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DISTRACTION OSTEOGENESIS IN FACIAL SKELETON

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ABSTRACT
Acute advancement of osteotomized bone segments is associated with various limitations, despite the fact that orthognathic surgery has become widely accepted for the repair of maxillomandibular deformities. Moreover, significant skeletal abnormalities, such those shown in syndromic patients, necessitate such extensive bone motions that the soft tissues around them are unable to adjust to their new position, which can lead to relapse or reduced function and appearance. New bone can be produced parallel to the direction of traction by gradually mechanically tractioning bone segments at an osteotomy site established in the craniofacial region, as several clinical and experimental studies have recently shown. Orthodontists and maxillofacial surgeons now have more options when it comes to correcting craniofacial malformations due to this condition, which is called distraction osteogenesis. Therefore, the aim of this article is to critically assess the current mandibular distraction devices and their clinical applications, review the historical development and biologic basis of mandibular distraction osteogenesis, and forecast the future evolution of mandibular osteodistraction techniques

INTRODUCTION:

Asymmetric facial features, congenital micrognathia, and maxillomandibular hypoplasia are rather common anomalies of the craniofacial complex. Osteotomies, acute orthopaedic motions, skeletal fixation, and/or interpositional bone grafts have historically been used to treat various skeletal abnormalities in nongrowing patients[1-5]. Although craniofacial reconstruction and traditional orthognathic surgery have been widely successful, they are nevertheless accompanied by a number of drawbacks[2,5,6]. The inability of the muscles to be severely stretched without running the danger of relapse is one of these restrictions[4,7-9]. Furthermore, unless additional soft tissue treatments are carried out, many congenital abnormalities necessitate such extensive musculoskeletal movements that the soft tissues will not adapt the alteration, resulting in poor function and esthetics[10-12].

Furthermore, there is limited potential for new bone formation with current surgical intervention, which only allows for drastic modifications in the spatial arrangement of bones. The full sculpting of the bones to optimise their three-dimensional structural, functional, and aesthetic requirements for the patient is not permitted.

Aiming to modulate de novo bone development through osteoconduction and/or osteoinduction, current efforts have been driven by these constraints. The process of distraction osteogenesis, sometimes referred to as callus distraction, is an alternate strategy that involves the production of new bone between the surfaces of bone segments that are progressively separated by traction. In particular, the procedure begins with the application of incremental tension to the reparative callus, which connects the separated bone segments[13-15]. It lasts for the length of time that this tendon is stretched. Parallel to the distraction vector,

the traction causes stress in the callus and promotes the growth of new bone. Significantly, distraction pressures exerted on bone also cause tension in the soft tissues around it, which starts a series of adaptive alterations known as distraction histogenesis[16].
Larger skeletal motions may be possible thanks to these adaptive changes in the soft tissues, which also reduce the risk of recurrence that comes with acute orthopaedic adjustments. In orthopaedics, distraction osteogenesis has evolved to be recognized as the preferred method of treating limb-length disparities, skeletal abnormalities, and severe bony defects. The successful use of progressive osteodistraction in the treatment of skeletal abnormalities of the mouth and maxillofacial region has been demonstrated in recent clinical publications. Slow progressive traction has made it possible to extend the mandible by up to 20 mm without experiencing any pain. An orthodontist must have a complete understanding of the history and potential future developments of osteodistraction because these disorders are typically addressed collaboratively.

HISTORY AND DEVELOPMENT

The advancement and refinement of dentofacial traction, craniofacial osteotomies, and skeletal fixation techniques served as the foundation for the creation of craniofacial distraction osteogenesis. These methods were later modified and combined into osteodistraction procedures, which were ultimately enhanced in light of distraction osteogenesis experiences on long bones[17].

Dentofacial Traction

Applying compressive and tensile pressures to the bones of the craniofacial skeleton is not a novel idea from the standpoint of orthodontics. Since the eighteenth century, dentistry has used the principles of dental traction to treat skeletal deficiencies. Fauchard wrote on the application of the expansion arch as early as 1728. The teeth widened to a normal form when the perfectly shaped metal plate was ligated to the dentition that was crowded. Nevertheless, this type of traction was restricted to the movement of teeth and had minimal impact on the morphology of the bone.
In 1859, Wescott[18] published the first account of the mechanical forces applied to the maxilla bones. The 15-year-old girl had a crossbite that he corrected with two double clasps spaced apart by a telescopic bar. In order to enable the deposition of "osseous material" in the space that was produced, he turned on the device twice a day for three weeks, followed by a stabilisation phase.

