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Original Research Article

Mandibular Distraction Osteogenesis for Severe Retrognathia: A Prospective 3D Analysis of Skeletal Stability, Soft Tissue Response, and Airway Volume Augmentation

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Abstract: ***Objective:*** This study aimed to evaluate the three-dimensional skeletal and soft tissue changes, along with oropharyngeal airway volume augmentation, following mandibular retrognathia. ***Materials and Methods***: A prospective cohort study was conducted on 24 consecutive patients (mean age: 22.3 ± 4.1 years; 14 females, 10 males) diagnosed with skeletal Class II malocclusion secondary to mandibular retrognathia. All patients underwent bilateral mandibular distraction using extraoral or intraoral devices following a standardized corticotomy protocol. Pre-distraction (T0) and 6-month post-consolidation (T1) assessments were performed using cone-beam computed tomography (CBCT) and standardized lateral cephalograms. Primary outcomes included: 1) Hard tissue changes (mandibular length [Co-Gn], SNB angle, overjet), 2) Soft tissue profile changes (lower lip to E-plane, pogonion projection), and 3) Oropharyngeal airway volume (measured from the posterior nasal spine to the epiglottis). Statistical analysis employed paired t-tests($p<0.05$significant). ***Results:*** All 24 patients completed the protocol. Mean mandibular advancement was 16.8 ± 2.3 mm at point B. Hard tissue analysis showed a significant increase in SNB angle (from 72.1° ± 3.2° to 77.8° ± 2.9°, $p<0.001$) and mandibular length (Co-Gn increase of 17.2 ± 2.1 mm, $p<0.001$). Overjet corrected from +9.5 ± 1.8 mm to +1.2 ± 0.6 mm. Soft tissue analysis revealed a significant anterior movement of soft tissue pogonion (12.5 ± 1.9 mm, $p<0.001$) and improved lower lip position relative to the esthetic plane. Most significantly, oropharyngeal airway volume increased by 38.7% (from 12.45 ± 2.11 cm^3 to 17.27 ± 2.45 cm^3, $p<0.001$). ***Conclusion:*** Within the limitations of this sample size (n=24), mandibular distraction osteogenesis is an effective procedure for correcting severe mandibular retrognathia, producing predictable and stable hard tissue advancements. The procedure induces a proportional, albeit slightly less, anterior movement of the overlying soft tissue chin and lip, significantly improving facial profile. A critical finding is the substantial and statistically significant increase in oropharyngeal airway volume, suggesting a potential therapeutic role for MDO in addressing retrognathia-associated airway compromise.

Keywords: Distraction Osteogenesis; Mandibular Retrognathia; Hemifacial Microsomia; Airway Volume; Soft Tissue Changes; 3D Analysis.

INTRODUCTION

Mandibular retrognathia, a three-dimensional deficiency in mandibular development, represents a profound clinical challenge with multifaceted repercussions extending beyond mere aesthetic concerns.[1] Characterized by a retruded chin, convex facial profile, and Class II malocclusion, this skeletal deformity is a primary contributor to oropharyngeal crowding and obstructive sleep apnea (OSA), while simultaneously imposing significant psychological and social burdens on affected individuals.[2] The traditional corrective mainstay for moderate cases has been orthognathic surgery, specifically the bilateral sagittal split osteotomy (BSSO) with rigid internal fixation. While effective for advancements up to 10-12 mm, BSSO is inherently limited in its application for severe deficiencies. Larger single-jaw advancements are associated with increased risks of skeletal relapse, neurosensory dysfunction of the inferior alveolar nerve, and suboptimal soft tissue adaptation due to the acute stretching of the muco-muscular envelope.[3]

The advent of distraction osteogenesis (DO)—a biological process of generating new bone between gradually separated vascularized bone segments—has fundamentally altered the surgical paradigm for severe craniofacial hypoplasias. First applied to the human mandible by McCarthy et al. in 1992, mandibular distraction osteogenesis (MDO) circumvents many limitations of acute advancement.[4] By allowing for larger, more stable skeletal movements (often exceeding 20 mm), MDO facilitates a concomitant, gradual adaptation of the soft tissue functional matrix—comprising skin, muscle, nerves, and vasculature. This "tissue engineering" approach is hypothesized to yield not only greater skeletal stability but also more favorable and predictable soft tissue aesthetic outcomes due to the phenomenon of histogenesis.[5]

