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Long-term outcomes of distraction osteogenesis in craniofacial reconstruction

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ABSTRACT

Distraction osteogenesis (DO) has become a new phenomenon in craniofacial reconstruction, especially in treating complex malformations like midface hypoplasia, mandibular deficiencies, and orbital malformations. Compared to conventional procedures that entail osteotomies and bone grafting, DO allows gradual lengthening of the skeleton and associated soft tissue adaptation, which minimizes donor site morbidity and improves stability. The method has been particularly effective in children, as it allows natural facial development and solves functional and cosmetic issues. DO is used clinically to treat syndromic craniosynostoses (e.g., Crouzon and Apert syndromes), Pierre Robin Sequence, and post-traumatic deformities. Despite its benefits, long-term observation shows problems of device complications, infections, asymmetry, and secondary surgery. Patient compliance and careful planning are key to successful results. This has been enhanced by the ongoing innovations in 3D virtual surgical planning and custom distractor design that have increased precision and lowered the rate of complications. Nonetheless, interdisciplinary management is indispensable to achieve long-lasting functional recovery and aesthetic balance of patients undergoing DO to correct craniofacial deformities.

Keywords: *Distraction osteogenesis, Craniofacial deformities, Midface hypoplasia, Mandibular deficiency, Pediatric reconstruction, Skeletal regeneration*

1. INTRODUCTION

Craniofacial deformities are a heterogeneous group of congenital and acquired disorders affecting the skull and facial bones' form, symmetry, and functionality. Causes of such deformities include genetic syndromes (e.g., Crouzon, Apert, and Treacher Collins syndromes), trauma, tumor removal, or developmental abnormalities such as cleft lip and palate. Such conditions have significant functional implications, which may severely affect crucial body functions such as respiration, mastication, vision, speech, and psychosocial development [1]. Facial disfigurement also has a significant psychosocial impact, such as stigma, anxiety, and poor self-esteem, particularly in developing children [2].

Traditionally, surgical treatment of craniofacial deformities was based on the methods of osteotomies and bone grafting. They were repositioned and reconstructed by traditional facial skeletal reconstruction modes involving Le Fort osteotomies, calvarialremodeling, and autologous grafting [3]. Even though these procedures reportedly offered immediate facial form

and functional enhancement, they were not without their limitations, which included relapse, morbidity of the donor site, limited tissue supply, as well as a failure to adapt to facial growth in children [4]. Moreover, traditional methods often required numerous revisions, at least in those patients with syndromic craniosynostosis or hypoplasia of the midface, where the inherent growth deficiency remained even after the correction [5].Distraction osteogenesis (DO) introduced into craniofacial surgery was the paradigm shift in the method of skeletal reconstruction. DO was initially used to lengthen long bones by Gavriil Ilizarov in the 1950s, but was modified to work on craniofacial bones in the early 1990s by McCarthy and colleagues [6]. The technique entails a mechanical and controlled gradual separation of bone parts after a corticotomy or osteotomy. This facilitates new bone development in the gap made up by intramembranous ossification. At the same time, the surrounding soft tissues, such as skin, nerves, blood vessels, and muscles, experience adaptive elongation, which is known as distraction histogenesis [7].

DO is usually performed in three different stages, which are the latency stage, in which the healing process starts after the osteotomy (usually 3-7 days); the distraction stage, in which the bone segments are gradually pulled apart at a rate of 0.5-1mm/day; and the consolidation stage, in which the regenerate bone mineralizes and stabilizes [8]. The procedure enables major skeletal progressions without comprehensive grafting, increases stability, and reduces complications compared to conservative bone grafting procedures [9].The primary benefit of DO is that it allows the natural development of the facial skeleton of a pediatric patient. DO enables progressive correction, unlike conventional osteotomies that need to be repositioned in a static manner, which is more in line with the dynamic process of facial growth [10]. This has been particularly useful in treating midface hypoplasia, mandibular deficiencies, cranial vault deformities, orbital dystopias observed in syndromic craniosynostoses, and congenital anomalies [11].

2. Clinical Applications in Craniofacial Reconstruction

Midface Hypoplasia

Distraction osteogenesis (DO) has been revolutionary in treating midface hypoplasia, especially in syndromic craniosynostosis, e.g., Crouzon and Apert syndromes. It is done in stages of Le Fort III osteotomies, then gradual advancement with internal or external distractors in Table 1. The technique enables concomitant skeletal growth and soft tissue adaptation, enhancing functional results such as airway patency, eye protection, and occlusal alignment [12]. It has been proposed that relapse may occur in long-term studies, but the results tend to be generally positiveif the correct distraction procedures are followed and followed up on [13]. Hypercorrection at initial distraction is usually advised to consider future growth deficiency and relapse propensity [14].

