactory occlusion, then orthodontic treatment may be considered. However, a number of patients will be unsuitable for orthodontics due to lack of anchorage, poor oral hygiene or dental condition or lack of sufficient motivation. If orthodontics is precluded for any of these reasons, occlusal rehabilitation by restorative techniques may also be considered but may also be limited by existing dental condition, oral hygiene or patient motivation. In this situation segmental surgery may be the only viable option.

Face bow recording and anatomical articulation are useful in planning treatment for correction of anterior open bite. They allow accurate assessment of the degree of posterior maxillary impaction required and an approximate assessment of the degree of mandibular autorotation. This is helpful in planning the need for mandibular osteotomy to correct anteroposterior jaw relationships.

Plain X-rays, particularly OPG and lateral cephalogram, will demonstrate fibrous union, gross segment displacement, site of previously inserted metalwork and if orthognathic techniques are being used, provide a basis for orthognathic work-up.
Treatment planning

It is important to consider the need for multidisciplinary involvement before treatment is undertaken. This may involve an orthodontist and occasionally a restorative dental surgeon, since some occlusal discrepancies may be amenable to occlusal adjustment, restorative or orthodontic treatment. As discussed above, other patients may require a joint orthodontic and surgical approach using standard orthognathic techniques, particularly if a pre-existing malocclusion or dental crowding existed or if sufficient time has elapsed since the injury to allow some compensatory dental changes to occur. On occasions, the amount of movement required at osteotomy is relatively small and this gives only a small acceptable margin of error in jaw and segment positioning at surgery. If positioning errors occur, then elastic traction may be adequate for correction in the early postoperative phase but should this prove inadequate, an assessment of the feasibility of orthodontic or restorative solutions is useful.

With regard to the detailed surgical movements, these are of course dictated by the establishment of an acceptable dental occlusion. Intraoperative occlusal wafers to assist accurate jaw and segment positioning are essential. Preformed arch bars facilitate intraoperative intermaxillary fixation and if significant edentulous areas exist, especially posteriorly, then acrylic saddles should be incorporated within the arch bars to facilitate jaw positioning and should be left in situ postoperatively to improve jaw stability and prevent loss of posterior ramus height in the early postoperative period.

Osteotomies

Maxilla

Indications

In order to correct occlusal abnormalities due to maxillary malunion, Le Fort I osteotomy is indicated. Osteotomy at Le Fort II or III level, or variations of these procedures tailored to the individual needs of the patient, may be required in some instances where simultaneous correction of midface deformity is necessary. However, primary treatment by open reduction with internal fixation and primary bone grafting have substantially reduced the need for more extensive maxillary osteotomies in the treatment of secondary posttraumatic deformity. Le Fort I osteotomy is therefore indicated for most cases of maxillary occlusal abnormality, when segmental or one-piece maxillary repositioning is necessary. In addition, maxillary osteotomy may be required in order to close an anterior open bite following bilateral condylar malunion.

Operative technique

Standard Le Fort I down fracture is carried out via a horseshoe-shaped buccal sulcus incision. Bone cuts of lateral maxillary wall, zygomatic buttress, lateral nasal walls, pterygomaxillary dysjunction and nasal septum are carried out in a similar way to standard orthognathic surgery. Following down fracture, the maxilla is mobilized and if indicated, segmentation of the maxilla can be carried out from the nasal aspect by making a horseshoe-shaped cut in the bony palate and extending this cut radially between the roots of the teeth either side of the site of the desired segmental cut. After segmentation, an acrylic palate retained with Adams cribs helps to control the segments and temporary intermaxillary fixation is applied using a prefabricated occlusal wafer to establish the desired position of the maxilla relative to the mandible. Any areas causing interference with establishment of the desired position of the maxilla are removed. This is particularly important in the nasal septum to avoid postoperative septal deviation and at the posterior maxilla in cases of maxillary impaction. The maxilla is then fixed with miniplates, at the piriform apertures and zygomatic buttresses.

Once the maxilla is fixed, the intermaxillary fixation is removed in order to check the newly established dental occlusion. This must be exactly as planned and must be achievable by gentle upward pressure on the chin point, insuring that no distraction of the mandibular condyles out of the glenoid fossae has occurred. If this happens, an anterior open bite will be detectable following removal of intraoperative intermaxillary fixation. If undetected at this stage, it would certainly become apparent in the early postoperative period. If on careful checking of the occlusion, any discrepancy, in particular anterior open bite, is detected, then the occlusal wafer and intermaxillary fixation must be reapplied and the maxilla repositioned and replated, following the removal of any persistent bony interferences, especially in the region of the maxillary tuberosity and pterygoid plates.

