Oral and Maxillofacial Surgery

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Chapter 1

Distraction Osteogenesis for Correction of Oral and Craniofacial Deformities

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Definition

Distraction osteogenesis (DO) is a biological process of new bone regeneration between surgically separated bony segments as a result of gradual traction at a specific rate and rhythm [1]. Synonyms for this process include osteodistraction, callus distraction, callotasis and, most accurately, distraction histogenesis. This latter term encompasses the active histogenes is not only in bone but in adjacent tissues including gingiva, skin, fascia, muscle, cartilage, blood vessels, and nerves [2,3]. Distraction osteogenesis is an alternative treatment to conventional orthognathic surgery for correction of craniofacial deformities [4]. It offers movements of greater magnitude and better post-operative stability compared to conventional orthognathic surgery [5].

History of Distraction Osteogenesis

Historically, bone-applied traction forces for lengthening purposes date back to Hippocrates, when rubber band systems were used as an attempt to stretch bone segments. In 1728, Fauchard used a shaped metal plate ligated to the teeth to repair crowding dentition. Further progress came over a century later when in 1859, Wescot reported the application of mechanical force on the maxilla to correct a crossbite. Shortly thereafter, similar procedures were described by Angel and Goddard in 1860 and 1893respectively [6].These orthodontic principles were expanded by Kingsley in 1892in order to repair mandibular retrognathia [7].The major principles specific to distraction osteogenesis were found at the opposite end of the body. Codvilla was the first to describe using traction forces for lengthening of the femur [8].It wasn't until 1937 that Kazanjian reported the use of incremental traction for treatment of mandibular retrognathia [9].

Though distraction procedures and successes had been documented, the specific biological principles of distraction remained unclear until the 1950, when Russian surgeon GavrielIlizarovin, widely considered the grandfather of modern distraction osteogenesis, described distraction biology and sequencing protocol. [1]Upon his findings, distraction experimentation began in earnest via animal testing, specifically for mandibular lengthening and midface advancement [10,11]. In 1992, McCarthy was the first to clinically use DO for mandibular lengthening [12].

Phases of Distraction

Distraction osteogenesis surgery comprises four sequential periods: osteotomy, latency, distraction and consolidation period.

Osteotomy

The first stage of distraction is where a full coricotomy of bone segment, imitating a fracture line, is created and predefined. Reciprocating saw and osteotomes are preferred over fissure burs to create a narrower and more regular space [13].

Maxillofacial tomography scan and prefabricated surgical guides may help in determining the location and design of the osteotomy line [14,15].

Latency Phase

Distraction must not be initiated immediately; the two bony segments must be allowed to rest in close approximation to one another so fracture callus formation may take place. This critical period is known as the latency phase [16]. The latency phase ranges from 0-7 days depending on age of the patient, type of bone, and location of the osteotomy [17].

Distraction Phase

The distraction phase involves gradual mechanical separation of the two bony segments. Its initiation marks the beginning of a dynamic microenvironment during which randomly oriented collagen is replaced by collagen aligned parallel to the distraction vector. Type-1 collagen production is increased and the blood vessels grow longer [13].This period lasts 1-2 weeks and yields five histological zones: a central zone of mesenchymal proliferation, two transitional zones immediately next to the central zone and characterized by fibrous and osteoid formation and two remodeling zones immediate to the transition zones, characterized by existence of osteoclasts and remodeling of the newly formed bone [18].

Rate of Distraction

As proposed by Ilizarov, a rate of 1 mm per day is optimum for bone regeneration during distraction [16]. A higher rate of distraction will result in fibrous union with soft tissue and neurological complications; a slower rate will lead to premature consolidation [1,19].

Rhythm of Distraction

Ilizarov recommended delivering 1 mm of distraction per day in frequent increments such as 0.5 mm twice daily or 0.25 mm 4 times daily [17]. Since increasing the rhythm of distraction will improve the outcome of distracted tissue and bone regeneration, continuous automated distraction has shown superior results compared to non-continuous distraction [20].

Consolidation Phase

The last phase of distraction, the consolidation phase, allows for the maturation and ossification of the regenerated bone. Bony fragments are stabilized using rigid fixation or by keeping the distraction device in place without any movements. It is the longest phase of distraction process; in long bones a ratio of 2 days consolidation for each mm elongation is proposed [21].The maxillofacial region is highly vascular, therefore, a shorter consolidation period of 3-5 weeks in children and 6-12 weeks in adults is sufficient [22].

Efforts have been made to reduce the time of the consolidation period and accelerate ossification and maturation of the regenerated bone using ultrasound [23], electrical stimulation [24], Low-level Diode laser [176] and osteogenic growth factors such as TGF-β [25] or BMP-2 [26] and FGF-2 [27]. Furthermore, animal experiments using local and systemic bisphosphates have shown consolidation period reduction and improved regenerated bone quality. Despite its experimental success, complications of systemic administration of bisphosphonate should be considered before its application to human subjects [28].