Craniofacial Osteotomies

Orthodontic therapy is available to rectify maxillomandibular skeletal discrepancies, however it is only for youngsters who are still growing. Surgical intervention has been used to get over this restriction in non- growing people. In 1848, Hullihen[19] achieved a successful partial osteoplastic resection of a prognathic mandible, which was the first surgical operation for the correction of a craniofacial abnormality. A wedge-shaped portion of bone was removed from each side of the mandibular body after the subapical osteotomy of the anterior jaw. However, it wasn't until the first decade of the 1900s that mandibular retrognathia was surgically treated. Blair[7] showed how to advance the mandible by performing a bilateral horizontal ramus osteotomy.

Advancement of the retrognathic mandible has also been promoted through mandibular corpus osteotomy[21]. Limberg states that vertical osteotomies of the mandibular body were carried out by Brown in 1918 and Bruhn-Linderman in 1921, respectively, and were followed by acute advancement of the anterior section. New bone development normally heals the resulting deficiency. However, there was little progress made with these osteotomies, and they were frequently linked to unstable bone segment fixation. Even though corrective osteotomies were becoming more and more popular at the time, it was clear that they had a number of drawbacks, particularly when paired with acute mandibular lengthening. Acute muscle stretching resulting in partial or complete relapse, significant postoperative displacement of bone segments owing to insufficient bony contact and fixation stability, and intraoperative nerve injury were among the issues[7,8,23].

Initial Mandibular Distraction Techniques:

Rosenthal performed the first mandibular osteodistraction surgery in 1927, according to Wassmund[24]. He did this by employing an intraoral tooth-borne appliance that was gradually triggered over the course of one month. In addition, Kazanjian[25] used slow incremental traction rather than sharp advancement in 1937 when performing mandibular osteodistraction. He first performed modified L-shaped osteotomies in the corpus, and then he fixed a wire hook to the symphysis, giving the distracted bone fragment direct skeletal fixation. An "over the face" appliance was positioned and turned on with an elastic band three days after surgery. This pulled the mandibular anterior portion forward by applying pressure to the chin. After seventeen days, the elastic force was eliminated. The complete consolidation of the jaw occurred after 11 weeks of occlusal splints secured by stiff bars.

Although the initial distraction osteogenesis procedures gradually pulled on the surrounding soft tissues and bone segments, this method was not quickly adopted. The main causes of this were the instability of osseous fixation, the lack of control over bone segment manipulation, and the inadequateness of distraction appliances. Rather, corrective osteotomies continued to be the primary method of treating mandibular abnormalities, particularly after Trauner and Obwegeser[2] introduced sagittal split osteotomies.

Skeletal Fixation

The adaption of external skeletal fixation to the mandible and the emergence of distraction osteogenesis protocols for limb lengthening reignited interest in mandibular osteodistraction, even if acute orthopaedic motions remained the preferred course of treatment. Haynes[26] published the first report on the use of external skeletal fixation for cranial fractures in 1939. He used this method on a mandibular complex fracture that was comminuted, using several pins attached to a stiff bar. Based on appliances for external skeletal fixing of the lower extremities, two further external mandibular fixation devices were created in 1941. Comparable in design, the Mowlem[27], Converse, and Waknitz[28] appliances comprised three primary components: a telescoping fixation bar placed in between the fracture and two sets of fixation pins with locking plates on either side. Double-plane-joint components and a threaded rod connecting the two pin fixation clamps were added by Stader[29] in 1942, modifying the mandibular external fixator even further. As the first mandibular device to allow for anteroposterior incremental compression or distraction, Stader's fixation appliance allowed for angular adjustments in two planes.

