Review Article

Revolutionizing Orthodontics: A Review on Distraction Osteogenesis Techniques and Trends

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Abstract:
Distraction osteogenesis (DO) is a biologically driven technique that enables gradual bone elongation and simultaneous soft tissue adaptation through controlled mechanical tension. Originally introduced in orthopedics, DO has revolutionized craniofacial reconstruction and orthodontics by eliminating the need for grafting procedures in cases of mandibular and maxillary deficiencies. This review highlights the fundamental principles, phases, and classifications of DO, emphasizing its role in correcting congenital and acquired craniofacial deformities. The paper also elaborates on orthodontic considerations, clinical indications, device classifications, complications, and recent advancements including internal distraction systems, 3D planning, and bioengineering approaches such as stem cells and growth factors. While DO offers multiple benefits like minimal relapse, better adaptation of soft tissues, and broader applicability across age groups, it is technique-sensitive and requires meticulous planning and patient compliance. The integration of modern technologies and biologic enhancers promises to refine this technique further, making it a cornerstone of skeletal orthodontic interventions.

Keywords: Distraction Osteogenesis, Craniofacial Deformities, Skeletal Orthodontics, Mandibular Lengthening, Bone Regeneration, Orthognathic Surgery, 3D Planning, Soft Tissue Adaptation, Complications of DO, Pediatric Distraction.

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INTRODUCTION:

Distraction osteogenesis (DO), colloquially known as "callotasis", is an orthopedic surgical method which harnesses the body's natural bone healing process to lengthen hypoplastic or deficient bones.[1] Distraction osteogenesis is used synonymously with "Osteo-distraction", "Trans osseous synthesis" or "bone lengthening".

Distraction Osteogenesis is defined as the creation of de novo bone and adjacent soft tissue after the gradual and controlled displacement of a bone fragment obtained by surgical osteotomy.

Distraction Osteogenesis (DO) involves gradual, controlled displacement of surgically created fractures (subperiosteal osteotomy) by incremental traction (Ilizarov, 1988), resulting in simultaneous expansion of soft tissue and bone volume due to mechanical stretching through the osteotomy site (Ilizarov, 1989).[2]

Distraction Osteogenesis is described as "A biological process of formation of new bone between the surfaces of bone segments sequentially separated by incremental traction" by Samchukov M.L., Cherkashin A.N., and Cope J.B.[3] Another definition was given by Aranson who stated, "Distraction Osteogenesis is defined as a gradual, dynamically induced, intramembranous process of ossification between two active bone surfaces that are temporarily separated by minimal energy techniques". The term distraction osteogenesis is synonymous with "Trans osseous synthesis" or "Osteo-distraction" or in simpler term, "Bone lengthening".[4] Among the relatively common anomalies of the craniofacial complex are congenital micrognathia, facial asymmetry, and maxillomandibular hypoplasia.

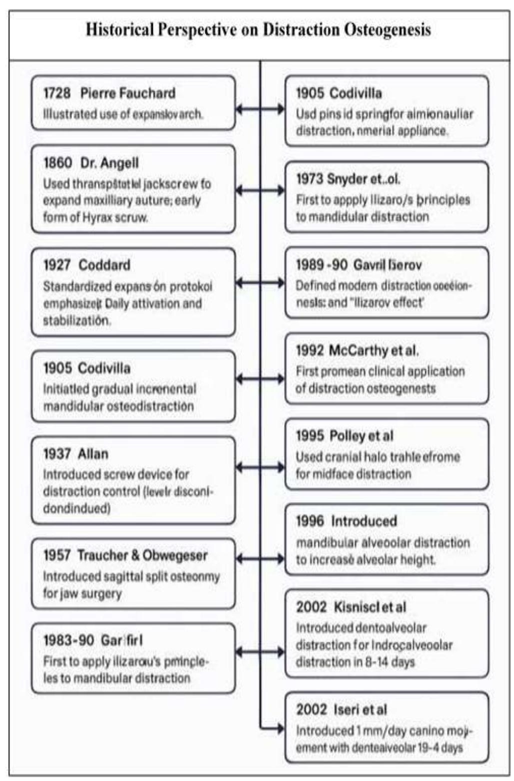
Facial asymmetry, mandibular hypoplasia, and congenital malformation of jaws are common abnormalities of the craniofacial complex.[5,6] Traditionally, skeletal deformities have been corrected via functional orthopaedics in growing patients or orthognathic surgery with skeleton fixation in non-growing patients.[7,8] Adaptation and stability of the adjacent muscles and soft tissues are one of the limitations and controversies related to orthognathic surgery and functional orthopaedics.

