The Versatility of Distraction Osteogenesis in Craniofacial Surgery

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Objectives: To review our preliminary results using distraction osteogenesis for the correction of craniofacial deformities and to determine its role in treating anatomic deformities and functional deficits relative to conventional craniofacial surgery.

Design and Setting: Retrospective clinical review; tertiary care center.

Methods: Twenty-four consecutive patients were treated with distraction osteogenesis during a 34-month period. Outcomes were compared with preexisting anatomic deformities and functional deficits using records of clinical assessments, photodocumentation, diagnostic imaging, and treatment planning aids.

Main Outcome Measures: Distraction achieved vs planned distraction based on clinical and radiographic assessment, clinical status of functional deficits before and after treatment, and objective rating of aesthetic improvement.

Conclusions: Preliminary results demonstrated good-to-excellent outcome in correcting facial skeletal deformity in 80% of patients. Functional outcomes included resolution or significant improvement of upper airway obstruction in 13 of 14 patients and correction of corneal exposure for all 5 patients with pre-existing exorbitism. Correction of malocclusion was less reliable. Problems related to the distraction devices, including failure of the advancement mechanism and fixation, were the most prevalent complications. Distraction osteogenesis represents an exciting new development in craniofacial surgery with several potential benefits, including less invasive surgery, the ability for earlier intervention, and the potential for correction of more severe deformities with improved posttreatment stability. The exact role of distraction osteogenesis relative to conventional techniques requires ongoing assessment.

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Although orthopedic surgeons have used distraction osteogenesis (DO) for several decades to repair long bone defects, the procedure is only now gaining acceptance for correction of craniofacial deformities. Bone distraction was first introduced by Codvilia nearly 100 years ago and subsequently popularized during the 1940s by Ilizarov, who developed a single-stage procedure to lengthen long bones without the use of grafting material. The feasibility of applying Ilizarov's principles to different craniofacial deformities was not considered until several decades after his pioneering work in the peripheral skeleton. Strictly speaking, the first reports of craniofacial DO were in the early 1960s, at which time rapid expansion of the palate was carried out in growing subjects; however, this involved distraction of a naturally occurring growth interface. Therefore, it was not until 1973, when Snyder et al described the Ilizarov technique to lengthen a canine mandible, that DO was first applied to surgical osteotomies of the facial skeleton. Interest in craniofacial distraction was slow to grow initially, with sporadic experimental reports appearing throughout the ensuing 2 decades. However, in the early 1990s, experimental investigation intensified following reports that examined lengthening canine mandibles and the use of DO to successfully close canine segmental lower jaw defects. Thereafter, several studies demonstrated the ability to apply osteodistraction at several different sites, including the mandible, lower maxilla, midface, and cranial vault, within a variety of animal models. The first clinical results of craniofacial DO were reported in 1992 by McCarthy et al in a small series of patients with congenital mandible deformities. Since then, several larger series with longer follow-up periods have appeared. More recently, the technique has been successfully used for midface and upper craniofacial skeletal defects.
PATIENTS AND METHODS

A medical record review was conducted to identify all patients who had undergone DO within the craniofacial skeleton since we began using this technique. A total of 24 patients who were treated during the 34-month period from March 1, 1997 to December 31, 1999, were identified and formed the case series for this study. Each patient underwent a comprehensive preoperative assessment, including clinical examination, photodocumentation, and appropriate diagnostic imaging. Cephalometric and Panorex x-ray films were used in 19 patients, and in 15 individuals computed tomographic (CT) scans with 3-dimensional reconstruction were obtained. Dental study casts were fabricated from impressions in 18 patients, and in 6 cases acrylic replicas of pertinent facial skeletal segments were constructed from preoperative CT scans. The preoperative data were analyzed to define the nature of the deformity and the objectives and goals of the reconstructive procedure being contemplated. The value of DO was weighed relative to other surgical options before selecting DO as the reconstructive procedure of choice. Skeletal tracings were used in most cases to plan the necessary osteotomies and desired vector of distraction.

The distraction procedures included 6 midface and 29 mandibular osteotomies with a total of 40 distraction devices inserted. Several designs are available from the various suppliers, and the devices used in this series are shown in Figure 3. Distraction devices can be broadly grouped into internal or external types based on the location of the main body of the distraction mechanism. Different designs are suited to different applications, and careful consideration is required to ensure that the appropriate device is selected for a given clinical situation.