Influence of Mechanical Environment on Bone Regeneration

Bone is a dynamic tissue under a continuous process of remodeling. It is highly adaptable and responsive to variety of physical and biochemical stimuli. There are multiple biological and mechanical factors that control the sensitivity and responsiveness of bone to mechanical stimulations [29].Bone remodeling rate in addition to the quantity and the quality of the new bone are affected by numerous factors like nutrition, medical conditions, and mechanical load. Changes in mechanical load specifically are detected by bone stem cells. The mechanical stumulus causes stem cell differentiation into bone forming cells [30,31]. Likewise, cytokines and signaling molecules are involved in the control of stem cell differentiation and new bone formation. These include pro-inflammatory cytokines, transforming growth factors and angiogenic factors. These same factors that contribute to normal bone growth and remodeling are critical to understanding induced bone production in distraction osteogenesis.

Osteotomy and Latency Phase

Following osteotomy, a hematoma is formed and the osteotomy gap serves as a chamber for regenerative tissue in the form of organized fibrous and fibrocartilaginous tissue arranged parallel to the distraction vector [32,33]. Levels of the pro-inflammatory cytokines IL-1 and IL-6 are upregulated which stimulate osteoclastic activity and recruit inflammatory cells [34].

Three to five days following osteotomy, collagen and vascular rich granulation tissue surrounded by mesynchymal cells is formed [35].This phase resembles fracture healing, during which there is upregulation of IL-1 and IL-6 which stimulate recruitment of inflammatory cells and help the formation of extracellular matrix [36]. BMP-2 and 6 are upregulated during the latency period and stimulate osteoblast differentiation [37].

Distraction Phase

During the distraction phase, BMP-2, -4 and -7 are upregulated and continue throughout the procedure and tapering off towards consolidation. These BMPs contribute to bone and cartilage formation [38].TGF- which inhibits ostoclastogenesis and stimulate differentiation of osteoprogenitor cells is also upregulated 3 times that f normal levels during the distraction phase [35]. VEGF is also upregluated and serves to stimulate formation of new blood vessels [39].Finally, increased expression of insulin derived growth factor-1 and FGF-2 promote osteoblast differentiation [40].

Consolidation Phase

During consolidation stage, the RANKL/OPG system is thought to be responsible for balanced bone turn over and bone maturation. The RANKL/OPG ratio increases towards the end of distraction and peaks within the third to fourth week of consolidation [41].

During late consolidation, TNF-α, an osteoclast activator, and osteocalcin, a mineralization promoter, are upregulated [42].

Clinical Applications of Distraction Osteogenesis in Oral and Craniofacial Region

Mandibular Deformities

Introduction and Indications

The most common treatments for Class II malocclusions are removable and fixed appliances. These devices are highly effective implements prior to late puberty, but have specific limitations. Post pubertal growth spurt cases utilizing orthodontic appliances alone are prone to relapse due to bone bending, therefore cannot be treated with orthodontics alone [43]. Another exception to the effectiveness of orthodontic appliances is severe adult retrognathia requiring skeletal modification. Since orthodontic appliances have an effect that is mainly dentoalveolar, treatment leaves skeletal deficits unaddressed [44,45]. For these patients, surgical intervention is necessary.

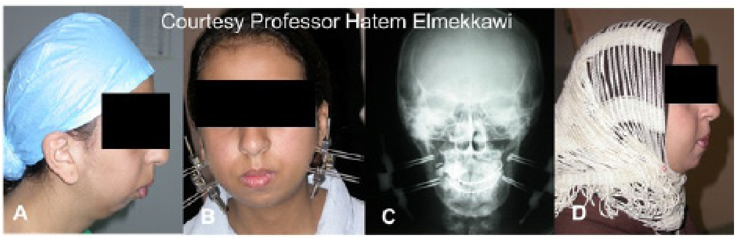

Figure 1: A. Shows clinical picture for severe mandibular retrognathia. B. Bilateral Extra-oral mandibular devices. C. PA radiograph showing distraction devices in place. D. Post-operative clinical picture showing the improvement of facial profile and chin position.

Standard orthognathic surgery involves bilateral sagittal split osteotomies (BSSO) or its alternative, distraction osteogenesis. The major advantage of distraction osteogenesis versus BSSO is neurosensory. Intrapoerative trauma to and acute stretching of the inferior alveolar nerve make BSSO notorious for persistent disturbance of the

IAN [46-48]. DO carries a much lower risk due to gradual IAN stretching without sacrificing post op skeletal stability [49].

A number of mandibular defects, from moderate to severe, are effectively treated by distraction osteogenesis to restore esthetics and function. Craniofacial microsomia (CFM), for example, is the second most common congenital malformation after cleft lip and palate [50,51]. Though its etiology is unknown, CFM is derived from anomolies in the first and second pharyngeal arches [52]. Its manifestations include hypoplasia of the orbits, ear, facial nerve, mandible and surrounding soft tissue, all of which vary in severity. CFM presents has a hemifacial presentation in 90% of cases and occurs bilaterally in 10% [51].

