DOI: 10.4274/TurkJOrthod.2026.2025.188

TURKISH JOURNAL OF ORTHODONTICS

Original Article

Comparison of the Effects of Functional Treatment and Orthognathic Surgery on Hyoid Bone Position Following Mandibular Advancement

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Cite this article as: Oğuz F, Göze Oğuz H, Karataş T. Comparison of the effects of functional treatment and orthognathic surgery on hyoid bone position following mandibular advancement. *Turk J Orthod.* 2026; 39(2): 75-86

Main Points

- Functional treatment and orthognathic surgery involving mandibular advancement can influence the position of the hyoid bone in individuals with skeletal Class II malocclusion.
- Functional treatment results in an antero-inferior displacement of the hyoid bone.
- Orthognathic surgery induces predominantly superior displacement of the hyoid bone with limited anteroposterior change.
- Hyoid position remained largely stable in untreated skeletal Class II individuals.

ABSTRACT

Objective: To compare the effects of functional orthopedic treatment and mandibular advancement induced by orthognathic surgery on hyoid bone position in individuals with skeletal Class II malocclusion, relative to an untreated control group.

Methods: Fifty-six individuals were divided into functional (n=20), surgical (n=16), and control groups (n=20). Lateral cephalometric images obtained at pretreatment (T0) and posttreatment (T1) were analyzed using WebCeph software. The linear (aC2-H, aC3-H, aC4-H, S-H, N-H, ANS-PNS-H) and angular (SNA, SNB, ANB, Go-H-S, H-S-N, H-PNS-ANS) describing hyoid bone position were measured. Data normality was assessed with the Shapiro-Wilk test, followed by one-way ANOVA or Kruskal-Wallis test, as appropriate. Intragroup changes were evaluated using paired tests, and post-hoc analyses were performed using Tukey honestly significant difference or Dunn-Bonferroni methods. Measurement reliability was confirmed (intraclass correlation coefficients >0.90).

Results: At T0, the orthognathic surgery group showed significantly higher aC2-H, aC3-H, aC4-H, S-H, N-H, and ANS-PNS-H measurements compared to the other groups ($p<0.05$), while angular variables did not differ significantly. At T1, intergroup differences in hyoid position were no longer significant ($p>0.05$). Intragroup analysis revealed significant increases in aC2-H, aC4-H, S-H, and N-H in the functional treatment group, whereas significant decreases in N-H, H-S-N, and H-PNS-ANS were observed in the orthognathic surgery group. Changes in the control group were minimal.

Conclusion: Functional treatment resulted in anterior-inferior displacement of the hyoid bone, whereas orthognathic surgery predominantly induced superior displacement without significant anteroposterior change. Both treatment modalities improved mandibular skeletal relationships, while hyoid position remained largely stable in untreated individuals.

Keywords: Hyoid bone, mandibular advancement, orthognathic surgery

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Received: December 27, 2025 **Accepted:** May 21, 2026 **Publication Date:** June 30, 2026

INTRODUCTION

The treatment of Class II malocclusions depends on multiple factors, including the severity of the maxillomandibular discrepancy, patient age, morphological characteristics of dental and skeletal structures, soft-tissue conditions, growth and developmental stage, and etiology of the malocclusion.[1] In growing patients, growth modification with functional appliances is generally considered the treatment of choice.[2,3] These appliances transmit functional forces to the jaws through the dentition, and with regular use, may improve the underlying skeletal discrepancy.[2-4] In patients with severe skeletal discrepancies who have completed growth and are not suitable candidates for camouflage treatment, combined orthodontic and orthognathic surgical treatment is indicated to reposition the dentofacial and skeletal structures.[5] Mandibular advancement is expected to induce positional changes in the jaws and associated skeletal landmarks during both functional treatment and orthognathic surgery. In this context, the position of the hyoid bone, which has a close anatomical and functional relationship with the mandible, may also be affected by these movements.

The hyoid bone, a freely movable structure located inferior to the mandible in the anterior midline of the neck, is an important component of the stomatognathic system.[6] Given its muscular attachments to adjacent structures, particularly the mandible, the position of the hyoid is influenced by functional activities such as mastication, swallowing, and respiration. Moreover, these muscular connections allow the hyoid bone to perform complex movements in coordination with mandibular motion. Several studies have demonstrated synchronous movement of the hyoid bone and mandible in the sagittal plane.[7-9] Furthermore, the hyoid musculature contributes to stabilization and dilation of the pharyngeal airway, and anterior displacement of the hyoid bone increases the resistance of the upper airway to collapse.[10,11] Therefore, hyoid position plays a critical role in conditions associated with upper airway narrowing, particularly obstructive sleep apnea (OSA).[12,13] Accordingly, skeletal Class II malocclusion characterized by mandibular retrusion and an inferiorly positioned hyoid bone has been identified as a risk factor for OSA.[14]

