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Original Article

# Comparative Effects of Maxillary Advancement Alone and in Combination with Mandibular Setback on Airway Anatomy and Function in Class III Malocclusion: A Controlled Prospective Clinical Study

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**Main Points**

- Maxillary advancement increased the volume of all sections of the pharyngeal airway and minimum cross-sectional area.
- Maxillary advancement had no significant impact on hyoid bone position or head posture.
- Mandibular setback with maxillary advancement led to an overall increase in pharyngeal airway volume but a reduction in hypopharyngeal volume and minimum cross-sectional area.
- Mandibular setback with maxillary advancement does not increase the risk of obstructive sleep apnea in young, healthy individuals.
- Maxillary advancement may help mitigate airway reduction caused by mandibular setback.

## ABSTRACT

**Objective:** The aim of this study is to evaluate the effects of maxillary advancement (MxA) and bimaxillary osteotomy (MdS-MxA) on upper pharyngeal airway volume (PAV), apnea-hypopnea index (AHI), hyoid bone (HB) position, and head posture (HP) in young and healthy individuals with skeletal Class III malocclusion.

**Methods:** This prospective clinical study included three groups: MxA, MdS-MxA, and Class I control group, with 12 subjects each. In the surgical groups, lateral cephalometric radiographs, cone-beam computed tomography images, and AHI measurements were obtained preoperatively and approximately six months postoperatively. Only pre-treatment records were collected for the control group. Depending on data distribution, parametric (Paired Samples t-test and ANOVA) or non-parametric (Wilcoxon Signed-Rank and Kruskal-Wallis) tests were used for intra- and inter-group statistical comparisons, with a significance level set at $p<0.05$.

**Results:** The maxillary forward movement for the MxA group was 5.34 mm. It was 5.32 mm in the MdS-MxA group, and the mandibular setback was 4.71 mm. Nearly six months after surgery, significant differences were observed among the groups in the sagittal positions of the jaws, the vertical position of the mandible, the vertical position of the hyoid bone, and PAV sections. No significant differences were found in HP, minimum cross-sectional area or AHI.

**Conclusion:** PAV increase was observed in both surgical groups. MdS-MxA did not have an effect on obstructive sleep apnea. Postoperative HB displacement was minimal, with a slight inferior shift observed in the MdS-MxA group.

**Keywords:** Body mass index, cone-beam computed tomography, hyoid bone, malocclusion, orthognathic surgical procedures, polysomnography

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## INTRODUCTION

A skeletal Class III anomaly is characterized by dentofacial disharmony and is often associated with various clinical manifestations. Defined in relation to the anterior cranial base in the sagittal plane, this anomaly may result from excessive mandibular growth, insufficient maxillary development, or a combination of both.[1] These skeletal discrepancies often lead to aesthetic, functional, and structural challenges, necessitating orthognathic treatment in skeletally mature individuals.[2] By combining orthodontic treatment with surgical interventions, this approach repositions the jaws and teeth in all spatial planes to enhance dentofacial harmony, optimize anatomical relationships, and improve quality of life.[3] The most commonly performed orthognathic surgical techniques for correcting skeletal Class III anomalies include bilateral sagittal split ramus osteotomy [mandibular setback (MdS); 10%)], LeFort I osteotomy [maxillary advancement (MxA); 50%], or a combination of both procedures [(MdS-MxA); 40%].[4] These surgical techniques affect both hard and soft tissues, often resulting in structural changes that influence surrounding anatomical regions.[5] The pharyngeal airway volume (PAV), hyoid bone (HB) position, and head posture (HP) are particularly important due to their influence on respiratory function.[6] These anatomical alterations can significantly affect respiratory function, leading to enhancements or complications in airway dynamics. Understanding the relationships among these factors is critical to achieving optimal surgical outcomes and improving patients' quality of life following surgery.

The function of the pharyngeal lumen is heavily influenced by the interaction of the mandible, tongue, soft palate, and lateral pharyngeal walls.[7] Orthognathic surgery can potentially modify the dimensions of the nasal and oral cavities and the PAV, depending on the direction and extent of jaw movement. Consequently, these surgeries can positively or negatively affect an individual's breathing capacity.[8,9] Evidence suggests that surgical techniques such as MxA, maxillomandibular advancement, and surgically assisted rapid maxillary expansion typically result in an increase in PAV.[10] In contrast, studies indicate that approaches involving MdS-MxA or MdS alone are associated with a reduction in PAV in Class III patients. Among these, MdS-MxA tends to produce less pronounced reductions in PAV.[11-13] The primary concern regarding such reductions is the potential development of obstructive sleep apnea (OSA), a subtype of sleep-disordered breathing (SDB). Objective sleep assessments, including the home sleep apnea test (HSAT) and full polysomnography (PSG), play a crucial role in identifying significant respiratory events and evaluating SDB. These tests measure various physiological parameters.