Once the correct maxillary position is established, any significant bony gaps or deficiencies are bone grafted. This is particularly important at piriform and zygomatic buttresses and at the anterior maxillary wall. These insure union, stability and support for the overlying soft tissues of the cheek. However, the use of bone grafts in Le Fort I osteotomies to correct posttraumatic occlusion is uncommon due to the relatively small movements involved.

If segmental surgery is necessary to reposition a dentoalveolar segment only, then this is best carried out via a full Le Fort I down fracture in the manner described above. This approach facilitates access for bone cuts, particularly in the palate, and removal of bony interferences between segments. Care must be taken to avoid injury to the dental roots adjacent to segmental bone cut, especially if preoperative orthodontic treatment has not been carried out. If palatal expansion is carried out then bone graft may be placed in the palatal osteotomy gaps to improve transverse stability.1 Previously described local segmental maxillary osteotomies have largely been superseded by the Le Fort I down fracture technique.

Outcome

There is very little literature devoted to the outcome of maxillary osteotomies for the correction of posttraumatic deformity, either one-piece or segmental procedures. Stability following osteotomies for posttraumatic deformity will be dependent to an extent on the nature of the original injury, its treatment and subsequent secondary procedures and the presence of soft tissue scarring which, if present, is likely to increase relapsing forces, a phenomenon well known in cleft osteotomy. Cohen & Kawamoto1 reported the results
of 25 patients with severe posttraumatic facial deformities, including 10 Le Fort I osteotomies. Although they present no detailed analysis of long-term outcome, they take the view that malocclusion following secondary correction should be rare. However, any adult non-orthodontic, orthognathic surgery demands meticulous technique and accurate positioning of segments.

Mandible
Patients presenting with malocclusion following mandibular injuries may present with non-union, fibrous union or malunion.

Non-union/fibrous union
Non-union and fibrous union may occur following fracture of any part of the mandible but most commonly affect fractures of the mandibular angle. In a study of 1432 mandibular fractures, Mathog et al. found an incidence of non-union of 2.8%. They reported increased incidence in men, in fractures affecting the body of the mandible and in patients with multiple fractures. Inadequate stabilization or reduction and osteomyelitis were found to be common. Other contributory factors included lack of prophylactic antibiotics, delay in treatment, presence of teeth in the line of the fracture, alcohol and drug abuse, an inexperienced surgeon and lack of patient compliance. Moreno et al. found that the overall complication rate, postoperative infection and postoperative malocclusion were significantly correlated with the severity of the original fracture and similar risk factors were identified by Haug & Schwimmer.

Treatment requires debridement of the fracture site and eradication of infection, with accurate reduction and fixation. In the absence of significant bone deficit this treatment should result in successful union. Since infected non-unions present with a mandibular continuity gap, temporary fixation of fragments is desirable to allow resolution of infection prior to bone grafting. Where there is intact overlying mucoperiosteum, this may be achieved by rigid internal fixation. However, in long-standing severe cases, the quality and availability of mucosal cover for the fracture may be poor. If internal fixation is used in these cases, dehiscence of the intraoral wound may occur with resultant plate exposure. In this situation immobilization is best achieved by use of an external fixator (Fig. 24.20). Once infection is eradicated and mucosal healing has occurred, cancellous or corticocancellous bone graft and internal fixation in the form of mesh or plates is carried out usually via an extraoral approach to avoid contamination of the bone graft by intraoral bacteria.

Technique
The fracture site is approached by a standard intraoral or extraoral incision. The fracture is mobilized, bone ends cut back to healthy bleeding bone and segments repositioned with the aid of temporary intraoperative intermaxillary fixation and use of an occlusal wafer for accurate location of the teeth. Where little or no bone gap is present, bone grafts may be unnecessary but in most cases cancellous or corticocancellous bone harvested from the iliac crest will restore mandibular continuity defects and insure bony union.

Outcome
Outcome is usually good although sensory loss in the region of the inferior dental nerve is common due to inevitable scarring and damage as a result of the original injury, primary treatment and subsequent secondary bone grafting.
Malunion may occur in the horizontal or vertical ramus of the mandible.

**Horizontal ramus**

Malunion of a fracture of the horizontal ramus usually requires direct osteotomy to recreate the fracture, mobilization and repositioning of the segments and placement of internal fixation, with the expectation of an excellent outcome.