Ilizarov Method

Ilizarov[13-15] then presented his distrac-tion osteogenesis method for extending limbs. He named the initial surgical bone division used in the process a "corticotomy," because it preserved as much of the periosteum and endosteum as possible. Specifically, Ilizarov used a small osteotome to split the bony cortex into two thirds, and rotating osteoclasis to finish the separation of the bones. He employed a 5– 7 day latency period (the interval between bone division and the start of traction pressures) in his distraction technique. Then, in four equal increments of 0.22 mm, the bone segments were gradually separated at a pace of 1 mm each day. After distraction was finished, the newly produced bone tissue in the distraction gap underwent remodelling during the consolidation stage, which lasted for a duration determined by the necessary remodelling of the regenerate tissue.

CURRENT TECHNIQUES

In 1973, the first paper was published that showed how Ilizarov's techniques may be used to the mandible. Snyder et al[30] created a crossbite by excising a unilateral 15 mm bone piece from a canine mandible in order to mimic a mandibular malformation. An extraoral distraction appliance was implanted and the shortened mandible was osteotomized 10 weeks later. The occlusion was restored after a 7-day latency period, during which the device was turned on at a rate of 1 mm per day for 14 days. After six weeks after fixation, reestablishment of the medullary canal and mandibular cortex across the distraction gap was observed.

A few years later, Michieli and Miotti[31] showed that intraoral mandibular lengthening was feasible using a similar distraction procedure. Using a tool affixed to the teeth, they performed a bilateral reverse step osteotomy, lengthening the mandibles of two dogs, one by 5 mm and the other by 15 mm. Upon histologic investigation, it was discovered that the parallel organised collagenous fibres were the source of new bone production. These fibres then underwent remodelling to form lamellar bone.

The first significant histologic assessment of 41 dogs' mandibular distraction regenerates was carried out in 1982 by Panikarovski et al[32] Collagenous fibres and capillaries aligned parallel to the direction of distraction comprised the fibrous interzone that was present in the centre region of the distraction gap. Longitudinal trabeculae, representing newly formed bone, arose from the remaining mandibular segments and advanced into the fibrous interzone. These investigations' findings showed that the process of forming new bone after gradual mandibular distraction was comparable to the process of limb lengthening.

In a related experimental investigation, distraction regenerates at various phases of creation were more thoroughly analysed by Karp et al[33]. Four zones were identified histomorphological as representing the distraction gap: a mature bone zone, a zone of expanding bone creation, a zone of bone remodelling, and a centre zone of fibrous tissue. The distraction osteogenesis technique's therapeutic adaptation to the craniofacial complex has a scientific foundation thanks to these investigations.

Extraoral Mandibular Distraction

McCarthy et al[34] was the first to use extraoral osteodistraction in a clinical setting on four infants who had congenital craniofacial abnormalities in 1989. They employed a Hoffman Mini Lengthener (Howmedica Co., Rutherford, NJ), which was pinned twice to the osteotomized bone segments. Drill holes were positioned along the osteotomy line and connected with a small osteotome to start the process of bone division. Following a seven-day delay, lengthening started at a daily pace of 1 mm, done in two increments of 0.5 mm. External fixation was sustained for an extra eight to ten weeks following a distraction period of 18 to 24 days.

Molina and Ortiz-Monasterio[35] made the procedures developed by McCarthy et al. simpler. Their method preserved the medial cortical plate by performing a corticotomy. They used what they called a semirigid extraoral fixation method, inserting a single fixation pin on either side of the corticotomy and fastening it to the distraction device. Molina and Ortiz-Monasterio claim that the muscles continuously apply pressure to the appliance, causing it to gently bend and reflecting the internal bone remodelling on the outside.

Even though these early findings showed that osteodistraction could be successfully applied to the human craniofacial skeleton, the earliest extraoral devices could only stretch the mandible in one direction, either vertically or horizontally. Using this approach, patients with mandibular deficits in the corpus or ramus may receive full correction of linear bone discrepancies. However, severe malformations frequently affect the ramus, corpus, and angle of the mandible in patients with congenital disorders involving mandibular microsomia or micrognathia. In these situations, independent distraction in two directions can more effectively address mandibular restoration.

The first people to employ bidirectional osteodistraction in the mandible were Molina and Ortiz-Monasterio. By performing double-level corticotomies (horizontal in the ramus and vertical in the corpus), they created two distraction sites and were able to extend both mandibular portions at the same time. Furthermore, subsequent adjustments to bidirectional devices allowed for an adjustment in the angular relationship between the two distraction vectors during lengthening, which allowed the gonial angle to be increased.

