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ORIGINAL RESEARCH—FACIAL PLASTIC AND RECONSTRUCTIVE SURGERY

The secondary correction of post-traumatic craniofacial deformities

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OBJECTIVE: To analyze the aesthetic and functional outcomes in a large series of patients who underwent secondary correction of post-traumatic craniofacial deformities (PTCD) and to highlight the underlying principles and formulate treatment guidelines.

METHODS: A single surgeon's retrospective case series of 57 patients who underwent correction of PTCD.

OUTCOME MEASURES: Evaluation by multiple surgeons who assessed aesthetic results and functional parameters after secondary correction of PTCD.

RESULTS: A good to excellent aesthetic outcome was achieved in the majority of patients. Traumatic telecanthus, enophthalmos, and occlusal deformity were the deformities most refractory to secondary correction. Aesthetic results were adversely affected by the severity and number of pre-existing abnormalities and by the presence of established deformities (beyond 6 to 12 months).

CONCLUSIONS: The basic principles of treatment include an initial major osseous reconstructive surgery to restore an anatomically correct craniofacial architecture followed by selective ancillary procedures to address soft tissue deficits and functional deformities. Soft tissue deformity is the major deterrent to achieving an ideal outcome.

Experienced surgeons recognize the challenge of restoring premorbid form and function to patients with established deformities after craniofacial trauma.[1,2] The factors that lead to persistent deformities after craniofacial trauma include severe comminution (especially that which requires bone grafting), lack of definitive treatment, excessively delayed initial treatment, and inadequate initial surgical repair. For a variety of reasons, trauma patients can experience unsuccessful initial management and the associated morbidities of a post-traumatic craniofacial deformity (PTCD) that would benefit from secondary correction.

The majority of such patients demonstrate craniofacial abnormalities across multiple adjacent anatomic sites. Clinical classifications of PTCD have traditionally followed the descriptions used for acute facial fracture patterns[3-5]; however, we classified the late deformities by anatomic regions: 1) frontobasilar, 2) nasoethmoid, 3) periorbital, and 4) maxillary-mandibular.

The purpose of the present case series was to review our experience in the surgical management of patients with PTCD. Given the broad subject, we limited our study to the aesthetic and functional results of secondary correction of anatomic skeletal deformities.

METHODS

Fifty-seven patients underwent procedures with a single surgeon (YD) to correct residual deformities after craniofacial trauma over a 10-year period from August 1997 to August 2007. Aesthetic and functional outcomes were assessed by multiple surgeons familiar with the management of maxillofacial trauma. Deformities were grouped according to the classification scheme proposed above. IRB approval was obtained for this study.

RESULTS

The study group included 42 males and 15 females who ranged in age from 18 to 69 years (mean age, 38.2 years). The initial fracture pattern was isolated to one skeletal region in 23 of 57 patients, involved two sites in 15 of 57 patients and three or more craniofacial sites in 19 of 57 patients (Table 1).

At the time of original trauma, management ranged from no treatment in five patients, closed reduction with or without maxillary-mandibular fixation in 14 patients, and the remaining 38 patients underwent open reduction internal fixation (ORIF).

The late skeletal deformities under consideration are categorized into groups based on common problems that require secondary correction (Table 2). The timing of secondary reconstruction was such that a range of 4 weeks to 16 years lapsed from the original injury to the first recon-

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Table 1
Number of fractures by anatomic site at the time of original injury

Fracture site	Number of original fractures
Anterior skull base	8
Frontal/fronto-orbital	18
Naso-orbito-ethmoid	19
Orbitozygomatic	24
Midface LeFort I	14
Lefort II	8
Lefort III	5
Palatoalveolar	3
Mandible	11

structive procedure with a median delay of 15.8 months. The various skeletal procedures performed are described in Table 3. A variety of ancillary procedures, such as septorhinoplasty, soft tissue augmentation, midfacial suspension, scar revision, canthoplasty, lacrimal system stenting, lipotransfer,[4] and browplasty were performed either in conjunction with the skeletal reconstruction or during later revisions.