The primary metric used in these assessments is the apnea-hypopnea index (AHI), which quantifies the severity of breathing disturbances. An AHI threshold of 5 events per hour is accepted as indicative of OSA.[10] While the impact of orthognathic surgery on AHI in patients with mild or severe OSA has been explored,[14,15] no study has specifically examined how different surgical techniques affect Class III patients with AHI values below the diagnostic threshold.

The HB, a horseshoe-shaped structure, is situated at the level of the third cervical vertebra and is connected to the mouth floor, tongue, larynx, epiglottis, and pharynx through various muscle attachments. It plays a critical role in essential physiological functions such as maintaining airway patency, mastication, phonation, digestion, and supporting head posture.[16] Orthognathic surgical procedures often result in positional changes to the HB position.[17] The literature includes numerous studies that investigate the short- and long-term effects of orthognathic surgery on the HB position, focusing on the type of surgery performed and the extent of jaw movement.[18] However, this remains an area of ongoing research and debate. Since the HB position is closely related to the mandible and the HP,[19] it is critical to understand how these surrounding structures are affected by orthognathic surgery to ensure stable and predictable treatment outcomes.

Therefore, this study aims to compare the postoperative effects of MxA alone and MdS-MxA on PAV, AHI, HB position, and natural HP and to evaluate how these outcomes differ from those observed in the Class I control group. Accordingly, the null hypothesis is that MxA and MdS-MxA do not have different effects on upper airway anatomy and function in Class III malocclusion.

## METHODS

This prospective controlled clinical study was conducted following approval from the Erciyes University Clinical Research Ethics Committee (decision no.: 2022/614, date: 14.09.2022). The sample size was determined using G*Power (ver. 3.1.9.7) analysis software. Based on a 1:1 group ratio, a significance level of $\alpha=0.05$, a power of $1-\beta=0.80$, and an effect size of $d=0.8$, a minimum of 10 individuals per group was required. The power analysis was based on differences in airway volume changes reported by Karaaslan et al.[14] To enhance the study's reliability and account for potential variability, 12 participants were included in each group. All procedures involving human participants adhered to the ethical principles outlined in the Declaration of Helsinki. Informed consent was obtained from all participants enrolled in this study. The study included 36 adults categorized into three groups: individuals with skeletal Class III anomalies who underwent MxA, those who underwent MdS-MxA, and a skeletal Class I control group (CI-C). The inclusion criteria for participants are provided in Table 1.

The exclusion criteria for all groups included systemic or chronic airway disease, dysmorphism, severe craniofacial anomalies, pathology in the oropharyngeal or nasal region, a history of pharyngeal airway surgery, or a history of allergy or allergic rhinitis. Table 2 presents the gender distribution, age, follow-up period, and BMI averages for each group, along with the mean sagittal jaw movement achieved through orthognathic surgery in the Class III surgical groups. MxA was performed using LeFort I osteotomy, while MdS was conducted using BSSO without genioplasty. Jaw movement was measured using CBCT records analysed with NemoFAB software (Madrid, Spain). Both surgical procedures were performed by the same surgical team at the Erciyes University Faculty of Dentistry Hospital.

**Table 1.** Inclusion criteria for participants according to groups

| MxA Group | MxA-MdS Group | CI-C Group |
|---|---|---|
| Skeletal and dental Class III (ANB°<0°) | Skeletal and dental Class III (ANB°<0°) | Skeletal Class I (0°<ANB°< 4°) |
| Normal growth pattern (26°<SN-GoGn°<38°) | Normal growth pattern (26°<SN-GoGn°<38°) | Normal growth pattern (26°<SN-GoGn°<38°) |
| Patients with Class I and Class II according to the Mallampati classification | Patients with Class I and Class II according to the Mallampati classification | Patients with Class I and Class II according to the Mallampati classification |
| AHI <5 | AHI <5 | AHI <5 |
| BMI within normal limits (18.5-24.9 kg/m²) | BMI within normal limits (18.5-24.9 kg/m²) | BMI within normal limits (18.5-24.9 kg/m²) |
| Patients aged between 18 and 25 years | Patients aged between 18 and 25 years | Patients aged between 18 and 25 years |
| Patients with maxillary retrognathia | Patients with maxillary retrognathia and mandibular prognathia | Orthognathic |
| The amount of surgical activation for the maxilla ranging between 4 and 7 mm | Total amount of surgical activation not exceeding 12 mm | None |

MxA, maxillary advancement; MdS-MxA, mandibular setback with maxillary advancement; CI-C, control group; BMI, body mass index; AHI, apnoea–hypopnea index.