The adaptability of distraction osteogenesis in patients with mandibular insufficiency was greatly enhanced by the use of extraoral bidirectional distraction appliances. Anatomically speaking, the mandible is made up of two parts that are joined at an acute angle in the midline to form a V-shaped bone structure. Each half of the mandible is made up of a vertical ramus and a horizontal corpus that are angularly oriented toward one another. Therefore, incremental angular corrections must be paired with separate lengthening of the mandibular corpus and ramus in order to rectify severe mandibular abnormalities in three-dimensional space. Two multidirectional extraoral distraction gadgets were consequently created, enabling the manipulation of bone segments in several spatial planes.

When it comes to extraoral distraction devices, clinicians have many advantages (e.g., simple attachment, easy manipulation, bidirectional and multidirectional distraction, application for very small children), but patients are wary of bulky external appliances due to social inconvenience and the possibility of permanent facial scarring. Furthermore, there are still design flaws in both of the extraoral multidirectional devices that are now on the market. While double-level lengthening is possible with the ACE/Normed device (Normed Medizin- Technik GmbH, Germany), multidimensional correction is only possible when the hinge screws are loosened. The Multi-Guide Mandibular Distractor

(Howmedica Leibinger, Inc., Rutherford, NJ) can rotate the bone segments in three dimensions gradually and independently, however it is not capable of bidirectional independent correction or two distraction sites. The main factor influencing the evolution of mandibular lengthening and widening toward the creation of intraoral devices was these drawbacks and restrictions.

Intraoral Mandibular Distraction

The results of intraoral mandibular widening on 11 patients with transverse deficits ranging from 4 to 7 mm were originally reported by Guerrero[36-46] in 1990. Two paths led to the advancement of intraoral mandibular distraction: (1) external device downsizing [37,38]; and (2) orthodontic expansion appliance modification[39,40]. The intraoral distractors are categorised as either tooth-borne (connected to the teeth only), hybrid (simultaneously attached to the teeth and bone), or bone-borne (attached to the bone exclusively)[41]. A bone-borne, miniature Uniguide Mandibular Distraction Device (Howmedica Leibinger, Inc.) designed for intraoral insertion was created in 1994 by McCarthy et al[38]. Like their extraoral appliance, the apparatus was made up of two clamps that were joined by a telescopic distraction rod and two pairs of pins that were affixed to the bone. A comparable device, the Intraoral Titanium Mandibular Distraction Device (Medicon Instrumente, Tuttlingen, Germany), was created concurrently in Germany by Wangerin[37]. The gadget eliminates the propensity for rotational movement by connecting mini- plates (for bone fixation) via a square- shaped distraction cylinder.

Mandibular osteodistraction procedures were greatly enhanced with the advent of intraoral appliances. The devices' subtle appearance and the lack of facial scars were the main benefits. However, there are design constraints with intraoral appliances that are mostly associated with the device's limited size and the oral cavity's restricted access. These restrictions led to the use of different strategies in the subsequent development of intraoral distraction equipment. For example, depending on the anatomic location of distraction—the horizontal corpus or ascending ramus—the French surgeons Diner et al[42] devised two types of intraoral bone-borne devices for mandibular lengthening.

Various tooth-borne, bone-borne, and hybrid intraoral devices for mandibular lengthening and broadening were presented by Guerrero et al[43]. The appliances can be adjusted and fastened to pairs of bendable metal arms with fork- shaped ends or orthodontic bands. Because the device is bendable, there is less chance of mandibular nerve damage from improper screw placement during surgery. Furthermore, after the consolidation phase, the appliance can be extracted by cutting its metal arms and withdrawing its fork ends, leaving the fixation screws in the bone.

In a similar vein, Razdolsky et al[39]. created a line of hybrid and tooth-borne devices called Oral Osteodistraction, LP, Buffalo Grove, Ill., where the distraction mechanism is affixed to miniplates or stainless steel crowns. Furthermore, a unique laboratory apparatus was created by them to enable preoperative records-based preprogrammed fabrication of the device along a predefined axis of distraction. Following the bonding of the device to the teeth or bone, the distractor mechanism is taken out, the corticotomy is executed with a specialised saw, and then the distractors are replaced.