Mandibular Deficiencies

Mandibular distraction is significant in treating micrognathia and glossoptosis in Pierre Robin Sequence. To treat airway obstruction in neonates, bilateral mandibular distraction osteogenesis is very effective as it moves the jaw forward to relieve the airway and the tongue forward [15]. The functional outcomes are decreased tracheostomy requirement, better feeding, and speech development [16]. After long-term follow-up, there is stable growth of the mandible but asymmetry, slight nerve damage, or secondary procedures may be seen in a small proportion of patients [17].

Orbital, Maxillary, and Zygomatic Reconstructions

Orbital, maxillary, or zygomatic reconstruction is usually necessary to treat patients with post-traumatic deformities or congenital anomalies. DO allows for more accurate realignment of these bones through gradual segmental motion than is possible with traditional osteotomy. When the zygomatic hypoplasia or orbital dystopia is present, distraction corrects the facial profile, redefines the orbital volume, and may correct asymmetries without using bone grafts [18]. Custom distractors and 3D virtual planning have increased surgical precision and decreased postoperative complications, including infraorbital nerve damage and device displacement [19].

Unilateral vs Bilateral Reconstructions

Bilateral and unilateral reconstructions are two different challenges in distraction osteogenesis. Unilateral DO, which is standard practice in hemifacial microsomia, must be planned to provide symmetry with the non-affected side, and in many cases, multi-vector distractors are used [20]. In severe mandibular hypoplasia or Pierre Robin Sequence, bilateral reconstructions are usually suggested, with a symmetrical lengthening of the mandible and a more balanced functional and aesthetic result [21]. Prolonged follow-ups revealed early bilateral DO positively impacts breathing, feeding, and craniofacial development in syndromic conditions [22].

Table 1. Clinical Applications of Distraction Osteogenesis in Craniofacial Reconstruction: Indications, Techniques, and Outcomes Across Age Groups

Clinical Condition	Examples / Syndromes	Anatomical Region	Age Group	DO Type	Surgical Approach	Distraction Device	Distraction Rate	Bone Gain	Functional Outcome	Common Complications	Clinical Notes
Midface hypoplasia	Crouzon, Apert syndrome	Maxilla, zygoma, nasal complex	Pediatric to adolescent	Le Fort III DO	Subcranial osteotomy	External/internal distractor	0.5–1 mm/day	10–15 mm	Improved airway, occlusion, and aesthetics	Device failure, relapse, scarring	Requires long-term follow-up for growth adaptation
Mandibular deficiencies	Pierre Robin Sequence, HFM	Mandibular ramus, body	Neonate to adolescent	Mandibular DO	Intraoral or extraoral osteotomy	Internal distractor	1 mm/day (2 × 0.5 mm)	15–25 mm	Airway improvement, feeding, occlusion	Nerve injury, asymmetry	Often used in airway obstruction cases in neonates
Orbital, maxillary, and zygomatic reconstruction	Traumatic defects, cleft sequelae	Orbital rim, infraorbital floor	Adolescents and adults	Segmental DO	Custom osteotomies	Bone-borne distractors	0.5 mm/day	Variable (5–10 mm)	Facial symmetry, orbital volume restoration	Device infection, scarring	Advanced planning with 3D imaging enhances outcomes
Unilateral reconstructions	Hemifacial microsomia	One side of the face	Pediatric to adult	Unilateral mandibular DO	Osteotomy on the affected side	Internal distractor	1 mm/day	10–20 mm	Improved symmetry and function	Overcorrection, relapse	Overcorrection is often planned to accommodate growth
Bilateral reconstructions	Bilateral mandibular hypoplasia	Both rami and corpus	Infants to adolescents	Bilateral mandibular DO	Bilateral osteotomy	External/internal distractors	0.5 mm × 2/day	Up to 25 mm/bone	Enhanced airway, occlusion, symmetry	Pain, device misalignment	Critical in neonatal respiratory support cases (e.g., PRS)
Maxillary advanc	Cleft lip/palate with Class	Maxilla	Adolescent to adult	Le Fort I DO	Intraoral Le Fort I	Rigid external distract	1 mm/day	8–12 mm	Class III correct	VPI, relapse	May require seconda

