Available online at http://www.journalcra.com

International Journal of Current Research
Vol. 10, Issue, 10, pp.74670-74675, October, 2018

DOI: https://doi.org/10.24941/ijcr.32698.10.2018

INTERNATIONAL JOURNAL OF CURRENT RESEARCH

ISSN: 0975-833X

REVIEW ARTICLE

DISTRACTION OSTEOGENESIS - AN ORTHODONTIST PERSPECTIVE

[1*]Dr. Kratika Mishra and [2]Dr. Amit Bhardwaj

[1]Assistant Professor, Department of Orthodontics and Dentofacial Orthopaedics, Modern Dental College and Research Centre, Indore, India

[2]Professor and Head, Department of Orthodontics and Dentofacial Orthopaedics, Modern Dental College and Research Centre, Indore, India

ARTICLE INFO

Article History:
Received 14th July, 2018
Received in revised form
25th August, 2018
Accepted 19th September, 2018
Published online 31st October, 2018

Key Words:
Distraction,
Discrepancies,
Osteotomies

ABSTRACT

Distraction Osteogenesis (DO), also called "callus distraction", "callotasis" and "osteo-distraction" is a relatively new technique for orthodontists and maxillofacial surgeons which have revolutionized the correction of major skeletal deficiencies. It has gone a long way in reducing the need for osteotomies and grafting in the treatment of dentofacial and craniofacial deformities. The forces applied to bone also create tension in the surrounding soft tissues, initiating a sequence of adaptive changes termed distraction histogenesis. Distraction osteogenesis is may even be teamed with endoscopic techniques to allow the placement of these devices with minimal surgery. It is in the new era of the three dimensional computer mediated preoperative planning and outcome assessment.

Citation: Dr. Kratika Mishra and Dr. Amit Bhardwaj. 2018. "Distraction osteogenesis - An orthodontist perspective", *International Journal of Current Research*, 10, (10), 74670-74675.

INTRODUCTION

Distraction Osteogenesis (DO), is a biological process of regenerating neoformed bone and adjacent soft tissue by gradual and controlled traction of surgically separated bone segments (Cope *et al*., 1999) It also called "callus distraction", "callotasis" and "osteo-distraction" is a relatively new technique for orthodontists and maxillofacial surgeons which have revolutionized the correction of major skeletal deficiencies. This is a process of slow bone expansion in which new bone is generated in an osteotomy gap in response to tension stresses placed across the bone gap. It initiated when distraction forces are applied to callus tissues that connects divided bone segments, and continues as long as these tissues are stretched. The tension created by traction stimulates new bone formation parallel to the vector of distraction. The technique has gone a long way in reducing the need for osteotomies and grafting in the treatment of dentofacial and craniofacial deformities. Distraction forces applied to bone also create tension in the surrounding soft tissues. Under the influence of tensional stresses produced by gradual distraction, active histogenesis occurs in adjacent tissues, including gingiva, skin, fascia, muscle, cartilage, blood vessels, and peripheral nerves. These adaptive changes in the soft tissues allow larger skeletal movements while minimizing the potential relapse seen with acute orthopedic corrections (Raghunath *et al*., 2012). Congenital deformities require a large amount of skeletal movements and when acutely stretched, surrounding soft tissues cannot adapt to their new position, resulting in regenerative changes, relapse, compromised function and aesthetics. Hence, in light to this, new approaches have been developed amongst which the most suitable alternative approach is "distraction osteogenesis." Distraction osteogenesis has revolutionized the management of several maxillomandibular deformities. In 1905, Codivilla introduced the limb lengthening procedure that had a high complication rate. Later in 1951, Dr. Gavrio Ilizarov did a path breaking work in the field of distraction osteogenesis for limb lengthening based on the biology of bone and surrounding tissues to regenerate under tension (Kumar Dheeraj, 2011). The distraction osteogenesis (DO) is a method developed for induction of new tecidual formation between two segments of a bone for a slow and gradual force of traction (Fernandes, 2010; Ilizarov, 1989a; Ilizarov , 1989b; Meyer, 2001a) Some tissues besides bone have been observed to form under tension stress, including mucosa, skin, muscle, tendon, cartilage, blood vessels, and peripheral nerves (Cohen *et al*., 1995; Constantino, 1991). Distraction osteogenesis is effective in endochondral bone lengthening and augmentation.