FUTURE DIRECTIONS

It is likely that a more thorough understanding of the biology of new bone formation under the effect of progressive traction will be established by the development of osteodistraction in the future for craniofacial applications. The following could be considered major trends:
(1) improving distraction protocols; (2) altering osteotomy techniques; (3) enhancing distraction devices; (4) using pharmaceutical agents like growth factors and cytokines to enhance the maturation of distractions; and (5) creating new methods for tracking the formation and remodeling of distractions.

Distraction Protocol

Both clinical studies with long-term outcome assessments and experimental research should serve as the foundation for future advancements in the distraction strategy. Research will most likely focus on determining the ideal values for the crucial distraction characteristics. According to the orthopaedic literature, these crucial factors are as follows[13,14]: (1) osteotomy technique with maximum preservation of blood supply to the osteotomized bone segments; (2) latency period duration; (3) rate (total daily lengthening) and rhythm (number of increments into which the total daily lengthening is divided) of distraction; (4) consolidation period duration; and (5) loading environment of the regenerate. These factors may likewise be expected to influence the result of distraction osteogenesis in the membranous bones of the craniofacial complex, since they influence the process in bones of endochondral origin. However, there aren't enough studies devoted to clarifying the crucial variables connected to mechanically induced bone development in the craniofacial region. Consequently, it is critical to thoroughly examine how each of these factors affects the development of new bone during osteodistraction in the craniofacial region.

Before distraction osteogenesis can be widely applied to deformities of the craniofacial skeleton, a number of other questions need to be answered. These include: How does distraction osteogenesis affect the developing craniofacial skeleton? Does it affect the long-term stability of bone lengthened by osteodistraction? What are the soft tissue limits to stretch during distraction osteogenesis? How does osteodistraction in the maxillomandibular region affect tooth eruption and movement? Does distraction affect the periodontal ligament and related oral soft tissues? Does distraction affect the periodontal ligament and associated oral soft tissues? Does distraction occur when an intraoral tooth-borne or hybrid device is used instead of a bone-borne (direct skeletal fixation) device? If so, does this occur with all devices, if any?

OSTEOTOMY PROCEDURES:

One of the most important elements of distraction osteogenesis will always be the osteotomy due to the structure of the mandible. Advances in osteotomy methods should lead to a division of bone without damaging the neurovascular bundle, endosteum, or periosteum. This is especially important at the ends of the osteotomized segments, where there is insufficient host bone, such as in the case of bone cuts between teeth. In order to enhance bone production within the regenerate tissue, Bell et al[44]. recently established that marginal alveolar bone at interdental osteotomy sites required to be maintained. Additionally, the osteotomy needs to be improved to enable for lengthening and repair of bone deformities while maintaining the greatest possible contact area between bone surfaces.

Light-cured adhesives[45], which are used in novel methods of soft tissue closure, can expedite surgical procedures while maintaining an intact barrier to the oral flora over the surgical site.

Distraction Devices

The creation of an optimal distraction device should move forward in the direction of a multidirectional intraoral appliance that can be adjusted both linearly and angularly at the same time. Bioresorbable polymers[46,47] can be used to tie the device to the mandible, making it easier to insert and remove the distraction component while preserving the appliance's necessary strength and rigidity. Accurate direction control and force calibration are possible with motorized distraction units that feature remote activation and monitoring. For the patient or parents, this would make the distraction activation process simpler. Lastly, for the device to be utilized in an outpatient context, it needs to be reasonably priced.

Enhancement of Regenerate Maturation

Future applications of craniofacial distraction osteogenesis will be expanded by our capacity to regulate regenerate formation during the distraction process, even though the majority of current research is still primarily focused on optimising distraction parameters and modifying distraction devices. By modifying the pace and rhythm of distraction in accordance with the radiographic appearance of the forming bone, regenerate formation can be regulated in endo-chondral bones, where the final length of the forming regenerate is typically more than 30 mm and the distraction duration is greater than 4 weeks. In comparison, regenerate tissue forms in a shorter amount of time (1 to 2 weeks) and the distraction is typically less than 20 mm when it comes to distracting craniofacial bones. With present monitoring techniques, it is frequently hard to visualise the regeneration throughout this time window. Consequently, it is not possible to modify the rate or rhythm of distraction in order to modify the formation of regenerates. In these situations, an alternative that may work is to amplify distraction by adding growth factors and cytokines to the milieu of reparative and formative cells in the distraction gap or by modifying the loading environment's mechanical forces during the consolidation phase. Recombinant human bone morphogenetic protein-2 (rhBMP-2)[48-50] and other growth factors have been shown to promote bone remodelling and healing at fracture and implant sites when added to the bone healing environment.