The overall aesthetic results were subjectively judged to be good or excellent in 45 of 57 patients and fair or unacceptable in 12 of 57 patients. Factors that predispose to a less favorable outcome include established defects (beyond 1 year), nasoorbitoethmoid location of the deformity, and associated soft tissue deformities. The mean time lapse from the initial injury to the secondary reconstructive surgery averaged 57 months in patients with less favorable outcomes versus 32 months for all patients within this series. Finally, although 38 ancillary procedures were targeted to correct soft tissue deformities in 32 patients, good or excellent results were obtained in only 19 patients. The most conspicuous residual soft tissue defects included scarring (both cutaneous and subdermal) and tissue atrophy. An illustrative case example is noted in Figures 1 through 7.

Table 2
Post-traumatic deformities categorized by site

Site	Deformity	Number of patients
Frontal	Contour deformity	12
Naso-orbito-ethmoid	Telecanthus	4
	Dorsal collapse	9
	Nasal deviation	15
Periorbital	Fronto-orbital deficiency	6
	Enophthalmos	12
	Hypophthalmos	2
	Orbitozygomatic asymmetry	18
Maxillary-mandibular	Midface deficiency	12
	Malocclusion	14

Table 3
Types and number of skeletal surgical procedures performed

Procedure	Number
Frontobasilar augmentation cranioplasty	11
Reduction cranioplasty	1
Sinus obliteration	6
Nasoethmoid telecanthus repair	4
Dorsal augmentation	9
Peri-orbital front-orbital augmentation	4
Fronto-orbital advancement	2
Orbital osteotomy	5
Orbital grafting floor	12
Walls/roof	5
Rims	5
Zygomatico-orbital segmental osteotomy	12
Complex arch reconstruction	3
Augmentation malarplasty	14
Reduction malarplasty	3
Maxillary osteotomy	11
bone grafting	4
Mandibular osteotomy	8
bone grafting	2

Postoperative complications were encountered in 17 patients and were considered minor in nature. Early problems most commonly included wound infection and wound dehiscence. Wound problems resolved with conservative measures. More serious early complications were related to transcranial osteotomies during secondary correction procedures. A single case of cerebrospinal fluid leak resolved with nonsurgical management, and all cases of early neurologic deficits resolved entirely within 2 months.

The most frequent late adverse effect was resorption of autogenous bone grafts, noted in four patients with periorbital onlay grafts. Other late complications include eyelid retraction or malposition in five patients, temporal wasting in seven patients, and alopecia along the scalp incision in four patients. Notably, every patient who experienced alopecia also underwent Reine clip application during coronal approach.

DISCUSSION

Although case reports exist, very few attempts to quantify and critically assess a large series of patients with PTCD are available in the literature. Our experience reported here presents a comparatively large number of cases of PTCD from which several distinct patterns emerged and from which treatment guidelines can be suggested.[2-9]

The timing of intervention and the status of the overlying soft tissue envelope are two key principles that, based on our review, deserve special discussion in every case of PTCD for which secondary correction is considered.

Our data support the concept that earlier correction of PTCD yielded better facial form than treatment of more