A number of classification systems have been developed for CFM. Classification of mandibular hypoplasia dictates treatment modality and can be based on the clinical presentation via the OMENS system [53] or 3dCT [54]. The OMENS system attempts to comprehensively grade all components of hemifacial microsomia (Orbit, Mandible, Ear, Nerve, Soft Tissue) on a scale of 1 to 3, 0 being normal, 1 abnormal size, 2 abnormal position, 3 abnormal size and position [55]. The 3dCT based system proposed by Swanson et al seeks to increase inter-evaluator consistency of classification. T0 represents the normal mandible requiring no treatment, T1 a mildly hypoplastic mandible requiring orhtodontics, T2 a severely hypoplastic mandible requiring distraction osteogenesis, and T3, an absent mandible or one dimished to the point where bone lengthening would not produce a functioning mandible. T2 mandibles are subdivided into A and B. 2A mandibles have appropriate horizontal length with condyles approximating an appropriate relationship to the glenoid fossa. 2B mandibles both horizontal and vetical deficiencies, causing the mandibular condyle to lie more medially than the glenoid fossa. The distinction between 2A and 2B is significant for DO treatment. 2A mandibles benefit from a mostly vertical distraction vector while 2B mandibles require an oblique vector to compensate for both vertical and horizontal defitcits.

Both classification systems have their strengths and weaknesses. Though the 3dCT based model is able to foster greater inter-evaluator consistencey, it has limitations for treatment planning, due to its lack of incorporation of soft tissues and nerve involvement [56]. Conversely, the O.M.E.N.S system is more useful for treatment planning in a multidisciplinary team, however, consensus on severity between clinicians is difficult to achieve [54].

Craniofacial microsomia is one of the many mandibular deficiencies that can benefit from distraction osteogenesis. There are over 100 syndromes associated with mandibular hypoplasia. Juvenile idiopathic arthritis, Russel Silver Syndrome, Treacher Collins and, most notably, Pierre Robin sequence have all been shown to benefit from distraction osteogenesis [57-60].

Surgical Procedure

Treatment of hemifacial microsomia involves simultaneous maxillomandibular distraction. A LeForte 1 oteotomy is performed on the maxilla followed by an osteotomy separating the ramus from the body of the mandible. Intermaxillary fixation is used to maintain proper orientation of the occlusal plane and a single mandibular distractor is used to generate bone between the segements and their respective origins [61]. While Type 2A and 2B mandibles requires unilateral osteotomy of the deficient mandibular segment combined with a LeForte 1 osteotomy, Type 3 mandibles require distraction in combination with costochondral bone grafting to generate sufficient stock bone for a distraction segment [62].

Devices

Mandibular distractors are available in two broad categories: internal and external.

Extraoral Devices: Extraoral distractors were first developed in 1989 by McCarthy [63]. As the name suggests, the distracting elements are located to the side(s) of the patient's face and fixed to the patients mandible with pins. The greatest indication for external distractors is the need for multiple distraction vectors [64]. Bi and multi directional distraction devices have been developed specifically for this purpose. The inevitable disadvantage to extraoral distractors, as compared to internal distractors, is post treatment scarring due to pin placement [65].

Intraoral Devices: Five years after the advent of extraoral devices McCarthy intruduced the first intraoral mandibular distraction device [63]. Intraoral devices allow distraction components to be hidden; they are especially beneficial in patients with moderate to severe mandibular retrognathia requiring one distraction vector only [66]. The major disadvantage of such a device is that it is nonadjustable, therefore, precise vector determination must be determined pre-operatively [67].

Maxillary Deformities

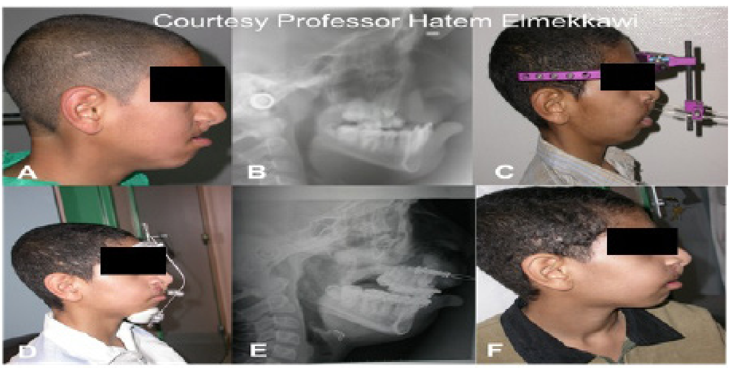

Figure 2: Maxillary advancement following cleft repair. A clinical picture shows maxillary retrognathia. B.Radiograph shows sever maxillary retrognathia. C. RED device in place. D. Post-distraction retention phase using face mask. E. Radiograph shows maxillary advancement with the Device in place. E. post-operative picture .