Correction of skeletal Class II malocclusion may reposition the mandible to a more favorable position, with anterior displacement of the hyoid bone and subsequent improvement in airway dimensions. To prevent potential respiratory problems, Li[15] recommended early orthodontic treatment in skeletal Class II patients with mandibular deficiency. Such treatment aims to advance the mandible, hyoid bone, tongue, and soft palate anteriorly, thereby increasing oropharyngeal dimensions and reducing the risk of airway obstruction.[16] In skeletally mature Class II individuals, orthognathic surgery is performed to reposition the mandible anteriorly. This advancement is generally accompanied by anterior displacement of the hyoid bone and an increase in airway dimensions. However, the extent and direction of the effects of this surgical advancement on hyoid bone position, compared with early Class II treatment applied during the growth period, remain insufficiently clarified in the literature. In the present study, lateral cephalometric radiographs (CEPH) were used to identify these positional changes. Despite certain limitations, CEPH are widely accepted and commonly used to evaluate orthodontic and orthognathic treatment outcomes.[9]

Only a limited number of studies have investigated hyoid positional changes following functional treatment or orthognathic surgery. However, no study to date has compared these two treatment modalities within the same study design while also including an untreated control group. Therefore, the aim of this study was to evaluate the effects of mandibular advancement, achieved by functional treatment and orthognathic surgery, on hyoid bone position. Changes observed in the treatment groups were also compared with natural growth patterns in untreated skeletal Class II individuals. The null hypothesis was that changes in hyoid bone position would not differ significantly among the functional treatment, orthognathic surgery, and control groups.

METHODS

Study Design and Patient Selection

This retrospective study used lateral CEPH of patients with skeletal Class II malocclusion who underwent functional orthopedic treatment or orthognathic surgery at the Department of Orthodontics, Faculty of Dentistry, İnönü University and whose records were available in the institutional archive. All CEPH were obtained using the same radiographic unit (Planmeca Proline XC, 00880 Helsinki, Finland) with standardized exposure parameters (72 kV, 6.0 mA, 18.7 s). Radiographs were taken with the ear rods positioned in the external auditory canals, the teeth in maximum intercuspation, the lips at rest, and the Frankfort horizontal plane parallel to the floor.

Ethical approval was obtained from the İnönü University Scientific Research Ethics Committee (approval no: 2025/8835, date: 02.12.2025). The cephalometric landmarks used in the study are illustrated in Figure 1.

Inclusion and Exclusion Criteria

Inclusion criteria were as follows: (1) skeletal Class II malocclusion [a point-nasion-b point (ANB) angle ≥ 4°]; (2) availability of high-quality lateral CEPH at the required time points; (3) completion of the respective treatment protocol for the functional and orthognathic groups; and (4) no history of orthodontic treatment in the control group. Exclusion criteria included the following: (1) craniofacial syndromes; (2) a history of maxillofacial trauma; (3) systemic conditions affecting growth and development; and (4) incomplete or poor-quality cephalometric records.

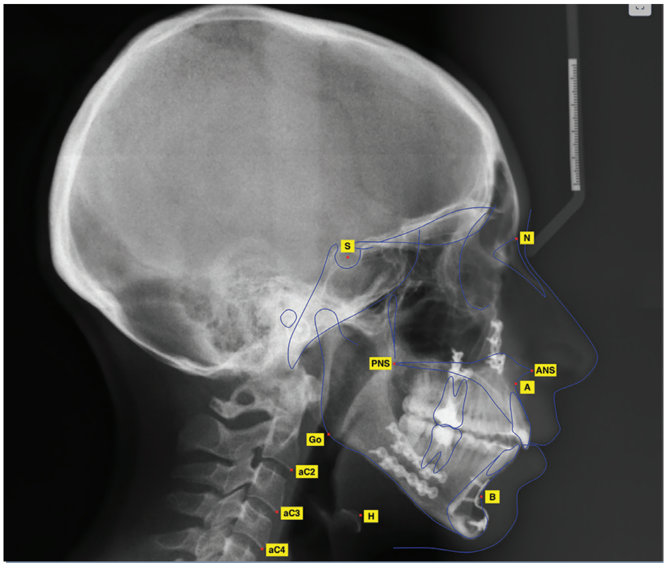

Figure 1. Cephalometric landmarks used in the study. S: Sella (central point of the pituitary fossa); N: Nasion (most anterior point of the frontonasal suture); A: Point A (deepest anterior point of the upper labial alveolar concavity.); B: Point B (deepest anterior point of the lower labial alveolar concavity); ANS: Anterior nasal spine (most anterior point of the pre-maxillary bone); PNS: Posterior nasal spine (posterior point of the hard palate); Go: Gonion (most posterior-inferior point at the angle of the mandible); H: Hyoidale (most anterosuperior point of the hyoid bone); aC2, aC3, aC4: Anteroinferior points of the second, third, and fourth cervical vertebrae, respectively.