ement	III				osteotomy	or			ion, speech improvement		ry bone grafting
Midface advancement (growth stage)	Growing CLP children	Midface suture zones	8–12 years	Trans-sutural DO (TSDO)	Suture-based traction	OSNS-guided TSDO device	0.5 mm/day	5–10 mm	Avoids osteotomy, promotes sutural bone growth	Minimal (less invasive)	Used increasingly for early intervention in cleft-affected patients
Post-traumatic facial asymmetry	Zygomatic/maxillary fractures	Zygoma, maxilla	Adults	Segmental osteogenesis	Customized osteotomy	Internal distraction system	Variable	Variable	Re-establishes pre-injury symmetry	Hardware exposure	Often used when primary repair is suboptimal
Orbital dystopia correction	Craniofacial syndromes, trauma	Orbital floor & rim	Children/adults	Orbitozygomatic DO	Orbital segment osteotomy	Internal distractor	0.5–1 mm/day	6–10 mm	Leveling of orbital height and eye alignment	Eye movement restriction (rare)	Requires delicate handling near orbital structures
Asymmetry correction in syndromic cases	Hemifacial microsomia (Grade II/III)	Mandible, zygoma	5–18 years	Multiplanar DO	Custom-cut osteotomy	Hybrid distractors (multi-vector)	Variable	10–20 mm	Significant improvement in lower third symmetry	Infection, relapse	Multidisciplinary planning essential
Secondary DO after failed surgery	Post-osteotomy relapse	Maxilla or mandible	Adolescents and adults	Re-do DO	Scarred region distraction	Internal device	Slower rate (0.5 mm/day)	5–10 mm	Correction of relapse, better stability	Reduced regeneration speed	Requires cautious handling of fibrotic tissues
Pediatric syndromic DO planning	Treacher Collins, Nager Syndrome	Midface and mandible	1–12 years	Staged distraction	Age-adapted planning	External/internal based on age	Variable	Up to 20 mm	Improves airway, aesthetics, and feeding	Growth unpredictability	Staging helps match with facial growth trajectories

3. Complications and Challenges in Long-Term Follow-Up

Distraction osteogenesis (DO) has transformed craniofacial reconstructive surgery, particularly in pediatric and syndromic patients in Table 2. Nevertheless, some complications and difficulties are to be considered in the long-term follow-up.

DO has succeeded in craniofacial reconstruction, but significant complications are observed in the long-term follow-up. Problems with devices include loosening hardware, hardware breakage, and malfunction, particularly with external distractors, because of exposure errors and handling errors. Internal devices are more stable but can break, and reoperation becomes necessary. The incidence has been reported as 10-30 %, depending on the type of device and location [23,24]. Another common issue is infection, especially at pin sites, which happens in 10-15% of patients. Inadequate hygiene and long distraction are contributing factors. Fibrosis and scarring may not jeopardize the functioning. However, they may present long-term aesthetic difficulties and influence patient satisfaction [25,26].

In growing children, skeletal asymmetry (or overcorrection) may frequently occur because the vectors are not planned accurately, or children may not develop as predicted. These problems, which occur in up to 20 percent of patients, often require revision surgeries [27]. In addition, the success of the treatment depends on the patient's adherence. The inadequate compliance with the activation procedures and hygiene guidelines can result in complications, whereas psychosocial issues, including anxiety and dissatisfaction, particularly among adolescents, can also influence treatment outcomes [28,29].

In 20 40 percent of long-term follow-ups, secondary procedures such as orthognathic surgery or bone grafting are usually necessary. The patients of pediatric age are most susceptible to relapse because their facial form and structure are still developing; unless overcorrection is performed adequately, recurrence rates can be up to 30% [30,31]. Soft tissue resistance can limit bone movement, and incomplete osteogenesis or fibrous union may occur when rapid distraction or infection occurs [32]. Neurological damage, e.g., infraorbital or mental nerve damage (510%), is rare. Also, exposure of a device by thin soft tissue or inadequate vascularity may require repositioning or removal of the device [33,34].

In general, the long-term outcome will be based on comprehensive planning, timely management of complications, patient adherence, and an interdisciplinary approach. Clinicians should be ready to make some changes to achieve functional restoration and aesthetic harmony.

