Distraction Osteogenesis as a Solution for Facial Deformity: A Review

Sarwar Alam†, Subodh Shankar Natu‡, S. Gokkulakrishnan§, K.Y. Giri¶, Himanshu Sharma*****

† Senior Lecturer, Department of Oral & Maxillofacial Surgery, Institute Of Dental Sciences, Bareilly, (U.P)
‡‡ Senior Lecturer, Department of Oral & Maxillofacial Surgery, Career Post Graduate Institute of Dental Science & Hospital, Lucknow,(UP)
§§ Professor and Head, Department of Oral & Maxillofacial Surgery, Institute Of Dental Sciences, Bareilly, (U.P)
¶¶ Professor, Department of Oral & Maxillofacial Surgery, Institute Of Dental Sciences, Bareilly, (U.P)
***** Senior Lecturer, Department of Oral & Maxillofacial Surgery, Institute Of Dental Sciences, Bareilly, (U.P)

ABSTRACT: Limb lengthening by distraction osteogenesis was first described in 1905. The technique did not gain wide acceptance until Gavril Ilizarov identified the physiologic and mechanical factors governing successful regeneration of bone formation. Distraction osteogenesis is a new variation of more traditional orthognathic surgical procedure for the correction of dentofacial deformities. It is most commonly used for the correction of more severe deformities and syndromes of both the maxilla and the mandible and can also be used in children at ages previously untreatable. The basic technique includes surgical fracture of deformed bone, insertion of device, 57 days rest and gradual separation of bony segments by subsequent activation at the rate of 1 mm per day, followed by a 812 week consolidation phase. This allows surgeons, the lengthening and reshaping of deformed bone. The aim of this paper is to review the principle, technical considerations, applications and limitations of distraction osteogenesis.

KEYWORDS: Distraction osteogenesis; Distraction Histogenesis; Callostasis; Biomechanics; Osteodistraction; Vector; Mechanical Strain

INTRODUCTION

Despite the fact that conventional orthognathic surgery and craniofacial reconstruction have experienced widespread success but in recent years the practice of surgery has been altered by an increased understanding and manipulation of biological systems; for example, induction of the native tissue.

Distraction osteogenesis of the craniofacial skeleton serves as an example of this most recent paradigm shift. It is a process of new bone formation between the surfaces of bone segments gradually separated by incremental traction.1,2,3 Distraction osteogenesis is a technique of applying controlled traction across the site of surgically produced bone disruption while it is healing. The mechanical forces are directed predominantly away from the site, and the technique takes advantage of the regenerative capacity of bone by creating and maintaining an active area of bone formation in the surgically created gap. The bone is lengthened along with its envelop.

HISTORY

There have been reports of this principle of distraction being used as early as in 1905, by Codvilla. In 1937 Kazanjian used "Over the Face" appliance activated by elastic bands. Later Stader in 1942 used mandibular external fixator. However it was Ilizarov in 1950s who established the scientific basis of this concept and showed that with this procedure lengthening of long bones without using a graft material was possible. Guerrero’s et al 1990 used intraoral distractor attached superiorly to teeth by orthodontic bands and inferiorly to bone by bendable forked arms.4 Molina and Ortiz-Monasterio were the first to use bidirectional osteodistraction in the mandible. Constantino et al 1990 did First application of transport distraction osteogenesis for reconstructing segmental mandibular defects.5 McCarthy et al. reported the first mandibular distraction in humans in 1992, using an extraoral distractor in patients with hemifacial microsomias.6 Cohen et al. were amongst the first to apply distraction osteogenesis to the midface in a patient with unilateral craniofacial microsomia.7

LAW OF TENSION STRESS EFFECT

Gradual traction of the tissues creates stress that activates tissue growth and regeneration. The shape and mass of the bone are influenced by the mechanical load and blood supply.1,2

CLASSIFICATION OF DISTRACTION OSTEOSTEOSTEOGENESIS

De Bartiani et al. 1986 classified distraction osteogenesis depending upon the place of tensional stress induction technique into Physeal Distraction and Callostasis.
He further classified physeal distraction into Distraction Epiphysiolysis & Chondrodiatasis. Samchukov et al 1998 classified it on the basis of distraction device used as Extraoral, Subcutaneous and Intraoral devices. Intraoral devices were further classified as (a) Submucosal and (b) Extramucosal devices.

**BIOLOGY OF DISTRACTION (TABLE 1)**

Bone formation in general may be through cartilaginous intermediate (endochondral ossification) or from recruitment and differentiation of primitive mesenchymal cells (membranous ossification) seen in distraction osteogenesis.