Three study groups were established:

- **Group 1 (functional treatment group):** Individuals treated exclusively with removable functional orthopedic appliances during the growth period.
- **Group 2 (orthognathic surgery group):** Individuals with skeletal Class II malocclusion who underwent mandibular advancement surgery. The majority of patients (n=12, 75%) underwent bimaxillary surgery, including maxillary impaction, whereas the remaining patients (n=4, 25%) underwent mandibular advancement alone.
- **Group 3 (control group):** Untreated individuals with skeletal Class II malocclusion.

Inclusion criteria for the functional treatment group consisted of patients who had completed treatment with functional appliances, such as a Monoblock, during the growth period. Treatment protocols were based on standard clinical practice in our department. No rapid maxillary expansion was performed in conjunction with functional appliance therapy. The appliance was used for approximately 12 months, comprising an active phase of approximately 8 months of full-time wear, followed by a retention phase of approximately 4 months of night-time wear. Exact treatment durations could not be fully standardized across all patients due to the retrospective nature of the study; however, all patients followed a similar clinical protocol.

The orthognathic surgery group included adult patients with skeletal Class II malocclusion who had completed growth. All individuals in this group underwent bilateral sagittal split osteotomy for mandibular advancement. Rigid internal fixation was achieved using titanium plates and screws. An occlusal splint was used intraoperatively and maintained for two weeks postoperatively as part of the stabilization protocol. Due to the retrospective design of the study, detailed evaluation of phase-specific treatment durations was limited. Pre-surgical orthodontic treatment was performed to achieve appropriate dental decompensation, followed by the surgical phase and post-surgical orthodontic finishing. The overall treatment duration was approximately 3.37±0.79 years.

The control group consisted of individuals with skeletal Class II relationships (ANB ≥4°) who had not received orthodontic treatment. Most subjects were in the pre-peak growth phase who were under clinical follow-up while awaiting appropriate timing for functional treatment. Selection of this group was based on the availability of untreated individuals within the institutional archive who met the inclusion criteria, while also considering ethical constraints related to unnecessary radiation exposure and withholding treatment. Accordingly, a limited number of skeletally mature individuals awaiting surgical intervention were also included. However, the overall age distribution indicates that the control group consisted predominantly of individuals in the growth period, which may help differentiate between treatment-related changes and physiological growth-related adaptations.

A priori power analysis was performed to determine the required sample size. For a three-group study design, a power analysis conducted using G*Power software (version 3.1; Heinrich Heine University of Düsseldorf, Germany) indicated that a minimum of 54 participants would be sufficient (effect size f=0.25, α=0.05, power=0.90).[17] A total of 56 individuals were included in the present study. Descriptive statistics of the study sample are presented in Table 1.

Cephalometric Analysis and Measurements

Pre-treatment (T0) and post-treatment (T1) lateral CEPH of all participants were analyzed using version 2.0 (AssembleCircle Corp., Republic of Korea), an artificial intelligence-assisted, web-based, automated analysis platform.[18] Prior to analysis, all radiographs were calibrated within the software. Following image upload, the system automatically identified anatomical reference points (landmarks). To ensure measurement accuracy, all landmark positions were individually reviewed by an experienced operator (H.G.O.), and any inaccurately placed landmarks were manually corrected.

To assess measurement reliability, a randomly selected subset of 15 patients was reanalyzed. All landmarks were re-evaluated by the same operator after a two-week interval to determine intra-operator reliability and were independently reassessed by a second operator (F.O.) to evaluate inter-operator reliability.

Table 1. Descriptive statistics for the groups				
Group	**n**	**Female**	**Male**	**Mean age (years ± SD)**
Functional Group	20	10	10	12.71±0.96
Orthognathic Group	16	11	5	17.90±1.59
Control Group	20	10	10	11.95±1.72
Total	56	31	25	13.92 ± 2.93
SD, standard deviation, n = sample size.				

Measurement variables were selected from angular and linear parameters commonly used in the literature to evaluate hyoid bone position and sagittal mandibular changes in skeletal Class II individuals (Table 2, Figures 1 and 2). Based on the defined cephalometric landmarks and reference planes, skeletal measurements reflecting the anteroposterior and vertical position of the hyoid bone, as well as the degree of mandibular advancement, were digitally recorded.

Statistical Analysis

All statistical analyses were performed using the R statistical software (version 4.5; R Foundation for Statistical Computing, Vienna, Austria) and RStudio 2025 (version 2025.05.1+513; Posit Software, Boston, MA, USA). Normality of the data distribution within each group was assessed using the Shapiro-Wilk test, with $p>0.05$ indicating normal distribution. Homogeneity of variances was evaluated using Levene's test, with $p>0.05$ indicating equality of variances for sella-nasion-a point (SNA) angle, sella-nasion-b point (SNB) angle, H-S-N, H-PNS-ANS, and ANS-PNS-H.