Monitoring of Regenerate Formation and Remodelling

Currently, noninvasive techniques like plain radiography are employed in clinical settings to assess the functional loading capacity of regenerate bone. Nevertheless, there is little evidence of a relationship between radiographic density and the biomechanical integrity of freshly produced bone[51,52]. To ascertain the ideal length of the fixation period, therefore, more trustworthy quantitative and qualitative methods utilising mechanical, histologic, and biochemical indicators must be created. The use of osteodistraction in fields other than deformity treatment will grow as fresh biological discoveries are integrated with existing theories of distraction osteogenesis. By extending the length or circumference of the dental arch, osteodistraction gives orthodontists more treatment options and may even eliminate the need for extraction therapy in circumstances when the arch is extremely crowded.

More individuals with tooth loss and alveolar ridge atrophy will require low-cost, functionally adequate methods of treating partially edentulous jaws as the population's mean age rises. For patients with alveolar ridge atrophy, distraction osteogenesis presents a chance to regenerate alveolar bone prior to implant or fixed partial denture insertion. After implantation, osseointegrated implants cannot passively emerge with the surrounding dentition. A similar issue that occurs less frequently is localized permanent teeth ankylosis. When combined with gradual callus separation, strategically inserted interdental osteotomies may offer more effective treatment than prosthodontic therapy alone.

CONCLUSIONS

Innovative approaches to surgical-orthodontic care of craniofacial skeleton developmental abnormalities are provided by the use of osteodistraction. Craniofacial osteodistraction developed from skeletal traction, osteotomy techniques, and external fixation methods, much as distraction osteogenesis in the long bones. Similarly, the molecular principles behind long bone separation are also applicable to craniofacial distraction. With osteodistraction, bone can be shaped into various forms to better address the skeletal abnormalities and asymmetries that exist in the body. Furthermore, bigger skeletal movements might be possible due to the phenomena of distraction histogenesis, which eliminates the intrinsic risk of relapse. In addition, a number of congenital deformities that necessitate considerable musculoskeletal motions may be treated with fewer treatments in the end, ultimately yielding the same results in terms of structure, function, and aesthetics that are frequently observed with contemporary orthognathic surgeries.

REFERENCES

1. Wolford LM, Wardrop RW, Hartog JM. Coralline porous hydroxylapatite as a bone graft substitute in orthognathic surgery. J Oral Maxillofac Surg 1987;45:1034-42.
2. Trauner R, Obwegeser H. The surgical correction of mandibular prognathism and retrognathia with consideration of genioplasty: part I, surgical procedures to correct mandibular prognathism and reshaping of the chin. Oral Surg Oral Med Oral Path 1957;10:677-89.
3. Caldwell JB, Amaral WJ. Mandibular micrognathia corrected by vertical osteotomy in the rami and iliac bone graft. J Oral Surg 1960;18:3-15.
4. Schendel SA, Epker BN. Results after mandibular advancement surgery: an analysis of 87 cases. J Oral Surg 1980;38:265-82.
5. Converse JM, Horowitz SL. The surgical-orthodontic approach to the treatment of dentofacial deformities. Am J Orthod Dentofacial Orthop 1969;55:217-43.
6. Cassidy DW, Herbosa EG, Rotskoff KS, Johnston LE Jr. A comparison of surgery and orthodontics in "borderline" adults with Class II, Division 1 malocclusions. Am J Orthod Dentofacial Orthop 1993;104:455-70.
7. Blair VP. Operations on the jaw-bone and face. Surg Gyn Obstet 1907;4:67-78.
8. Babcock WW. The surgical treatment of certain deformities of the jaw associated with malocclusion of the teeth. J Am Med Assoc 1909;53:833-9.
9. Ellis E, III, Carlson DS. Stability two years after mandibular advancement with and without suprahyoid myotomy: an experimental study. J Oral Maxillofac Surg 1983;41:426-37.
10. Caldwell JB, Hayward JR, Lister RL. Correction of mandibular retrognathia by vertical L osteotomy: a new technic. J Oral Surg 1968;26:259-64.
11. Longaker MT, Siebert JW. Microsurgical correction of facial contour in congenital craniofacial malformations: the marriage of hard and soft tissue. Plast Reconstr Surg 1996;98:942-50.
12. Vargervik K, Ousterhout DK, Farias M. Factors affecting long-term results in hemifacial microsomia. Cleft Palate Craniofac J 1986;23(Suppl 1):53-68.
13. Ilizarov GA. The tension-stress effect on the genesis and growth of tissues: part II, the influence of the rate and