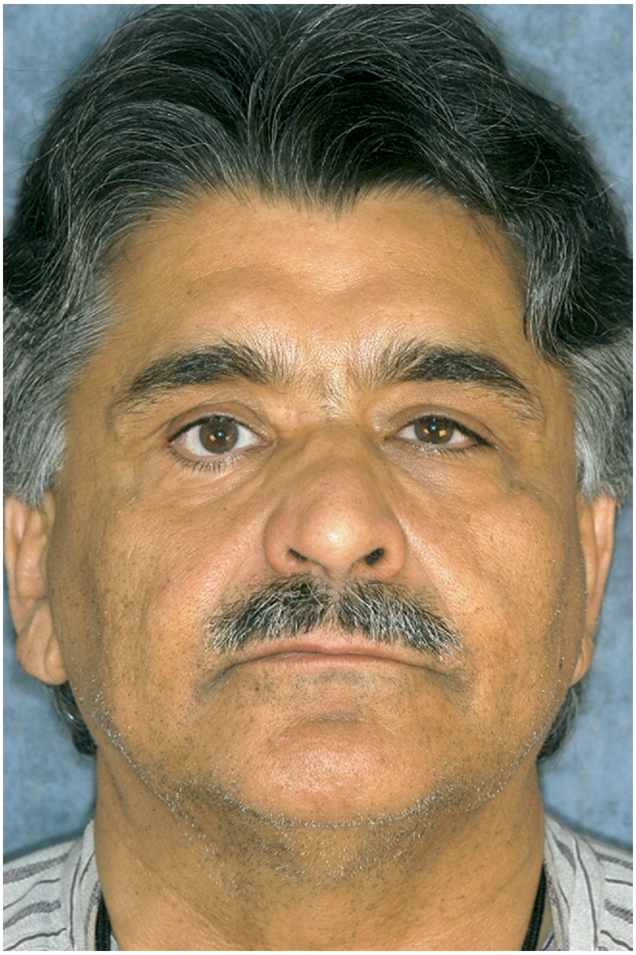

Figure 1 Preoperative frontal view of patient 3 years status post-ORIF right orbitozygomatic fracture elsewhere. Note flattening of malar eminence, increased orbital volume.

established deformities, particularly when performed within 3 to 6 months of the acute injury. Beyond 1 year, the timing of repair has much less or no influence on the eventual aesthetic and functional outcome. Our findings parallel sim-

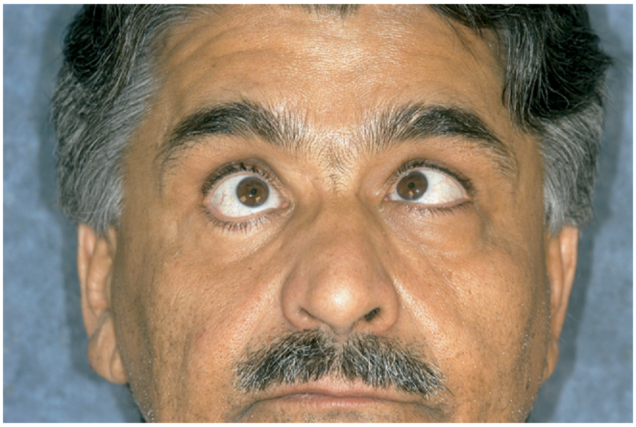

Figure 2 Preoperative view with gaze to right demonstrates extraocular muscle entrapment.

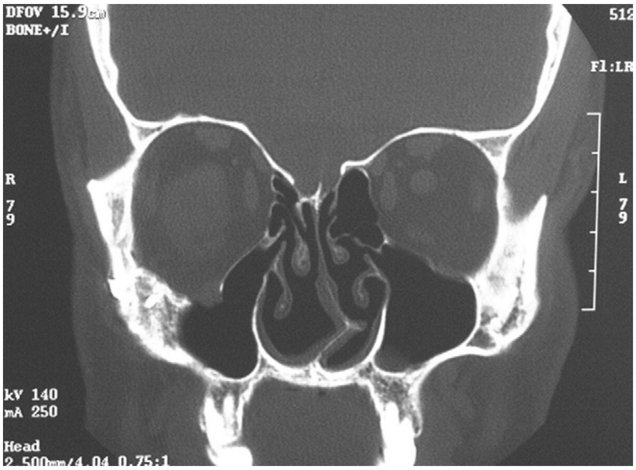

Figure 3 Preoperative CT scan in the coronal plane demonstrates rotated malpositioned right zygoma and entrapped inferior rectus muscle with increased orbital volume.

ilar observations by other authors and are most likely related to the gradual scarring and adaptation of the overlying soft tissues to an altered skeletal framework.[3] This process occurs over a period of roughly one year and, when established, imparts substantial resistance to the repositioning of displaced bony segments. Furthermore, the increased tension exerted by a scarred soft tissue envelope on the repositioned bony segments increases the risk of bone resorption.