The underlying principle of DO, as described by Ilizarov, is “the mechanical induction of new bone between bony surfaces that are gradually distracted.” The process of DO begins with careful preoperative assessment and planning, which are critical to success. During the initial surgery, osteotomies are performed and the distraction device is inserted. A waiting period (latency phase) is allowed to elapse so that osseous healing is initiated at the bony gap, periosteal integrity is restored, and callus formation begins. The bone segments at either end of the gap are then progressively distracted over several days (distraction phase) during which osteogenesis is induced, producing a so-called regenerate of immature bone laid down between the cut bone ends. With time, the bone remodels into a more mature state (consolidation phase), and the surrounding soft tissues accommodate to their new positions and lengths.

Distraction can be divided into either elongation DO or transport DO, depending on whether a foreshortened bone is being increased in length (elongation) or a segmental defect is being repaired within a bone that is otherwise of normal length (transport). In addition, DO has been categorized into monofocal, bifocal, and trifocal types, depending on the number of foci at which osteogenesis occurs (Figure 1). Monofocal elongation DO currently represents most of the clinical applications in the craniofacial skeleton. The histologic and physiologic principles that underlie DO have been well documented in long bones and more recently in the craniofacial skeleton. During the distraction phase, bone formation occurs in response to the tension-stress forces exerted on the regenerate, and healing proceeds primarily by a reparative membranous ossification process (Figure 2). The middle of the regenerate consists of a fibrous central zone where osteoid is deposited with collagen fibers oriented parallel to the direction of distraction. Ossification occurs as a primary mineralization front advances from either end of the fibrous central zone, resulting in a bridge of immature bone across the distraction gap. Bone modeling begins during the consolidation phase and continues throughout a 1- to 2-year period, eventually transforming the regenerate into a mature osseous structure similar in size and shape to the adjacent preexisting bone. Although the volume and architecture of the new bone are comparable to the adjacent bones, animal studies have shown that mineral content and radiodensity are less. The tensile strength of the regenerated segment is approximately 75% of the native bone. In addition to bony changes, there are effects on the adjacent soft tissues that occur in response to osseous distraction. Muscle and soft tissue mass increases via a process referred to as distraction histogenesis. Clinically, this offers a distinct advantage since several craniofacial anomalies have soft tissue

Latency time ranged from 4 to 7 days after placement of the devices, and in general a shorter waiting period was used in the younger patients. Perioperative antibiotics were used in all cases. During the distraction phase, all the devices were advanced at the rate of 1 mm per day. Turnings were performed twice daily (0.5 mm each time) if possible and once daily (1.0 mm) if the former was not convenient. Once the distraction was completed, the devices were left in place from 4 to 17 weeks with a mean of 8.3 weeks. The consolidation time was determined by considering the site of distraction, the magnitude of distraction, and the presence of any adverse bone healing factors. In addition, weekly radiographs were obtained to semiquantitatively assess mineralization of the regenerate. Following consolidation, all the devices were removed in a second operative procedure and patients were monitored periodically in clinic.

For each patient, the results were reviewed with consideration of the following variables: planned vs actual distraction (magnitude and direction) achieved, improvement in facial form measured using an objective semiquantitative scale, and functional improvements. The magnitude of distraction was ascertained from radiographic monitoring and clinical measurement using reliable reference surface landmarks such as the dentition wherever applicable. Functional evaluation included assessment of sinonasal symptoms (obstruction, sinusitis, sleep disturbances), ophthalmologic symptoms (congenital cataract, lacrimal drainage, visual disturbances), and masticatory function (occlusion, mandibular movement). The nature of any complications and their outcome were also noted. Data were then analyzed to formulate relevant observations and conclusions regarding the clinical utility of craniofacial DO based on our experience.
Figure 1. Three types of distraction osteogenesis have been described: monofocal, bifocal, and trifocal. A. Monofocal distraction is used to lengthen abnormally shortened bones and involves separation of 2 bone segments across a single osteotomy. B. Bifocal distraction is used to repair a segmental defect and requires creation of a transport disk, which is then distracted across the defect until it docks with the opposing bone segment. C. Trifocal distraction is similar to bifocal distraction attempts to halve the distraction time by transporting 2 disks from opposite ends of a defect to dock in the middle. Arrows indicate distraction vectors; large arrow heads, distraction regenerate; and small arrow heads, docking site. Reprinted from Costantino PD, Shybut G, Friedman CD, et al.10(p44)

Factors that affect bone healing can be local or systemic in nature. Viability of osteocytes and osteoblasts is essential to provide sufficient osteogenic capacity to form a viable regenerate. The functional level of the regenerated neurovascular structures, however, was less than normal.