While the capacity of MDO to lengthen the mandibular body and ramus is well-documented, a comprehensive, quantitative analysis of its tripartite impact remains a critical gap in the literature. Specifically, three interconnected domains require precise concurrent evaluation in a controlled cohort: 1) The hard tissue outcome, quantified through three-dimensional (3D) skeletal changes; 2) The soft tissue response, defining the precise ratio and vector of profile change relative to skeletal movement; and 3) The functional airway consequence, objectively measured as a volumetric change in the oropharyngeal space.[6] Prior studies have often focused on one or two of these domains in isolation, or have been limited by retrospective design, heterogeneous samples, or two-dimensional analysis. The interplay between skeletal advancement and airway augmentation is of particular clinical urgency. Mandibular retrognathia is a key anatomical risk factor for OSA, as the retropositioned mandible pulls the genioglossus and associated suprahyoid musculature posteriorly, narrowing the retroglossal airway.[7] The theoretical promise of MDO is to anteriorly reposition this muscular complex, thereby enlarging the pharyngeal lumen. However, objective, volumetric data from CBCT to substantiate the degree of this enlargement, and its correlation with the amount of distraction, is essential to establish MDO as a definitive functional surgery for airway pathology.[8]

Therefore, this prospective cohort study was designed to provide an integrated, quantitative assessment of MDO in severe mandibular retrognathia. By employing a standardized protocol in a consecutive series of 24 patients, and utilizing precise 3D CBCT analysis, this research aims to: (a) quantify the magnitude and stability of skeletal advancement, (b) determine the soft tissue adaptation ratios at key aesthetic landmarks, and (c) objectively measure the resultant increase in oropharyngeal airway volume. The findings seek to validate the holistic efficacy of MDO and establish evidence-based correlations between surgical movement and functional-aesthetic outcomes.

Methodology

Study Design, setting and population

This study employed a **prospective, single-arm, longitudinal cohort design**. The study was conducted at the **Department of Oral and Maxillofacial Surgery and the Craniofacial Orthodontics Unit of a tertiary care dental hospital**. The target population comprised **skeletally mature adolescents and adults (aged 18-30 years) diagnosed with moderate to severe, non-syndromic mandibular retrognathia** requiring surgical-orthodontic correction with an advancement magnitude exceeding conventional orthognathic limits (>12 mm).

Inclusion and Exclusion Criteria

- **Inclusion Criteria:**
    1. Diagnosis of skeletal Class II malocclusion due to mandibular retrognathia (SNB < 75°, ANB > 7°, overjet > 7mm).
    2. Age between 18 and 30 years at the time of surgery.
    3. Planned mandibular advancement via bilateral MDO as the primary treatment modality.
    4. Good general health (ASA I or II).
    5. Provision of informed consent.
- **Exclusion Criteria:**
    1. Presence of syndromic craniofacial anomalies (e.g., Pierre Robin Sequence, Treacher Collins) except non-syndromic Hemifacial Microsomia (Pruzansky-Kaban Type I/IIA).
    2. Previous mandibular or maxillofacial trauma or surgery.
    3. Systemic conditions contraindicating elective surgery or affecting bone metabolism (e.g., uncontrolled diabetes, osteoporosis).
    4. Active temporomandibular joint arthralgia or degenerative disease.
    5. Pregnancy.

Sample Size Calculation

Given the highly specialized surgical intervention and the prospective longitudinal design requiring stringent inclusion criteria, a sample size calculation was based on feasibility and precision. A power calculation for a paired t-test (α=0.05, β=0.20, power=80%) indicated that **18 subjects** would be sufficient to detect a large effect size (Cohen's d = 0.8) in the primary airway volume outcome, based on pilot data (SD of change = 2.0 cm^3, expected mean change = 4.0 cm^3). To account for a potential attrition rate of up to 25%, a total sample size of **N = 24** was targeted and successfully enrolled. This aligns with sample sizes reported in similar high-precision surgical cohort studies.

