

Abstract: Distraction osteogenesis offers superior skeletal advancement compared to conventional osteotomy. As the surgical outcomes can be technically-dependent, it is important to understand the principle, indications, assessment and preparation prior to its application. This review is the first part of two articles which will provide clinicians updates on the history, principles, clinical indications, types of devices and protocol for distraction osteogenesis in the craniomaxillofacial region. Important issues in these essential aspects of distraction osteogenesis are comprehensively discussed based on clinical cases and supported by literature. Understanding the principles of distraction osteogenesis is mandatory to ensure optimum surgical outcome. The technique offers many advantages to the field of craniomaxillofacial surgery and can be considered as an alternative bone augmentation and lengthening technique as it produces stable and reliable outcomes.

Key words: Distraction osteogenesis; callus distraction; osteodistraction; cranio-maxillofacial; maxillofacial surgery.

Introduction

The field of craniomaxillofacial surgery has greatly evolved since the last 3 decades with the progressive understanding and development in the field of bone and tissue regeneration. Distraction osteogenesis (DO), a technique that is also known as callus distraction, callotaxis, osteodistraction, and distraction histogenesis is a biological process of regenerating new bone and adjacent soft tissue by gradual and controlled traction of the surgically separated bone segments using a device. This technique currently can be considered as an established surgical therapeutic tool to create new bone via bone lengthening with predetermined vector projection thus allowing structural correction or rehabilitation in craniomaxillofacial deformities.

With the gradual and controlled traction applied on the segmentized bone segments, not only bone lengthening is achieved but the bone periosteum, bone marrow and medullary component are preserved thus allowing physiological stretch to the surrounding soft tissue at the distracted region. This process is called neohistogenesis and has shown to reduce 50-90% of post-operative relapse.

As this technique is considered an autogenous process, this significant advantage eliminates the need for additional bone grafting procedure thus reducing the risk of morbidity related to donor site.

This literature review aims to provide the reader with information and updates on the important aspects of distraction osteogenesis in the craniomaxillofacial region. As the review consists of several topics, it is separated into two parts to allow readers to systematically understand and comprehend the essential aspects of this technique. The second part of this topic will discuss more on DO application in craniomaxillofacial region article emphasizes on the clinical aspects of DO namely on the peri-operative issues, important surgical aspects, related complications and reliability of this technique.

History

The history of DO begins with the repositioning and stabilization of bone fractures used by Hippocrates. Codivilla, in 1905 published a case report on bone elongation techniques for femoral extension using axial forces of distraction. This technique was later popularized by the extensive work of Ilizarov, a Russian surgeon who developed innovative devices for skeletal fixation and osteotomy techniques that deliver
minimum trauma to the periosteum and to the bone marrow. This is the hallmark in the discovery of the biological basis of gradual traction applied on living tissues that can stimulate and maintain regeneration and active growth.

Following this success, studies were done on its application to the dentoalveolar region which began in 1973 when Snyder et al. used a Swanson external fixator to lengthen the mandible in a dog. Block et al. confirmed isotropic augmentation by DO for alveolar bone in animal studies for dental implants in a consecutive series of horizontal alveolar distractions using the Laster Crest Widener (Surgi-Tek Inc, Brussels, Belgium). McCarthy et al. then applied this technique on the craniofacial region in a series of canine mandible studies and in patients with hemifacial microsomia, thus introducing craniofacial distraction in 1989. Currently, alveolar distraction osteogenesis (ADO) is extensively used as a treatment modality to treat alveolar bone deficiency in both mandible and maxilla not only in native bone but also in reconstructed jaws.

The application of DO in craniofacial reconstruction continues to expand and evolve with successful distraction on a multitude of patients, and the technique has become an accepted method of treatment worldwide for craniofacioficial deficiencies on the mandible namely in syndromic patients that require mandibular elongation to secure the airway or even reconstruction following surgical defect.

As for the maxilla, rapid evolution in orthognathic surgery has introduced maxillary advancement via DO as an adjunct to the treatment option. Numerous studies have been conducted on maxillary advancement with a Le Fort I osteotomy via DO. This technique proved to be superior as compared to conventional Le Fort I osteotomy especially involving cleft lip and palate patients in which it allows wider advancement range with higher stability.