Several factors influence the physiologic process of DO, and these can be separated into 2 basic groups: bone healing factors and distraction factors as outlined here:

<table>
<thead>
<tr>
<th>Local Factors</th>
<th>Systemic Factors</th>
<th>Bone-Healing Factors</th>
<th>Distraction Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Osteoprogenitor supply</td>
<td>Age</td>
<td>Osteogenic cell production</td>
<td>Rate of distraction</td>
</tr>
<tr>
<td>Blood supply</td>
<td>Metabolic disorders</td>
<td>Osteocytic activity</td>
<td>Frequency of distraction</td>
</tr>
<tr>
<td>Infection</td>
<td>Vitamin D deficiency</td>
<td>Osteoclast activity</td>
<td>Latency period</td>
</tr>
<tr>
<td>Soft tissue scarring</td>
<td>Connective tissue disease</td>
<td>Osteoblastic activity</td>
<td>Rigidity of fixation</td>
</tr>
<tr>
<td>Bone stock</td>
<td>Steroid therapy</td>
<td>Osteogenetic activity</td>
<td>Adequate consolidation period</td>
</tr>
<tr>
<td>Prior radiation therapy</td>
<td>Calcium deficiency</td>
<td>Osteoinductive activity</td>
<td>Length of regenerate</td>
</tr>
</tbody>
</table>

Figure 2. Schematic representation of the stages of bone formation during distraction osteogenesis: (1) zone of fibrous tissue, (2) zone of bone mineralization, (3) zone of bone remodeling, and (4) zone of mature bone. Adapted from Karp et al.10(p7)

Successful osteogenesis, and therefore many advocated that a corticotomy-only bone cut be performed through a minimal periosteal opening. More recently, however, investigators have demonstrated that the periosteum alone can provide sufficient osteogenic capacity to form a viable regenerate in the well-vascularized membranous bone of the craniofacial skeleton. Therefore, although some clinicians continue to advocate corticotomy, most reports of craniofacial DO describe the use of a complete osteotomy, taking care to preserve as much of the surrounding periosteum as possible. Prior radiation therapy to the distraction site has been shown to not adversely influence the results of distraction in the canine model, and when using DO to repair segmental defects, the status of the surrounding soft tissues will likely be the key factor that influences outcome.

Latency, rate, and rhythm of distraction are variables that influence the quality of the regenerate. Of these factors, the effect of latency is the most controversial. Most craniofacial surgeons have empirically applied the conclusions from long bone studies and recommend waiting periods of 4 to 7 days following osteotomy and before initiating the distraction process. In younger children, the high rate of bone metabolism favors a shorter waiting period. Some clinicians, however, use a zero latency period and begin distracting right at the time of appliance insertion. They claim no adverse effects on outcome while substantially shortening the treatment period.

Waiting too long before distraction (beyond 10 to 14 days) substantially increases the risk of premature bone union. In contrast to latency, the rate and frequency (rhythm) of distraction are believed to be important factors. If widening of the osteotomy site occurs too rapidly (>2 mm per day), then a fibrous nonunion will result, whereas if the rate is too slow (<0.5 mm per day), premature bone union prevents lengthening to the desired dimension. These findings in long bones have been empirically applied to the craniofacial skeleton, and most studies have described a rate of 1.0 mm per day. According to Ilizarov's work in long bones, the ideal rhythm of DO is a continuous steady-state separation of the bone fragments. This is impractical from a clinical standpoint, and therefore, most reports recommend distraction frequencies of 1 or 2 times daily. The length of the consolidation phase has been recommended as ranging from 6 to 12 weeks in long bones, de-
pending on the length of the distraction segment. In the craniofacial skeleton, most authors advocate 4 to 8 weeks, with the general rule that the consolidation period should be at least twice the duration of the distraction phase. Distraction in load-bearing bones, such as the mandible, is an indication for a longer consolidation time. Finally, appliance rigidity during distraction and consolidation is a critical element to ensure that bending or shearing forces do not result in microfractures of the immature columns of new bone within the regenerate, which lead to focal hemorrhage and cartilage interposition.