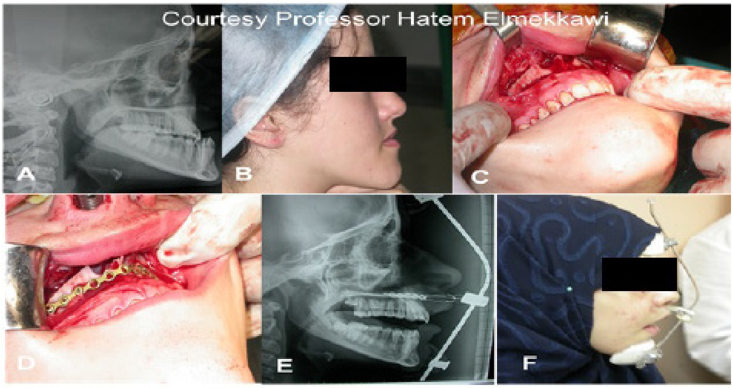

Figure 3: Maxillary advancement A. Pre-operative radiograph. B clinical picture showing flat facial profile. C. Incision and LeForte 1 osteotomy. D Plates attached to the down fractured maxilla. E. radiograph showing the maxillary advancement with facemask in place. E. post-operative picture showing the improvement of facial profile.

Maxillary growth impairment is often associated with cleft lip, cleft palate, and serious skeletal and/or dental pathological conditions, all of which generally require orthognathic surgical procedures. The maxillary retrusion in the anterior-posterior direction is often accompanied with Class III malocclusion. Furthermore, the dental arch often becomes narrow due to the unilateral or bilateral palatal collapse of the lesser maxilla [68,69]. The resultant maxillary hypoplasia causes the mandible to rotate in the anterior and superior direction. This can lead to collapse of the vertical dimension and loss of facial height and psuedo prognathism, a challenging problem requiring complex treatment [69].The conventional method to restore sufficient anterior-posterior relationship is the LeForte I (LF1) osteotomy, the outcomes of which have shown to be relatively unstable due scarring forces and risk of relapse [69-71]. Maxillary hypoplasia that is seen in cleft lip and palate patients is often difficult to treat with the conventional orthognathic surgeries. Bringing the maxillary bone forward using conventional techniques has been associated with the risk of developing velopharyngeal insufficiency [72]. However, distraction osteogenesis does not contribute to development of such complications. Distraction osteogenesis uniquely preserves posterior dentition and velopharyngeal relationships, hence, distraction osteogenesis has become a reliable procedure for management of maxillary deficiencies especially in cases with soft tissue limitations and large advancement needs [69,73,74].

Indications

There are a number of indications for which distraction osteogenesis of the maxilla should be considered. Maxillomandibular discrepancies more than 10mm cannot be adequately corrected using conventional LF1 advancement of the maxilla and are better candidates for distraction osteogenesis [75]. The estimated relapse after conventional LF1 surgery is between 22-40% in the horizontal and 19-70% in the vertical plane [71,72].In cases with significant relapse after conventional surgeries, distraction osteogenesis should be considered. DO can also be used for patients with cleft lip and palate that lack soft tissue or have severe soft tissue scaring, poor bone quality and possess aberrant dentition [76].Furthermore, distraction osteogenesis can be performed in growing patients aging from 6 to 15 years, whereas the conventional LFI osteotomy is mainly performed in patients approaching skeletal maturity [77-79].

Surgical Technique

The maxilla is exposed by vestibular incision with the following structures properly dissected; pyriform rim, nasal septum, the zygomatic buttress and the infraorbital foramen and nerves. The level of theLF1 osteotomy will depend on the desired amount of soft tissue and bone movement as well as distractor type. After the nasal septal and pterygomaxillary osteotomies are performed, the mobility of the LF1 segment should be tested [79,80]. Both internal [81] and external [76] distractors have shown to be successful in maxillary distraction osteogenesis.

Midface Deformities

The two most common anomalies of the midface observed by pediatric surgeons are midfacial clefts with hypertelosrism and facial retrusion with faciocraniosynostosis [82]. The faciocraniosynostosis syndromes, such as Crouzan and Apert syndrome, are malformations that result from premature closure of cranial sutures that result in midface hypoplasia and related functional and esthetic problems [83].Orthognathic surgery in these patients aims to restore function, esthetics, occlusion, and airway patency by advancing the midface [83,84].The conventional surgical procedure to correct hypoplastic midface and/or aberrant skull shape, is a Le Fort (LFIII) osteotomy [85,86]. However, continual advancement in the field of oral maxillofacial surgery lead to a variation of the LFIII technique, one utilizing distraction osteogenesis [87]. This technique enables modification of the growth vectors and formation of new tissues [82,88]. In 1955, Cohen et al [87]. Were the first to describe using this technique to the midface of a 4-years old with unilateral craniofacial microsomia and anophthalmia. Since then, experience has further developed the technique, making distraction osteogenesisan effective and reliable procedure for the management of midfacial hypoplasia [82,84].

Indications

Distraction osteogenesis is a technique sensitive and labor-intensive procedure that should only be used for cases with specific indications. It offers two main advantages over conventional techniques: larger movements and less relapse, hence distraction osteogenesis is indicated whenever large boney movement is required [74,89]. Studies show conventional LFIII advancements of 2 to 17mm, whereas the LFIII distraction osteogenesis can produce advancement anywhere from 5 to 22mm [90]. Furthermore, distraction osteogenesis is used for conditions when high relapse is anticipated through conventional methods [74].

Midface hypoplasia is associated with a number of medical conditions that mainly affect the airways, orbits, occlusion and facial esthetics, all of which can have a significant psychosocial impact on patients [84]. Patients with craniofacial dystosis are at high risk of upper airway obstruction and obstructive sleep apnea, which is secondary to nasopharyngeal constriction produced by midface retrusion [84,91]. LFIII distraction osteogenesis has successfully improved clinical obstructive symptoms and airway expansion [92].

