Alveolar Distraction Osteogenesis: Revive and Restore the Native Bone

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Abstract

In prosthodontics, knife-edge bony alveolar ridges can cause a problem in their rehabilitation. The distraction osteogenesis process raises the medullary component of the alveolus, allowing the labial plate of the existing natural bone to be displaced. This process involves mobilization, transport, and fixation of a healthy segment of bone adjacent to the deficient site. It entails use of the gradual controlled displacement of surgically created fractures, which results in simultaneous expansion of soft tissue and bone volume. A mechanical device, the alveolar distraction device, is used for this purpose. This modality of treatment can be used in implant dentistry cases for rehabilitation of resorbed ridges. The objective of this overview is to explain this procedure wherein the alveolar housing, including the osseous and soft-tissue components, is enlarged in a single, simultaneous process, which makes creation of an appropriate alveolar morphology possible.

Resorption of bone is unavoidable when it comes to alveolar ridges, be it due to improper functional loading, trauma, or just simply a matter of time. Hence, the treatment plan today is "First Rehabilitate, then Restore."

Rehabilitation of the alveolar ridges before placement of implants has become the norm for ideal ridges for the best possible treatment outcome. The options available are as follows:

1. *Onlay bone grafting*:[1] In this procedure, bone is harvested from the same individual but from another site and placed in the defect region. This technique, apart from being time consuming, also requires excellent skill and a secondary site for operation, and hence has greater chances of infection. Even though this method has proven to be successful, there is a certain amount of resorption of the new bone fragment, which cannot be stopped, hence the need for overcorrection.
2. *Interpositional bone grafting*:[1] This is the second treatment option for rehabilitation of resorbed ridges. The procedure is essentially similar to that of onlay bone grafting where an additional site for surgery is required from where bone is harvested, but it is placed between the plates of the bone opened up by an osteotomy procedure. This method suggests that bone integration will be better if placed between freshly exposed surfaces of bone, rather than just placing it on top of the bone. But this technique, too, has certain limitations, and the amount of lengthening that can be done is limited.
3. *Guided bone regeneration*:[2] These techniques are based on the criteria that reflect the biologic behavior of different tissues such as gingival epithelium and connective tissue during wound healing. Placement of a physical barrier, such as an expanded polytetrafluoroethylene membrane, titanium mesh, or collagen membrane, is used in conjunction with particulate graft material. This technique has shown satisfactory results, but there are chances of losing the particulate bone graft material via seepage, and thus the expected level of bone augmentation may not be achieved.
4. *Distraction osteogenesis (DO)*:[3] Several new techniques were developed to overcome these limitations. One such technique, advocated by G. A. Illizarov, gaining widespread popularity, is a method of gradual bone distraction/separation known as DO.

Dr. Alessandro Codvilla evolved a novel approach to avoid further grafting procedures to help in maintenance of an ideal ridge contour.[4] This technique uses gradual separation of the bone surfaces to induce new bone formation between the two ends. This is done by applying incremental traction to the separated bone ends, which results in new bone formation between them. The new bone formation is parallel to the vector of the traction.

History

Dr. Alessandro Codvilla (1905) used the combination for this procedure to perform the first limb lengthening procedure, using an external pin fixator and oblique osteotomy of the femur. The most significant contribution to the development of the concept of DO was made by a Russian surgeon, Gavril Ilizarov (1951), who developed low-energy corticotomy techniques and a unique protocol for limb lengthening using a 5- to 7-day latency period followed by distraction at the rate of 1 mm/day in four increments of 0.25 mm.[4-7]

Based on clinical experience, Ilizarov discovered two biological principles, "Ilizarov effects":[8,9]

1. Tension-stress effect on the growth and genesis of tissues. This suggested that when two bone plates are separated, there is pressure acting on one side and tension on the other side of the device in situ. Thus, due to these physiologic changes, the osteoblasts are stimulated to grow, thus helping in new bone formation.
2. The influence of blood supply and loading on the shape of bones and joints.

Distraction osteogenesis

There are a few basic steps in DO as follows:[10]

1. *Osteotomy*: Surgical separation of bone into two segments. This is done using an oscillating saw or a fissure bur. After deciding the site where osteotomy must be performed, a full surgical cut is performed, which will facilitate the placement of the distractor device.[7,8] This results in establishment of discontinuity in the mechanical integrity of bone, which triggers an evolutionary bone-repair process called fracture healing. Traditionally, fracture healing has been described in six stages (impact, induction, inflammation, soft callus, hard callus, and remodeling). Osteotomy causes loss of mechanical integrity, triggering fracture healing, which involves recruitment of osteoprogenitor cells, followed by cellular modulation (osteoinduction) and establishment of environment template (osteoconduction). The above process results in formation of a reparative callus around the fractured bone segments. A horizontal osteotomy is usually performed 4 mm from the crestal bone for placement of intraosseous distraction devices.[11]
2. *Latency*: The time between osteotomy and onset of traction. Latency represents the time required for the reparative callus to form. Initially, there is formation of a hematoma, which is converted into a clot. This is followed by vasoformative elements leading to capillary proliferation. Callus formation is a response determined by the osteoprogenitor cells originating in the periosteum and endosteum. Histologically, it involves gap healing and direct bone apposition. This period is usually 5 days in most cases, as that is the time required for the cells to integrate, but it is advised to wait 4 to 21 days (mean latency period 7.26 ± 2.31 days)[3,11,12] for alveolar distraction.
3. *Distraction*: Application of traction force.[10] During normal fracture healing, the soft callus ossifies and becomes a hard callus, which happens by replacement of the fibrocartilagenous tissues by osteoblasts. During osteodistraction, the normal fracture healing is disrupted. The growth stimulating effect of tension activates the biologic elements of intersegmentary connective tissue.[10] This includes the following:

   a. Prolongation of angiogenesis
   b. Increased fibroblastic proliferation
   c. Intensification of biosynthetic activity.

