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Maxillofacial Distraction Osteogenesis

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Review Article

Maxillofacial Distraction Osteogenesis

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Distraction osteogenesis in the maxillofacial skeleton is an increasingly popular alternative to many conventional orthognathic surgical procedures. This review summarizes recent data regarding the biological and biomechanical basis of distraction osteogenesis, its advantages and disadvantages, and special considerations in maxillofacial distraction. Intraoral mandibular distraction osteogenesis, maxillary and midfacial distraction, and alveolar distraction osteogenesis are discussed. This review also discusses sutural expansion/maxillary protraction osteogenesis and orthodontically induced periodontal osteogenesis, which are similar to physeal osteogenesis. In the near future, improved understanding of biomolecular mechanisms that mediate distraction osteogenesis may guide the development of targeted strategies that use molecular mediators, growth factors, or stem cells to improve the efficiency and quality of bone regeneration. ***(Taiwanese Journal of Orthodontics. 29(4): 196-203, 2017)***

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INTRODUCTION

Distraction osteogenesis was first used for elongation of the long bones to correct bony and soft tissue defects after fracture or infection. Ilizarov discussed the scientific basis and clinical efficacy of distraction for lengthening long bones in the extremities.[1] Distraction osteogenesis in the maxillofacial skeleton is also an increasingly popular alternative to many conventional orthognathic surgical procedures. For patients with moderate to severe abnormalities of the maxillofacial skeleton, distraction techniques provide additional treatment alternatives.

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Since the initial report of distraction of the maxillofacial skeleton by McCarthy et al. in 1992,[2] distraction has been successfully used in the mandible,[2,3] maxilla or midface,[4] zygomatic arch,[5] and in the mandibular condyles.[6]

The use of distraction osteogenesis in the craniofacial skeleton has increased in the past two decades. The most common applications are in cases of severe hypoplastic maxillofacial bones; in maxillofacial asymmetry, for example, hemifacial microsomia;[2,7,8] and in lengthening of severe hypoplastic mandible, for example, Pierre Robin or Treacher Collins syndromes, resulting in obstructive sleep apnea.[9,10] Other indications for distraction are hypoplastic maxilla in cleft lip or palate patients.[9,11,12]

This review briefly discusses and compares various techniques used for distraction osteogenesis in the maxillofacial skeleton. Given the depth of research on distraction osteogenesis, this review will focus on recent developments.

BIOLOGICAL AND BIOMECHANICAL CONSIDERATIONS IN DISTRACTION OSTEOGENESIS

Biological considerations

The objective of distraction osteogenesis is to manipulate the bone healing process by stretching an osteotomized area before calcification occurs in order to stimulate the formation of additional bone and soft tissue. New bone growth is stimulated by mechanically stretching a soft callus. The bone healing process after distraction osteogenesis is essentially the same as that in any bone fracture. Distraction osteogenesis, however, interrupts the normal fracture healing process by gradual application of traction to the soft callus. Studies demonstrated that the best results are obtained if the distraction is performed within several days after initial healing and callus formation and if the segments are separated at a rate of 0.5 to 1.5 mm per day.[13] Distractions performed in this manner have proven effective for bone lengthening in both orthopedic and craniofacial surgery. Although new bone formation (distraction regenerate) is mostly direct intramembranous bone formation, some focal regions of cartilage may also occur.[14] The regenerated bone is eventually remodeled into mature bone.

In gradual bone distraction, mechanical stimulation induces biological responses that contribute to bone regeneration. Bone is regenerated by a cascade of biological processes, which may include differentiation of pluripotential cells, angiogenesis, osteogenesis, bone mineralization, and remodeling.[15-17] Animal studies have demonstrated the effectiveness of gradual bone distraction for regeneration of maxillofacial bones, and gradual bone distraction is now common in clinical practice.

The distraction osteogenesis process is driven by the activities of molecular mediators of inflammation (cytokines, particularly interleukines IL-1 and IL-6), the transforming growth factor β (TGF-β) super family of bone morphogenic proteins (BMPs, including BMP-2, BMP-4 and BMP-6), and mediators of angiogenesis.[17,18]

The five clinical stages of distraction osteogenesis are the osteotomy stage; the latency stage (the time during which reparative callus forms, i.e., the time from bone division to onset of traction); the distraction stage (the time from application of gradual traction to formation of new bone); the consolidation stage (the time from discontinuance of traction forces until maturation and corticalization of regenerated bone); and the remodeling stage (the time from the initial application of full functional loading to the completion of regenerated bone remodeling).[14,19]