As distraction healing is a highly dynamic cellular process, tensile strains are the leading stimuli for bone regeneration. Mechanical signals play an integral role in bone hemostasis. It is generally suggested that distraction forces leading to cellular deformation are signalled to the cellular genome through mechanotransduction. Nuclear proto-oncogene c-fos and c-jun are found to be unregulated at early stages of distraction and are related to the mechanotransduction and embryonic bone development.

Mechanotransduction, or the conversion of a biophysical force into a cellular response, is an essential mechanism in bone biology. It allows bone cells to respond to a changing mechanical environment. Mechanotransduction can be categorized in an idealized manner into (1) mechanocoupling, which means the transduction of mechanical force applied to the tissue into a local mechanical signal perceived by a bone cell; (2) biochemical coupling, the transduction of a local mechanical signal into biochemical signal cascades altering gene expression or protein activation; (3) transmission of signals from the sensor cells to effector cells, which actually form or remove bone; and ultimately (4) the effector cell response.

Low magnitude of tensile strain (2-8% equibiaxial) in the tissues have anti inflammatory effects and inhibit proinflammatory gene expression such as IL-1beta and COX-2 causing bone formation, whereas tensile strain of high magnitude (15% equibiaxial) induce proinflammatory gene expression rapidly upregulating COX-2 mRNA expression and PGE synthesis resulting in bone resorption. Application of tension favors the transdifferentiation of chondroblasts and fibroblasts into osteoblasts. Thus, tension causes chondroblast to express type I instead of type II collagen. Supporting the theory that tension favors intramembranous but not endochondral ossification.

Danis hypothesized that distraction osteogenesis of long bone relies on two local factors: (a) mechanical stretching multiplicates the fibroblastic population of undifferentiated mesenchymal cells; (b) hypoxia, by vessel elongation and cellular compaction, induces osteogenic stress protein metabolism. Progressive return to aerobic conditions by neoangiogenesis assures the permanency of the new osseous structures.

After performing the osteotomy there is disruption of cortex followed by migration of inflammatory cells and formation of hematoma and procallus. As distraction process progress there is marked vascular response including increased angiogenic mediator expression and blood vessel formation. There is synthesis of type I collagen and fibrovascular bridge which acts as a body for stretching. Collagen fibers oriented along the axis or vector of distraction forces. This is followed by initial mineralization which appears 10-14 days of distraction.

Distraction forces applied to bone also create tension in the surrounding soft tissues, initiating a sequence of adaptive changes in different tissues, including: skin, blood vessels, nerves, muscle, ligament, tendon and cartilage.

**REGULATORY FACTORS FOR DISTRACTION TYPE BONE HEALING**

Physical and biological parameters affecting the success of distraction osteogenesis include the macro and microscopic bone anatomy, the direction and amount of the applied distraction forces, and the regenerative capacity of the tissues involved. Force transduction via adjacent structures (joints, ligaments, muscles, and soft tissue) influences the regeneration of the tissue between the bone fragments by modulating the stress produced within the callus, which is plastic and malleable. Controlled elongation of the callus results in increase in length of bone without significant disruption of healing process followed by adequate period of immobilization resulting in calcified new bone with normal architecture.

Various factors which regulate bone formation like: BMP (2,4,5,6 and 7) expressed from beginning of distraction until 2 weeks, Insulin like growth factor I and II, Fibroblast growth factor, Transforming growth factor beta-1. Rh-BMP-2 has been shown to accelerate bone formation in mandibular and tibial distraction models.

**RECENT EXPERIMENTAL WORK IMPLICATION TO PROMOTE REGENERATION, FORMATION AND MATURATION AND MATURATION IN DISTRACTION OSTEOSTENOGENESIS** (TABLE 2)

**HISTOLOGY OF DISTRACTION OSTEOSTENOGENESIS**

1982, Panikarovsky et al performed the first significant histologic evaluation and following zonal structure of the distraction was demonstrated two zones of mineralization with longitudinally oriented primary osteons, divided by a fibrous interzone with collagen bundles directed parallel to the vector of distraction.

Animal studies by Karp et al reported current concept of 5 histomorphologic zones with 4 transitional areas between the zones. The five zones are: the central zone, the two paracentral zones, and the two proximal/distal zones.

The four transitional areas are the two areas of vasculogenesis and the two areas of mineralization fronts.