We have been using DO since early 1997 for several indications within the craniofacial skeleton, including the correction of form and function. This study was undertaken to review our experience with DO and evaluate its role and future place in the management of the difficult challenges that craniofacial patients typically present.

RESULTS

Congenital deformities comprised most of the cases (22), whereas 2 patients had acquired defects. Table 1 gives the various underlying diagnoses present in the overall group. The youngest group consisted of 8 patients who presented with glossoptosis-micrognathia and upper airway obstruction as the main indication for distraction. These patients had a mean age of 32 months (range, 6 days to 5 years) and consisted of 6 individuals with isolated glossoptosis-micrognathia (3 with Pierre Robin sequence), 1 patient with Nager syndrome, and 1 patient with maxillomandibular synagnathia. Craniofacial dys-
ostosis patients (3 with Crouzon syndrome, 1 with Apert syndrome, and 1 with Pfeiffer syndrome) who required midfacial advancement had an average age of 5 years, whereas 6 patients with orofacial clefts and craniofacial dysostosis underwent distraction at an average age of 7.6 years. Follow-up in the overall group ranged from 6 to 36 months, with a mean of 14 months following the end of the consolidation phase.

The cases were separated into midface and mandible procedures (Table 2), and the actual length of distraction achieved was compared with the preoperative desired length. In 18 patients, the devices were turned the planned number of revolutions, and in 14 of these the desired length of distraction was fully achieved, whereas in the other 4 the distracted length was within 2 mm of the desired length based on radiologic follow-up. In 6 other patients, the devices could not be advanced the desired number of revolutions because of mechanical problems with the distraction devices (4), compliance problems (1), and soft tissue breakdown with device exposure at the osteotomy site (1).

Cosmetic results were rated objectively by the treating surgeon using an arbitrary scale of excellent, good, fair, or unsatisfactory. The results were tallied for 20 patients for whom aesthetic considerations were applicable, and the results were good to excellent in 80% of the group (Table 3). Midfacial advancements achieved the best cosmetic outcome (Figure 4). Most hemifacial microsomia patients were rated as good; however, within this group it was noted that lower face asymmetry was difficult to fully correct. Cosmetic results were less predictable in 8 patients, with symmetric mandibular deficiency ranging from fair to excellent (Figure 5 and Figure 6).

Functional deformities fell into 3 basic groups: airway obstruction, exorbitism (corneal exposure), and malocclusion. Airway obstruction was identified in 14 patients as follows: 8 individuals with obstruction as the main indication for distraction (6 with glossophtosis-micrognathia, 1 with Nager syndrome, 1 with maxillomandibular synagathia) and 6 patients in whom obstruction was an associated finding (5 with midfacial deficiency, 1 with Hallermann-Streiff syndrome). The group treated primarily for airway obstruction included 2 infants with glossophtosis-micrognathia who required urgent endotracheal intubation after birth for whom consultations were requested for tracheostomy to manage the airway. Both of these patients underwent external bilateral mandibular body distraction and eventually were successfully extubated, thereby avoiding tracheostomy. The remaining 6 patients had preexisting tracheotomies: 4 of these patients underwent decannulation, 1 was pending tube removal following unrelated surgery, and 1 has failed attempts at decannulation. All 5 patients who underwent Le Fort III advancement demonstrated some degree of preexisting oropharyngeal or nasopharyngeal obstruction and disturbed sleep patterns. Formal sleep studies were available for 3 of these patients before and after advancement, demonstrating resolution of moderate sleep apnea based on the respiratory index. One patient with Hallermann-Streiff syndrome noted subjective clinical improvement of associated airway obstruction. Exorbitism and varying degrees of problems with corneal exposure were present in all 5 patients with craniofacial dysostosis. Midface advancement was able to sufficiently improve corneal protection and decrease the conjunctival inflammation in these patients.