Procedure for Data Collection

Data collection followed a strict timeline:

1. **Pre-operative (T0 - Baseline):** Within one month prior to surgery, all patients underwent standardized data acquisition:
   - Clinical examination and photographic documentation.
   - High-resolution Cone-Beam Computed Tomography (CBCT) scan in natural head position.
   - Lateral cephalogram generated from CBCT data.
2. **Intervention:** Execution of the planned MDO protocol as described in the surgical plan.
3. **Post-operative (T1 - Endpoint):** At 6 months after the completion of the distraction activation phase (following the 12-week consolidation and distractor removal):
4. An identical CBCT scan and lateral cephalogram were acquired using the same machine and positioning protocol as at T0.
5. **Data Extraction:** A single, calibrated examiner (blinded to the time point) performed all measurements on de-identified digital imaging data using dedicated software. Hard tissue, soft tissue, and airway analyses were performed sequentially.

Data analysis

All patient data were anonymized using a unique study identification code. The linkage file was password-protected and stored separately from the research data. Digital imaging data (CBCT DICOM files) and measurement databases were stored on a secure, HIPAA/GDPR-compliant hospital server with encrypted access. Quantitative measurements were entered into a structured spreadsheet (Microsoft Excel). Data integrity checks (range checks, logic checks) were performed before export to statistical software (IBM SPSS v.26).

RESULTS

Table 1: Demographic and Clinical Characteristics of the Study Cohort (N=24)

Characteristic	Value (Mean ± SD or n (%))
Age (years)	22.3 ± 4.1
Sex	
Male	10 (41.7%)
Female	14 (58.3%)
Primary Diagnosis	
Non-syndromic Retrognathia	18 (75.0%)
Hemifacial Microsomia (Type I/IIA)	6 (25.0%)
Distraction Device	
Internal Unidirectional	16 (66.7%)
Extraoral Bidirectional	8 (33.3%)

Characteristic	Value (Mean ± SD or n (%))
Mean Distraction Distance (mm)	16.8 ± 2.3
Mean Activation Period (days)	16.8 ± 2.3
Mean Consolidation Period (weeks)	12.0 (fixed protocol)

Table 1 summarizes the demographic and baseline characteristics of the cohort. The mean age of the 24 patients (14 females, 10 males) was 22.3 years (±4.1). Non-syndromic mandibular retrognathia was the primary diagnosis in 18 patients (75%), while 6 patients (25%) had associated Hemifacial Microsomia (Type I/IIA). Internal distraction devices were used in 16 cases (66.7%), with the remaining 8 cases utilizing extraoral devices. The mean distraction distance achieved was 16.8 mm (±2.3), corresponding to a mean activation period of 16.8 days.

Table 2: Comparison of Hard Tissue (Skeletal) Parameters Pre- (T0) and Post-Distraction (T1)

Parameter	Pre-Distraction (T0) Mean ± SD	Post-Distraction (T1) Mean ± SD	**Mean Change (T1-T0)**	**p-value**
SNA (°)	80.3 ± 2.8	80.1 ± 2.9	-0.2 ± 0.4	0.083
SNB (°)	72.1 ± 3.2	77.8 ± 2.9	**+5.7 ± 1.1**	**<0.001***
ANB (°)	9.8 ± 1.5	4.1 ± 1.3	**-5.7 ± 1.2**	**<0.001***
Mandibular Length (Co-Gn, mm)	106.5 ± 5.2	123.7 ± 5.8	**+17.2 ± 2.1**	**<0.001***
Overjet (mm)	+9.5 ± 1.8	+1.2 ± 0.6	**-8.3 ± 1.5**	**<0.001***
Adv. of Skeletal Pogonion (Pg, mm)	-	-	**16.1 ± 2.0**	**<0.001***

*Paired t-test, significant at $p < 0.05$

Table 2 details the highly significant hard tissue changes. The key sagittal skeletal parameter, the SNB angle, demonstrated a mean increase of 5.7° (±1.1), rising from 72.1° (±3.2) to 77.8° (±2.9) (p<0.001). Consequently, the ANB angle showed a corresponding significant decrease of 5.7° (±1.2) (p<0.001). The SNA angle remained stable, confirming the isolated mandibular effect. In linear terms, the mandibular length (Co-Gn) increased substantially by 17.2 mm (±2.1) (p<0.001), and skeletal pogonion advanced by a mean of 16.1 mm (±2.0). The dental relationship was normalized, with overjet reduced from a pre-operative mean of +9.5 mm (±1.8) to +1.2 mm (±0.6) at T1 (p<0.001).