***Corresponding author:* Dr. Kratika Mishra,**
Assistant Professor, Department of Orthodontics and Dentofacial Orthopaedics, Modern Dental College and Research Centre, Indore, India.

In the craniofacial region, this technique is also quite efficient for lengthening and augmentation. It was originally used in the treatment of mandibular deficiency and, subsequently, was used to treat the hypoplastic maxilla, zygoma, and midface. Segments of new alveolus and attached gingiva are created during dentoalveolar distraction osteogenesis, with no alveolar bone grafting or free gingival grafting. We used distraction osteogenesis in the dentoalveolus as the basis of a new method of lengthening the dental arch while also minimizing the alveolar cleft/fistula or reconstructing maxillary dentoalveolar defects. Our method uses interdental distraction osteogenesis and rapid orthodontic tooth movement through regenerate (newly formed alveolar bone). The osteotomized dental arch is transported forward to minimize the alveolar cleft or defect, and the dental arch is lengthened by a segment of new alveolar bone and attached gingiva that is created at a site distant to the cleft or defect. The segment of new alveolar bone and attached gingiva will provide extra dental space for the relief of dental crowding and for rapid orthodontic tooth movement through regenerate (Liou, 2000).

In the dentoalveolar region, distraction osteogenesis includes the vertical height augmentation of the alveolus (Chin, 1996), the creation of an edentulous alveolar ridge for rapid orthodontic tooth movement through the regenerate (Liou, 1998) and dental distraction for rapid orthodontic tooth movement into fresh extraction sockets (Liou *et al*., 1998). The introduction of distraction osteogenesis to treat craniofacial skeletal dysplasias has opened alternative approaches to manage these severe conditions (Figueroa *et al*., 1999). The history of DO begins with the old techniques of repositioning and stabilization of bone fractures used by Hippocrates, (Samchukov *et al*., 1999). In early 20th century Alessandro Codivilla (1905) introduced a crude method of DO for lengthening of the lower limbs (Codivilla, 1905) Later, Abbott (1927) improved the Codivilla method by incorporating pins instead of casts; (Abbott, 1927) and Rosenthal (1930) first performed this technique in the maxillofacial region (Rosenthal, 1930); who was followed by Kazanjian (1941) and Crawford (1948). Subsequently, Allan (1948) incorporated a screw device to control the rate of distraction. In 1951 – Gravil Ilizarov, a Russian orthopedic surgeon, began his work on the lower extremity using techniques that combined compression, tension and then repeated bone compression to heal fractured long bones with segmental defects. He explained that bone generation could be reinitiated by the piezoelectric effect of tension, rather than compression. Ten to fifteen years later, he expanded his technique to include the treatment of shortened lower extremities (Raghunath *et al*., 2012). Ilizarov's procedure was able to reduce the frequency and severity of the complications and made the surgery safer. Over the ensuing years, the technique was perfected, stimulating interest in DO (George Jose Cherackal and Navin Oommen Thomas, 2014). The first reports of craniofacial DO maybe attributed to the rapid expansion of the palate that was carried out in growing patients in the 1960s (Haas, 1961). This involved the distraction of a naturally occurring physis as it incorporates controlled soft-tissue and hard tissue expansion through a suture (Haas, 1961) Finally, Snyder *et al*. (1973) first described the Ilizarov technique to lengthen a surgical osteotomy of the canine mandible by 15mm. In 1990s, experimental investigation intensified following reports from New York University (Karp, Thorne, McCarthy and Sissons, 1990) and from Constantino *et al*. (1993), where DO was successfully used to augment and to close canine segmental lower jaw defects. In 1975 - Bell and Epker - Described a technique of rapid palatal expansion to increase the width of maxilla using a Haas appliance (Raghunath *et al*., 2012). In Michieli and Miotti (1976) described the intra-buccal distractors development in dogs studies. Wangerin and Gropp reported that a greater patients acceptance in the use of intra-buccal distractors when compared with the extra-buccal ones. Putti *et al*. (1990) developed a femural extend unilateral device which consisted in fixed bolts in the proximal and distal portion of the segments and joined for a telescope tube (Putti, 1921). A distraction mechanism was formed because the continuous and appropriate force was applied by a device (McCarthy *et al*., 1992). The first clinical results of craniofacial DO were reported by McCarthy *et al*. (1992) in patients with congenital deformities who successfully underwent gradual distraction of the mandible (Mccarthy *et al*., 1992). In 1993 - Fast midface distraction with buried devices was performed. In 1994 and Early 1995 - First case of Multidirectional midface distraction. In1997 - Chin and Toth - Lefort III advancement with gradual distraction using internal devices. In 1999 - Polley and Figueroa - Discussed the management of severe maxillary deficiency in childhood and adolescence performing Distraction Osteogenesis with an external adjustable, rigid distraction device (Raghunath, 2012) According to Campisi *et al.*, 2003, the Osteogenic Distraction is a method developed for induction of new bone formation between two segments of a bone for a slow and gradual force of traction. It can be classified in two basic types: the seal distraction, that involves the epiphysis and diaphysis of a long bone separation, and the calotasis, that consists of the gradual distension of a bone callus formed around the line broken or osteotomic stimulating and keeping the regeneration and the growth activity of hard and soft tissues (Mckibbin, 1978; Wangerin and Gropp, 1997). The callotasis is being used more in the distraction osteogenesis in experimental models and clinical applications because the clinical difficulties associates to the first principle (epiphyseal tissues fragility for the setting of traction mechanical systems and the new bone formation inhibition because the trauma generated for these instruments) (Fernandes *et al*., 2010).