Variables meeting parametric assumptions (ANB, aC2-H, aC3-H, aC4-H, S-H, N-H, and Go-H-S), intergroup were analyzed using one-way analysis of variance (ANOVA). Variables that did not satisfy these assumptions were analyzed using the Kruskal-Wallis H test. Sex distribution among groups was compared using the chi-square test. When statistically significant differences were identified, post-hoc analyses were conducted using Tukey's honestly significant difference test following ANOVA and the Dunn-Bonferroni test following the Kruskal-Wallis test. Sex-related differences were assessed using the Mann-Whitney U test for within-group comparisons and analysis of covariance (ANCOVA), including the group × sex interaction, for comparisons of treatment-related changes. Statistical significance was set at $p<0.05$ for all analyses.

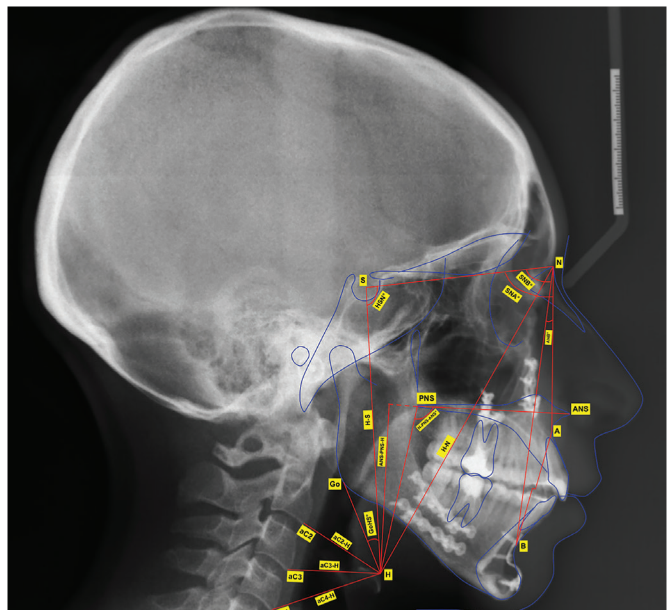

Figure 2. Cephalometric landmarks and measurements used in the study.

Table 2. Condylar morphometric parameters and definitions	
Measurement	**Description**
SNA°	Maxillary sagittal position relative to the cranial base (S; sella, N; nasion, A; point A).
SNB°	Mandibular sagittal position relative to the cranial base (B; point B).
ANB°	Sagittal skeletal discrepancy between maxilla and mandible.
Go-H-S°	Angle formed between gonion (Go), hyoid (H), and sella (S).
H-S-N°	Angle formed between the hyoid (H), sella (S), and nasion (N).
H-ANS-PNS°	Angle formed between the hyoid (H) and the palatal plane (ANS-PNS).
aC2-H (mm)	Distance from hyoid bone to the anteroinferior point of C2.
aC3-H (mm)	Distance from hyoid bone to the anteroinferior point of C3.
aC4-H (mm)	Distance from hyoid bone to the anteroinferior point of C4.
S-H (mm)	Distance from sella (S) to the hyoid bone (H).
N-H (mm)	Distance from nasion (N) to the hyoid bone (H).
ANS-PNS-H (mm)	Vertical distance between the hyoid bone and the palatal plane (ANS-PNS).
SNA, sella-nasion-a point; SNB, sella-nasion-b point; ANB, a point-nasion-b point.	

RESULTS

A total of 56 individuals were included in the functional treatment, orthognathic surgery, and control groups (Table 1). Reliability analysis demonstrated excellent measurement consistency, with intrarater and interrater intraclass correlation coefficients exceeding 0.90 for all cephalometric variables. No statistically significant difference in sex distribution was observed among the three groups (chi-square test, χ^2=1.626, df=2, p=0.444).

Baseline (T0) measurements are presented in Figure 3 and Table 3. Significant intergroup differences were also observed in several hyoid bone positional measurements. Specifically, linear measurements were significantly higher in the orthognathic surgery group than in the other groups ($p<0.05$). Post-hoc analyses confirmed that the functional treatment group had significantly lower hyoid positional values than the orthognathic surgery group. In contrast, no statistically significant differences were observed for the SNA, SNB, ANB, Go-H-S, H-S-N, or H-PNS-ANS measurements among the three groups ($p>0.05$; Table 3). Post-treatment (T1) measurements are presented in Figure 4 and Table 4. No statistically significant differences were observed among the groups for any variable ($p>0.05$; Table 4). Changes between T0 and T1 are presented in Figure 5 and Table 5. Although significant intergroup differences were observed for some variables, the majority of the parameters did not show any significant differences after treatment.

The intragroup changes between the T0 and T1 periods are presented in Figure 6. Significant changes were observed in the functional treatment group for aC2-H, aC4-H, S-H, N-H, ANS-PNS-H, SNB, and ANB measurements. In the orthognathic surgery group, significant changes were found for the variables N-H, SNA, SNB, H-S-N, and H-PNS-ANS variables. In the control group, only S-H and ANB showed significant changes. Significant sex-related differences (ΔT1-T0) were observed in the functional treatment group for aC2-H (p=0.029), S-H (p=0.015), and ANS-PNS-H (p=0.029), whereas no significant differences were observed in the other groups ($p>0.05$; Supplementary Table 1). ANCOVA demonstrated no main effect of sex on the magnitude of change.