Earlier operations enable a more accurate preoperative assessment of the extent to which the skeletal deformity results from skeletal malposition versus bone resorption. Abnormal contours that result from intact but improperly located bone segments are best corrected by refracture osteotomies, anatomic reduction, and rigid fixation. Predictable results can be achieved when such operations are performed within the first few months after an injury. Beyond this early period, bony remodeling often dictates that the osteotomies that best repair the established skeletal defor-

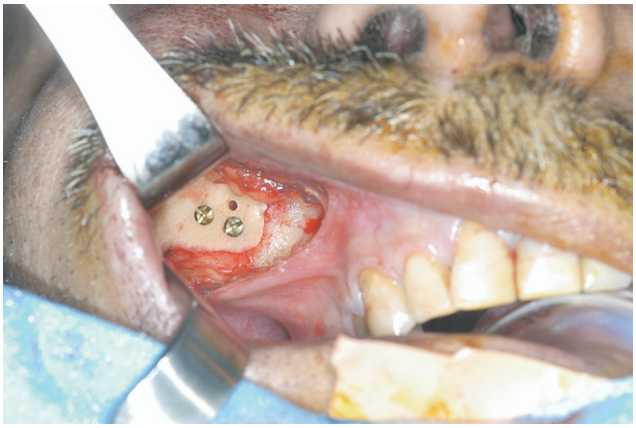

Figure 4 Iliac bone graft fixated with lag screw technique to the maxilla after refracture osteotomy to mask persistent loss of volume due to remodeling.

Figure 5 Endoscopic midface soft tissue envelope suspension.

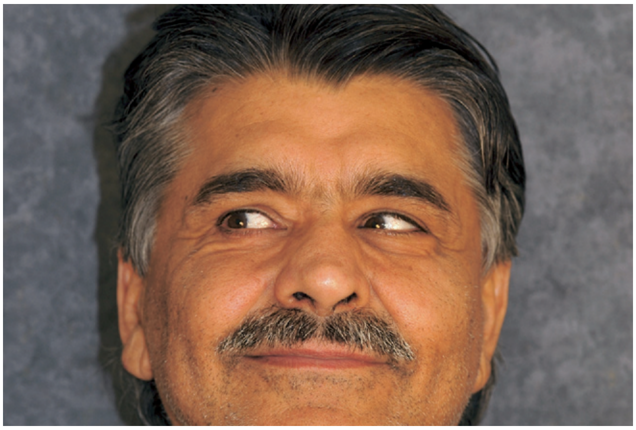

Figure 7 Postoperative view demonstrates re-establishment of extraocular motility on gaze right.

mity often differ somewhat from the original fracture pattern. This is especially true if a combined intracranial-extracranial or an occlusal altering procedure is being contemplated.

Bone loss typically follows cases with significant comminution and displacement owing to resorption of poorly vascularized or inadequately fixated fragments. In these cases we favor passive insertion of grafts into bony gaps after the adjacent osseous segments are spanned by rigid plate fixation, thereby preventing compressive loads from potentially inducing bone resorption. The bone grafts are secured to either the metal plates or the remaining bony segments with lag screw techniques and at least two screws in each graft so as to immobilize the grafts, prevent torsion, and minimize bony resorption. We favor iliac bone grafting over calvarial or costal sources due to the availability of iliac bone in large quantities, its moldable nature in adults, and the accessibility of cancellous bone for packing around osteotomy sites. In this series, of the four cases of significant graft resorption, three involved calvarial bone whereas only one implicated an iliac bone graft.