Surgical Technique

Initially a zig-zag incision is created on the coronal suture to expose the lateral frontotemporal skull, nasion, lateral orbital region, temporal fossa, zygomatic arch and zygomatic body [93].Standard osteotomies are then performed through the zygomatic arch, frontozygomatic suture, floor of the orbit, and nasion. In the medial aspect, the vomer and ethmoid are disconnected from the cranial base. A transmucosal approach or coronal approach is then used to osteotomize both of the pterygoid plates. Once completed, full mobilization of the distraction segment is verified [93]. Both internal [94,95]. and external distraction devices have shown to be effective in midface distraction osteogenesis [95].

Craniosynostosis Treatment

Craniosynostosis occurs due to premature closure of one or more cranial sutures. Any abnormality in these sutures can alter the shape of the cranial vault and potentially undermine the neurologic function of the patient [96].The prevalence of craniosynostosis has been estimated to be 1 in 2100-2500 live births [97].Craniosynostosis can be familial, syndromic, or idiopathic. The most common syndromes that account for the syndromic cases of craniosynostosis are Crouzon's, Apert's and Pfeiffer's syndromes that effect the craniofacial structure [98]. Non-syndromic cases of craniosynostosis are more prevalent than the familial or syndromic cases, with non-syndromic sagittal craniosynostosis being the most common type of all craniosynostosis [99]. Sagittal craniosynostosis leads to a scaphocephalic or dolicocephalic head shape. Unilateral coronal craniosynostosis and the unilateral lambdoid craniosunostosis result in plagiocephalic head shapes, and bilateral coronal fusion causes a brachiocephalic head shape deformity [100,101]. The more sutures involved in craniosynostosis, the greater the resultant functional disturbance. Craniosynostosis can result in cranial deformity and restrict overall cranial growth, which can lead to increased intracranial pressure, visual impairment and limit brain growth [102-104]. This combined with psychosocial concerns for the child commonly leads to early treatment [100]. Traditionally, all repairs are performed by open calvarial reconstruction, which encompasses excision, reshaping and substituting the deformed segments containing fused sutures [100]. Due to the inherent risks of open cranial vault reconstruction and later relapse, minimally invasive procedures such as endoscopic suture release, spring assisted surgery and distraction osteogenesis have been developed in an effort to decrease the morbidities associated with surgery [100-106].

Indications

Distraction osteogenesis was first used to treat craniosynostosis in the late 1990's. Since then it has been acknowledged by many craniofacial surgeons as an effective treatment modality and has frequently been used for the following craniosynostosis condition:

Non-Syndromic Sagittal Synostosis

The main surgical objective in patients with single suture synostosis is to remove the synostosis for growth accomodation purposes. This allows brain expansion and inhibition of possible craniofacial distortion [107]. Open cranial vault surgery at 8-10 months has proven successful in correcting cranial shape [107], decreasing intracranial hypertension and addressing cosmetic concerns, however it lacks in other areas. The procedure requires along operative time and has a high prevalance of persistent cranial vault boney defects. These associated flaws have led to exploration of less invasive procedures such as distraction osteogenesis [108-111]. In order to release the fused sagittal suture from the parietal bone, an osteotomy is placed parallel to the suture. A number of distractors are positioned parallel to the vector of distraction in the coronal plane or transverse to the excised suture.

Surrounding skin is then sutured overlaying the distractors with the distracting arms externalized. Once cranial index measurements and plain radiography indicate that sufficient cranial form has been established, the external distractors are trimmed close to the skin. Usually 2 to 4 months later the distractors are removed via a second surgery. The need for second surgery is considered to be one of the disadvantages of distraction osteogenesis [112]. It has been shown that in order to decrease the intracranial pressure and achieve normal skull shape in scaphocephaly or sagittal synostosis, the posterior cranial expansion needs to be greater than the anterior cranial expansion. This is achieved by placing separate anterior and posterior distractors, which will help modulate the differential lateral expansion of the superiors and inferior cranial vault with favorable cosmetic outcomes [113].

Syndromic Craniosynostosis (Fronto-Orbital Advancement)

In syndromic craniosynostosis, the most common suture affected is the coronal suture, which leads to a small anterior cranial vault that is the result of bronchial synostosis. Fronto-orbital advancement is the most popular surgery for correction of such deformities [114] and is indicated in patients with minor to severe syndromic craniosynostosis [114,115]. Conventional fronto-orbital surgeries have major drawbacks such as withdrawal of the advanced frontal bone flap, persistence of large boney defects and bilateral depression on the pterional areas and, most importantly, limited advancement (less than 20 mm) [114-116]. In order to overcome these shortcomings, fronto-orbital distraction osteogenesis can be used especially in cases where large advancements are required. Distraction osteogenesis allows for advancements greater thant-20mm to 25mm, a much larger span than conventional methods are capable of providing [114,115]. Furthermore, distraction osteogenesis has shown to be advantageous in older children that exhibit mild to moderate syndromic severity and is capable of avoiding boney defects [115].