One of the major demerits of orthognathic surgery is that it permits only acute changes in the spatial arrangement of skeleton rather than provide de novo bone formation and which requires the needs of bone graft. It does not permit the change in shape and size of the bones to maximize the structural integrity, functional balance and esthetic of the patient.

CLINICAL RATIONALE FOR DISTRACTION OSTEOGENESIS

- Orthognathic surgery has gained a generalized acceptance for maxillo-mandibular deformity correction but several limitations are associated with it.
- One of the major limitations is the inability of the surrounding soft tissues to be acutely stretched. The surrounding soft tissues may not adapt to this new position thereby resulting in degenerative changes, relapse and compromised aesthetics and function.
- The other major factor is the limited possibility of new bone formation between the osteotomized segments in cases of severe deformities.
- This leads to the need of placement of a graft between the osteotomized segment to prevent relapse and to provide skeletal rigidity and stability.

Historical Perspective on Distraction Osteogenesis:



Indication and Contra-indication of Distraction Osteogenesis [9,10,11]

Indications and Relative Contraindications for Distraction Osteogeneseis	
Indications	**Relative Contraindications**
Midface Abnormalities • Maxilla and orbit advancement (LeFort I and III osteotomies) **Cleft Lip and Palate** • Alveolar gap closure **Lower Face Abnormalities** • Hemifacial mandibular microsomia (unilateral distraction • Mandibular hypoplasia • Severe mandibular retrognathia/micrognathia **Syndromic Conditions** • Pierre Robin syndrome (bilateral distraction) • Treacher Collins syndrome • Crouzon syndrome **Post-Traumatic Conditions** • TMJ ankylosis deficient growth post-trauma	• Poor nutritional status • Inadequate bone height and width • Old age • Osteoporosis • Necrotic / irradiated bone • Systemic disease (contraindicated for general anesthesia)

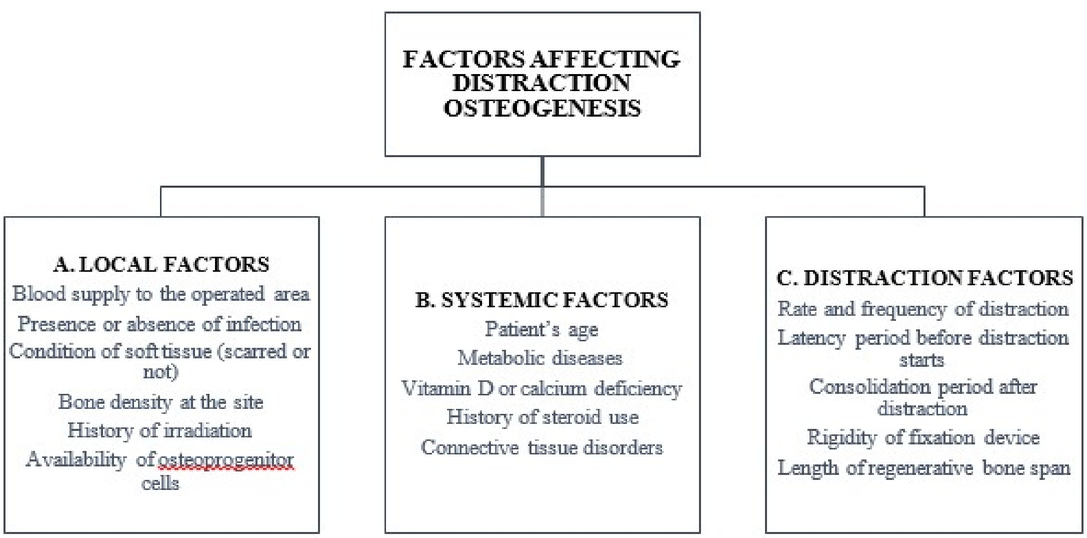
Advantages and Disadvantages of Distraction Osteogenesis [12-18]