**Table 2.** Sample description

| | MxA (n=12) | MdS- MxA (n=12) | CI-C (n=12) |
|---|---|---|---|
| Gender (Female/Male) | 2/10 | 7/5 | 6/6 |
| Age (Years) | 22.7±2.4 | 23.6±2.6 | 18.2±3.4 |
| Follow-up period (Month) | 7.14±0.79 | 7.25±0.74 | - |
| Body mass index (BMI) (kg/m²) | 22.6±3.6 | 22.9±3.1 | 21.8±3.3 |
| Maxillary advancement (mm) | 5.34±1.23 | 5.32±0.52 | - |
| Mandibular setback (mm) | - | -4.71±0.66 | - |

MxA, maxillary advancement; MdS-MxA, mandibular setback with maxillary advancement; CI-C: control group.



### Acquisition of Records and Measurements

This study utilized multiple diagnostic tools, including lateral cephalometric radiographs (LCR), cone beam computed tomography (CBCT) images, an HSAT device, and body mass index (BMI) data. In the surgical groups, records were obtained at two time points: before surgery (T1) and at least six months postoperatively (T2). For the CI-C group, only pre-orthodontic treatment records (T1) were included, serving as a baseline for comparison.

HP for all participants was determined and recorded using an inclinometer device (MPU-6050 Six-Axis MEMS MotionTracking, TDK Invernesses, Tokyo) mounted on glasses with a motion-sensitive receiver attached to the arm. Based on the recorded quantitative values, lateral cephalometric radiographs (LCRs) were obtained using an X-ray machine (OP300; Instrumentarium Dental, Tuusula, Finland) while participants maintained a natural HP in a standing posture, with lips at rest and teeth in centric occlusion (Figure 1). The LCR images were transferred to Dolphin Imaging software (Dolphin Imaging, USA) for angular and linear measurements (Figure 2), including those related to the HB position, HP, and jaw positions. In the surgical groups, LCRs were taken approximately 12 weeks before surgery to assess incisor inclination, position, and surgical activation amount. Postoperatively, LCRs were taken as a control measure before the orthodontic finishing phase.

CBCT images were obtained from the surgical groups approximately one week before surgery for three-dimensional (3D) surgical planning and splint fabrication and approximately after six months postoperatively for control assessments. In the CI-C group, CBCT images were taken before orthodontic treatment to evaluate impacted teeth, tooth roots, and the temporomandibular joint. All CBCT scans were acquired using a NewTom 5G device (Quantitative Radiology, Verona, Italy) with participants in a supine position parallel to the floor. The vertical guideline was aligned through the glabella and philtrum, centered on the face, while the horizontal guideline passed through the lateral canthus of the eye. CBCT image files were converted to DICOM format and imported into NemoFAB software for airway analysis. Pharyngeal airway volume (PAV, mm³) and minimal cross-sectional area (mCSA, mm²) were calculated, with airway volume measurements divided into three sections: the nasopharynx, oropharynx, and hypopharynx (Figure 3).

The AHI of all participants was determined using an HSAT device (Alice NightOne) to conduct a home sleep breathing test. The AHI value was calculated by transferring one night of sleep data from each participant to a computer and analysing it with the device's Sleepware G3 software. The test was performed over three consecutive nights, and the final AHI score was obtained by averaging the data collected across these nights.

Height (m) and weight (kg) measurements were recorded for each participant. Body mass index (BMI) was calculated using the formula BMI=kg/m² by dividing each participant's weight (kg) by the square of their height (m) (Table 2).