The central zone is the most cellular and most blastema-like. The transitional area of mineralization front shows nascent trabeculae in perfect alignment with the line of tensile force.
Karp et al. observed longer and thicker bone trabeculae toward the center of the distraction gap at 14 days after the end of distraction and a continuity of bone bridges between the ends of the 2 original bones at 1 month. At 2 months after distraction, the initial gap was filled with mineralized bone and showed remodeling areas, mainly in dense cortical zones.6

**DISTRACTION PROTOCOL**

Adequate exposure of the site is performed, distractor is fixed in desired position and vector by one or two screw on either side of marked osteotomy line on the bone. Distractions is then removed and the osteotomy completed through and through. Distractions is then repositioned back on to the predetermined place. Osteotomy is checked by activating the distractor for unhindered separation of bone. Distraction is deactivated leaving a small gap between osteotomised segments and closure of flap is then performed. Distractions is finally activated for few turns depending upon size of the bone.

1. OSTEOOTOMY

Osteotomy is the surgical separation of a bone into two segments. The Incision to access the bone must be conservative in length, with minimal dissection of the periosteum to ensure good blood supply close to the osteotomy site. Osteotomy must be performed with copious irrigation to prevent heating. After distractor is fixed, osteotomy is completed and distractor is activated 2 mm. Bell et al demonstrated that marginal alveolar bone at interdental osteotomy sites had to be maintained in order to maximize bone formation within the regenerate tissue.15 In rabbit tibias, Richards et al. reported a greater bone regeneration when the distraction followed an osteotomy of 30 degrees compared with one vertical to the bone.16 It has been speculated that an increase in shear forces may provide greater stimulation of osteoblasts and ossification centers.

2. LATENCY PERIOD

It is the resting period after osteotomy and before active traction starts. It ranges from 0 7 days, allows callous formation.6 During this period histologically initial clot formed is converted at 3 days into granulation tissue which becomes increasingly fibrous due to the presence of collagen and increasingly vascular through the appearance of new capillaries.6 There is initiation of recruitment of mesenchymal stem cells from the bone medulla and adjacent periosteum.21

**Distraction Phase:**

This phase usually lasts 1-2 weeks, and the traction modifies the normal development of the regeneration process. A dynamic microenvironment is created with formation of tissue parallel to the distraction vector, increased and prolongation of angiogenesis, increased proliferation of spindle-shaped fibroblast-like cell, which present a phenotypic variation.6

This type of spindle-shaped cell is situated peripherally and throughout the vessels, producing more type I collagen parallel to the distraction vector.

Cope et al in his study on beagle mandibular elongation model reported that after distraction there is atrophy of epithelium with disappearance of papilla and loss of intercellular connection in granular and spinous layers with increased formation of dilated capillaries in lamina propria, mild inflammatory infiltrate and distribution of collagen fibres parallel to distraction vector.22 At 2 weeks of consolidation he found mucosa to begin having normal appearance, conjunctive papilla begin to appear with increased epithelial thickness and cells recovered normal architecture. Epithelium completely gained normalcy at 8 weeks.22

3. RATE OF DISTRACTION

Tension stress law, as proposed by Ilizarov, postulated distraction rate of 1 mm per day as the optimum rate for bone regeneration during distraction osteogenesis.23,24 Daily distraction aligns collagen fibres into parallel bundles that channel growing vessels and perivascular cells into longitudinal compartments.6 While intermittent distraction results in microtrauma in the distraction zone due to relative large movement and higher distraction force. Vessels are disrupted and micro-haematomas are formed. The healing process is interrupted and has to restart after each activation of the distractor leading to delayed healing.24,25

Increasing rate (2 mm/day) nonunion, fibrous union or bone weakening. Increasing distraction rate is associated not only with poor bone formation but also with severe soft-tissue contractures and nerve problems.26

Decreasing rate (0.5 mm/day) leads to premature consolidation.1,2

4. RHYTHM OF DISTRACTION

Ilizarov suggested rhythm of distraction in increments of 0.5 mm 2 times a day or 0.25 mm 4 times a day. Excessive expansion pressure may cause ischemia, leading to possible tearing of the soft tissue, nerve, muscle and periodontal problems.

5. STABILIZATION/CONSOLIDATION PERIOD

Consolidation is a period after the end of the distraction when the fragments are stabilized in their final position. To enable this distractor is not activated anymore and then used as a rigid fixation device. This period varies from 8 12 weeks. During this period mineralization of callus occurs in osseous gap.