frequency of distraction. Clin Orthop Rel Res 1989;239:263-85.

14. Ilizarov GA. The tension-stress effect on the genesis and growth of tissues: part I, the influence of stability of fixation and soft tissue preservation. Clin Orthop Rel Res 1989;238:249-81.
15. Ilizarov GA. Clinical application of the tension-stress effect for limb lengthening. Clin
16. Samchukov ML, Cherkashin AM, Cope JB. Distraction osteogenesis: origins and evo- lution. In: McNamara JA Jr, Trotman CA, eds. Advances in Craniofacial Orthopedics. Volume 34. Craniofacial Growth Series. Ann Arbor: Center for Human Growth and Development, University of Michigan; 1998:1-35.
17. Samchukov ML, Cherkashin AM, Cope JB. Distraction osteogenesis: Origin and Evolution. 1998. http://www.globalmednet.com/do.
18. Wescott A. A case of irregularity. Dent Cosmos 1859;1:60-8.
19. Hullihen SP. Case of elongation of the under jaw and distortion of the face and neck, caused by a burn successfully treated. Am J Dent Sci 1848;9:157-65.
20. Converse JM, Shapiro HH. Treatment of developmental malformations of the jaws. Plast Reconstr Surg 1952;10:473- 510.
21. Limberg A. Treatment of openbite by means of plastic oblique osteotomy of the ascending rami of the mandible. Dent Cosmos 1925;67:1191-200.
22. Limberg A. A new method of plastic lengthening of the mandible in unilateral micro- genia and asymmetry of the face. J Am Dent Assoc 1928;15:851-71.
23. ickerill HP. Double resection of the mandible. Dent Cosmos 1912;54:114-9.
24. Wassmund M. Lehrbuch der Praktischen Chirurgie des Mundes und der Kiefer. Band 1. Leizig: Hermann Meusser 1935;275.
25. Kazanjian VH. The interrelationship of dentistry and surgery in the treatment of deformities of the face and jaws. Am J Orthod Oral Surg 1941;27:10-30.
26. Haynes HH. Treating fractures by skeletal fixation of the individual bone. South Med J 1939;32:720-4.
27. Mowlem RM, Buxton JLD, MacGregor AB, Barron JN. External pin fixation for fractures of the mandible. Lancet 1941;2:391-3.
28. Converse JM, Waknitz FW. External skeletal fixation in fractures of the mandibular angle. J Bone Jt Surg 1942;24A:154-60.
29. Waldron CW, Kazanjian VH, Parker DB. Skeletal fixation in the treatment of fractures of the mandible. J Oral Surg 1943;1:59- 83.
30. Snyder CC, Levine GA, Swanson HM, Browne EZ Jr. Mandibular lengthening by gradual distraction: a preliminary report. Plast Reconstr Surg 1973;51:506-8.
31. Michieli S, Miotti B. Lengthening of mandibular body by gradual surgical-orthodontic distraction. J Oral Surg 1977;35:187-92.
32. Panikarovski VV, Grigorian AS, Kaganovich SI, Osipian EM, Antipova ZP. Characteristics of mandibular reparative osteogenesis under compression-distraction osteosynthesis: an experimental study. Stomatolog 1982;61:21-5.
33. Karp NS, McCarthy JG, Schreiber JS, Sissons HA, Thorne CH. Membranous bone lengthening: a serial histological study. Ann Plast Surg 1992;29:2-7.
34. McCarthy JG, Schreiber J, Karp N, Thorne CH, Grayson BH. Lengthening the human mandible by gradual distraction. Plast Reconstr Surg 1992;89:1-8.
35. Molina F, Ortiz-Monasterio F. Mandibular elongation and remodeling by distraction: a farewell to major osteotomies. Plast Reconstr Surg 1995;96:825-40.
36. Guerrero C. Expansion mandibular quirurgica. Rev Venez Ortod 1990;1-2:48.