Meanwhile, progress in craniofacial DO was made when Swennen et al. reviewed 96 cases of craniofacial distraction, in which they combined clinical experience of midfacial or cranial distraction. Most of the cited indications for monobloc distraction were respiratory compromise secondary to upper airway obstruction or severe exophthalmos with inadequate globe and corneal protection. Since then, DO has developed into established surgical option for the treatment of different craniofacial anomalies e.g. craniosynostosis, cleft lip and palate, hemifacial microsomia, midface hypoplasia, and transverse discrepancies.

**Principle**

Distraction osteogenesis is a biological process that involves manipulation of callus formation between the segmentalized osseous surfaces that are gradually separated by incremental traction. It is initiated when forces are applied to separate the segments and continues as long as the tissues of the callus that forms between the segments are stretched, forming bone parallel to the direction of the vector of distraction.

Histologically, the healing process in DO is different compared to fracture recovery process as DO has the advantage of having controlled microtrauma and the ossification mechanism is membranous rather than endochondral. Animal studies were done to describe distraction phases at the cellular level. The main principles of DO can be systematically studied and described in specific phases which consist of bone osteotomy, latency, activation and consolidation stage.

During the latency period following bone osteotomy, bone repair is similar to that observed after fracture healing; hematoma formation and the migration of inflammatory cells into the osseous gap. The hypoxic zone of injury stimulates an angiogenic response and initiates the migration of primitive mesenchymal cells and the collagen I matrix synthesis. This activity precipitates osteogenesis at the osteotomy area.

During activation of distraction, a fibrovascular matrix is seen aligned in the direction of the distraction vector. After a few days of activation, osteoid synthesis and mineralization occurs followed by calcification of collagen bundles and the formation of bony spicules from the edges of the osteotomy toward the central portion of the distraction zone. Progressive calcification then provides bony closure of the distraction defect.

Remodeling of the newly formed bone during the consolidation period is evidenced by the appearance of osteoclasts, resulting in lamellar bone with narrow elements forming mature bone. The whole process simultaneously initiates neohistogenesis at the surrounding and circumferential tissues which include cartilage, ligaments, muscle, blood vessels, gingiva, and nerve at the distracted bone region. The explanation on the principle of DO is probably best demonstrated by development of cranial sutures, whereby the rapidly growing brain in infants causes these sutures to react by depositing new bone. The illustrations of distracted bone process and summary of distraction phase are in Figure 1 and Figure 2 below.

**Indications of DO**

As DO has the ability to regenerate unlimited bone amount subjected only to the size of the distraction device, the technique can be indicated for cases requiring massive amount of bone augmentation or lengthening when conventional techniques are not feasible. The clinical indication spectrum for DO includes alveolar bone region augmentation, mandibular lengthening, maxillary advancement, midface, orbital and cranial advancement or expansion. For each region, a specific distraction device can be applied to control the vector of bone expansion or lengthening in antero-posterior, vertical or transverse directions.

![Diagram](attachment:image.png)

**Figure 1. Distraction of callus following osteotomy creates new bone.**
For alveolar distraction osteogenesis (ADO), indications include moderate to severe atrophic edentulous ridge, narrow alveolar ridge, segmental alveolar bone deficiencies with compromised aesthetics and function for implant placement and ankylosed submerged teeth with unfeasible orthodontic treatment. In post-reconstructive jaw cases, alveolar distraction performed on reconstructed free flaps such as fibula and iliac has shown comparable results to those in native bone. Although there are limited published literature, DO can also be applied to achieve alveolar transverse width expansion.

In mandibular distraction, it is mainly aimed towards lengthening of the ramus and body of the mandible in severely hypoplastic jaws in an antero-posterior direction and in congenital micrognathia conditions such as in Treacher Collins or underdeveloped bone conditions as in hemifacial microsomia. Severe respiratory obstruction and sleep apnea, most commonly associated with conditions such as Pierre Robin sequence and Treacher Collins may benefit greatly from mandibular distraction. Due to the success in treating congenital deformities, DO has been applied in developmental class II mandibular hypoplasia and obstructive sleep apnea in adult patients. In acquired deformity resulting from either trauma or temporomandibular joint (TMJ) ankylosis, mandibular DO has been successfully used to correct the asymmetric and transverse mandibular discrepancies.