Biomechanical considerations

The selection and placement of the distraction device requires consideration of several factors. The biological and mechanical forces that shape the regenerated bone are the main considerations when positioning the distraction appliance. Biological forces that affect the morphology of regenerated bone are produced by the surrounding neuromuscular envelope. The clinician can optimize the mechanical forces by adjusting the distraction devices to skeletal anatomy, by using intermaxillary elastics during the active phase of distraction, and by adjusting the intercuspation of the dentition. When planning the distraction procedure, the clinician must carefully consider the potentially large impacts of forces produced by both biological and mechanical systems and must anticipate their resultant effects.[20]

ADVANTAGES AND DISADVANTAGES OF DISTRACTION OSTEOGENESIS

The advantages of distraction are: (1) its gradual effects, not only in bony skeleton, but also in the associated soft tissues such as skin, subcutaneous tissue, and muscles related to mastication and facial expression, (2) the larger potential movement it can achieve as compared to the conventional orthognathic surgery, and (3) its potential use for correcting a structural deficiency in the jaw bone at an early age. Its main disadvantage is that precise movement is not possible. For example, although distraction can move the mandible or maxilla forward, it cannot achieve a precise pre-planned position of the jaw or teeth, which requires an orthognathic procedure.[21] Therefore, the prime candidates for distraction of the jaw are patients with craniofacial syndromes who are likely to need intervention at an early age to achieve large distances of movement and who do not require a highly precise correction of the jaw relationship. Early treatment, however, is unlikely to be followed by normal growth of the distracted area, and further orthognathic surgery or a second round of distraction is usually required. Another major disadvantage of the technique is residual cutaneous scarring resulting from the transcutaneous fixation pins. If avoidance of scarring is a major concern, the preferred approach is an intraoral approach for the osteotomy and pin insertion.[22]

SPECIAL CONSIDERATIONS IN MAXILLOFACIAL DISTRACTION

In contrast with distraction of the limbs, distraction of the jaws involves several special considerations: (1) facial proportion and esthetics increase the complexity of movement required in bony segments of the jaw; (2) different areas of the jaw may substantially differ in the shape of the bones, complex muscle attachments, function, and histology; (3) different areas of the jaw may substantially differ in bone developmental patterns, e.g., membranous bone in the jaw substantially differs between the mandible and the maxilla; (4) after early childhood, dental occlusion requires precise control of the magnitude and direction of jaw movement.[21]

Maxillofacial retraction also requires several days of latency period, several weeks for active lengthening and several months for consolidation until mature lamellar bone is formed for stable results. The need to wear distraction devices for up to several months may introduce compliance issues, especially in patients required to wear uncomfortable external devices.[23–25]

Advances in dental technology and biomechanical engineering have resulted in the use of intraoral distraction devices worldwide. The introduction of these intraoral bone-borne devices has eliminated the need for bulky and cumbersome extraoral distraction devices and their many disadvantages, including external scarring, pin tract infection, nerve or tooth bud injury and poor patient compliance.[23–25]

INTRAORAL MANDIBULAR DISTRACTION OSTEOGENESIS

Mandibular lengthening distraction

Distraction osteogenesis for lengthening the mandible is quite difficult compared to that for lengthening a limb. The design and placement of the distractor are also more complex. To avoid dentition/tooth germs injury in a short mandible, manipulation from the ramus is preferable to manipulation from the mandibular body. Although early devices developed for mandibular distraction were extraoral, bone-borne or tooth-borne intraoral devices are common nowadays.[20] Tooth-borne appliances are usually fabricated in orthodontic laboratories whereas bone-borne appliances can be purchased from several different instrument companies. The cost difference is considerable. Vector control can be difficult with either appliance. Tooth-borne appliances may not be possible in the mixed dentition period or when dentition is compromised by periodontal disease. Intraoral applications have relatively better patient acceptance because they avoid the potentially negative psychosocial effects of wearing an extraoral distraction appliance. However, a second surgical procedure is required for removal. Development of resorbable appliances may obviate the need for surgical removal.[26]

Mandibular lengthening distraction is an effective treatment for tongue-based airway obstruction in children with severe Pierre Robin sequence. This technique has proven effective for alleviating upper airway obstruction secondary to micrognathia and has a success rate of approximately 95% in preventing tracheostomy.[27,28]

Mandibular widening distraction

Mandibular widening distraction, i.e., surgical widening of the mandible, is also known as mandibular symphyseal distraction osteogenesis, transmandibular symphyseal distraction osteogenesis, and mandibular midline osteodistraction.