Advantages	Disadvantages
Allows 10–30 mm mandibular lengthening with gradual soft tissue adaptation and minimal relapse	Skin scars (can be minimized by intraoral incisions)
Applicable to complex bony and soft tissue anatomy	Technique- and equipment-sensitive surgery
Effective in neonates, infants, and pediatric OSA patients	May require second surgery for device removal; requires patient compliance
Less invasive than bone grafting procedures	Transient TMJ changes
Avoids intermaxillary fixation	Adequate bone stock is required
No need for bone grafting or donor-site morbidity	Opposing surfaces must support callus formation
Enables mandibular widening	Risk of damage to tooth germ
Fewer adverse TMJ effects in asymmetric lengthening	Possibility of premature consolidation
Reduced hospital stay and lower cost compared to bone grafting	Risk of inferior alveolar nerve injury
Less need for blood transfusion	Potential for bilateral coronoid ankylosis
Wide age range applicability (children >2 years to adults)	Clockwise mandibular rotation tendency
Multiplanar and multidirectional distraction possible; minimal nerve damage	Does not address underlying growth disturbances

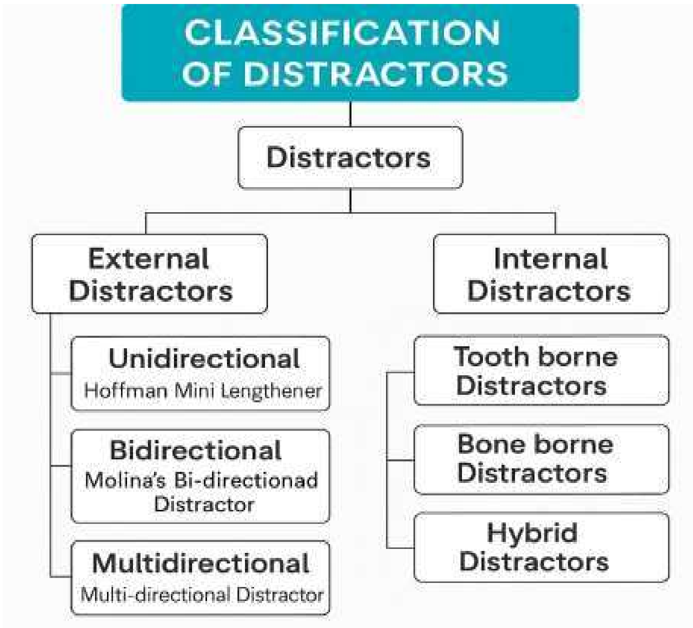
Complications Associated with Distraction Osteogenesis[19,20]

Phase	Complications
Intra-Operative	Bleeding or pain - Injury to nascent tooth bud by pin - Partial bone fracture - Nerve injury - Instability or breakage of the distraction device
During Distraction	Early bone calcification - Patient discomfort - Poor compliance with device use - Difficulty in eating - Infection around pins
Post-Distraction	Malunion or poor callus healing - Recurrence due to soft tissue pressure - Chronic nerve injury - Facial scarring from external devices - Temporomandibular joint (TMJ) issues - Altered speech
Shorter treatment duration than BSSO	Newly formed bone is less mineralized; devices can be bulky and uncomfortable
No extractions needed; better prognosis	High treatment cost

Factors Affecting Distraction Osteogenesis [21]



Classification of distractor devices :[22,23,24]



Unidirectional- The Hoffman Mini Lengthener device was introduced by McCarthy in 1989.(Fig.1) It was used for mandibular lengthening and was fixed externally. Device is adapted by rotation of clamp and sliding the other along the telescope distractor shaft.[25,26]

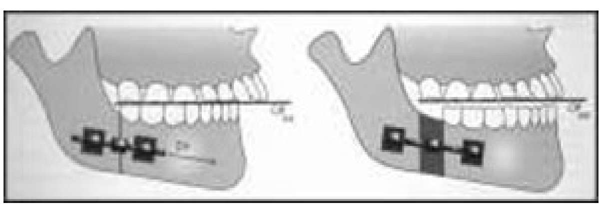


Fig 1. Unidirectional distractor

Bidirectional- Molinas Extraoral Distractor useful in cases with severe hypoplasia of mandible. Indication is post single or double osteotomy, distraction can be done both horizontally or vertically. It has two geared arms and a middle screw for changing angulation.[25] Extraoral Multi -Directional Distractor indicated in cases with midface development defects. In order to bridge the gap between the patient's diagnosis and the age at which they can have bimaxillary repositioning osteotomies, orthodontic preparation is required. Costochondral grafts are implanted in damaged mandibular locations in children.[26] Guerrero - Intraoral Device for Mandibular Widening first introduced in 1987, this was first device of its kind for widening mandible. (Fig. 2) A vertical symphyseal osteotomy is required prior and custom-made hyrax is placed. Activated 48 hours post-surgery and upon completion of distraction, acrylic is flowed around appliance to maintain expansion and stabilize it.[27]