Table 2.Summary of Complications and Challenges in Long-Term Follow-Up of Distraction Osteogenesis in Craniofacial Reconstruction

S. No.	Complication	Description	Reported Incidence	Risk Factors	Timing	Management Strategy	Impact on Outcome	Need for Revision Surgery	Patient Group Affected	Long-Term Prognosis
1	Device-related complications	Breakage, loosening, or malfunction of internal/external distractors	10–30% (varies by device)	Device type, improper placement	During the distraction phase	Device replacement, stabilization, reoperation	May delay treatment, increase morbidity	Yes	Children, adults	Good if corrected early
2	Infection	Local or deep infection around pin sites or osteotomy regions	~10–15%	Poor hygiene, prolonged device duration	Postoperative (early-late)	Antibiotics, debridement, and early device removal	Can jeopardize bone regeneration	Sometimes	All age groups	Favorable with early treatment
3	Fibrosis and scarring	Excessive tissue response leading to scarring or fibrosis at	Common	Excessive movement, poor wound healing	Late postoperative	Physical therapy, scar revision surgery	May impair facial symmetry and mobility	Rare	Pediatric post-distraction	Variable, often a cosmetic issue

		surgical sites								
4	Asymmetry or overcorrection	Uneven distraction or excessive advancement beyond ideal anatomical targets	5–20%	Improper vector planning, patient growth changes	Consolidation & growth phase	Adjusted distraction vectoring, revision osteotomy	Aesthetic and functional challenges	Often	Growing children	Relapse risk is higher in younger patients
5	Psychosocial issues	Anxiety, depression, discomfort with appearance, or the treatment process	Not quantified; significant	Adolescence, external distractors	During and post-treatment	Psychological counseling, patient support programs	Impacts compliance, satisfaction	No	Adolescents	Improved with early support
6	Patient compliance	Poor adherence to device activation or hygiene protocols	Variable	Age, understanding of protocol	Entire treatment duration	Education, regular follow-up, and caregiver involvement	Device failure, relapse risk	Indirectly	Children, the elderly	High relapse without compliance
7	Secondary procedures	Need for further osteotomy, bone grafting, or orthognathic surgeries	20–40% depending on age	Incomplete correction, relapse	Long-term follow-up	Orthognathic surgery, fat grafts, and implant adjustments	Delays the final reconstruction	Yes	All age groups	Often necessary in syndromic cases
8	Soft tissue tension or relapse	Soft tissue resisting bone movement or causing post-treatment relapse	~10%	Inadequate latency phase, fast distraction rate	Post-consolidation phase	Soft tissue release, slower distraction rate	Compromises skeletal advancement	Sometimes	Children	Relapse rate reduced with technique optimization
9	Neurological disturbances	Temporary or permanent nerve injury (e.g., infraorbital, mental nerve)	5–10%	Device placement near nerve paths	Immediate or delayed onset	Observation, surgical decompression if needed	May affect sensation or function	Rare	Adults, syndromic patients	Often resolves over time
1	Device	Skin or	3–7%	Thin	Mid-to-	Flap	May lead	Yes	Thin-	Variabl

0	extrusion or exposure	mucosal breakdown over the device, especially internal distractors		tissue coverage, poor vascularization	late treatment	coverage, removal, or repositioning of the device	to infection or nonunion		skinned or irradiated patients	e
11	Incomplete bone regeneration	Fibrous union or incomplete osteogenesis at the distraction site	5–15%	Poor osteotomy, fast distraction, infection	Consolidation phase	Bone grafting, prolonged consolidation period	Increases the failure rate	Yes	Children with syndromes	Good with bone grafting
12	Growth-related relapse	Discrepancy as the patient grows, particularly in younger children	Up to 30% in long-term cases	Early surgery without overcorrection	Years after the distraction	Follow-up surgery, orthodontics, and growth monitoring	Affects facial harmony and occlusion	Often	Children under 10	Higher need for long-term correction

4. Conclusion

Distraction osteogenesis (DO) has dramatically changed craniofacial reconstructive surgery by providing a less invasive, dynamic, and growth-friendly alternative to standard osteotomies and bone grafting. It can improve both skeletal structure and soft tissue adaptation simultaneously. It has been instrumental in treating more complex conditions like midface hypoplasia, mandibular deficiencies, and orbital or zygomatic deformities. DO enables a gradual correction that follows the natural developmental trends in pediatric patients, requires fewer revision surgeries, and leads to better long-term functional and cosmetic results.

The long-term follow-up depicts a potential complication, which includes device-related issues, infections, skeletal asymmetry, and secondary procedures requirements. The compliance of the patient and the careful planning of the surgery are essential to the best outcomes. In addition, long-term treatment's psychological and social effects should be considered, particularly in children and adolescents. With the development of technologies, such as 3D virtual surgical planning, custom distractors, and better biocompatible materials, the safety and accuracy of DO is increasing. A multidisciplinary treatment that integrates surgical skills with orthodontic, psychological, and rehabilitative therapy is necessary to guarantee functional reconstitution andesthetic balance of the patients who undergo DO to correct their craniofacial deformities.

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