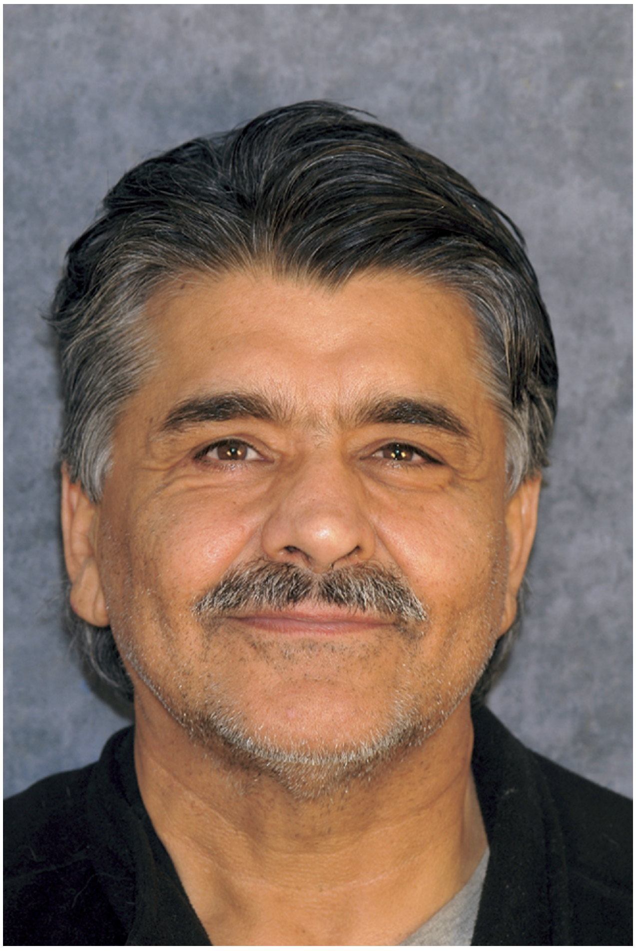

Figure 6 Postoperative frontal view demonstrates improved midfacial volume and support as well as improved apparent orbital volume.

Contour abnormalities, particularly of the malar, frontal, and nasal regions, are amenable to simple augmentation or reduction procedures. We have had favorable experiences with autogenous lipotransfer, hydroxyapatite cement, or alloplastic implants composed of porous polyethylene, expanded polytetrafluoroethylene and silicone facial implants in the aesthetic refinement of PTCDs, with or without segmental repositioning and bone grafting.[10-14] These surgical options must be considered in concert with a patient's aesthetic goals, risk profile, and the tissue quality of the recipient bed.

Our results support the following recommendations pertaining to specific subsites within the craniofacial skeleton:

Frontal: Reconstruction of the frontal region with augmentation procedures predictably improves contour deficiencies. Our experience with iliac bone grafts revealed less resorption over time when compared with calvarial bone grafts. Hydroxyapatite cement is a reasonable alternative but should be used with caution in the frontal sinus region and should generally not be placed in contact with this sinus.[14] When intracranial access is required to facilitate orbital osteotomies, one can consider a frontal calvarial remodeling procedure to advance depressed frontal segments. Simple non–bone-containing titanium mesh cranioplasty is also a reasonable alternative. Bony frontal protuberances are easily treated by reduction contouring. Obliteration of the frontal sinus is recommended if there is a history of recurrent frontal sinusitis or where a mucocele has developed.[15,16] In our series, 10 frontal sinuses required obliteration. A pericranial flap was used in 80 percent of frontal sinus obliterations, and this remains our preferred technique except in cases of frontal region soft tissue trauma that renders the pericranium unusable. Autologous fat grafts (10%) and cancellous bone grafts (10%) are used when a pericranial flap is not a viable option.

Naso-ethmoid: The principal skeletal deformities encountered in this region include telecanthus and dorsal nasal collapse. Invariably there are also associated nasal problems such as deviated bony nasal pyramids, vestibular stenosis, internal nasal valve collapse, tip deformities, and airway obstruction. In managing telecanthus, it is useful to determine the extent to which various underlying factors are playing a role in each individual case. Important considerations are the anatomy and location of the remaining nasoethmoid bony complex and whether or not the displaced medial canthal tendon has retained its bony insertion. In all cases, a transnasal fixation procedure is critical to normalize the intercanthal distance and prevent late telecanthus. Transnasal fixation can be achieved either with wire or suture between canthal-bearing bone segments of the medial orbital wall or directly to the canthal complex itself. If the tendon complex has lost its bony insertion, then this should be re-established and, in cases of absent bone along the lacrimal crest, the tendon must be pulled through bone grafts and secured with a mini–bone anchor to achieve a solid and reliable repair.[17] Our data indicate that transnasal canthopexy alone does not always provide an ideal correction, particularly when significant displacement of the nasoethmoid-medial orbit is present. In such instances, segmentalization with medial repositioning of the canthal-bearing segment is necessary in addition to a transnasal canthopexy, and the technical difficulty of such techniques should not be underestimated.