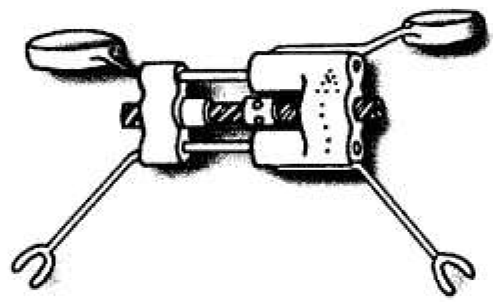


Fig 2. Bidirectional distractor

Distractor Orientation: The distraction device orientation is along the three vectors for distraction, namely, vertical, horizontal and oblique.[28] This is pictographically described in Figure 3.

Fig 3- Vectors of distraction a) vertical, b) horizontal and c) oblique

According to various planes in which distraction is carried out, they are subdivided into multiple models as follows:[29]

- **Model I-** Transverse plane- Distractor oriented parallel to lateral mandibular surface {fig 4. (A)}
- **Model II-** Transverse plane- Distractor oriented parallel to midsagittal axis and to each other as well {fig 4. (B)}
- **Model III-** Transverse plane- Distractor parallel to lateral mandibular surface {fig 4. (C)}

- **Model IV-** Transverse plane- Distractor parallel to each other {fig 4. (D)}
- **Model V-**Sagittal plane- Distractor at an angle to occlusal plane {fig 4. (E)}
- **Model VI-** Sagittal plane- Distractor parallel to occlusal plane {fig 4. (F)}

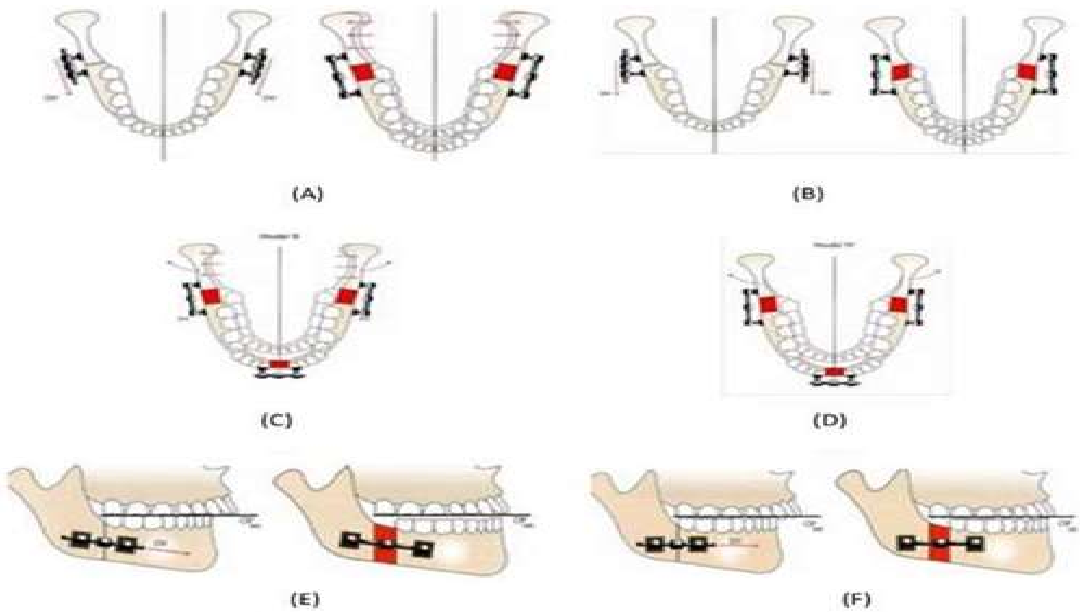


Fig 4 - (A) Model I Transverse plane (B) Model II Transverse plane (C) Model III Transverse plane (D) Model IV Transverse plane (E) Model V Sagittal Plane (F) Model VI Sagittal plane

Orthodontic Consideration:

PRE DISTRACTION ORTHODONTICS	DURING DISTRACTION OSTEOGENESIS	POST DISTALIZATION ORTHODONTICS
• For functional and cosmetic outcome. • Teeth to be positioned with respect to basal bone. • Distraction stabalizing appliance	• Bands , brackets , headgear, distraction stabilizing appliance, maxillary expansion appliance, functional appliance can be used.	• Distarction device is eliminated. • Newly produced bone across distratcion gap provides support for mandibular tooth bearing section.