**Figure 1.** Recording the patient's dynamic head posture and transferring the natural head posture to the cephalostat

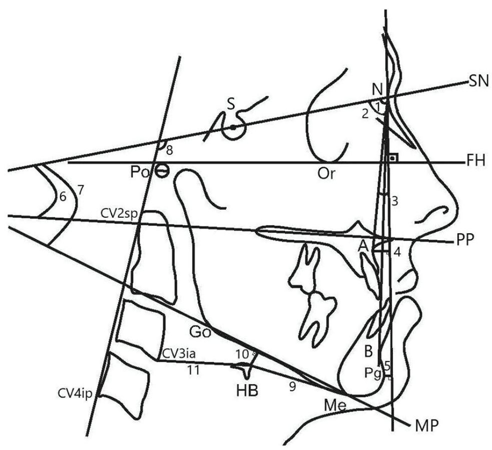


**Figure 2.** Lateral cephalometric measurements. **1) SNA°:** The angle between the anterior cranial base (SN plane) passing through the Sella (S) and Nasion (N) points and the NA plane passing through the N and A points. **2) SNB°:** The angle between the SN plane passing through the S and N points and the NB plane passing through the N and B points. **3) ANB°:** The angle formed between the NA and NB planes. **4) N⊥ A (mm):** The perpendicular distance from point A to the vertical line drawn from N to FH. The FH plane is the line formed by connecting the Orbitale (Or) and Porion (Po) points. **5) N⊥ Pog (mm):** The perpendicular distance from the Pogonion (Pog) point to the vertical line drawn from N to FH. **6) SN-PP°:** The angle between the SN plane and the palatal plane (PP) [anterior nasal spine (ANS)- posterior nasal spine (PNS)]. **7) SN-MP°:** The angle between the SN plane and the mandibular plane (MP) (Gonion-Menton) **8) CVT-SN°:** The angle between the cervical vertebrae tangent (CVT) [passing through the most superior-posterior point of 2nd cervical vertebra (CV2sp) and the most inferior-posterior point of the 4th cervical vertebra (CV4ip)] and SN plane. **9) HB-Me (mm):** Linear distance from the hyoid bone (HB) to Menton. **10) HB-Cv3 (mm):** Linear distance from the HB to the most inferior-anterior point of 3rd cervical vertebrae (CV3ia). 11) HB-MP (mm): The perpendicular distance of from HB to the MP.

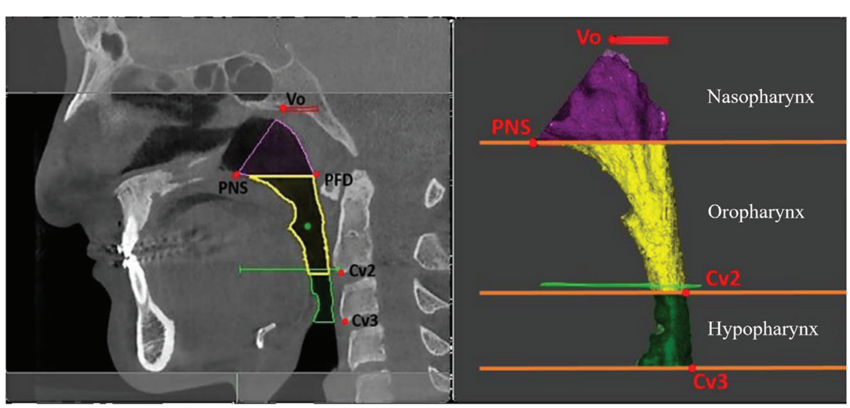


**Figure 3.** The sections and boundaries of the upper posterior airway with volumetric measurements.

### Statistical Analysis

Statistical analyses of the data were performed using IBM Statistical Package for Social Sciences (SPSS, version 21). The normality of data distribution was assessed using the Shapiro-Wilk test. For intra- and inter-group comparisons, parametric tests (Paired Samples t-test and ANOVA) were applied to normally distributed variables. In contrast, non-parametric tests (Wilcoxon Signed-Rank and Kruskal-Wallis) were used for non-normally distributed variables. Results were evaluated with a 95% confidence interval, and p-values below 0.05 were considered statistically significant.

## RESULTS

To assess measurement error in the records obtained from the participants, half of the lateral cephalometric radiographs (LCRs) and cone-beam computed tomography (CBCT) images were randomly selected. All measurements were repeated by the same researcher (HBB) after one month. The reliability of the measurements was assessed using Pearson correlation and Cronbach's alpha analysis. The Pearson correlation coefficient ranged from 0.877 to 0.952, while the Cronbach's alpha coefficient ranged from 0.812 to 0.946. No statistically significant difference was found between the initial and repeated measurements.