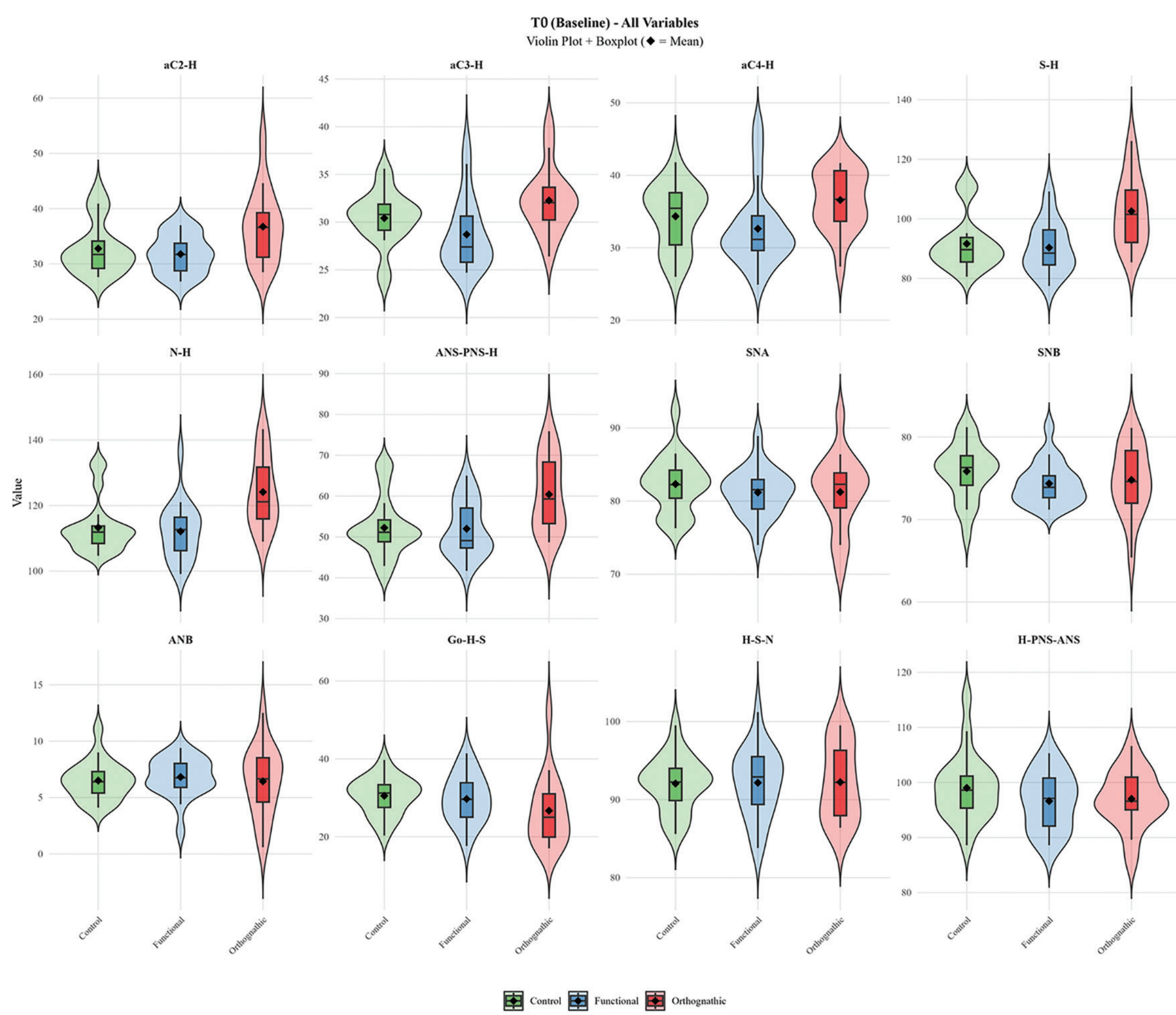

Figure 3. Violin and box plots illustrating the distribution of linear and angular measurements related to hyoid bone position in the control, functional treatment, and orthognathic surgery groups at baseline (T0).