It has been suggested that the best time to for FAO by distraction osteogenesis is 4 or 5 months of age so that the cranial bone achieves enough thickness for distraction [114]. In order to perform distraction osteogenesis via internal distraction method [117,118], a specific craniotomy is performed under a single large bone flap encompassing the frontal bone and the anterior cranial fossa. Another osteotomy is performed in the supraorbital area while making sure that the bone flap is not dissected from the underlying dura to ensure blood supply to the bone flap. Incremental advancement of 1mm per day is initaited after approximately one week. A study by Satoh et al. has shown up to 27mm of advancement by distraction osteogenesis due to gradual advancement [115]. Once consolidation is achieved, a second surgery is performed to remove the device [114].

Posterior Cranial Vault Distraction Osteogenesis

Lambdoid suture synostosis and sagittal suture synostosis in the posterior area leads to flattening of the posterior cranial vault [119]. The majority of the volume expansion of the infant skull occurs in the posterior area of the cranial vault during first year of life. Intracranial pressures in patients with syndromic bicoronal craniosynostosis cause more advanced growth in the middle of the cranial fossa as compared to the posterior fossa [120,121]. This condition, dubbed Chiari malformation, is secondary to disproportionate growth between hindbrain and posterior fossa and exhibits a strong association with syndromic craniosynostosis [121,122]. Posterior cranial vaults have been indicated in the following situations: cephalocranial disproportion with acceptable overall shape, cephalocranial disproportion with Chiari 1 malformation, Turribarchycephaly, shunt related slit ventricle syndrome and asymmetric cranium [107].

In comparison to the fronto-orbital cranial vault, the posterior cranial vault encompasses a larger volume and provides a greater volume increase per millimeter advancement [123]. The expansion achieved by the fronto-orbital advancement adjusts the anterior cranial volume and retruded orbital bandeau, however, the globe to orbital proportion limits the volume expansion achieved by this technique. The posterior cranial expansion in the occipital area address this shortcoming and allows for a greater enlargement of the intracranial cavity [107,114]. Volume expansion achieved via traditional cranial vault surgery is limited due to the restricted capacity of the scalp to stretch over the expanded calvarial construct. Furthermore, cranial vault surgery caries the risk of significant blood loss, particularly in cases of intracranial hypertension and dural-cutaneous venous connections [107,124]. Distraction osteogenesis of the posterior cranial vault as an alternative approach which addresses many of shortcomings associated with the aformentioned traditional surgeries [125,126]. Posterior cranial vault distraction osteogenesis involves an initial posterior osteotomy in the coronal direction. The osteotomy continues from the vertex inferiorly to a point near the asterion located within the squamous temporal bone. Additionally, vertex osteotomies are performed inferiorly towards the occipital bone and traverse the lateral sinus. These osteotomies are then angled posteriorly to join in the midline near the inion, which will reduce any noticeable step deformity at the end of the distraction process [107]. Two distraction devices are positioned with uniform parallel vectors in a parasagittal direction and collinear orientation to prevent any device stress complications secondary to converging vectors [121].

Distraction for Management of Airway Obstruction

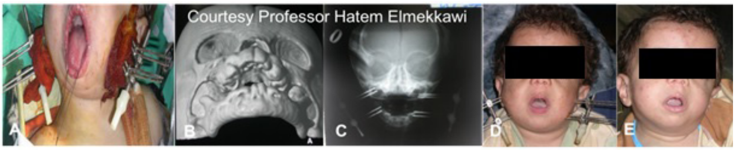

Figure 4: Pierre Robin Sequence. A. Bilateral extra- oral mandibular devices in place. B. 3D image showing mandibular retrognathia. C. PA radiograph showing the gap and the devices in place. D. Distraction devices in place after a period of distraction. E. Post-operative picture.

Distraction osteogenesis has found use in cases of congentical syndromic and non-syndromic micrognathia and midface hypoplasia, specifically in cases of upper airway obstruction leading to hypoxia or obstructive sleep apnea [127,128]. Nearly every case of micrognathia and midface hypoplasia in infants and children has some degree of airway obstruction due to one or more of the following: glossoptosis, short porterior face height, midface deficiency, and choanal atresia [64]. Etiology depends on the associated syndromes which include Treacher Collins and Nager syndrome, craniofacial microsomia, syndromic and non-syndromic Pierre Robin sequence, and syndromic and non-syndromic midface hypoplasia.

Tongue-lip adhesion (TLA) and tracheostomy are the two common alternative treatments for the treatment of airway collapse related to micrognathia. Douglas proposed the tongue-lip adhesion procedure in 1946 in an effort to hold to tongue in the anterior position [129]. Tracheostomy enables complete bypasses of the upper airway obstruction. DO has gained popularity due to morbidities associated with tracheostomy, including tracheomalacia, chronic bronchitis, laryngeal stenosis, delayed speech, and compromised psychosocial interactions [130,131].