37. Wangerin K, Gropp H. Intraoral distraction osteogenesis for lengthening of the hori- zontal mandibular ramus. International Congress on Cranial and Facial Bone Distraction Processes. Paris, France 1997;036.
38. McCarthy JG, Staffenberg DA, Wood RJ, Cutting CB, Grayson BH, Thorne CH. Intro- duction of an intraoral bone- lengthening device. Plast Reconstr Surg 1995;96:978-81.
39. Razdolsky Y, Pensler JM, Dessner S. Skeletal distraction for mandibular lengthening with a completely intraoral toothborn distractor. In: McNamara JA Jr, Trotman CA, eds. Advances in craniofacial orthopedics. Volume 34. Craniofacial Growth Series. Ann Arbor: Center for Human Growth and Development, University of Michigan; 1998:117-40.
40. Guerrero C. Intraoral distraction osteogenesis to widen or lengthen the jaws using the Guerrero-Bell distractor. International Congress on Cranial and Facial Bone Distraction Processes. Paris, France 1997;053.
41. Samchukov ML, Cope JB, Harper RP, Ross JD. Biomechanical considerations for mandibular lengthening and widening by gradual distraction using a computer model. Am J Oral Maxillofacial Surg 1998;56:51-9.
42. Diner PA, Kollar EM, Viguier E, Maurin N, Vasquez MP. Intraoral submerged bidirectional device for mandibular distraction. International Congress on Cranial and facial Bone Distraction Processes. Paris, France 1997;017.
43. Guerrero C, Bell WH, Flores A, Modugno VL, Contasti G, Rodriguez AM, et al. Distraccion osteogenica mandibular intraoral. Odontol Dia 1995;11:116-32.
44. Bell WH, Harper RP, Gonzalez M, Cherkashin AM, Samchukov ML. Distraction osteogenesis to widen the mandible. Br J Oral Maxillofac Surg 1997;35:11-9.
45. Judy MM, Matthews JL, Boriak RL, Burlacu RE, Utecht RE. Heat-free photochemi- cal tissue welding with 1,8- napthalmide dye with visible light (420nm). SPIE Proceed 1993;1876:175-9.
46. Suuronen R, Manninen MJ, Pohjonen T, Laitinen O, Lindqvist C. Mandibular osteotomy fixed with biodegradable plates and screws: an animal study. Br J Oral Maxillofac Surg 1997;35:341-8.
47. Harada K, Enomoto S. Stability after surgical correction of mandibular prognathism using the sagittal split ramus osteotomy and fixation with poly-l-lactic acid screws. J Oral Maxillofac Surg 1997;55:464-8.
48. wasaki M, Nakahara H, Nakase T, May JR, Takaoka K, Caplan AI, et al. Bone morphogenetic protein 2 stimulates osteogenesis but does not affect chondrogenesis in osteochondrogenic differentiation of periosteum-derived cells. J Bone Min Res 1994;9:1195-204.
49. Aspenberg P, Jeppsson C, Wang JS, Bostrom M. Transforming growth factor beta and bone morphogenetic protein 2 for bone ingrowth: a comparison using bone chambers in rats. Bone 1996;19:499-503
50. Zegzula D, Buck D, Brekke J, Wozney JM, Hollinger JO. Bone formation with use of rhBMP-2. J Bone Jt Surg 1997;79A:1778-90.
51. Panjaba MM, Lindsey RW, Walter SD, White AA. The clinician's ability to evaluate the strength of healing fractures from plain radiographs. J Orthop Traum 1989;3:29-32.
52. Panjaba MM, Walter SD, Karuda M, White AA, Lawson JP. Correlations of radi- ographic analysis of healing fractures with strength: a statistical analysis of experimental osteotomies. J Orthop Res 1985;3:212-8.