Distraction Osteogenesis

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Abstracts: Exploitation of the regenerative capacity of bone has spawned a diverse spectrum of modalities to correct osseous defects. Distraction osteogenesisis a process of new bone formation betweenthe surfaces of bone segments gradually separatedby incremental traction. Surgical methods of distraction osteogenesis represent a reliable biologic approach to correct difficult congenital, post-traumatic, or other acquired skeletal deformities. Distraction osteogenesis can be used to lengthen the ramus and the body of the mandible, as well as for ridge augmentation. It can also protract the maxilla or if necessary the entire mid-facial complex in cases of severe deformity.Distraction osteogenesis provides a viable alternate for the correction of transverse deficiencies through true skeletal mandibular widening providing a new paradigm for patients whose treatment alternative and results were previously limited. [Shivarampanya NJIRM 2015; 6(4):99-104]

Key Words: Biomechanics, distraction histogenesis, distraction osteogenesis, mandibular distraction, maxillary distraction.

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Introduction: Distraction osteogenesis [DO] is a biological process of new bone formation between the surfaces of bone segments that are gradually separated by incremental traction. This process is initiated when a traction force is applied to the bone segments and continues as long as ccallus tissues are stretched. Traction force generates tension within the tissues to stimulate new bone formation parallel to vector distraction. Distraction forces applied to the bone also creates tension in surrounding soft tissues initiating sequence of changes termed distraction histogenesis.[1]Though conventional orthognathic surgeries and cranio-facial reconstruction have been successful, there are several limitations associated with these surgeries. Due to these limitations, recent approaches are directed towards modulation of bone growth through, osteo-conduction and osteo-induction.[5]

Biomechanics of Distraction:

Distraction osteogenesis (DO)presents a unique form of clinical tissue engineering using an easily controlled mechanical condition (i.e., slow gradual distraction of the corticotomized or osteotomized bone fragments) Clinician is able to guide the formation of new bone and its spatial orientation to form a structural part of the distracted bone. This happens without application of any growth factor or other controlling agents. The technique also works during the gradual transportation of a bone segment.2,3The critical factors of the process appear to be the stability of fixation, the rate of daily distraction, and the preservation of the local soft-tissue envelope and vascular supply.[4]

The process of distraction involves an interaction of mechanical and biologic factors that influence each other. The factors that determine the local mechanical environment at the distraction site include the applied distraction forces, the rigidity of the fixation, the amount of physiological loading {muscle action}, the properties of the soft tissues, including the tissue formed at the distraction site.[5]

Ideal requirements of contemporary distraction devices[6]:

Possibility to allow a controlled multiplanar (three-dimensional) distraction and compression of the corticotomy site. The device should allow distraction around a smooth arc, facilitating reconstruction of any bone curvature.

Pin clamps should allow placement of thefixation pins in any plane independent of each other. Pin clamps should allow the use of pins with different diameters in order to allow the use of pins of the maximum thickness in each location. Fixator body should involve a ball-joint type of structure to compensate for any pin malposition.

Thread designs of the pins should be matched with the specific anatomy of craniofacial lamellar bone.

Fixator should be of small size, MRI compatible and radiolucent if possible.

Classification of various distraction techniques [7]

1. Pure lengthening procedures
    - Deficient mandible
    - Deficient maxilla
2. Corrective distraction osteotomies
    - Correction of asymmetries
    - Expansion of mandibular symphysis
3. Bone segment transportation (transport distraction)
   Reconstruct a mandibular defect by using transport distraction
4. Stimulation of growth
   Transport distraction for the regeneration of the mandibular condyle.

Classification based on transport of bone segments[4]: *Unifocal distraction*: Distraction of simple corticotomy e.g. unilateral or bilateral lengthening of the mandible.

Bifocal distraction: Unilateral transport of bone segment to fill a segmental defect, e.g. Reconstruct a mandibular defect by using transport distraction.

Trifocal distraction: Bilateral transportation of two separate bone fragments to reconstruct a large defect, e.g. Reconstruction of mandibular symphyseal defect.

Steps in the clinical application of distraction osteogenesis[4]:

1. Detailed preoperative planning, including determination of precise correction of angular deformities.
2. Selection of an appropriate distraction device with known stiffness properties under different loading conditions.
3. Selection of pins of optimal design and diameter
4. Creation of an atraumatic bone discontinuity (corticotomy) at an optimal site.
5. Careful creation of a pin-bone interface and subsequent prevention of pin loosening.
6. Construction of a stable external fixation configuration, followed by regular tightening of the critical components.
7. Selection of a rate and rhythm of the distraction matched with the biologic process of distraction osteogenesis.
8. Intermittent halt or even reverse motion (compression) in the case of delayed osteogenesis
9. Maintenance of the protective fixation after cessation of the distraction, supplemented by dynamization (gradual disassembly of the fixator frame) if necessary
10. Inductive bone grafting in selected' cases of delayed consolidation
11. Removal of the distraction device after sufficient maturation of the distraction new bone {remodeling)
12. Protection of the distracted bone from undue stresses during the final remodeling period

Sequential periods of distraction:1) Osteotomy 2) Latency 3) Distraction period 4) Consolidation 5) Remodelling.