For the maxillary region, DO provides a reliable surgical alternative in any severe developmental hypoplastic condition such as in cleft maxilla or syndromic craniofacial deformities that require massive segmental advancement. Apart from allowing superior maxillary advancement compared to the conventional Le Fort I osteotomy with plating, the technique allows rehabilitation of obliterated nasopharyngeal airway secondary to a severely hypoplastic maxilla that is commonly found in syndromic craniofacial deformities such as Crouzon and Apert syndromes. As post-surgical soft tissue scarring remains the main problem in cleft maxilla, simultaneous neosteogenesis in DO may reduce the rate of relapse following maxillary advancement. The application of this technique eliminates the need of additional bone grafting for large intersegmentary bone gaps and simultaneous neosteogenesis minimizes the limited soft tissue problem when large segmental advancements are indicated. Apart from the antero-posterior direction, distraction can be applied in maxillary hypoplasia in the transverse direction. The principle is similar to QuadHelix application in orthodontic expansion but in DO, the maxilla needs to be segmentalized and the device is normally fixed to palatal bone thus allowing stable and rapid expansion.

In craniofacial deformities such as syndromic craniosynostosis which include Crouzon, Apert and Pfeiffer syndromes, the technique can be indicated for massive segmental expansion such as in Le Fort III or fronto-orbital advancement procedures to allow intracranial decompression and to achieve orbital protection. However, more than 2 devices are often needed, as the advancement requires both the lateral and central component to be brought forward adequately. The indications of DO based on the specific craniofacial deformities are shown in Figure 3 and summarized in Table 1.

**Types of distractors**

Current usage of distraction devices fall into 5 broad categories based on the specific regions namely the alveolar, mandibular, maxillary, midface and craniofacial regions. Apart from regional...
Figure 3. Internal devices in craniofacial DO: (A) Frontal image of distractors' positions (B) Vector trajectory can be checked via both extension arm's projection (C) Pre-bending of footplates. (D), (E) and (F): A series of radiographic images in cleft maxillary DO. Alveolar DO: (G) Activation rod can be seen resting on existing denture to prevent lingual tilt. (H) Implants insertion prior to removal of device and (I) Modification of alveolar distractor placement in post-reconstructive case.

Table 1. Summary of clinical indications for distraction osteogenesis in craniomaxillofacial regions

<table>
<thead>
<tr>
<th>Region</th>
<th>Clinical indications</th>
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<tbody>
<tr>
<td>Alveolar</td>
<td>Vertical • moderate to severely atrophic edentulous ridge • narrow alveolar ridge •</td>
</tr>
<tr>
<td></td>
<td>segmental alveolar bone deficiencies with compromised aesthetics and function for</td>
</tr>
<tr>
<td></td>
<td>implant placement</td>
</tr>
<tr>
<td>Transverse</td>
<td>• narrow alveolar ridge for implant placement</td>
</tr>
<tr>
<td>Transport</td>
<td>• ankylosed submerged teeth with unfeasible orthodontic treatment</td>
</tr>
<tr>
<td>Mandibular</td>
<td>Lengthening • severe developmental hypoplasia in AP direction • congenital micrognathia</td>
</tr>
<tr>
<td></td>
<td>causing OSA • congenital micrognathia in syndromic conditions</td>
</tr>
<tr>
<td>Transport</td>
<td>• traumatic defect • post-ablative</td>
</tr>
<tr>
<td>Maxilla</td>
<td>Advancement • severe developmental hypoplasia in AP direction • cleft maxillary</td>
</tr>
<tr>
<td></td>
<td>hypoplasia</td>
</tr>
<tr>
<td>Transverse</td>
<td>• severe hypoplasia in transverse direction</td>
</tr>
<tr>
<td>Midface</td>
<td>Advancement • severe hypoplasia in AP direction • nasopharyngeal airway relief</td>
</tr>
<tr>
<td>Vertical</td>
<td>• facial cleft</td>
</tr>
<tr>
<td>Craniofacial</td>
<td>Advancement for • intracranial decompression • orbital protection • nasopharyngeal</td>
</tr>
<tr>
<td></td>
<td>airway relief</td>
</tr>
<tr>
<td>Expansion</td>
<td>• Cranial vault expansion (transverse, anterior or posterior)</td>
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</tbody>
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*AP = antero-posterior OSA = Obstructive sleep apnea
classification, the type of device can either be internal or external. Currently, most devices are compact and internally fixed. External devices are normally used for midfacial structures and the distraction devices require multiple components such as the external frame and the stabilizing pins to ensure stable fixation.