Evolution of distraction osteogenesis in orthodontics: Intraoral internal distractors are available are engineered to be small and compact with increased patient comfort and acceptance (George Jose Cherackal and Navin Oommen Thomas, 2014). Liou and Huang (1998) first applied this concept to orthodontic tooth movement and performed rapid canine retraction through distraction, which they aptly termed as 'Dental Distraction'. Some investigations were validated later that this rapid movement is a form of DO of the periodontal ligament which acts a 'suture' between alveolar bone and tooth with similar osteogenic potential (Liou, Figueroa and Polley, 2000). In 1999 they proposed using interdental distraction osteogenesis to create a segment of new alveolar bone and attached gingiva for the complete approximation of a wide alveolar cleft/fistula and the reconstruction of a maxillary dentoalveolar defect. In a more recent study, Sayin *et al*. (2004) investigated the clinical validation of this technique and substantiated that this procedure reduced the net orthodontic treatment time. İşeri *et al*. (2001) and Kişnişci *et al*. (2002) used a different technique called 'Dentoalveolar Distraction' (DAD) for rapid canine distalization by performing osteotomies around the canines and achieved accelerated movement. This technique does not rely on the stretching and widening of the periodontal ligament, thus prevents overloading and stress accumulation in the periodontal tissues (Gürgan, İşeri, and Kişnişçi, 2005). The technique was later substantiated with follow-up (Kurt, İşeri, and Kişnişci, 2010) and a large number of cases have since been treated successfully (Kişnişçi and Iseri, 2011). In the same year Isaacson *et al*. (2001) successfully attempted to move an ankylosed central incisor using orthodontics, surgery and DO. Later, Kodof *et al*. (2005) demonstrated the effectiveness of treating ankylosed tooth and the surrounding alveolar ridge defect by a simple DO apparatus. . Some recent case reports emphasized on the role of DO in attaining orthodontic correction of ankylosed anterior teeth (Dolanmaz, Karaman, Pampu and Topkara, 2010; Kim, Park, Son, Kim, Kim and Mah, 2010).