Table 3. Descriptive statistics of pretreatment (T0) measurements across the three study groups

Variable	Control group	Functional group	Orthognathic group	p-value
SNA (°)	82.33±3.90	81.18±3.29	81.24±5.26	0.648
SNB (°)	75.84±3.35	74.36±2.59	74.79 ±4.19	0.246
ANB (°)	6.50±1.73	6.82±1.73	6.44±3.06	0.713
Go-H-S (°)	30.51±4.82	29.69±6.23	26.68±9.14	0.100
H-S-N (°)	92.05±3.49	92.16±4.35	92.23±4.84	0.969
H-PNS-ANS (°)	99.02±6.13	96.61±5.15	97.02±5.19	0.548
aC2-H (mm)	32.77±4.70	31.77±3.42	36.74±6.52	0.040*
aC3-H (mm)	30.41±2.83	28.70±3.69	32.27±3.42	0.006**
aC4-H (mm)	34.34±4.36	32.63±5.45	36.59±4.09	0.023*
S-H (mm)	91.64±9.06	90.33±8.54	102.55±11.71	0.002**
N-H (mm)	113.30±8.17	112.11±8.68	124.11±10.77	0.001**
ANS-PNS-H (mm)	52.26±7.35	52.01±6.63	60.42±8.97	0.006**

*p<0.05; **p<0.01. Values are presented as mean ± standard deviation.
SNA, sella-nasion-a point; SNB, sella-nasion-b point; ANB, a point-nasion-b point.

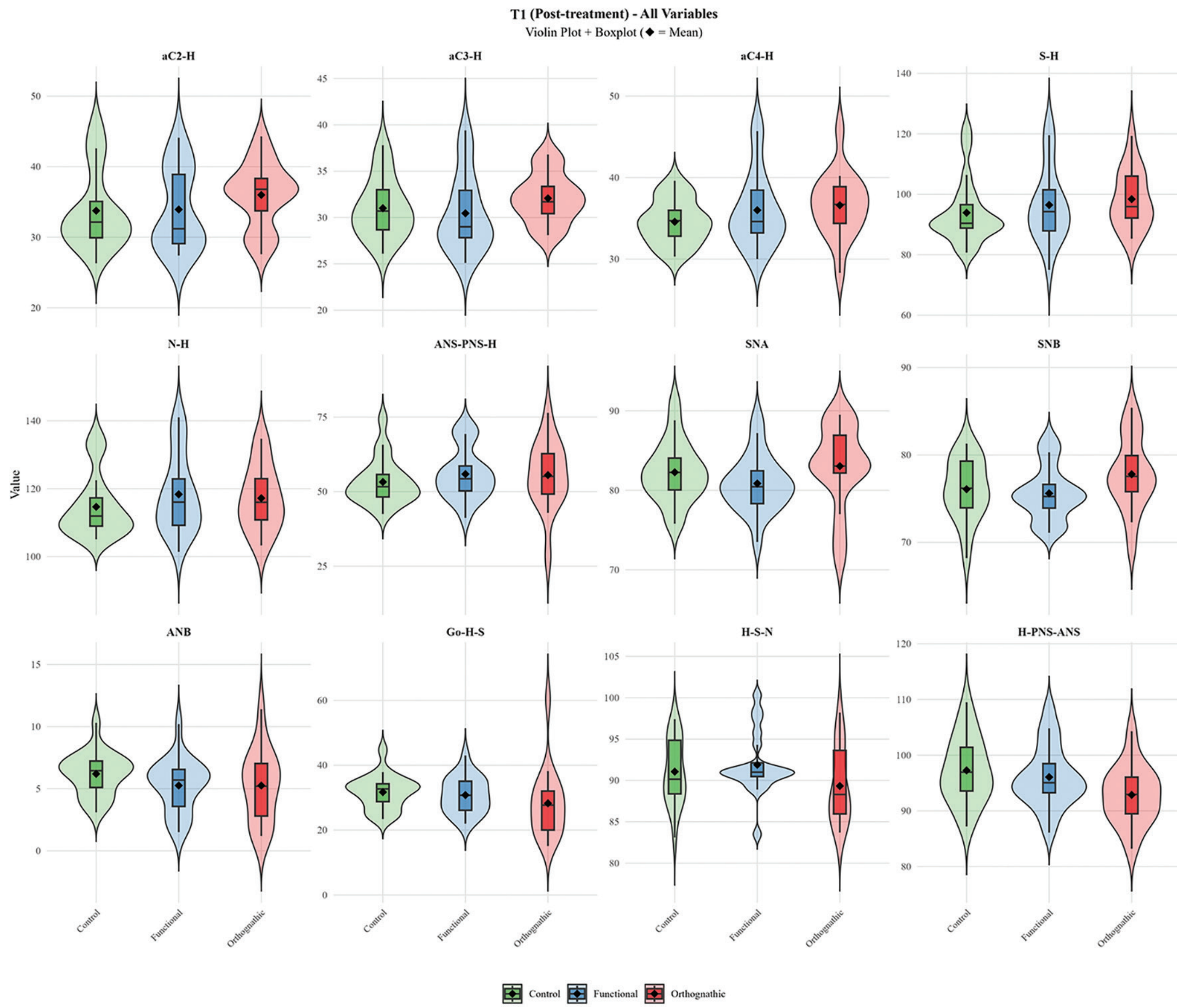

Figure 4. Violin and box plots illustrating the distribution of linear and angular measurements related to hyoid bone position in the control, functional treatment, and orthognathic surgery groups post-treatment (T1).