**Angle, ramus and condylar fractures**

Malunion of fractures behind the tooth-bearing segment of the mandible result in displacement of the whole dentoalveolar arch. Uncomplicated angle and ramus fractures rarely result in malunion because they are amenable to open reduction with internal fixation. However, mandibular condyle fractures are often treated non-surgically by closed methods of reduction, intermaxillary fixation and elastic traction. Displacement of the mandible and resulting malocclusion may occur for a variety of reasons. Severe condylar malposition with dislocation allows vertical shortening of the ascending ramus and this may be associated with restricted mouth opening or deviation on opening due to mechanical disruption of the temporomandibular joint. The functional status of the temporomandibular joint is an important factor in the choice of technique adopted for correction of the occlusal deformity. If temporomandibular joint function is significantly compromised, reduction of the dislocation may be necessary, along with disc repositioning. If temporomandibular joint function is acceptable, ramus osteotomy is indicated in order to avoid joint surgery and the possibility of surgically induced limitation of mouth opening. Vertical ramus shortening may also occur following angular displacement of the condylar neck without dislocation if telescoping of the proximal and distal fragments occurs, particularly if the molar teeth are absent and there is lack of posterior occlusal support. It may also be seen following condylar resorption.39

In unilateral condylar fractures, malunion results in shortening of the ipsilateral ramus height, transverse cant of the lower occlusal plane, gagging of the occlusion on the ipsilateral posterior molars and contralateral open bite. In addition, there may be posterior displacement of the ipsilateral mandible resulting in obvious chinpoint asymmetry, as well as cross or scissors bite (Fig. 24.21). If bilateral malunion occurs, then both ascending rami shorten, with an increase in mandibular and lower occlusal plane angle, bilateral occlusal gagging on the posterior molars, anterior open bite, with class II jaw relationship and, if severe, lip incompetence (Fig. 24.22).

**Treatment**

**Unilateral**

The aim of treatment in unilateral cases is to restore the pretraumatic ramus height and correct posterior mandibular displacement if present. This corrects the occlusal plane cant and restores a normal occlusion and can be achieved by either performing an osteotomy at the site of the original fracture, repositioning and if necessary interpositional bone grafting to maintain lengthening of the ramus, or by a ramus osteotomy distant from the fracture site, e.g. vertical subsig.
Fig. 24.22: Vertical ramus osteotomy to correct posttraumatic malocclusion. (a) Preoperative malocclusion. (b) Retromandibular incision marked. (c) Vertical ramus osteotomy performed. (d) Temporary intermaxillary fixation with occlusal wafer. (e) Fixation of osteotomy. (f) Wound closure.
Fig. 24.23: Bilateral sagittal split osteotomy to correct postoperative malocclusion. (a) Preoperative malocclusion due to unilateral condylar fracture. (b) Preoperative cephalogram. (c) Preoperative OPG. (d) Postoperative occlusion following osteotomy. (e) Postoperative PA cephalogram. (f) Postoperative OPG.
be difficult and carry significant risk of postoperative trismus or ankylosis. In this situation vertical subsigmoid osteotomy, inverted L or sagittal split osteotomy is indicated where temporomandibular joint function is adequate. Where temporomandibular joint function is compromised, reduction of the condylar fragment and disc repositioning may be necessary despite the surgical difficulty and risk of surgically induced restriction of mouth opening postoperatively.

Where temporomandibular joint surgery or condylar reduction is not necessary, the particular type of osteotomy chosen is governed by the direction and extent of displacement. Rubens et al\(^40\) recommend that when horizontal movement is the primary goal, sagittal split osteotomy is appropriate. Where vertical correction is required, they recommend use of an intra- or extraoral ramus osteotomy. However, they also point out that other factors such as facial scarring, ease of condylar segment manipulation and available bone influence the approach selected.

Bilateral condylar malunion usually results in anterior open bite and class II jaw relationship. This is best treated in the same way as a developmental high angle class II anterior open bite, utilizing standard orthognathic and if necessary orthodontic techniques. This approach effectively accepts the reduced ramus height and therefore a reduced posterior face height. The correction is achieved by adjusting the maxilla to accommodate this reduced posterior face height by carrying out a posterior maxillary impaction. This results in an increase of the occlusal plane angle, but this is of little significance and will result in a stable correction of the anterior open bite component of the deformity, as a consequence of mandibular autorotation. Mandibular autorotation will also result in a degree of anterior mandibular projection and this may be sufficient to correct the mild class II skeletal relationship. The degree of anterior projection as a result of autorotation may be assessed preoperatively by surgical simulation.