The means and standard deviations of the measurements at T1 and T2 in the surgical groups and at T1 in the control group, along with intergroup comparisons, are presented in Table 3. Statistically significant differences were observed in preoperative SNA, SNB, ANB, SN-MP angles, N⊥A, N⊥Pog, and HB-MP distances, as well as in PAV sections and mCSA ($p<0.05$). Conversely, no significant differences were found between the groups for SN-PP, CVT-SN angles, HB-CV3, HB-Me distances, and AHI ($p>0.05$). Comparison of T2 data with the control group revealed significant differences in SN-MP angle, N⊥A, N⊥Pog, HB-MP distances, and nasopharyngeal and oropharyngeal volume measurements ($p<0.05$). No significant differences were observed in the remaining parameters ($p>0.05$).

Intragroup comparisons of preoperative and postoperative measurements within the surgical groups are presented in Table 4. In the MxA group, maxillary advancement alone resulted in statistically significant changes in SNA and ANB angles, N⊥A and N⊥Pog distances, all pharyngeal sections, mCSA, and AHI ($p<0.05$). However, no significant changes were observed in the SNB angle, HB position, or CVT-SN angle ($p>0.05$). In the MdS-MxA group, significant changes were observed in all measurements except for SN-PP and SN-MP angles and HB-Me and HB-CV3 distances.

## DISCUSSION

The effects of orthognathic surgery on anatomical structures and their impact on patients' quality of life, including chewing, breathing, speech, dentofacial aesthetics, and sleep quality, remain a key research focus. Skeletal Class III anomalies are less common than other sagittal anomalies; however, they are a primary indication for orthognathic treatment due to their adverse effects on facial aesthetics and bite function. The design of the surgical intervention is planned according to the affected jaws from the anomaly, with a strong emphasis on achieving an aesthetic outcome and occlusion. However, excessive focus on facial aesthetics during surgical planning may inadvertently compromise respiratory function, especially when sleeping. To reduce the risk of OSA, combining MdS with MxA is often recommended in cases requiring mandibular repositioning.[11] However, the precise limitations of such combined movements remain unclear. In the present study, a comparative analysis was conducted to evaluate the effects on upper airway anatomy and function. Two surgical approaches were examined: (1) a single-jaw surgery involving 5.34 mm of maxillary advancement in individuals with retrognathic maxilla, and (2) a double-jaw surgery involving 5.32 mm of maxillary advancement combined with 4.71 mm of mandibular setback in individuals with both retrognathic maxilla and prognathic mandible. Except for a few parameters, no statistically significant differences were observed between the groups in the postoperative period. Therefore, the null hypothesis was accepted, indicating that the two surgical approaches produced comparable outcomes in terms of upper airway anatomy and function.



Before orthognathic surgery, all groups had AHI values below the diagnostic threshold; however, significant differences were observed in PAV and mCSA values. The MdS-MxA group demonstrated the largest oropharynx, hypopharynx and mCSA measurements, while the control group had the greatest nasopharyngeal volume. In the MxA group, maxillary advancement resulted in a 19% increase in the nasopharynx, 10% in the oropharynx, 3% in the hypopharynx, and a 24% increase in mCSA. These findings indicate that MxA promotes expansion across all three sections of the PAV, with the degree of expansion gradually decreasing from top to bottom. MdS-MxA surgery led to a 19% increase in the nasopharynx and a 5% increase in the oropharynx while causing a 4% volumetric reduction in the hypopharynx and a 15% decrease in mCSA. A study involving an MdS of at least 9 mm reported a significant postoperative reduction in PAV, oropharyngeal, hypopharyngeal volumes, and retroglossal mCSA, accompanied by an increase in AHI.[11] Our finding suggests that MxA may offer partial protection against the constrictive effects of MdS on the oropharynx, hypopharynx, and mCSA, confirming recent studies.[20-22] Total PAV also increased in both surgical groups (MxA: 11% and MdS-MxA: 6%). Despite the observed reductions in mCSA and hypopharyngeal volume in the MdS-MxA group, these changes did not negatively affect AHI. Both surgical procedures significantly reduced AHI values, and no significant difference was observed between the groups approximately 6 months after surgery. Therefore, in young and healthy individuals, MdS-MxA does not function as a contributing factor to the development of OSA.