   The shape-forming effect of tension causes an alteration in the phenotypic expression of the fibroblasts.[7] These "distraction fibroblasts" give a hypertrophic appearance to the intermediate filament. These fibroblasts secrete collagen along the long axis of the distraction vector. Between the third and seventh day, angiogenesis is seen. During this phase, the rate of angiogenesis is approximately 10 times higher than that seen in normal fracture healing. During the second week of distraction, primary trabecule begins to form.[7] Osteogenesis begins at the existing bone ends and progresses toward the center of the distraction gap. By the end of the second week, the osteoid begins to mineralize. The mixture of fibrous and cartilage tissue within the interzone suggests that both membranous and endochondral processes play an important role in distraction bone formation. Distraction is the actual process of separation of the two bone ends by means of a mechanical device. Two basic principles are to be followed in distraction:[7]

   a) Rate: The amount of separation that can be done per day is 1 mm, and the total amount of distraction that can be achieved is around 10 to 15 mm, depending on the amount of distraction required and the size of the distractor device.[7]
   b) Rhythm denotes the number of activations required for alveolar distraction. Two activations per day are done, and the patient is usually admitted to the clinic and kept under observance. The pitch of the device is set in such a way that 1 mm of distraction is brought about after four turns of the screw (pitch of screw maintained at 0.25 mm or 0.5 mm). This has been shown to produce better results.[7]

4. *Consolidation*: The period after completion of distraction. Consolidation allows the mineralization of the newly formed bone. During this period there is complete mineralization of the distraction regenerate. Although this is predominantly by intramembranous ossification, isolated islands of cartilage can be seen, suggesting endochondral bone formation. In addition, focal regions of chondrocytes are seen surrounded by mineralized bone, suggesting a transchondroid bone formation.[7,8]
5. *Remodeling*: Begins at the completion of distraction and continues through the consolidation phase and may extend up to 1 year after completion of distraction. In this phase, the initially formed bony scaffold is reinforced by parallel fibers of lamellar bone. Both the cortical bone and the marrow cavity are restored.[7]

Distraction vector planning

Distraction vector planning is an integral part in placement. Distraction vector defines the desired direction the distal segment should move during lengthening. Despite careful planning, the actual movement factors that affect the distraction vector include osteotomy design and location, distraction device orientation, masticatory muscle influence, occlusal interference, distraction device adjustments, and orthodontically/orthopedically applied forces.[10]

Although the factors mentioned earlier also influence the final outcome, the most important factor is the orientation of the distraction device. To minimize the adverse biomechanical effects, the device should be placed parallel to the desired vector of distraction. Based on the orientation of the distraction vector, the distraction device can be placed vertically, horizontally, or obliquely.[10]

Established indications for alveolar DO[13,14]

1. Craniofacial reconstruction
2. Advancement in cleft lip and palate
3. Neocondylar genesis
4. Dentoalveolar unit augmentation
5. Traumatic injury causing alveolar bone loss
6. Bone atrophy
7. Reoperation after earlier augmentation procedure failure
8. Resection
9. Congenital malformation
10. Ankylosis
11. Postgrafting
12. Discontinuity defects

Advantages

1. Soft tissue follows the bone; hence, additional soft-tissue recontouring is avoided.[15]
2. The initial osteotomy procedure is less invasive as compared to the other major augmentation procedures.[16,17]
3. Avoids limitations of complications possibly associated with conventional bony mobilization and repositioning.
4. The potential for substantially larger movements and greater postoperative stability exists.[18]
5. Surgical intervention is possible in the very young patient and, apparently, much earlier than with standard craniofacial techniques.[3]

Disadvantages[19,20]

1. Does not correct underlying growth disturbances in craniofacial patients
2. Requires a second procedure to remove the distraction appliances
3. Pain is caused when the two bone segments are undergoing distraction
4. Experience with the technique is limited

Complications[21]

A number of problems can arise with the distraction process (e.g., patient noncompliance, skin perforations, bone fracture of the segments undergoing distraction). These problems necessitate a repeat surgical procedure to reosteotomize the bone segments. Infection at the distraction site may impair the osteogenesis process. During the consolidation phase, nonunion or delayed union results if micromovement across the regenerate occurs. Excessive scarring is also possible, particularly when using external devices. Finally, a relative lack of control in repositioning the bone segments exists compared with conventional surgery, which leads to a less than ideal final position.

Adequate bone volume and maturity in the distracted region may provide a better implant success rate than following bone grafting due to greater bone resorption expected in the long term. In comparing vertical guided bone regeneration and DO, Chiapasco et al[11] found that the mean ridge height loss between implant placement and abutment connection 1 to 3 years after prosthetic loading was significantly greater in the guided bone regeneration group, suggesting that DO may be a more effective technique. Results obtained after implant placement and loading have been encouraging, but future long-term follow-up studies are necessary to evaluate the criteria of implant survival and success.

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