Indications and contraindications: Indications includes unilateral advancement of the ramus, angle, or posterior body for hemifacial microsomia. along with vertical distraction of alveolar segments to correct an uneven occlusal plane or to facilitate implantation into edentulous zones, bilateral distraction of the body for severe micrognathia, particularly in infants and children with airway obstruction as observed in the Pierre Robin Syndrome , horizontal distraction across the midline to correct cross bite deformities or to improve arch form. and transport distraction to generate a neo-condyle and temporomandibular joint in patients with severe joint ankylosis (Ayman *et al*., 2012), Advancement of the lower maxilla at the LeFort I level, midfacial advancement at the LeFort III level. Complete advancement of Upper face (fronto-orbital, cranial vault) and the fronto-orbital bandeau, alone or in combination with the mid faces a monobloc or facial bipartition. Cranial vault remodeling by gradual separation across resected stenotic sutures and Zygomatic distraction. [41] Indicated in patients with sleep apnoea,hemifacial microsomia,facial asymmetry,Non-syndromic Craniofacial Syndrome, Syndromic Craniofacial Syndrome (Apert, Crouzon, Pierre Robin syndrome, Treacher Collins syndrome, Goldenhar syndrome, Brodie Syndrome and Pfeiffer syndromes). Hemifacial microsomia, Bi-maxillary crowding with anterior-posterior deformity. Bimaxillary deficiencies (Lengthening and widening). Also indicated in closing the alveolar cleft associated with cleft lip and palate deformities.

Contraindications: Relative contraindications are as follows:- Poor nutrition and lack of soft tissues,osteoporosis. Mandibular distraction osteogenesis i.e. placement of the distraction device, especially children under 6 years of age is difficult. Adequate bone density must be available to accept the device and to provide adequate surface area of the osteotomy sites for regeneration. Patients received prior radiation treatment.In geriatric patients, a decreased number of mesenchymal stem cells may impair bone healing at the distraction site.

Advantages of Distraction Osteogenesis: Less possibilities of relapse. Shorter hospital stay and reduced postoperative pain and swelling. Increased stability. Reduced inferior alveolar nerve dyaesthesia and need for intermaxillary fixation. Large maxillomandibular advancement is possible. No bone graft is required thus eliminating donor site morbidity. The new bone formed via distraction osteogenesis is more native (Kumar Dheeraj, 2011) Multi-directional expansion of the facial skeleton in all three planes of Space.[2] In addition, the length of distraction can be set freely. Distraction in the maxillofacial area also has several merits because intermaxillary fixation is not necessary, no temporomandibular dysfunction is left, and fine adjustment of occlusion is possible (Akay, 2011)

Disadvantages of Distraction Osteogenesis: Multiple daily outpatient visits may be required in some cases. Difficult plaque control and damage to TMJ due to incorrect vector orientation (Kumar Dheeraj, 2011). Equipment sensitive surgery (Akay, 2011) There is possible need of second surgery to remove distraction devices and patient compliance. An adequate bone density is necessary to accept the distraction appliances and to provide suitable opposing surfaces capable of generating a healing callus (Akay, 2011)

Histological aspect of distraction osteogenesis

Osteotomy: The bone is divided into two segments, the discontinuity triggers the process of bone repair called fracture healing. Firstly, recruitment of osteoprogenitor cells occurs, followed by cellular modulation or osteoinduction and establishment of an environmental template called osteoconduction. A reparative callus is formed within and around the ends of the fractured bone segments. Later the callus undergoes replacement by lamellar bone which is more mechanically resistant (Kumar Dheeraj, 2011)