Malocclusion and related masticatory disturbances were the most prevalent functional problem in our group of patients, presenting in 16 of 24 patients overall. Unfortunately, they were also the most refractory to correction. In the 6 patients with maxillary deficiency, anteroposterior malrelationships ranged from moderate to severe class III skeletal disharmony. These patients underwent midfacial advancement and 3 were corrected to class 1, whereas the remaining 3, although substantially improved, were left with some degree of class III relationship (Figure 4). Hemifacial microsomia patients (6) presented with mild to moderate degrees of ipsilateral class II molar relationships, midline shift, and occlusal cant. Although the anteroposterior

| Table 1. Number, Age, and Diagnoses of Patients Included in the Study Group |
|---------------------------------|-----------------|----------------|
| Diagnosis                        | No. of Patients | Mean Age (Range) |
| Congenital anomalies             |                 |                 |
| Glossophtosis-micrognathia       | 6               | 27 mo (6-5 y)   |
| Crouzon, Apert, or Pfeiffer syndrome | 5           | 5 y (4-7 y)     |
| Hemifacial microsomia            | 6               | 7.6 y (5-11 y)  |
| Other                            |                 |                 |
| Treacher Collins syndrome        | 1               | 12 y            |
| Hallermann-Streiff syndrome      | 1               | 31 y            |
| Maxillomandibular synagathia     | 1               | 4.5 y           |
| Nager                            | 1               | 4.0 y           |
| Cleft lip or palate              | 1               | 14 y            |
| Acquired deformities             |                 |                 |
| Segmental mandible defect        | 1               | 52 y            |
| Bilateral condylectomies         | 1               | 56 y            |

<p>| Table 2. Distraction Procedures Performed and Lengths of Distraction |
|---------------------------------------------------------------|-----------------|-----------------|-----------------|</p>
<table>
<thead>
<tr>
<th>Procedure</th>
<th>No. of Patients</th>
<th>Mean Length of Planned Distraction, mm (Range)</th>
<th>No. of Distractions Achieved</th>
</tr>
</thead>
<tbody>
<tr>
<td>Le Fort III</td>
<td>5</td>
<td>23.7 (22-26)</td>
<td>5</td>
</tr>
<tr>
<td>Le Fort I</td>
<td>1</td>
<td>22</td>
<td>1</td>
</tr>
<tr>
<td>Bilateral lengthening</td>
<td>10</td>
<td>20.5 (12-30)</td>
<td>7</td>
</tr>
<tr>
<td>Unilateral lengthening</td>
<td>6</td>
<td>19.2 (16-26)</td>
<td>4</td>
</tr>
<tr>
<td>Segmental repair</td>
<td>2</td>
<td>22 (2-24)</td>
<td>1</td>
</tr>
</tbody>
</table>

<p>| Table 3. Cosmetic Results in 20 Patients |
|-----------------------------------------|-----------------|-----------------|-----------------|-----------------|</p>
<table>
<thead>
<tr>
<th>Result</th>
<th>Midfacial Deficiency</th>
<th>Unilateral Mandibular Deficiency</th>
<th>Bilateral Mandibular Deficiency</th>
<th>Total</th>
</tr>
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<tr>
<td>Excellent</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>Good</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>Fair</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>6</td>
<td>6</td>
<td>8</td>
<td>20</td>
</tr>
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</table>
relationships underwent favorable changes, 5 of these patients developed posterior open bites on the distracted side, which did not fully close with postoperative guided eruption of the posterior maxillary teeth. Furthermore, shifts in the mandibular midline to the contralateral side were noted in 4 patients. Distraction of the shortened hemimandible to the desired length was complicated by deviation of the mandibular midline to the opposite side and development of crossbites in 4 of the 6 patients. Of the various preexisting occlusal deformities, open bite and transverse crossbites were the most refractory to correction. In 6 patients with anterior open bites, 1 experienced closure and 1 was improved, whereas the remaining 4 were no better at the end of treatment. Posterior crossbite, present in 8 patients before DO, was corrected in only 3.