**Fig. 24.24:** Bimaxillary osteotomy to treat anterior open bite and mandibular asymmetry following bilateral condylar fracture. See Fig. 24.21 for preoperative clinical appearance. (a,b) Pre and postoperative lateral cephalograms.
using an anatomical articulator. If autorotation is insufficient to correct anteroposterior discrepancy, then bilateral sagittal split mandibular advancement is indicated. As in orthognathic cases, in some patients addition of advancement genioplasty may enhance the esthetic result and improve lip competence where needed.

Operative technique

Unilateral

Access is gained via a posterior intraoral buccal sulcus incision or submandibular, retromandibular (see Fig. 24.22b) or preauricular extraoral incisions. Depending on the technique chosen, the old fracture line is osteotomized or a ramus osteotomy carried out distant from the fracture site (see Fig. 24.22c). Once this has been done, temporary, intraoperative intermaxillary fixation with an occlusal wafer is applied (see Fig. 24.22d). Following this, posterior and upward traction on the proximal fragment will keep the condyle in its retruded position. The condyle may be located in the glenoid fossa or outside the confines of the glenoid fossa if dislocated. In this situation, intraoperative judgment of the correct condylar position is a little more difficult but the surgeon should err on the side of overcorrection if doubt exists. This maneuver will reveal the extent of the ramus height deficit. If direct fracture osteotomy or inverted L osteotomy has been carried out, a suitably sized bone graft is inserted into the osteotomy gap and internal fixation applied. If vertical ramus osteotomy or sagittal split has been carried out, no bone graft is necessary and having repositioned the proximal segment, fixation is applied (see Fig. 24.22e). In some cases of unilateral injury, a contralateral sagittal split osteotomy may be required in order to achieve the preplanned occlusion. This can be assessed preoperatively using an anatomical articulator and intraoperatively, when the occlusion can be assessed following osteotomy on the injured side. If a satisfactory occlusion is achieved, contralateral osteotomy may be unnecessary. If satisfactory occlusion cannot be achieved contralateral osteotomy must be carried out.

Bilateral

Posterior maxillary impaction, mandibular autorotation and advancement are well described in the orthognathic literature and the use of these techniques in a posttraumatic situation usually demands little or no modification (Figs 24.23, 24.24).

Outcome

The techniques described are effective in correcting the esthetic and functional problems associated with posttraumatic malocclusion. In a study of 21 patients, Becking et al\(^41\) reported stable dental and cephalometric results in 20 patients. Similarly, Spitzer et al\(^42\) reported occlusal correction and normal mandibular movement in a group of 14 patients. Rubens et al\(^40\) presented four cases with successful outcome, including correction of occlusion and resolution of temporomandibular joint and muscle pain.

Traumatic tissue loss

Severe posttraumatic tissue loss is uncommon in civilian practice. It may occasionally be encountered following gunshot injuries.
Fig. 24.25: Road traffic accident with severe lower third facial injury involving bilateral mandibular fracture, severe soft tissue disruption and complete traumatic glossectomy. (a,b) Appearance on presentation. (c) Tracheotomy, plating of fracture and soft tissue repair, defect in floor of mouth dressed with Whitehead varnish pack. (d) OPG showing mandibular fixation.
Fig. 24.25: (e) Radial forearm free flap to repair floor of mouth and tongue defect. (f,g) Avascular necrosis of right mandibular body treated by removal of fixation, debridement and application of external fixator. (h) Mandibular defect following non-union. (i) Reconstruction with DCIA free vascularized bone flap.
Fig. 24.25: (j) OPG showing mandibular reconstruction. (k) Endosseous implants placed into DCIA bone graft. (l) Lingual movement of lower incisors due to lip pressure following loss of tongue. (m) Appearance following orthodontic treatment using implants as anchorage. (n) Intraoral appearance of radial forearm flap. (o) Facial appearance at commencement of orthodontic treatment.
wounds, high-speed road traffic accidents or industrial accidents. Often there is a combination of hard and soft tissue loss demanding a variety of primary and secondary reconstructive techniques with multiple operations in order to restore lost form and function. Initial management usually follows traditional principles of trauma management and subsequent correction may involve pedicle or free tissue transfer to replace hard and soft tissue. The recent development of osteogenic distraction in the craniofacial skeleton gives another option for replacement of tissue deficits along with their closely associated soft tissues. Each case will be different and must be planned and treated on its own merits, but Figure 24.25 shows a case which illustrates many of the principles and problems involved in these patients.

References

2. Tessier P 1971 Total osteotomy of the middle third of the face for faciosynthesis or for sequelae of Le Fort III fractures. Plastic and Reconstructive Surgery 48: 533