Table 3. T1 and T2 comparison across all groups.

| | T1 | | | | | T2 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Measurements | MxA ($\bar{x}$±SD) | MdS-MxA ($\bar{x}$±SD) | CI-C ($\bar{x}$±SD) | Test value | p-value | MxA ($\bar{x}$±SD) | MdS-MxA ($\bar{x}$±SD) | CI-C ($\bar{x}$±SD) | Test value | p-value |
| SNA° | 76.66±4.47[a] | 76.51±4.05[a] | 80.93±3.38[b] | 7.41* | 0.025 | 83.24±2.68 | 83.57±1.99 | 80.93±3.37 | 4.010* | 0.135 |
| SNB° | 81.43±3.27[ab] | 84.23±3.30[b] | 79.43±3.61[a] | 10.08* | 0.006 | 81.14±1.71 | 82.00±2.16 | 79.43±3.61 | 3.702* | 0.157 |
| ANB° | -4.89±2.76[a] | -7.43±2.67[a] | 1.50±0.47[b] | 25.14* | <0.001 | 2.05±1.23 | 1.29±0.85 | 1.50±0.47 | 3.548* | 0.170 |
| N⊥ A (mm) | -4.74±0.93[a] | -4.48±0.47[a] | -0.23±0.62[b] | 157.21† | <0.0001 | 0.74±0.40[a] | 0.81±0.34[a] | -0.23±0.62[b] | 16.94* | <0.001 |
| N⊥ Pog (mm) | -2.23±1.01[a] | 0.33±0.79[b] | -1.41±0.44[c] | 32.99† | <0.0001 | -1.90±0.82[a] | -4.28±0.79[b] | -1.41±0.44[a] | 24.624* | <0.001 |
| SN-PP° | 8.28±4.47 | 8.42±3.37 | 7.73±2.39 | 0.19* | 0.911 | 9.89±2.37 | 8.13±3.57 | 7.73±2.39 | 5.54* | 0.063 |
| SN-MP° | 31.96±3.05[a] | 36.08±4.03[b] | 34.05±2.52[ab] | 6.15* | 0.046 | 32.83±1.97[a] | 36.63±4.18[b] | 34.05±2.52[ab] | 9.556* | 0.008 |
| CVT-SN° | 103.10±2.41 | 103.48±8.78 | 106.13±5.67 | 0.268* | 0.875 | 102.12±2.18 | 107.10±7.70 | 106.13±5.67 | 3.776* | 0.151 |
| HB-Me (mm) | 37.64±5.89 | 37.38±5.90 | 34.42±7.65 | 2.298* | 0.317 | 38.29±2.81 | 36.60±4.76 | 34.42±7.65 | 3.922* | 0.141 |
| HB-Cv3 (mm) | 35.58±5.76 | 34.97±4.98 | 35.30±5.42 | 0.038† | 0.963 | 36.47±5.44 | 35.07±4.19 | 35.30±5.42 | 0.209* | 0.901 |
| HB-ML (mm) | 11.58±4.12[ab] | 13.11±4.22[b] | 8.59±2.27[a] | 10.515* | 0.005 | 12.30±5.89[ab] | 14.33±3.98[a] | 8.59±2.27[b] | 10.198* | 0.006 |
| Nasopharynx ($mm^3$) | 4359.06±128.7[a] | 3968.31±172.5[b] | 5095.31±230.7[c] | 46.591† | <0.001 | 5206.27±122.9[a] | 4746.87±236.7[b] | 5095.31±230.7[a] | 15.986* | <0.001 |
| Oropharynx ($mm^3$) | 8753.01±167.7[a] | 9207.23±146,3[b] | 9004.02±197.6[c] | 2793.4† | <0.001 | 9655.86±229.9[a] | 9562.27±186.5[a] | 9004.02±197.5[b] | 21.536* | <0.001 |
| Hypopharynx ($mm^3$) | 4175.89±160.6[a] | 4865.88±178.2[b] | 4091.89±116.5[a] | 10.183* | 0.006 | 4303.00±179.5[ab] | 4655.95±158.9[a] | 4091.89±116.4[b] | 8.596* | 0.01 |
| mCSA ($mm^2$) | 168.39±27.19[a] | 242.99±20.56[b] | 194.74±34.82[c] | 21.683* | <0.001 | 208.10±22.76 | 205.71±15.45 | 194.74±34.82 | 4.686* | 0.096 |
| AHI | 2.18±0.95 | 1.70±0.94 | 2.23 ± 0.92 | 1.159† | 0.326 | 1.67±0.63 | 1.42±0.65 | 2.23±0.92 | 4.761* | 0.092 |

[a, b], there is a statistically significant difference between groups with different superscript letter; [ab], there is no statistically significant difference between groups with common superscript letter; *, Kruskal-Wallis test; †, ANOVA test; Statistical significance: $p<0.05$.
MxA, maxillary advancement; MdS-MxA, mandibular setback with maxillary advancement; CI-C, control group; $\bar{x}$, mean; SD, standard deviation.