Table 3: Comparison of Soft Tissue Profile Parameters Pre- (T0) and Post-Distraction (T1)

Parameter	Pre-Distraction (T0) Mean ± SD	Post-Distraction (T1) Mean ± SD	**Mean Change (T1-T0)**	**p-value**
Soft Tissue Pogonion (Pog') Adv. (mm)	-	-	**12.5 ± 1.9**	**<0.001***
Lower Lip to E-plane (mm)	+4.2 ± 1.8	-0.6 ± 1.1	**-4.8 ± 1.2**	**<0.001***
Facial Convexity Angle (G'-Sn-Pog')	165.2 ± 4.5	172.8 ± 3.9	**+7.6 ± 2.3**	**<0.001***

Parameter	Pre-Distraction (T0) Mean ± SD	Post-Distraction (T1) Mean ± SD	**Mean Change (T1-T0)**	**p-value**
Soft Tissue:Hard Tissue Ratio (Pog':Pg)	-	-	**0.78:1**	-

*Paired t-test, significant at $p < 0.05$

Table 3 presents the significant soft tissue profile adaptations that accompanied the skeletal movement. The soft tissue pogonion advanced by a mean of 12.5 mm (±1.9), yielding a soft tissue-to-hard tissue advancement ratio of 0.78:1 at the chin. The lower lip retruded relative to the aesthetic plane, with the distance to the E-plane decreasing by 4.8 mm (±1.2) ($p<0.001$). Overall facial convexity improved significantly, as evidenced by an increase in the soft tissue facial convexity angle (G'-Sn-Pog') of 7.6° (±2.3) ($p<0.001$).

Table 4: Comparison of Oropharyngeal Airway Parameters Pre- (T0) and Post-Distraction (T1)

Parameter	Pre-Distraction (T0) Mean ± SD	Post-Distraction (T1) Mean ± SD	**Mean Change (T1-T0)**	**% Change**	**p-value**
Airway Volume (cm^3)	12.45 ± 2.11	17.27 ± 2.45	**+4.82 ± 1.05**	**+38.7%**	**<0.001***
Min. Cross-Sectional Area (mm^2)	78.3 ± 15.6	112.5 ± 18.9	**+34.2 ± 8.7**	**+43.7%**	**<0.001***
Antero-Posterior Width at MCSA (mm)	7.1 ± 1.5	9.8 ± 1.8	**+2.7 ± 0.9**	**+38.0%**	**<0.001***

*Paired t-test, significant at $p < 0.05$; MCSA = Minimum Cross-Sectional Area

Table 4 outlines the critical functional airway outcomes. The oropharyngeal airway volume increased by a mean of 4.82 cm^3 (±1.05), representing a 38.7% enlargement from a pre-operative mean of 12.45 cm^3 (±2.11) to 17.27 cm^3 (±2.45) at T1 ($p<0.001$). The airway's most constricted region also improved markedly; the Minimum Cross-Sectional Area (MCSA) increased by 34.2 mm^2 (±8.7), or 43.7%, and its antero-posterior dimension widened by 2.7 mm (±0.9) ($p<0.001$ for both).

Table 5: Correlation Analysis (Pearson's r) Between Skeletal Advancement and Secondary Outcomes

Primary Predictor	Correlated Outcome Variable	**Pearson's r**	**p-value**	**Interpretation**
Advancement at Point B (mm)	Soft Tissue Pog' Advancement (mm)	0.91	**<0.001***	Very Strong Positive Correlation
Advancement at Point B (mm)	Airway Volume Increase (cm^3)	0.82	**<0.001***	Strong Positive Correlation
Advancement at Point B (mm)	MCSA Increase (mm^2)	0.79	**<0.001***	Strong Positive Correlation

*Significant at $p < 0.05$

Table 5 reveals strong and statistically significant correlations between the magnitude of skeletal advancement and the secondary outcomes. The advancement at Point B showed a **very strong positive correlation** with the forward movement of soft tissue pogonion ($r=0.91$, $p<0.001$). Furthermore, it demonstrated **strong positive correlations** with both the increase in total airway volume ($r=0.82$, $p<0.001$) and the increase in the Minimum Cross-Sectional Area ($r=0.79$, $p<0.001$).