The benefit of DO for patients with respiratory obstruction is derived from the resultant anterior tongue base position, preventing airway collapse during sleep [64]. In a systematic review, Briek et al demonstrated that overall, DO treatment for mirognathia has a 95% success rate in treating airway obstruction and preventing tracheostomy, which is important to consider since successful airway reestablishment for cannulated patients is 81% due to GERD, swallowing dysfunction and tracheostomy related complications [128]. DO for these patients has been found to be less invasive and of shorter duration than traditional techniques that require bone grafts and soft tissue flaps, though overall treatment is longer and requires more follow up visits [132].DO for airway obstruction can be performed at any age based on the severity of airway obstruction. Most severe syndromic and non-syndromic patients receive early treatment due to morbidities associated with apnea such as growth retardation, poor feeding, cor pulmonale [133], lack of weight gain, and failure to thrive [134].

DO does not have the same success rate for all cases of micrognathia. Patients with syndromic micrognathia were shown to have a 90.7% success rate post DO as compared to the 97.6% success rate patients with isolated micrognathia [128]. Failures seen in syndromic patients are related to the numerous other contributors to apnea beyond skeletal defecit, including but not limited to central apnea, laryngomalacia and neurologic abnormalities [128,135]. Therefore, determining the cause of airway obstruction is critical and careful pre op planning is required. A directed physical exam as well as laryngoscopy, endoscopic examination, pulse oximetry, plain lateral cephalogram, polysomnography and MRI can be utilized for this purpose [136].

Should the patient meet all criteria for benefiting from DO, treatment planning can begin. Combinations of photographs, lateral cephalograms, panoramic, and three-dimensional CT are used to plan the operation. Cases requiring unidirectional movement of the mandible or maxilla employ the use of an acrylic occlusal splint to guide bone cuts interoperatively. Complex cases, specifically those involving buried, nonadjustable distractors, are planned using three dimensional CT and surgical simulation software [137]. This helps identify possible interferences along the distraction path and adjusts vectors accordingly, as well as creates a stereolithograph for stent fabrication and precise distractor placement. Following surgery, distraction progress is determined via lateral cephalogram while airway patency progress is monitored via polysomnography and endoscopic exam [136].

Bone Transport Distraction (Figure 5)

Distraction osteogenesis is not only used to lengthen existing bone but also fill in missing portions of bone in both the mandible and maxilla. The process of bone transport distraction osteogenesis (BTDO) has been used in numerous experimental studies with the aim of creating an alternative treatment for patients with resected benign tumors such as ameloblastoma, myxoma, giant cell granuloma recurrent keratocyst, as well as malignant squamous cell carcinomas [138].BTDO also has the potential to treat segmental bone defects caused by blast injuries, high impact trauma, osteoradionecrosis and osteomyelitis.

Figure 5: Bone transport distraction osteogenesis: A. Radiograph showing mandible after tumor resection with reconstruction plate in place. B. Picture showing resected mandible. C. El-Mekkawi bone transport distraction device in place. D. Post-operative picture. E. 3D image showing the regenerated segment.

History

Prior to the implementation of distraction osteogenesis, massive reclamation of bone structure in the oral maxillofacial region required autogenous block grafts. Non vascularized block grafts have proven to have a high failure rate that increases in proportion to the size of the graft [139], however, these grafts have a low incidence of medical complications. Vascularized block grafts have a lower failure rate, but carry a higher risk of medical complications [140,141]. As well as donor site morbidity [142-144]. The polarizing aspects of these grafting materials have spurred researchers and surgeons towards the alternative, bone transport distraction osteogenesis.

BTDO is a relatively new method of replacing bony deficiencies in the maxillofacial region. More research is required to fully evaluate the benefits and disadvantages of this method; however, numerous experimental trials and animal tests have shown its benefits. BTDO segments have proven to have equal density, properties, and form of surrounding bone and are capable of supporting implants [145-148]. Soft tissues surrounding consolidated segments tend to maintain their overall integrity despite the extensive and expedient stretching. Furthermore, segments containing teeth are capable of being distracted without affecting dentoalveolar health [149].

Surgical Procedure

Bone transport distraction osteogenesis requires a reconstruction plate that bridges two existing bony segments [150]. Distraction segements can consist of native bone as well as non-vascular grafts [151]. Though novel devices that approximate the curvature of the mandible have proven to successfully regenerate bone, discrepancies in regenerated mandibular contour are still noted and require secondary surgery [152].

Complications

Transport disc osteogenesis is not without its own set of complications. As with all distraction methods, the success of BTDO depends on patient compliance, follow up visits, and the mechanical integrity of the distraction device. Soft tissue dehiscience is a possible complication due to stretching caused by the high rate of distraction. Problems specific to BTDO involve bone union at the joining end of the distraction segment. Fiberous tissue resultant from trauma or past surgeries can interfere with distraction vectors or block distraction segment fusion at the docking end [138,150]. This non-union can be overcome via dissection of fiberous tissue and filling with cancellous bone graft, bone substitute, or osteoinductive material [153,154].

Alveolar Distraction

Alveolar distraction osteogenesis has proven to be an invaluable procedure in development of the alveolar ridge in implant site preparation. First clinically implemented in 1996 by Michael Chin and Bryant A. Toth, alveolar DO has proven to have definite advantages in comparison to block graft placement [155]. Alveolar DO has been proven capable of regaining twice as much bone as compared to intraoral bone grafts [156,157]. Other advantages include low infection and resorption rates, as well as a reduced implant placement time [13].