Osteotomy is the surgical separation of bone into two segments; Latency is the period from bone division to the onset of traction and represents the time required for reparative callus formation between the osteotomized bone segments. The stage of fracture healing lasts from 1-3 days during which the clot is replaced by granulation tissue.Soft callus stage last for 3 weeks, Distraction periodis the time when a traction force is applied to bone segments and a new bone or distraction regenerate is formed within the intersegmentarygap. During osteodistraction the normal process of fracture healing is interrupted by the application of gradual traction to the soft callus through the application of tensional stresses to the intersegmentary tissues of the soft callus. Consolidation begins after achieving the desired amount of lengthening when traction forces are discontinued. This period allows mineralization and corticolization of the newly formed bone tissue prior to distraction device

removal. Remodelling is the time after removal of the distraction device which is approximately one year after completion of distraction. During this period, both the cortical bone and marrow cavity are restored.

Noninvasive monitoring of distraction include

- Quantitative computerized axial tomography (QCT)[8]
- Ultra- sound and magnetic resonance imaging (MRI)[9]
- Single-photon (SPA) and dual- photon (DEXA) absorptiometry[10]
- Acoustic ultrasound attenuation[11]

Effect of traction on different anatomical structures:[4]

Nerve Tissues: As the inferior alveolar nerve is encased within bony canal, damage during distraction may be due to intraoperative manipulation during osteotomy, contact with fixation pins or due to post operative hematoma. Constriction by narrowing of the medullary canal due to bone ingrowth during distraction can also cause damage. The risk of neurovascular impairment greatly increases with an increase in the number of osteotomies.

Skeletal Muscle: Bone lengthening takes place as bone is divided into multiple segments whereas soft tissues are stretched without surgical separation. As different biological mechanisms are involved in soft tissue response to gradual stretching the process is called distraction histogenesis**.** Two important mechanisms occur during distraction histogenesisi.e.soft tissue regeneration following disruptive and degenerative changes and neo-histogenesis as a result of generalized, cellular proliferation and growth.

Periodontal Ligament: Patients may develop mobility of the mandibular incisors or may have pain or widening of the PDL at the osteotomy site. These adverse effects may be due to surgical trauma or due to increased expansion rate. Bell W.H. (1997) showed crestal bone loss with mandibular mid-line distraction when immediate expansion wascarried out after interdental osteotomy cut. Variables affecting osteogenesisinclude age, blood supply, osteotomy site, latency period, rate and frequency of distraction, device stability. [5]

Mandibular distraction :

Unilateral mandibular distraction is mainly indicatedin hemifacialmicrosomia, post traumatic injuries, facial hemiatrophy, and condylar hypoplasia.[12] Bilateral mandibular distraction is indicated mainly inTreacher Collins syndrome, bilateral craniofacial microsomia, post ankylosis, developmental micrognathia**,** Nager's syndrome**,** transport distraction for regeneration of the mandibular condyle, mild skeletal Class II deformities.

Due to the anatomic complexity of the mandible, it is essential to accurately evaluate the deformity and form a definitive treatment plan preoperatively using panoramic and cephalometric radiographs along with CT and mandibular models.The vector of distraction may be in the vertical direction when deficiency is located in mandibular ramus.If the deficiency is in mandibular corpus the vector is placed horizontally. If there is a deficiency in both ramus and corpus the distractor is placed obliquely.Presurgical and post distraction orthodontic treatment must be included to improve the final outcome.[13]

Intraoral mandibular distraction[4]:

The intraoral device is usually unidirectional. This device is usually helpful for increasing ramus and corpus length as well as the angle between ramus and corpus. **Distraction Protocol:** Analgesic antibiotics and steroids are administered during first three post operative days.Distraction begins on day 4 by turning the rod once or twice to obtain 1mm of lengthening per day.Post surgicalsequelae include temporary loss of function of buccal aperture on the distracted side.Mandibular advancement is usually performed in a single stage, where over correction can be performed in order to compensate for further growth disturbances during lengthening.

Midsymphysealdistraction osteogenesis[14]:

Mandibular symphyseal DO was introduced by Guerrero.Midsymphyseal distraction osteogenesisis usedfor correcting transverse mandibular discrepancies and crowding of teeth.[15] Traditional

approaches for correcting mandibular crowding are extraction of teeth and arch expansion. However, this treatment may present some complications, including changes in the facial profile, lack of improvement of dark buccal corridors, the tendency for extraction spaces to reopen, and, sometimes, objections to extractions by patients, parents, and referring dentists.