**Table 4.** Intragroup comparison of surgical groups.

| | | MxA | | | MdS-MxA | | |
|---|---|---|---|---|---|---|---|
| | | ($\bar{x}$±SD) | Test value | p | ($\bar{x}$±SD) | Test value | p value |
| SNA° | T2 | 83.24±2.68 | 6.008[a] | <0.001 | 83.57±1.99 | 6.991[a] | **<0.001** |
| | T1 | 76.66±4.47 | | | 76.51±4.05 | | |
| SNB° | T2 | 81.14±1.71 | -0.455[a] | 0.658 | 82.00±2.16 | -3.059[b] | **0.002** |
| | T1 | 81.43±3.27 | | | 84.23±3.30 | | |
| ANB° | T2 | 2.05±1.23 | 9.05[a] | <0.001 | 1.29±0.85 | 10.254[a] | **<0.001** |
| | T1 | -4.89±2.76 | | | -7.43±2.67 | | |
| N⊥ A (mm) | T2 | 0.74±0.40 | 29.38[a] | <0.001 | 0.81±0.34[a] | 36.667[a] | **<0.001** |
| | T1 | -4.74±0.93 | | | -4.48±0.47 | | |
| N⊥ Pog (mm) | T2 | -1.90±0.82 | 3.241[a] | 0.008 | -4.28±0.79 | -24.969[a] | **<0.001** |
| | T1 | -2.23±1.01 | | | 0.33±0.79 | | |
| SN-PP° | T2 | 9.89±2.37 | 1.273[a] | 0.229 | 8.13±3.57 | -0.458[a] | 0.656 |
| | T1 | 8.28±4.47 | | | 8.42±3.37 | | |
| SN-MP° | T2 | 32.83±1.97 | 1.27[a] | 0.23 | 36.63±4.18 | 0.754[a] | 0.467 |
| | T1 | 31.96±3.05 | | | 36.08±4.03 | | |
| CVT-SN° | T2 | 102.12±2.18 | -1.258[a] | 0.234 | 107.10±7.70 | 2.366[a] | **0.037** |
| | T1 | 103.10±2.41 | | | 103.48±8.78 | | |
| HB-Me (mm) | T2 | 38.29±2.81 | 0.364[a] | 0.723 | 36.60±4.76 | -0.586[a] | 0.467 |
| | T1 | 37.64±5.89 | | | 37.38±5.90 | | |
| HB-Cv3 (mm) | T2 | 36.47±5.44 | 0.685[a] | 0.508 | 35.07±4.19 | 0.099[a] | 0.467 |
| | T1 | 35.58±5.76 | | | 34.97±4.98 | | |
| HB-ML (mm) | T2 | 12.30±5.89 | 0.556[a] | 0.590 | 14.33±3.98 | 2.425[a] | **0.034** |
| | T1 | 11.58±4.12 | | | 13.11±4.22 | | |
| Nasopharynx ($mm^3$) | T2 | 5206.27±122.9 | 14.743[a] | <0.001 | 4746.87±236.8 | 5.958[a] | **<0.001** |
| | T1 | 4359.06±128.7 | | | 3968.31±172.5 | | |
| Oropharynx ($mm^3$) | T2 | 9655.86±229.9 | 9.046[a] | <0.001 | 9562.27±186.6 | 66.148[a] | **<0.001** |
| | T1 | 8753.01±167.7 | | | 9207.23±146.3 | | |
| Hypopharynx ($mm^3$) | T2 | 4303.00±179.5 | 7.336[a] | <0.001 | 4655.95±158.9 | -10.181[a] | **<0.001** |
| | T1 | 4175.89±160.6 | | | 4865.88±178.2 | | |
| mCSA ($mm^2$) | T2 | 208.10±22.76 | 10.534[a] | <0.001 | 205.71±15.45 | -3.059[b] | **0.002** |
| | T1 | 168.39±27.19 | | | 242.99±20.56 | | |
| AHI | T2 | 1.67±0.63 | -3.485[a] | 0.005 | 1.42±0.65 | -2.228[b] | **0.026** |
| | T1 | 2.18±0.95 | | | 1.70±0.94 | | |

[a]Paired Samples t-test; [b]Wilcoxon signed-rank test, Statistical significance: $p<0.05$.
MxA, maxillary advancement; MdS-MxA, mandibular setback with maxillary advancement; $\bar{x}$, mean; SD, standard deviation.