Table 4. Descriptive statistics of postreatment (T1) measurements across the three study groups

Variable	Control group	Functional group	Orthognathic group	p-value
SNA (°)	82.27±3.86	80.86±3.59	83.04±5.26	0.099
SNB (°)	76.08±3.48	75.61±3.08	77.80±4.24	0.179
ANB (°)	6.20±1.72	5.25±2.11	5.26±2.87	0.236
Go-H-S (°)	31.72±5.20	30.80±5.57	28.28±10.92	0.155
H-S-N (°)	91.06±3.89	91.89±3.78	89.33±4.57	0.080
H-PNS-ANS (°)	97.27±5.92	96.06±5.55	92.86±5.26	0.073
aC2-H (mm)	33.76±5.63	33.94±5.70	35.99±4.67	0.416
aC3-H (mm)	31.00±3.20	30.46±4.14	32.08±2.67	0.196
aC4-H (mm)	34.56±2.71	35.99±4.61	36.60±4.02	0.261
S-H (mm)	93.88±10.49	96.45±12.46	98.39±9.62	0.310
N-H (mm)	114.66±9.20	118.34±11.49	117.21±9.57	0.488
ANS-PNS-H (mm)	53.23±7.73	55.89±8.66	55.55±11.38	0.442

Values are presented as mean ± standard deviation.
SNA, sella-nasion-a point; SNB, sella-nasion-b point; ANB, a point-nasion-b point.

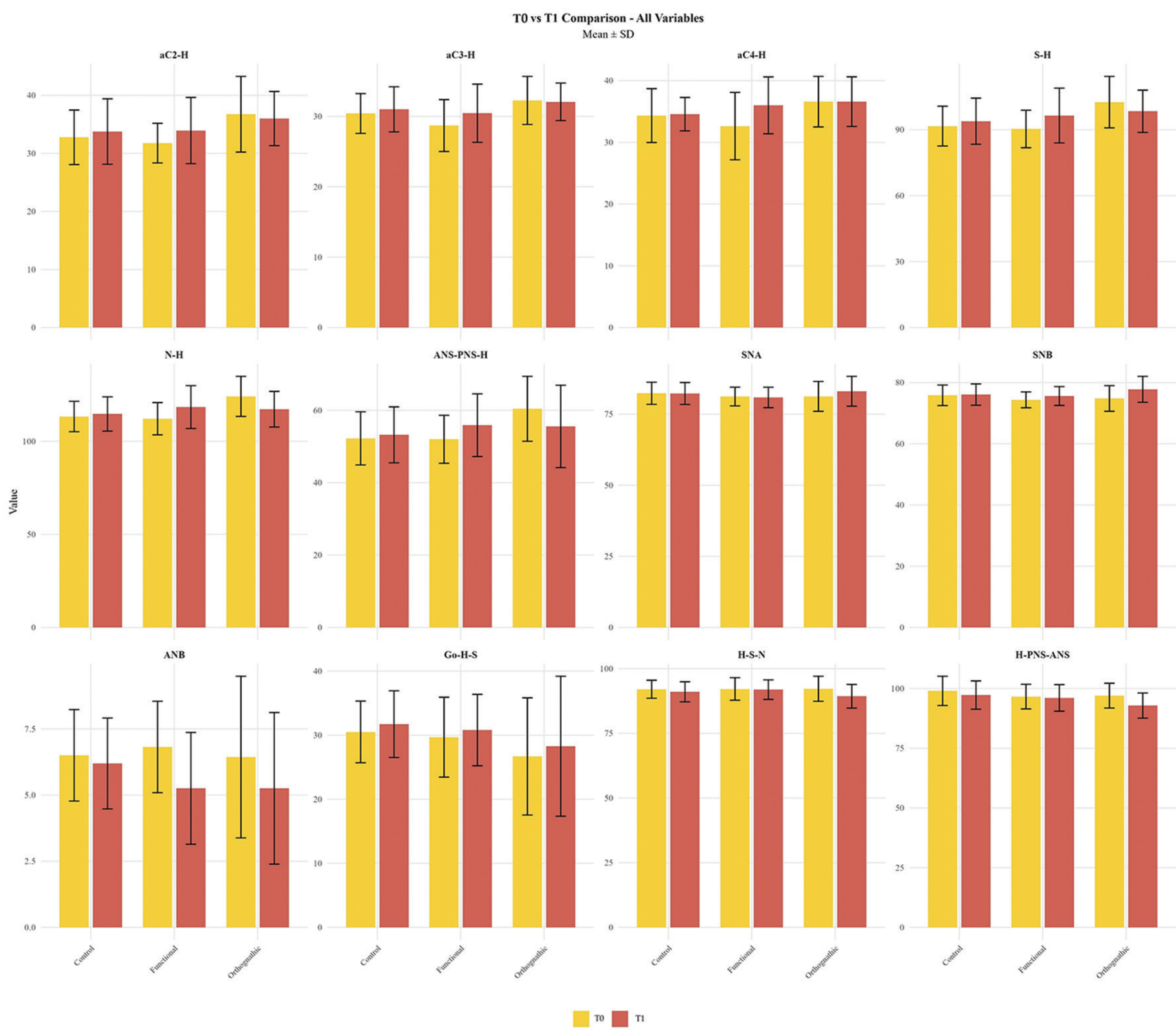

Figure 5. Bar charts illustrating mean ± standard deviation values of linear and angular measurements related to hyoid bone position at baseline (T0) and post-treatment (T1) in the control, functional treatment, and orthognathic surgery groups. Yellow bars represent T0 values and red bars represent T1 values. Error bars indicate standard deviations.