**VARIABLES THAT MODIFY DISTRACTION PROTOCOL**

There are number of variables which modify the protocol such as less time necessary for optimal hard and soft tissue response in younger patients.27 Midline expansion can be performed only after the age of 12 years.28 Otherwise there appears to be no age-limit for the performance of the...
procedure. Deficient hard and soft tissue prolongs latency period in order to promote the initial healing. Larger the magnitude of distraction and amount of bone gained greater is the stabilization period. Genioglossus musculature can be lengthened to a maximum of 20% resting length. Some intersegmental micromotion is necessary for ideal bone formation. Too much rigidity of the plate leads to stress shielding effect causing mechanical stress bypass, which apparently prevents the final stages of normal bone reconstitution. While too much movement leads to fibrous or cartilaginous healing.

Distance from the callus surface to the activating screw is crucial. The closer it is to the central axis of the bone/callus the more effective the stretching. If it is not in line with the central axis then there will be a turning movement. Cross sectional area of bone formed and its strength is equal to the cross sectional area at the site of osteotomy of the mandible.

Radiation therapy is known to be associated with Hypoxia, Hypocellularity and Hypovascularity hence could adversely affect formation of regenerate during distraction osteogenesis. Several cytokines and transcription factors have been involved in recruitment, differentiation, and proliferation of bony precursors. During distraction, insulin-like growth factors, bone morphogenetic proteins, and transforming growth factors have been implicated. Different external agents such as radiotherapy may interrupt the complex cascade in which these factors are involved.

**TYPES OF DISTRACTORS**

Craniofacial distraction devices can be External or Internal deriving anchorage either from bone known as Bone borne distractors or tooth known as Tooth borne distractors. It could be Hybrid i.e. it derives anchorage from both tooth and bone. According to vector these could be Uniplaner applying distraction force in one vector, Biplaner applying distraction force in two vectors or Multiplaner applying distraction force in more than two vectors.

**INDICATIONS**

This technique may be used for: Deformity correction, Lengthening, Widening, Bone transport and Alveolar ridge augmentation of the mandible, midface and upper face, in both congenital and acquired conditions.

**ADVANTAGES**

Includes: No bone transplantation with the difficult resection of the bone graft. Minimal risk of infection because vital bone is distracted. Not only the bone but also the soft tissue is distracted, so that the new bone is permanently stabilized. The results of the distraction can be reproduced. Simple surgical procedure which does not essentially differ from standard osteosynthesis techniques used in OMF surgery.

The distraction regenerate has neovascularity, which appears to be more resistant to infection than is the case with bone grafting.

**DISADVANTAGES**

Includes: Require a second surgical procedure for removal. Soft tissue scars may develop at the pin tracts. Difficult to apply to small bone fragments. The range of movement is limited.

**COMPLICATION**

Immediate complication includes: Damage to the primary or secondary dentition. While early includes Infection, Distractor loosening, Paraesthesia, Problems of compliance. Late complication are Occlusal disharmony, Incorrect vector, Relapse, Premature bony consolidation, Facial nerve damage, Condylar resorption, Alterations in the articulation, Injury through the distractor, Fibrous union: Correlated to decrease in level of osteocalcin and type I collagen fibres.

**CONCLUSION**

Although orthognathic surgery has gained a generalized acceptance for maxillomandibular deformity correction, several limitations are associated with acute advancement of osteotomized bone segments. Large skeletal discrepancies require such extensive bone movements that the surrounding soft tissues might not adapt to their new position, resulting in relapse or compromised function and esthetics. The application of osteodistraction offers novel solutions for surgical-orthodontic management of developmental anomalies of the craniofacial skeleton as bone may be molded into different shapes along with the soft tissue component gradually thereby resulting in less relapse.

**REFERENCES**

### Table 1: Biology Of Distraction

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<td>Marked vascular response with synthesis of type I collagen</td>
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### Table 2

**Recent experimental work implications to promote regeneration, formation and maturation in distraction osteogenesis**

| Cell therapy: Transplantation of osteoblast like cells to the distracted callus | Enhances angiogenesis and mineralization |
| Grafting with demineralized bone matrix | Bone healing at a faster rate than normal |
| Application of resorbable calcium sulfate | Increases rate of osteogenesis and consolidation |
| Application of bisphosphonate | Improves BMD, BMC and mechanical properties of bone undergoing distraction osteogenesis |
| Application of hormones: Recombinant growth hormone; 2 beta-(3-hydroxypropoxy)-1 alpha, 25 dihydroxyvitamin D3 (ED-71) | Stimulating effect on regenerate bone healing without changing the callus microstructure |
| Growth factors: bFGF; IGF; VEGF | Stimulates bone formation |
| Low intensity pulsed ultrasound | Regenerates bone formation in distraction osteogenesis |
| Electrical stimulation; Direct current, Capacitively coupled electromagnetic field | Regenerates bone formation in distraction osteogenesis |