In the few instances in which it is truly indicated, distraction osteogenesis provides a highly predictable means of widening the mandibular symphysis. Distraction of the mandibular symphysis can achieve both osteogenesis (new bone formation) and histogenesis (new soft tissue formation). The formation of new periosteum over the distracted area enables widening of the symphysis. Without permanent retention, however, soft tissue pressures at the corners of the mouth can cause reversion of the canines to their original width and recurrence of incisor crowding. No data are currently available regarding stability of the teeth after removal of retainers in a symphyseal distraction.[29]

MAXILLARY AND MIDFACE DISTRACTION

Maxillary widening distraction

Surgically assisted rapid palatal expansion (SARPE) is the conventional treatment of choice for correcting transverse maxillary deficiency in adults.[30,31] However, SARPE has a high relapse rate during the post-retention period.[32,33] The most reliable and stable procedure for correcting maxillary skeletal transverse problems is the miniscrew implant-assisted rapid palatal expansion (MARPE) procedure.[34,35] The MARPE can be used in adult patients with narrowing and severe crowding in the maxillary arch. Bicortical hard palate anchorage increases implant stability,[36,37] parallel expansions in the coronal plane, and bone-borne palatal expansion.[35]

In addition to providing a non-surgical means of separating the midpalatal suture, the MARPE protocol expands the maxilla and surrounding craniofacial structures. Opening the circummaxillary sutures widens the surrounding craniofacial structures, including the zygoma and the nasal bone. Because of its lower cost and risk compared to other surgical treatment options, the use of MARPE for nonsurgical orthopedic expansion in adult patients is expected to increase in the future.[34,35]

Maxillary lengthening distraction

Distraction osteogenesis has been used for gradual lengthening of the midface in children with craniofacial syndromes (e.g., Crouzon and Apert syndromes), cleft lip and palate, hemifacial microsomia, and midface hypoplasia from other causes. Midface distraction can be performed with an external or internal device.[38] If the patient can tolerate an external device, it can achieve better 3-dimentional control during the distraction process. Cranial fixation with a rigid external distractor (RED) device has also proven effective.[4] Although both external and internal techniques can be used, most available devices are unidirectional as in mandibular applications. Recently developed bidirectional and multidirectional devices will almost certainly increase the use of distraction to correct maxillary and midfacial deformities.[39]

The MARPE opens the circummaxillary sutures and the skeletal miniscrew implants serve as an orthopedic anchorage device in creating favorable maxillary protraction protocols that are less invasive compared to miniplates. The MARPE protocols also have potential applications in nonsurgical maxillary protraction in adult patients.[40]

ALVEOLAR DISTRACTION OSTEOGENESIS

Techniques for restoring alveolar ridge reduction include alloplastic augmentation,[41] autogenous onlay bone grafting,[42] and guided tissue regeneration (GTR).[43] However, each technique has certain limitations in cases of severe alveolar bone defects. In these cases, alveolar distraction osteogenesis can potentially increase volume and mechanical strength in alveolar bone by promoting new bone formation in a rapid and predictable manner before dental implant placement.[44,45]

Of the various alveolar bone augmentation techniques, the most widely used techniques are bone grafting and distraction osteogenesis. The advantage of alveolar distraction osteogenesis is that it increases soft tissue formation. Therefore, it provides greater vertical augmentation compared to bone grafting.[46,47] However, the use of this technique is subject to potential complications related to the distraction device and insufficient bone formation.[48]

SUTURAL EXPANSION/MAXILLARY PROTRACTION OSTEOGENESIS AND ORTHODONTICALLY INDUCED PERIODONTAL OSTEOGENESIS

Maxillofacial sutures are osteogenic tissues between opposing membranous bones, and the periodontal membrane is an osteogenic tissue between a dental alveolus and a tooth. Both of these osteogenic tissues have been studied extensively in experimental and clinical research in orthodontics and dentofacial orthopedics. Examples include rapid maxillary expansion (RME) and/or maxillary protraction as well as on the tension side of the periodontal membrane during orthodontic tooth movement.[49] Orthodontically-induced periodontal osteogenesis is a technique developed for rapid canine retraction.[50]

In maxillary and midface distraction osteogenesis mentioned previously, maxillary protraction protocols that use MARPE appear promising for nonsurgical correction of midfacial retrusion in adult patients.[40]

CONCLUSIONS AND FUTURE PERSPECTIVES

In the near future, improved understanding of biomolecular mechanisms that mediate distraction osteogenesis may lead to the development of new targeted strategies for the improving bone regeneration by using different molecular mediators, growth factors, or stem cells.[17,18] Development of biodegradable devices also avoids the need for a second surgery to remove distraction devices.[51,52]

As in conventional orthognathic surgery, distraction osteogenesis requires a team of various clinical specialists, including an orthodontist, an oral and maxillofacial surgeon, and a plastic and reconstructive surgeon. Researchers at several medical centers are now developing three-dimensional computer models of distraction that can aid clinicians in treatment planning by simulating and predicting treatment outcomes. The most effective designs for the rapidly evolving surgical appliances used for distraction osteogenesis improve biomechanical efficiency, control, and patient comfort. Although procedures for maxillofacial distraction osteogenesis will change with advancing technology, distraction osteogenesis is expected to be an essential treatment modality in orthodontics and oral and maxillofacial surgery for managing maxillofacial anomalies.

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