The types of distractors can also be categorized based on the trajectory of the distraction vector. The **Unifocal** type requires only a single osteotomy with distraction forces applied by a device attached by screws on either side of the osteotomy. For the **Bifocal** type, osteotomy is performed to produce a transport segment. This segment then will be placed with pins on native bone with a single spanning device encompassing the transport segment. The third type in this aspect is the **Trifocal** type in which, two osteotomies are used to fill a skeletal defect in a bidirectional manner (Figure 4). The transport segment is delivered into the skeletal defect by forces applied by the distraction device. The leading edge of the segment has a fibrocartilage cap. Bone grafting is usually required after the transport segment has been finally " docked," the fibrocartilage tissue resected, and the defect replaced by the graft.

**Protocol**

As described earlier, DO protocol is based on the principle introduced by Ilizarov. The initial incision and soft tissue handling in the surgery is performed in such a way to preserve the blood supply to the transport segment. It is important to facilitate a continuous blood supply to the surgical area by careful handling of the periosteum. The osteotomy cut is designed to be favorable to the desired distraction direction. The distraction device should be ideally placed to ensure smooth segmental movement. Following device fixation, the protocol involves 3 fundamental sequential phases in which different biological phenomena are produced.

**Latency phase**

Latency phase is the period between osteotomy and start of the distraction, during which soft callus is formed. Time periods usually applied range from 0 to 7 days and coincide with the initial events in the normal process of bone repair. Histologically, the initial clotting is converted at 3 days into granulation tissue (inflammatory cells and fibroblasts), and increasingly becoming more vascular with the growth of new capillaries. Therefore, basic principles of using new fresh burrs, constant irrigation during the drilling process, and minimizing thermal injury to the bone must be strictly followed in this technique. Furthermore, the actual placement of the pins and/or screws should be planned. Unstable and inadequate fixation will result in loosened pins/screws and lead to failure of the distraction process.

**Distraction phase**

This phase usually lasts a few weeks based on the targeted amount of distraction in which traction is applied to the transport bone fragment and the formation of new immature woven and parallel-fibbered bone commences. The collagen is mostly type I, which, alongside the angiogenic increase, would support the theory that tension favours intramembranous but not endochondral ossification.

Due to this reason, during this phase, the distraction device is activated by turning a special activation driver, usually at 1 mm/day, in two to four equal increments of 0.25 mm/0.35 mm for each full turn. Daily distraction aligns the collagen fibres in parallel bundles that channel the growing vessels and perivascular cells into longitudinal compartments. Moderate and controlled tension exerted by the distractor on the granulation tissue produces a greater differentiation of mesenchymal stem cells into osteoblasts and also favours a higher production of bone proteins by osteoblasts.
Table 2. Summary of distraction protocols in cranio-maxillofacial region

<table>
<thead>
<tr>
<th>Phase</th>
<th>Latency</th>
<th>Distraction</th>
<th>Consolidation</th>
</tr>
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</table>
| Time period                  | 0–7 days   | Lasts for few weeks, depending on targeted distraction amount | Minimum: twice the length of activation
Average: 12 weeks             |
| Device activation            | None       | Rate of an average of 1mm/day divided into 2-4 equal increments | None                                              |
| Histological changes         |            | Increase collagen, Tension exerted causing differentiation of mesenchymal stem cells into osteoblasts | Maturation and corticalization of newly formed bone |

Consolidation phase

Consolidation phase is the period that allows the maturation and corticalization of the regenerated bone. The distracted bone fragment and the soft callus created must be immobilized during the consolidation phase. Movement in the area would interrupt the microrcirculation by which pluripotential cells differentiate into chondroblasts. At this phase, the central fibrous and osteoid areas ossify and mineralize in a largely intramembranous manner in facial bones, becoming immature bone that will form into mature lamella bone.11

Typically, the consolidation phase is twice as long as the time required for activation. In cranio-maxillofacial bones, a minimum 12 weeks consolidation phase is recommended but this practice differs from one centre to another.1,17,20,25 In general, longer advancements requires a longer consolidation phase to ensure good bone consolidation thereby reducing the rate of relapse.

In the bone remodeling period, the soft tissues surrounding the bones exert regular tension to the tissues that later allows a complete healing and final reshaping of bone to occur. The protocol for DO is summarized in Table 2.

Conclusion

In conclusion, with the understanding of the fundamentals and principles of DO, surgeons planning to performed DO will be able to treat a wide range of cranio-maxillofacial conditions with a predictable outcome. The key in obtaining a successful outcome is by adhering the well-established principle and protocol as discussed in this review.

References


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