DISCUSSION

The findings of this prospective study, encompassing a precisely measured cohort of 24 patients, affirm mandibular distraction osteogenesis (MDO) as a transformative procedure for severe retrognathia. The results demonstrate its tripartite efficacy: achieving substantial and stable skeletal correction, inducing a proportional and aesthetically favorable soft tissue response, and, most critically, effecting a significant volumetric expansion of the compromised oropharyngeal airway. This integrated outcome underscores MDO's unique position as a procedure that concurrently addresses form, function, and physiology.

The primary objective of MDO—significant anteroposterior elongation of the hypoplastic mandible—was unequivocally met. The mean increase in SNB angle of 5.7° and the linear advancement of over 16 mm at the skeletal chin represent a correction magnitude that typically lies beyond the reliable scope of conventional orthognathic surgery. This aligns with the foundational work of McCarthy et al. (1992), who pioneered the technique and emphasized its capacity for "skeletal expansion" rather than mere repositioning.4 The stability observed at the 6-month post-consolidation mark, with minimal change in overjet, supports the biological principle of distraction histogenesis, wherein gradual traction allows the bone and its associated soft tissue envelope to adapt in unison, reducing the biomechanical forces that predispose to relapse seen in large, acute advancements via bilateral sagittal split osteotomy (BSSO).9

The soft tissue response observed in this study offers valuable insight into the aesthetic dividends of the distraction process. The soft tissue-to-hard tissue advancement ratio of 0.78:1 at pogonion exceeds the frequently cited ratio of approximately 0.6:1 for BSSO.10 This suggests that the gradual advancement inherent to MDO may engender superior soft tissue adaptation through neohistogenesis of the dermal and muscular matrix, as theorized by Rachmiel et al. (2001).5 In their longitudinal analysis, they posited that the slow stretch minimizes soft tissue compression and scarring, allowing the skin and musculature—particularly the mentalis and suprahyoid groups—to lengthen and redrape more naturally. This phenomenon not only enhances profile aesthetics but may also contribute to the functional stability of the result by allowing the orofacial musculature to re-establish balanced tonicity in its new position.

Perhaps the most compelling finding of this study is the 38.7% mean increase in oropharyngeal airway volume, strongly correlated with the degree of skeletal advancement (r=0.82). This quantitative evidence powerfully substantiates the role of MDO as a primary surgical intervention for airway pathology secondary to skeletal deficiency. The retropositioned mandible directly pulls the tongue base and suprahyoid musculature posteriorly, narrowing the retroglossal airway—a key anatomical site in obstructive sleep apnea (OSA).7 By anteriorly repositioning this muscular complex, MDO directly enlarges the pharyngeal lumen. This finding is consistent with and extends the work of Hsu et al. (2020), who reported a 35% volumetric increase in a similar cohort.8 Our data, which also documents a 43.7% increase in the minimum cross-sectional area (the likely site of collapse), provides even more direct evidence of the procedure's potential to alleviate anatomical obstruction. This positions MDO not merely as an aesthetic corrective but as a definitive, structure-modifying treatment for select patients with retrognathia-associated sleep-disordered breathing.

Conclusion

Within the defined parameters of this study, mandibular distraction osteogenesis proves to be a highly effective and multifaceted intervention for severe mandibular retrognathia. It reliably produces large, stable skeletal advancements, induces an advantageous soft tissue profile change through gradual adaptation, and delivers a profound, dose-dependent enlargement of the oropharyngeal airway. These results validate MDO as a comprehensive surgical strategy that successfully bridges the goals of craniofacial reconstruction, aesthetic enhancement, and functional rehabilitation.

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