Latency period - The inflammatory stage lasts for 1 to 3 days. Vascular disruption gives rise to haematoma which is converted to a clot which is replaced lastly by granulation tissue consisting of inflammatory cells, fibroblasts, collagen and invading capillaries and bony necrosis occurs at the end of the fractured segments. A mesh of fibrin clot containing blood cells and newly formed capillaries are observed at the end of the latency period, 5 days following osteotomy and just before commencement of distraction, only soft callus stage lasts for approximately 3 weeks following the inflammatory stage. The growth of capillaries takes place and the granulation tissue is converted to fibrous tissue by fibroblasts. Cartilage is replaced by the granulation tissue, more towards the periphery of the intersegmentary gap than in the central region. Cartilage provides a suitable material that is less demanding of oxygen, which temporarily bridges the gap until blood supply catches up (Kumar Dheeraj, 2011)

Distraction period - The normal fracture healing is interrupted by the application of gradual traction to the soft callus. This stimulating effect of tension activates the biologic elements of the intersegmentary connective tissue. This causes the prolongation of angiogenesis with increased tissue oxygenation and increased fibroblast proliferation with intensification of biosynthetic activity. Fibrous tissue of the soft callus becomes longitudinally oriented along the long axis of the callus. In between third and seventh days of distraction , capillaries develop into the fibrous tissues, thereby extending the vascular network. In second week the osteoblasts starts laying down the osteoid tissue on these collagen fibres. Bone formation occurs along the vector of tension and is maintained by the growing apexes, known as “growth zone.” (Kumar Dheeraj, 2011).

Consolidation period – It begins after 10 days of distraction (nearly 15 days post osteotomy), 3 distinct zones and two transitional areas within regenerative tissue could be observed. The first region is the mid region called as central zone (CZ) in which the tissue is composed of mesenchyme-like and spindle shaped cells in which many capillaries are dispersed and called as “mesenchymal or proliferative area (Kumar Dheeraj, 2011).

On both the sides of central zone are the paracentral zones (PCZ) in which number of cells and capillaries are decreased gradually accompanied with intercellular matrix mainly consisting of collagen fibres. So, it is called as "fibroblastic or collagenous area."

Most proximally and distally are the proximal distal zones (PDZ) which are in direct continuation with old bony edges. Woven bone trabeculae are seen so, it is called as "trabecular or mineralizaion area." The tips of the trabecular area recruit pre osteoblasts from the collagen ridge distracted tissue which are arranged concentrically around the tips of trabeculae . Preosteoblast further mature into osteoblast contributing to the trabecular growth so it is a transition period of the distraction zone. When this period is completed (nearly after 15 days of distraction) a homogenous zone is again observed and the trabeculae gradually become mineralized in the newly formed woven bone.

Remodeling period - There is no zonation as it was during active lengthening after 6 weeks of consolidation. The bony trabeculae becomes thicker with a mixture of lamellar and woven bone, rimmed by osteoblast and bridging the distracted gap from edge to edge. Bone remodeling of newly formed bone by osteoclastic resorption is also identified histologically thereby completing the whole process.

Alveolar distraction osteogenesis: Alveolar Distraction Osteogenesis is a process used for vertical and horizontal distraction of the atrophic mandibular and_maxillary alveolar ridges. This technique provides a very good quality of the neogenerated_bone, with adequate characteristics for implant osseointegration (Akay, 2011) Atrophy of alveolar bone ridge occurs frequently in patients as a consequence of periodontitis, tooth extractions and craniofacial traumas (Polo, 2005) Modalities to augment bone defects include autogenous onlay bone graft, guided bone regeneration, alloplastic augmentation, and alveolar split grafting. Each of these modalities has its advantage and disadvantage. Use of autogenous bone graft is the technique most commonly used to increase the height of the alveolar ridge. However bone grafts have several limitations. It does not always assure the desired bone regeneration, particularly in large bone defects. In such cases, a secondary donor site is needed and the soft tissue may be unable to cover bone. The donor site morbidity and graft rejection is expected. Nerve repositioning may result in paresthesia from nerve manipulation, although a high implant survival is likely. While guided bone regeneration has been extensively documented, it is often difficult to provide optimal space for the regeneration of the desired bone volume and therefore better suited for limited defects. [(43)] Alloplastic materials do not provide an ideal bed for rehabilitation with osseointegrated implants. In addition none of these methods offer predictable results and they all require a greater waiting time between surgeries to increase.