A variety of complications manifested during the distraction phase of the process. Problems with the distraction device occurred in 4 patients. In 2 cases, the turning mechanism failed and revision surgery with device replacement was undertaken (Figure 6). In the other 2 patients, the fixation became unstable during the distraction phase and surgical reinsertion was also performed. Notably, in 3 of these 4 patients, the desired direction or magnitude of distraction was not attained at the completion of the distraction phase. In 2 other patients, patient noncompliance was clearly identified, also resulting in significantly less advancement than planned for. Late complications were primarily related to adverse soft tissue effects, including linear scarring at the transcortaneous pin sites with external devices (4), temporal wasting (2), transient trismus (2), and infection (2). The patient with the oncologic segmental mandibular defect developed wound breakdown, infection, and hardware exposure, leading to abandonment of the distraction procedure. Notably, there were no cases of fibrous nonunion across the distraction sites, and at the time of internal device removal, healthy bone regenerate was verified (Figure 7).

Our results demonstrate that DO is a useful technique and can be a powerful tool for the correction of various structural deformities and functional deficits throughout the craniofacial skeleton. The early outcomes described herein support ongoing evaluation to assess the long-term efficacy of
Figure 5. A 5-year-old girl with primary mandibular-maxillary synphnathia and associated glossoptosis-micrognathia requiring a tracheostomy since infancy. A, Preoperative acrylic model used for treatment planning demonstrates a markedly micrognathic and retrognathic mandible. B, Intraoperative photograph showing bilateral posterior body osteotomies and insertion of internal Stryker-Leibinger (Kalamazoo, Mich) intraoral devices. Panorex x-ray films: C, before and D, after 21 mm of horizontal advancement. Profile views: E, before and F, 12 months after treatment showing good improvement in lower face profile.
craniofacial DO and its role relative to conventional craniofacial techniques. The extent of bony advancement that we achieved has been retained throughout the follow-up period in all patients, which would suggest an increased resistance to relapse, a well-documented problem with conventional craniofacial advancements. Furthermore, in patients with severe skeletal deficiencies or soft tissue scarring, the advancements planned and achieved using DO were well beyond what could have been hoped for using conventional surgery. In most of our cases, the desired advancements were achieved within 2 mm based on clinical or radiographic follow-up. Factors identified as contributing to a shortfall in the distraction length included device failure and patient noncompliance.

Careful selection and planning are critical to a successful outcome. Initially, all of the necessary preoperative data are acquired and analyzed to precisely define the existing deformities. The various subunits of the craniofacial skeleton that need mobilization and repositioning can then be identified to determine the nature of the desired osteo-

Figure 6. A 31-year-old woman with Hallerman-Streiff syndrome had residual micrognathia and severe malocclusion following a previous attempt at correction with bilateral sagittal split osteotomies and conventional mandibular advancement. A, Lateral 3-dimensional computed tomographic scan demonstrating mandibular hypoplasia and marked displacement of the condyles anteriorly out of the hypoplastic glenoid fossae. Treatment consisted of posterior body osteotomies and distraction using internal distraction appliances. Planned bilateral advancement was 30 mm. The distraction vector was horizontal in orientation. Midway during the distraction phase, one of the devices was noted to have failed with lack of advancement when activated. B, Despite replacement of the device, only 24 mm of distraction was achieved because of premature consolidation at the osteotomy sites. Profile views: C, before and D, after show a fair cosmetic outcome 18 months following surgery.
otomies and the vector (direction and magnitude) of distraction (Figure 8). Preoperative considerations for mandibular distraction include the preexisting shape of the lower jaw (ramus height, body length, gonial angle), mandibular size (mandibular length), position of the lower jaw relative to the maxilla and cranial base, presence of asymmetry, and mandibular plane angles. Midface considerations during planning include the degree of exorbitism, the presence of anteroposterior deficiency within the midfacial bony structures, midface position relative to the cranial base and the mandible, vertical midface deficiency or elongation, maxillary plane, and occlusal plane angles. Whenever the desired movements will affect occlusion, a complete occlusal analysis needs to be undertaken, including anteroposterior occlusal relationships, transverse relationships, the presence of open bite deformities, occlusal plane angles, and incisor inclinations. The planning phase requires cooperation between the surgeon and orthodontist if the skeletal movements will affect the dentition. Once the osteotomy design and vector of displacement have been determined, selection of the appropriate mode of distraction and the specific appliances to be used requires careful evaluation. Internal appliances are more suited for uncomplicated movements where displacement in only one direction is required. Once internal appliances are in situ, modification of the distraction vector is not possible. External devices have the advantage of allowing multidirectional distraction in several different planes of movement. They provide a greater degree of freedom in selecting the desired vector of distraction (both angular and linear movements are possible) and

Figure 7. Intraoperative view at the time of removal of internal distraction devices following the consolidation phase in a young patient who underwent Le Fort III distraction. Note the quality of the maturing bone regenerate in the distraction gap (instrument tip).