Vertical Alveolar Ridge Distraction

Vertical ADO is mostly used for major anterior maxillary reconstructions as well as interforaminal implant placement in mandibular overdenture preparation [156]. For posterior regions, its use is found mostly in the mandible, allowing for longer implants and shorter crown heights. Vertical AOG is performed less frequently in posterior maxillary segments [156]. Other indications for DO include unfavorable implant/crown relationship, poor position and direction of implants, prosthetic complications, untreatable ankylosed teeth, and difficulties maintaining oral hygiene [156,158].

Devices

Three forms of alveolar distraction systems are available: extraosseous, intraosseous, and distraction implant.

Surgical Procedure

For all vertical alveolar distractions, the distraction segment must be made in a trapezoidal fashion to prevent distraction segement entrapment [159]. Oscillating saws are preferred over fissure burs in order to create the minimum space necessary and preserve soft tissue [13].

Horizontal Alveolar Ridge Distraction

For 4 mm wide ridge, horizontal ADO is an alternative to osteotome, punch-tip pilot/implant analog, and segmental split ridge techniques [160].

Devices

ADO via laster crest, extension crest, and multidirectional crest devices has been shown to reduce morbidity and avoid grafting complications altogether. The specific contraindication for horizontal ADO is alveolar ridges deficient in cancellous bone between buccal and lingual cortices [160].

Surgical Procedure

Application of the Laster crest device requires a furrow in the alveolar crest combined with 2 10mm vertical cuts in the buccal cortex. The buccal cortex is then greenstick fractured with an osteotome and the distractor is tapped into place. Extension crest devices work in a similar fashion to the Laster crest with one major functional difference: extension crest expands in a rotational fashion with the device fulcrum deep in the alveolar bone, while Laster crest plates expand parallel to one another.

The mutlidirectional distractor is a tooth borne device that can provide both vertical and horizontal alveolar ostoegenesis. The distraction segement is produced with one vertical and two horizontal osteotomies then anchored with intraosseous abutments against the basal bone [160].

Complications of Alveolar Ridge Distraction

Alveolar distraction osteogenesis has a number of associated complications, most of which are not severe. The most frequent complications seen are insufficient bone formation during consolidation period and regression of distraction distance. Resorption of bone post-procedurally is typically insignificant, ranging from 0.3mm to 1.8mm [157,161,162].

A frequently noted complication involves incorrect distraction vector placement, especially in intraosseous distractors where vectors are non-adjustable post placement [163]. For these cases, vector correction can be accomplished intra or post procedurally with orthodontic appliances and temporary prosthesis. Healed osteotomized fragments must be re-osteomotized and placed in the correct position [164].

Another common post-op complication is need for further grafting. Nearly 1 in 5 patients who undergo alveolar DO for implant placement require bone grafting post procedurally. Implant dehiscence is also a risk associated with poor osseointegration, implant fenestration, lack of attached gingiva, and lack of height. Overall, the implant failure rate following alveolar DO is comparable to or less than that of block grafts [165,166]. Prudent timing of implant placement and modulated functional loading after

AOG may help reduce trabecular bone loss [167].

Despite the more gradual alteration of soft tissues in alveolar OD, soft tissues can still be compromised. ADO devices, especially extraosseous ones, tend to put great strain on the mucosa and periosteum, resulting in loss of attached gingiva and possible need for connective tissue grafts [168].

Severe complications include fracture of the mandible and fracture of the distractor. Mandibular fracture is most likely during the consolidation period [164] in patients with 10mm or less pre-operative mandibular height [169]. A fractured distractor should be removed as soon as possible, regardless of the stage of the procedure [164].

Distraction of Irradiated Bone

Adequate blood supply is a requirement for successful bone regeneration by distraction osteogenesis [170]. Radiotherapy, especially in patients receiving a 60 Gy or greater dose, causes hypovascularity, hypocellularity and hypoxia in bone tissue, all of which increase the incidence of osteonecrosis of the jaw [171]. Experimental studies involving DO in irradiated canine mandibles have shown successful bone regeneration, fortifying the clinical application of DO in irradiated patients [172]. Subsequent clinical studies reported favorable outcomes of bone of distraction osteogenesis in irradiated patients [138,173].

The reported complications of distraction osteogenesis in irradiated bone include failure of the device, infection, insufficient bone formation and non-union. Adjunctive measures, like hyperbaric oxygen, have been proposed to optimize the outcome of distraction in irradiated bone [138]. Complications of DO in irradiated bone are found to be in the same range as non-irradiated patients, further supporting the use of distraction osteogenesis as a treatment option for irradiated patients [174].

Computer Assisted DO

Computed tomography to identify the anatomical structure and the contour of affected bone was used for reconstruction of a 3-D model. Model simulations are used to perform virtual distraction, predefine osteotomy locations, and determine distraction vectors. The computer-assisted preoperative planning and virtual surgery are potentially valuable in the treatment of facial deformities [15,175].

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