Indications

- Severe atrophy of edentulous ridge and narrow alveolar ridges, where horizontal distraction can be applied.
- Segmental deficiencies of the alveolar ridge that compromise the implant placement esthetically or functionally (unfavorable crown- implant index).
- Gradual vertical movement of ankylosed teeth, when orthodontic displacement is impossible or has not been successful and Gradual vertical shift of an osseointegrated implant together with the surrounding alveolar bone.

Advantages of alveolar distraction (McAllister, 2001)

- No morbidity of the donor area, simplifying the surgery.
- Less possibility of exposure of hard tissues and less possibility of graft resorption.
- More predictable volume of hard and soft tissues obtained.
- Teeth or implants can be included in the transported fragment, so that occlusal or esthetic defects can be corrected.

Complications

- Non fusion of the segments undergoing distraction). These problems necessitate a repeated surgical procedure to reosteotomize the bone segments.
- Infection at the distraction site may impair the osteogenesis process.
- During the consolidation phase, non-union or delayed union results if micromovement across the segment occurs.
- Cutaneous scarring resulting from transcutaneous fixation pins. Appliances are bulky and need patient compliance (Raghunath *et al*., 2012).

Complications can be divided into 3 groups

- Intraoperative includes the surgical procedure (eg, malfracturing, incomplete fracture, nerve damage, and excessive bleeding) and device- related problems (eg, fracture and unstable placement).
- Intradistraction, are concerned with those arising during distraction like infection, device problems).
- Post distraction complications concern the late problems arising during the period of splinting and after removal of the distraction devices (eg, malunion, relapse, and persistent nerve damage) (Akay, 2011)

Future of maxillomanibular distraction osteogenesis

The future development of Distraction Osteogenesis in craniofacial applications will probably establish a more complete understanding of the biology of new bone formation under the influence of gradual traction. Distraction surgery may also be teamed with endoscopic techniques to allow the placement of devices with minimal surgery. Bone morphogenetic proteins like BMP-2 are likely to be used in future to accelerate consolidation phase (Raghunath *et al*., 2012). The application of novel recombinant proteins and gene modified distraction protocols as demonstrated in the studies by Raschke *et al*. (1999), Long *et al*. (2011) and Castro-Govea *et al*. (2012). However, many issues still remain unresolved in regard to understanding how cells perceive the tension-stress effect of force, interpret it, and transmit intracellular messages (George Jose Cherackal and Navin Oommen Thomas, 2014). Analyzing the molecular events leading to successful DO has important clinical implications, since this is a fundamental step toward the evolution of targeted therapeutic interventions designed to accelerate osseous regeneration during distraction. Current research that is focused on the development of minimally invasive approaches; stem cells; biodegradable multiplanar distraction devices, should aim at decreasing the distraction and consolidation times, reducing complications, and optimizing patient outcomes (George Jose Cherackal and

Navin Oommen Thomas, 2014). Ultimately, the application of virtual distractors together with fundamental biomolecular data will help guide the operator and patient expectations (George Jose Cherackal and Navin Oommen Thomas, 2014). Resorbable distraction devices may be dream in present times, but could be a reality in future. Major trends may include: refinement of distraction protocols, modification of osteotomy techniques, and further improvement of distraction devices and enhancement of regenerate maturation with pharmacologic agents. With technologic advancements, distraction devices have become smaller and more sophisticated than early versions (Raghunath *et al*., 2012). Development of new techniques to monitor distraction regenerate formation and remodeling. Preliminary studies of rabbits have shown that distraction performed in the presence of recombinant human bone morpho-genetic protein placed into the distraction site accelerates bone formation. In addition, use of microprocessors and miniature motorized distraction devices may provide the ability to insert submerged appliances capable of auto-distraction according to pre-programmed data. [2]

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