Camouflage can play an important role in diminishing the appearance of telacanthus. Recognizing that dorsal nasal deficiency will accentuate the appearance of telecanthus, we have used dorsal nasal augmentation to enhance the nasal profile and diminish the appearance of increased intercanthal distance.

Orbitozygomatic: Displacement of the orbitozygomatic complex was most common in a posterior, inferior, and lateral direction as shown in our series and reported by others.[5] The resultant midfacial asymmetry includes increased facial width and deficient malar projection on the affected side. In comminuted cases, bone resorption may contribute to the malar depression. Orbitozygomatic deformities that are of minor severity are nicely managed with augmentation or reduction procedures to camouflage the asymmetry. These contouring methods are particularly useful in cases where such a technique can obviate the relatively greater morbidity of refracture osteotomy and repositioning. Adjunctive soft tissue resuspension with an endoscopic midface lift is often also helpful in optimizing the aesthetic result. More severe cases, however, will require repositioning of the displaced bony segments and bone grafting to restore lost bony structure. When performing refracture osteotomies of the zygomatic complex, one often encounters difficulty in mobilizing and repositioning the zygoma segment, a problem that in established deformities may well be related to soft tissue tethering. Therefore, it is important to completely free the zygoma of all soft tissue attachments, including the masseteric insertion. Multiple site fractures with comminution present real difficulties in reconstruction due to the lack of intact reference points on which to base accurate orbitozygomatic repositioning. Some authors have recommended an "outside-in" approach that uses reconstruction of the zygomatic arch as the first step in re-establishing proper midfacial dimensions.[18-20] In practice, however, we have found that although the arch can be restored fairly accurately in an anteroposterior dimension, correct spatial orientation in the transverse plane is not reliable when the surrounding reference points are missing. Alternatively, restoring lateral projection of the malar complex can, in most cases, be accomplished by anatomic reduction along the greater wing of the sphenoid in the lateral orbit. If this reference is lost, as in severely comminuted cases, then we feel that an "inside-out" approach starting at a stable medial landmark, such as the occlusion, and sequentially repositioning fragments in a lateral direction yields proper midfacial width.

The most complex periorbital fractures result in orbital dystopia with 4-wall orbital displacement. Vertical orbital dystopia is an uncommon sequela after craniofacial trauma and requires an intracranial-extracranial approach to perform a box osteotomy, resection of a supraorbital bar, and elevation of the orbital segment including the orbital roof.

Late enophthalmos results from an absolute increase in the bony orbital volume and a smaller contribution from associated soft tissue factors. Orbital volume increases are manifest primarily by orbital floor defects with loss of the retrobulbar convexity while herniation of orbital fat, entrapment of periorbital or extraocular muscles, and fibrosis of soft tissues contributes to a decrease in orbital contents and subsequently abnormal globe position.[1-3,5,8] Ocular dystopia that result from the aforementioned complications must be distinguished from vertical orbital dystopia in which case the entire bony orbit, including the orbital roof and supraorbital rim, is inferiorly displaced.

The principles in correcting enophthalmos are as follows: 1) circumferential dissection of the periorbita to free all soft tissue attachments to bone and facilitate forward displacement of the globe, 2) full dissection of the entire bony defect with complete visualization of all margins, 3) reduction of herniated contents back into the orbital cavity while entrapped soft tissue, 4) segmental osteotomy with repositioning to restore normal orbital volume, and 5) restoration of orbital wall defects with internal orbital implants supported by remaining stable bone. When repairing orbital wall defects, it is crucial to place implants posterior to the axis of the globe and respect the normal retrobulbar convexity during orbital floor reconstruction. Alloplasts such as porous polyethylene or titanium mesh are useful in cases of enophthalmos repair. Although autologous bone grafts are a viable option for orbital reconstruction, we prefer alloplastic materials for their greater malleability and ease of replicating the contours of the bony orbit and avoiding the need for additional graft harvest as well as late graft resorption.