Maxillary distraction:
Mainly used in the correction ofunilateral cleft lip and palate,bilateral cleft lip and palate,mandibular prognathism, nasomaxillary dysplasia, deficiency of midface, developmental micrognathia, midface hypoplasia (craniofacial synostosis syndromes), mild skeletal class III deformities, narrow maxillary arch.[16]

Alveolar bone distraction:
Distraction osteogenesis of the edentulous alveolar ridges may be considered an alternative to many other surgical techniques, such as alloplastic graft augmentation, autogenousonlay bone grafting, and guided bone regeneration.[17]Alveolar distraction is now widely used for treating severe forms of alveolar ridge atrophy.[18,19]Ilizarov, when describing the concept of distraction osteogenesis, suggested that new bone is forming parallel to the vector of distraction, which may even be perpendicular to the longitudinal bone axis in cases with lateral distraction for tibial widening. Alveolar defects may result from a variety of pathological process including developmental anomalies,maxillofacial trauma, and periodontal disease.Distraction osteogenesis has been used for vertical as well as horizontal augmentation.[20,21] Distraction osteogenesis also helps in simultaneous placement of the implant[22]Distraction osteogenesis could be a possible alternative to bone grafting.[23]

Role of parathyroid hormones:
Studies have demonstrated that intermittent PTH administration induces strong anabolic effect on bone. Intermittent PTH treatment enhances new bone formation during mandibular distraction in a rat model and therefore may be effective in shortening the consolidation period.[24]

However PTH therapy is not recommended for more than 2 years as it has shown to result in the induction of osteosarcoma in a rat model.[25]

Attempts at accelerating distraction osteogensis:
Several attempts to enhance the newly forming bone have been described which include the application of external stimuli and administration of biological agents either systemically or locally. Several growth factors like transforming growth factors beta (TGF-β), insulin growth factor (IGF)[26],platelet derived growth factor (PDGF)[27] and fibroblast growth factors (FGF) are shown to have positive effect.

Of all the osteogenic growth factors BMPs (BMP 2 & BMP 7) seem to be the most promising in stimulating the bone formation in the context of DO.[28] The expression of various members of the BMP signaling pathway was extensively analyzed and it was shown that BMP ligands, receptors, transcription factors and downstream targets are upregulated during the distraction phase and down regulated once the mechanical forces of distraction cease.[29,30]

Histological analysis and the cell behavior in the distraction regenerate[31]of the mandible in the goat after 4 and 8 weeks consolidation revealed an intra-membranous type of ossification which occurred simultaneously in following phases:

Intialphase:characterized by multiple ossification centers scattered randomly in the reparitve framework.

Collgenic phase:collagen fibers were initially scattered withtin the ground subustance and many collagen fibers coalesced together to form bundles and become embedded in the osteoid to form trabecula.

Osteogenic phase: characterized by osteobalst congregated on the surface of the newly formed bony trabecula.

Lacuna formation phase: where the osteocytes (trapped osteoblasts) assist in osteonal development and its mineralization

Advantages of distraction osteogenesis[32]
Principle advantage of DO is that it allows correction of deformities at a younger age. Other advantages include low rate of relapse, reduced

nerve dysaesthesia, seating of the condyle elimination of bone grafting, early bone loading, shorter in-hospital stay, reduced post-operative swelling and pain, increased stability, reduced need for intermaxillary fixation, three dimensional corrections.

Disadvantages of distraction osteogenesis: include residual cutaneous scarring, multiple daily out-patient visits, poor 3D control, increased post-operative pain, difficult access for the orthodontist, difficult plaque control, damage to temparomandibular joint and lastly cost- benefit.

Distraction osteogenesis can fail due to following reasons: Ischemic fibrogenesis (with failure of mineralization), cystic degeneration fibrocartilage non-union, late buckling, bending, or fracture of the regenerate bone, axial deviations.

Bone healing complications of distraction procedures: includes acute translation of the corticotomy, gradual axial deviation at the distraction site, premature consolidation, incomplete corticotomy, delayed consolidation, incomplete lengthening, incomplete deformity correction and recurrent shortening deformity.

Conclusion: Distraction osteogenesis is a reliable method for regeneration of bone deficiencies: the technique depends upon the blood supply, stable fixation, and gradual stretching. Different devices that provide stable fixation (e.g., external fixators plates, intramedullary nails) can propagate distraction osteogenesis and therefore allow for creative applications to areas such as the facial bones. The principles of preservation of blood supply, close apposition of cut bone surfaces to allow early bridge formation, and gradual distraction at regular rhythm allow successful application of this method to most skeletal structures. With the abundant literature available on delivery systems for BMPs and other growth factors, including various biomaterials, gene delivery, tissue engineering techniques and use of nano particles, continued research and advancement in this era may soon allow distraction osteogenesis to replace major cranio-facial operations.

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