Phases of Distraction Osteogenesis

Distraction process includes following fundamental sequential phases in which different biologic phenomenon is induced.

1. Osteotomy cut
2. Latency period
3. Distraction phase
4. Consolidation phase

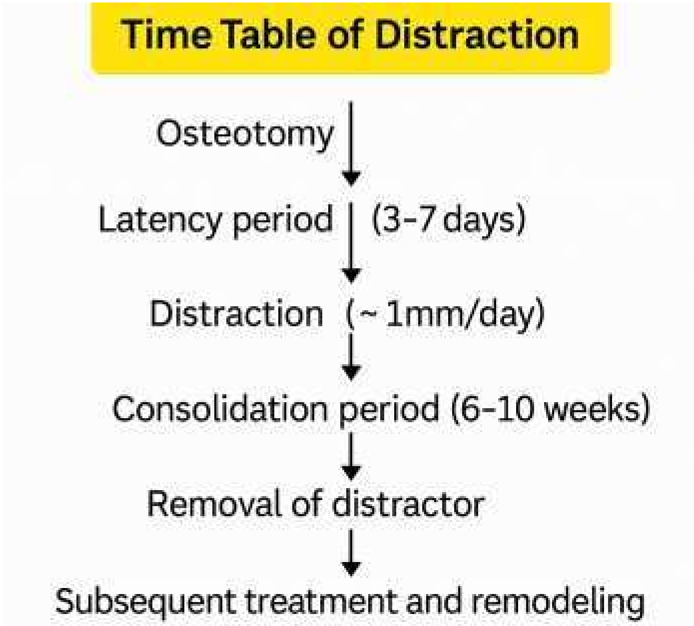


Fig 5 - The phases of distraction osteogenesis

According to Karp et al., at histologic level, the healing process in DO differs from that of a healing in fracture in two basic aspects.[30]

1. In DO controlled micro trauma is present in between distraction gap.
2. In DO, instead of endochondral ossification, membranous ossification occurs. In DO there are three sequential phases of different biologic phenomena: (Fig. 5)

- **Surgical phase -** In order to separate the segments while maintaining the medulla and periosteum's blood supply to the bone, a procedure known as a corticotomy involves performing an osteotomy to the cortical layer of the bone. The distraction rhythm in distraction osteogenesis indicates the frequency of the device activated each day, whereas the distraction rate reflects the daily displacement of the bone in millimetres (mm).

- **Latency period:** It is a time period between performed osteotomy and start of distraction. Latency period allows the surgical site to pass through the initial inflammatory stage of wound healing, into the reparative phase. This period varies from 0 to 7 days depending upon surgical trauma. During the latency period, restoration of bone is likely to be that observed after fracture i.e. hematoma formation, callus formation around (periosteal callus) and between (endosteal callus) the osteotomized bone segments. This callus tissue contains inflammatory cells, fibroblasts, a rich fibrin matrix, and collage, invading capillaries and cells with osteogenic potential. Accord ing to Macarthy distraction gap obviously is a hypoxic zone of injury which stimulates an angiogenic response and initiates the migration of primitive mesenchymal cells and the synthesis of collagen I matrix.

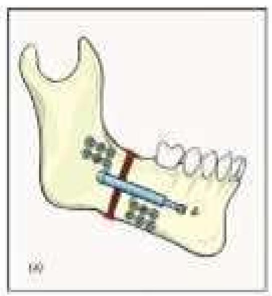


Figure 6.a) Latency phase which is preceded by surgical phase and in which hem atoma form ation

Distraction period: This is the period in which traction is applied to the osteotomized bone and there is formation of new imma ture woven bone, fibers of which are parallel to distraction force. The typical protocol for distraction is 0.25 mm four times/day or at a rate of 1 mm/day.The stiff distraction device must be used in accordance with recommended protocol in order to achieve desired bone growth. By rotating an axial screw, which moves between 0.25 and 0.5 mm each turn (depending on the mechanism being utilized), the device is turned on. The soft callus may be stressed if the rate of distraction is too high, which could lead to thinning of all dimensions in the middle section of the regeneration and the formation of a "Hour Glass" at the distraction point. This has to distraction osteogenesis with how "Pulling Taffy Apart" works.[31] On the other hand, lower rate and frequency can result in early ossification, which would complicate the distraction inadvertently. Clinicians around the world often aim for a daily distraction rate of 1.0–1.5 mm and limit activation frequency to 2-4 times.