Reports on the movement of HB following MdS surgery have shown considerable variability. While some studies have documented posterior and superior displacement, others have reported inferior movement or positional stability.[18] Moreover, it has been reported that HB may return to its original position following MdS to preserve airway resistance.[6] In the present study, no significant difference was observed in the anteroposterior position of HB among the groups either before or after orthognathic surgery. However, a significant difference in vertical position was found between the MdS-MxA group and the control group. Postoperatively, HB remained stable in the MxA group, whereas a slight inferior displacement of approximately 1.2 mm was observed in the MdS-MxA group. This result may be attributed to the compression of soft tissues in the submandibular region due to the posterior movement of the mandible without any rotation after surgery, consequently causing HB to shift inferiorly. In essence, this displacement was not associated with any significant reduction in total upper airway volume or worsening of AHI scores. Therefore, the observed positional change represents a compensatory adaptation rather than a functionally significant impairment.

The CVT-SN angle is a reliable and reproducible indicator of HP in relation to craniofacial morphology.[23] In this study, MxA did not affect the CVT-SN angle; however, the MdS-MxA group exhibited a statistically significant yet clinically insignificant

3.6° increase in HP. CVT-SN increase following MdS has been suggested as a compensatory mechanism to maintain PAV. Head extension in this study was primarily attributed to a reduction in hypopharyngeal volume and mCSA rather than total PAV.[12] However, no significant difference in HP was observed between the pre- and post-operative groups.

A recent systematic review emphasized the need for further studies to assess the effects of orthognathic surgery in specific patient groups based on gender, age, and the extent of mandibular setback.[24] Additionally, comparing different orthognathic surgical procedures under standardized conditions is crucial.[6] Thus, this study gathered data from multiple sources while maintaining standardized conditions to enhance the reliability of findings by carefully matching participants in terms of age, BMI, AHI, and Mallampati classification, ensuring greater homogeneity within the study groups and meticulously analysing factors influencing PAV. HP was assessed using an inclinometer, and LCR images were obtained accordingly. While LCRs were historically used to evaluate the airway dimension and mCSA, CBCT imaging may be the preferred method even though it has certain limitations like other methods. CBCT offers advantages over conventional radiography by providing 3D visualization of craniofacial structures and better differentiating soft tissues and PAV.[20] This study used CBCT to precisely measure PAV and mCSA, with images acquired in the supine position. However, due to the unreliability of the supine position in determining natural HP, LCRs taken with the patient standing were also used. Diagnostic tests utilizing the HSAT device have been documented as adequate for the preliminary screening of patients at risk of OSA.[25] We used this device to assess changes in AHI as it allows remote evaluation. To our knowledge, this study is the first to compare Class III surgical groups with a control group in the extant literature.



### Study Limitations

This study has several limitations. First, the findings reflect early-stage postoperative results and may not capture long-term outcomes. Second, there was an unequal gender distribution among the groups, which may have influenced the generalizability of the results.

## CONCLUSION

The following conclusions may be drawn from the results of this study:

- Maxillary advancement (MxA) increased pharyngeal airway volume (PAV) across all sections, whereas combined mandibular setback and maxillary advancement (MdS-MxA) led to a reduction in hypopharyngeal volume and minimum cross-sectional area (mCSA) despite an overall increase in total PAV.

- Postoperative displacement of the hyoid bone (HB) was minimal. A slight inferior shift observed in the MdS-MxA group, likely due to soft tissue adaptation.

- Neither surgical approach significantly impacted apnea-hypopnea index (AHI), suggesting that MdS-MxA does not contribute to the development of obstructive sleep apnea (OSA) in young and healthy individuals.

### Ethics

**Ethics Committee Approval:** This prospective controlled clinical study was conducted following approval from the Erciyes University Clinical Research Ethics Committee (decision no. 2022/614, date: 14.09.2022).

**Informed Consent:** Informed consent was obtained from all participants enrolled in this study.

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### Footnotes

**Author Contributions:** Concept - C.I.; Design - C.I.; Data Collection and/or Processing - H.Ç.B.; Analysis and/or Interpretation - H.Ç.B., C.I.; Literature Search - H.Ç.B., C.I.; Writing - C.I.

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