Maxillary-mandibular: The overriding consideration in correction of jaw abnormalities is restoration of the premorbid occlusion. When correcting malocclusion that result from malunion, we found that resorting to osteotomy designs different than the original fracture pattern yielded a better final result.[9] Mandibular nonunion responds well to debridement of the original fracture with realignment of the occlusion, cancellous bone grafting, and locking plate fixation. Maxillary deformities following LeFort fractures most commonly demonstrate midface retrusion, decreased midfacial height, anterior open bite, and mandibular overclosure secondary to posterior displacement of the maxilla, anterior cephalad telescoping, and the inferior pull of the pterygoid musculature on the fractured pterygoid plates. LeFort I osteotomy and repositioning, regardless of the original midfacial fracture pattern, is generally the easiest solution to correct a malocclusion. When planning occlusal correction, careful attention to the transverse dentoalveolar relationships will allow one to determine if segmental osteotomies of the maxilla are required to correct posterior crossbites. Our results identified malocclusion as one of the more refractory deformities to correction. In particular, open bite deformities with crossbites were problematic. This difficulty relates to the fact that none of the patients, for a variety of reasons, underwent preoperative orthodontic preparation to reverse the changes in dentoalveolar tooth positions that occur as a response to malocclusion. Nonetheless, attempting improvements in severe malocclusion, even if the ideal bite is not achieved, is warranted so as to improve masticatory function and create a better biomechanical environment for the mandible.

Functional Deficits

Functional deficits can be grouped into three major physiologic systems for consideration and treatment planning: 1) ophthalmologic, 2) sinonasal, and 3) masticatory. Very often, functional deficits may be a patient's chief concern, and several ancillary procedures were shown to substantially improve function.

The most common ophthalmologic deficit amenable to treatment is diplopia, and this problem derives more from extraocular eye muscle (EOM) function than globe position alone.[2] The inferior rectus and superior oblique muscles are the EOMs most frequently involved by post-traumatic and postsurgical scarring. The principles of correction generally involve creation of a stable and rigid orbital architecture followed by delayed EOM surgery. Craniofacial surgery to correct malpositioned periorbital bony segments may exacerbate diplopia or induce it in cases where none existed previously, and patients should be counseled with respect to this possibility. Lacrimal drainage obstruction, although rather frequent in the first few months after trauma to the periorbital region, tends to resolve in the vast majority of cases so that persistent exophoria and dacrocystitis were uncommon in our series (2 patients).

Functional problems of the sinonasal system tend to derive from obstruction of either the nasal airway or the paranasal sinuses. Septorhinoplasty and endoscopic sinus procedures were successfully applied in the management of these problems.

Masticatory dysfunction, as reviewed above, is primarily related to malocclusion; however, diminished mandibular movement can also seriously impair oral function. Trismus may result either from temporomandibular joint (TMJ) dysfunction or impingement of the coronoid process on a displaced zygomatic component. Coronoid impingement can be corrected by orbitozygomatic repositioning or transoral coronoidectomy if a repositioning procedure is not being considered. TMJ dysfunction requires careful consideration of multiple factors and management can include a variety of techniques that include: occlusal equilibration, occlusal splints, comprehensive physiotherapy, and surgical procedures (including replacement) of the TMJ. Consultation with a clinical unit experienced with TMJ dysfunction is advisable when addressing this cause of masticatory deficits.

CONCLUSIONS

Correction of post-traumatic craniofacial deformities constitutes a challenging but worthwhile endeavor. Careful preoperative assessment, establishment of reasonable reconstructive goals, and detailed surgical planning are critical to ensure the best possible outcome. The basic principles of treatment include an osseous reconstructive surgery as early as possible to restore the anatomically correct craniofacial architecture followed by selective ancillary procedures to address soft tissue deficits and functional deformities. Deformities are classified into groups with common reconstructive considerations based on anatomic subsites (frontobasilar, nasoethmoid, periorbital, and maxillary-mandibular). Soft tissue deformities typically manifest as scarring, malposition, and tissue loss and, in many cases, soft tissue complications represent the most significant deterrents to achieving an ideal outcome.

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FINANCIAL DISCLOSURE

None.

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