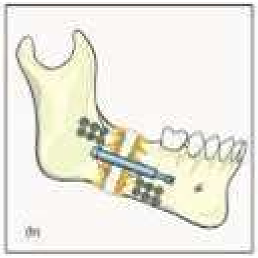


Figure 6.b)Distraction phase in which the bone gap is increased at margins by osteogenesis.

Consolidation period (neutro-fixation): In the period of consolidation mineralization of newly formed regenerate occurs. Usually, in the cases of craniofacial distraction the consolidation phase is of 6–12 weeks for adults. This phase comprises an extended period of immobility during which the stretched callus is supported by the device as it matures, maintaining the callus's stretched and stable posture and avoiding cartilaginous intermediate. The first step in remodelling is to provide lamella bone with elements of bone marrow time to develop. The consolidation period lasts between four and twelve weeks, on average eight weeks. According to clinical recommendations, the consolidation phase should last twice as long as the activation phase. The distraction site's location and the rate of bone metabolism determine when the consolidation period begins.[32]

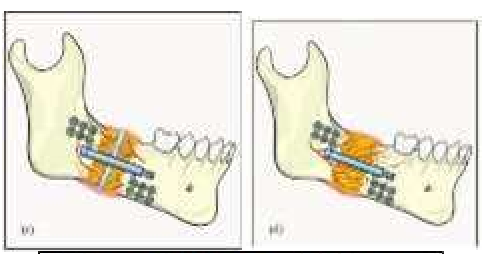


Figure 6. c) Consolidation phase, centre of bone gap experiences osteogenesis.
d) Late consolidation phase

Remodelling phase-This phase primarily consists of formation of lamellar bone. It is in this stage the distractor is removed after establishment of continuity bone &alveolar canal. The need for further intervention should be identified at earliest and also relapse should be checked in follow up visits which will ensure good prognosis.[33]

Bone formation and resorption both occur in distraction osteogenesis, so if process of bone resorption is blocked by antiresorptive agents such as bisphosphonates, hypothetically, it may lead to enhanced bone formation. Abbaspour et al. in their animal studies have recognized the positive effect of bisphosphonates in distraction process.

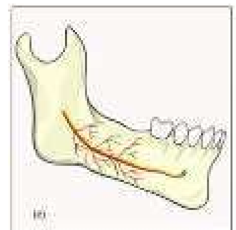


Figure 6.e) Remodelling phase, continuity of bone and alveolar canal established.

Recent Trends in Distraction Osteogenesis : [34-38]

- Internal Distraction Devices

Smaller, less invasive devices now used instead of bulky external distractors. Better patient comfort, hygiene, and esthetics.
Often resorbable or self-removing materials.

- 3D Planning & Navigation

3D imaging (CBCT) and CAD/CAM technology used for pre-surgical planning. Enables customized distractors and precise vector control.
Improved outcomes and reduced complications.

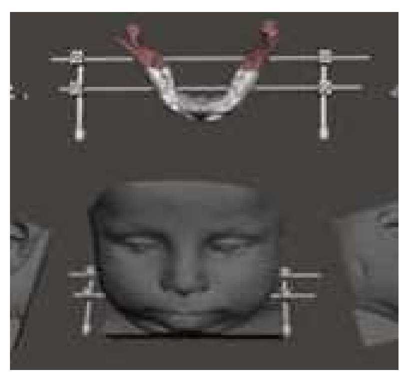


Fig 7. 3D planning & navigation

- Distraction in Paediatric Patients

Increasing use in craniofacial syndromes and cleft-related deformities. Earlier intervention possible due to minimally invasive techniques.

- Alveolar Ridge Distraction

Enhanced techniques for vertical bone augmentation in implantology. Supports dental implant placement in atrophic ridges.

• Distraction with Stem Cells & Growth Factors
Tissue engineering integrated with DO.
Use of BMPs (Bone Morphogenetic Proteins) and MSCs (Mesenchymal Stem Cells) to accelerate bone regeneration.

• Accelerated Protocols
Research into shortened latency and consolidation periods using: Low-Level Laser Therapy (LLLT)
Pulsed Electromagnetic Fields Platelet-Rich Plasma (PRP)

• Distraction in Orthognathic Surgery
Used for severe skeletal discrepancies instead of traditional osteotomies. Hybrid techniques: combining DO with Le Fort and BSSO.

• Digital Monitoring & Remote Activation
Smart distractors in development: allow remote monitoring and activation. Increased precision and patient compliance.

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