Figure 8. Careful preoperative planning to determine the vector of distraction is a critical element for success. A, Distraction of the lower jaw can be horizontal, vertical, or oblique, depending on the nature of the preexisting deformity. Assessment should consider the height of the posterior ramus (Ar-Go), the length of the mandibular body (Go-B), and the overall length of the mandible (Ar-B). A horizontal vector (H) is used to primarily correct deficient length of the mandibular body. A vertical vector (V) is selected to increase an abnormally short posterior ramus. Oblique vectors (O) are useful to increase both ramal height and body length. Note that cases with an abnormal gonial angle (Ar-Go-Me) are best managed with an external device capable of angular distraction. Go indicates gonion; B, “B” point; Ar, articulare; SN, sella-nasion plane; MP, mandibular plane; and Me, menton. B, Planning for midface distraction should consider the linear and angular measurements that describe the size and relationship of the orbitomaxillary complex to the cranial base. Key measurements are illustrated and the accompanying numeric values are approximate norms for adults. Each patient should be assessed relative to age-specific norms, keeping in mind, however, that inherent growth deficiencies will persist despite distraction osteogenesis. It is therefore useful to overcorrect close to adult values when treating patients who have completed most of their midfacial growth. S indicates sella; N, nasion; Po, porion; Or, orbitale; Ba, basion; MxP, maxillary plane; ANS, anterior nasal spine; Me, menton; SE, sphenoethmoid intersect; PNS, posterior nasal spine; and A, “A” point.
the ability to change the vector of incremental advancements during the distraction phase as necessary. This is advantageous in controlling occlusal relationships. Furthermore, external appliances are typically retained via transcutaneous threaded pins, which facilitates use in very young patients whose facial skeleton size may preclude using the plate and screw fixation necessary to secure internal devices. Lastly, external devices are easily removed following consolidation in contrast to internal devices, which often require a major surgical procedure to expose and retrieve. Disadvantages with external devices are unavoidable scars as a result of the transcutaneous fixation pins. These produce at times a severe linear scar that grows as the pins are splayed during the distraction process. Also, external devices can be bulky, and having the appliances on for 8 to 12 weeks can be a drawback for some patients.

In our series, the best aesthetic results were obtained in the midfacial advancement cases and to a lesser degree in patients with hemifacial microsomia. Cases with bilateral micrognathia did not achieve as favorable a cosmetic outcome. This may have been contributed to by the younger age group of the micrognathia patients. Because of the lack of a proven track record using distraction techniques in the very immature facial skeleton, we tended to be conservative in setting our distraction length objectives with these patients. Furthermore, in these patients, the primary objective of distraction was to improve or eliminate upper airway obstruction.

Functional results were encouraging, particularly in resolving or significantly improving airway obstruction. Distraction osteogenesis holds great potential for addressing the structural problems that contribute to acute respiratory obstruction in patients with glossoptosis-micrognathia or other disorders with small jaws. Our results indicate that early intervention in infants and young children with DO can prevent the need for tracheotomy or allow early decannulation in children with existing tracheotomy. Because most glossoptosis-micrognathia patients improve spontaneously over time, the cases should be carefully selected. We have reserved mandibular distraction for those with severe micrognathia and obstruction in which case conservative surgical techniques have a lower success rate. These patients include those who would otherwise go on to tracheotomy or those with an existing tracheotomy tube who are not demonstrating “catch-up” growth. Less severe cases can still be adequately managed with more conservative techniques, such as lip-tongue adhesion. Impressive improvements in the nasopharyngeal airway were also seen in the patients undergoing midfacial advancement. Furthermore, these patients experienced resolution of conjunctival exposure associated with exorbitism. Occlusal correction proved less amenable to correction using DO. Anteroposterior discrepancies had the best improvement; this is not surprising considering that the planned vectors of distraction used to correct the skeletal base disharmony coincided with the necessary movements needed to improve the dental bases in most patients. Transverse deficiencies, crossbites, and open bites, on the other hand, were not of primary concern when planning the distraction strategy. Notably, most of the patients were left with some occlusal discrepancies that are within the realm of orthodontic correction, although a few will eventually require finishing orthognathic procedures.

The timing of intervention has always been a contested issue in craniofacial surgery. During the past several years, improved expertise and biotechnology have allowed better results during manipulation of immature bone using conventional techniques. Nonetheless, considerable drawbacks exist when attempting to reposition and internally fixate bone segments in young patients. Uncontrolled and excessive fragmentation during manipulation of fragile bone segments, inadequate bone stock in which to secure metal plates and screws, and injury to developing tooth buds are all well-recognized risks in this setting. Distraction osteogenesis represents a major advancement in addressing this problem owing to the lack of intraoperative repositioning and the minimal fixation requirements.

The less invasive nature of DO permits advancements in earlier age groups than conventional surgery whenever such intervention would be appropriate. In our group, the distraction procedures were carried out well ahead of the age groups considered typical when using conventional surgical repositioning. The results yielded substantial improvements in form and function at an earlier developmental period. Another argument in favor of DO that was borne out in our study is the ability to achieve very large degrees of advancement. When attempting such movements with conventional craniofacial repositioning, the restrictive soft tissue envelope often physically precludes extreme advancements. It seems that the gradual movement in DO is able to overcome the soft tissue pull through a stepwise adaptative process. The long-term outcome of earlier intervention with DO, particularly as it relates to stability, remains to be seen because most studies still do not have long enough follow-up. Early reports demonstrate excellent stability of distraction procedures relative to conventional craniofacial repositioning, particularly in cases with large advancements or restrictive soft tissue envelopes. However, despite the potential for improved results, the distraction procedure will not reverse or correct the underlying syndrome-specific abnormalities, and growth will eventually lag at the affected areas as the patient ages after treatment. Thus, intervention at an earlier age with DO may or may not preclude additional surgery. In severe deformities, however, the patient will have several years of considerably improved form and function, and if revision procedures are necessary at the end of skeletal maturity, they will be technically easier to perform.

In summary, DO has great potential for several congenital and acquired osseous defects that can be encountered within the craniofacial skeleton. Numerous advantages have been cited among the growing number of advocates for craniofacial DO: (1) The surgery is less invasive and associated with a shorter hospital stay, less tissue dissection and bone manipulation, and decreased blood loss. (2) There is no need for bone grafting to maintain repositioned segments. (3) There is no risk of growth restrictions secondary to plate fixation. (4) In severe skeletal deficiencies, there is the potential for substantially larger osseous movements and greater stability postoperatively, especially in cases with a scarred soft tissue bed. (5) There is the potential for improved soft tissue aug-

CONCLUSIONS

In summary, DO has great potential for several congenital and acquired osseous defects that can be encountered within the craniofacial skeleton. Numerous advantages have been cited among the growing number of advocates for craniofacial DO: (1) The surgery is less invasive and associated with a shorter hospital stay, less tissue dissection and bone manipulation, and decreased blood loss. (2) There is no need for bone grafting to maintain repositioned segments. (3) There is no risk of growth restrictions secondary to plate fixation. (4) In severe skeletal deficiencies, there is the potential for substantially larger osseous movements and greater stability postoperatively, especially in cases with a scarred soft tissue bed. (5) There is the potential for improved soft tissue aug-

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mentation associated with distraction histogenesis.

(6) Finally, surgical intervention is possible in younger age groups. Experience with the technique is still limited, and more investigation is necessary to refine technique and improve the design and reliability of distraction devices. Investigations are undertaken to determine the feasibility of combining endoscopic techniques to perform the initial osteotomies with insertion of external distraction appliances. As experience with distraction increases, its exact role in correcting craniofacial deformities will eventually become apparent. Currently, it seems that DO is most useful for more severe anomalies in which there is a need for earlier intervention, the risk of relapse with conventional techniques is high, and conventional osteotomies are not feasible.

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