Table 5. Intergroup comparison of pre- (T0) and posttreatment (T1) and it's treatment related changes (ΔT1-T0)

Measurement	Control (n=20)				Functional (n=20)				Orthognathic (n=16)				Group comparison
	T0	T1	Δ T1-T0	p-value[a]	T0	T1	Δ T1-T0	p-value[a]	T0	T1	Δ T1-T0	p-value[a]	p-value[b]
SNA	82.33 (3.90)	82.27 (3.86)	-0.06 (1.79)	0.751	81.18 (3.29)	80.86 (3.59)	-0.32 (1.61)	0.385	81.24 (5.26)	83.04 (5.26)	+1.80 (1.75)	<0.001**	0.099
SNB	75.84 (3.35)	76.08 (3.48)	+0.24 (1.84)	0.567	74.36 (2.59)	75.61 (3.08)	+1.25 (1.82)	0.006**	74.79 (4.19)	77.80 (4.24)	+3.01 (2.11)	<0.001**	0.179
ANB	6.50 (1.73)	6.20 (1.72)	-0.31 (0.60)	0.031*	6.82 (1.73)	5.25 (2.11)	-1.57 (1.28)	<0.001**	6.44 (3.06)	5.26 (2.87)	-1.18 (2.31)	0.059	0.236
Go-H-S	30.51 (4.82)	31.72 (5.20)	+1.21 (5.85)	0.367	29.69 (6.23)	30.80 (5.57)	+1.11 (5.58)	0.385	26.68 (9.14)	28.28 (10.92)	+1.59 (5.89)	0.296	0.155
H-S-N	92.05 (3.49)	91.06 (3.89)	-0.99 (3.37)	0.204	92.16 (4.35)	91.89 (3.78)	-0.27 (3.61)	0.746	92.23 (4.84)	89.33 (4.57)	-2.91 (2.80)	<0.001**	0.080
H-PNS-ANS	99.02 (6.13)	97.27 (5.92)	-1.75 (5.30)	0.156	96.61 (5.15)	96.06 (5.55)	-0.55 (4.73)	0.606	97.02 (5.19)	92.86 (5.26)	-4.16 (5.12)	0.005**	0.073
aC2-H	32.77 (4.70)	33.76 (5.63)	+0.99 (2.89)	0.142	31.77 (3.42)	33.94 (5.70)	+2.16 (4.14)	0.030*	36.74 (6.52)	35.99 (4.67)	-0.74 (4.50)	0.623	0.416
aC3-H	30.41 (2.83)	31.00 (3.20)	+0.59 (3.21)	0.421	28.70 (3.69)	30.46 (4.14)	+1.76 (4.42)	0.092	32.27 (3.42)	32.08 (2.67)	-0.19 (2.95)	0.796	0.196
aC4-H	34.34 (4.36)	34.56 (2.71)	+0.22 (5.26)	0.850	32.63 (5.45)	35.99 (4.61)	+3.37 (5.98)	0.021*	36.59 (4.09)	36.60 (4.02)	+0.01 (4.00)	0.990	0.261
S-H	91.64 (9.06)	93.88 (10.49)	+2.24 (4.66)	0.044*	90.33 (8.54)	96.45 (12.46)	+6.12 (9.11)	0.007**	102.55 (11.71)	98.39 (9.62)	-4.16 (9.97)	0.256	0.310
N-H	113.30 (8.17)	114.66 (9.20)	+1.36 (4.30)	0.174	112.11 (8.68)	118.34 (11.49)	+6.23 (11.24)	0.023*	124.11 (10.77)	117.21 (9.57)	-6.90 (11.21)	0.011*	0.488
ANS-PNS-H	52.26 (7.35)	53.23 (7.73)	+0.97 (3.72)	0.256	52.01 (6.63)	55.89 (8.66)	+3.71 (6.98)	0.032*	60.42 (8.97)	55.55 (11.38)	-4.88 (9.24)	0.059	0.442

[a]dependent samples t-test, [b]independent samples t-test/Kruskal-Wallis test, *p<0.05, **p<0.01.
Values are presented as mean ± SD.
SD: standard deviation; SNA, sella-nasion-a point; SNB, sella-nasion-b point; ANB, a point-nasion-b point.

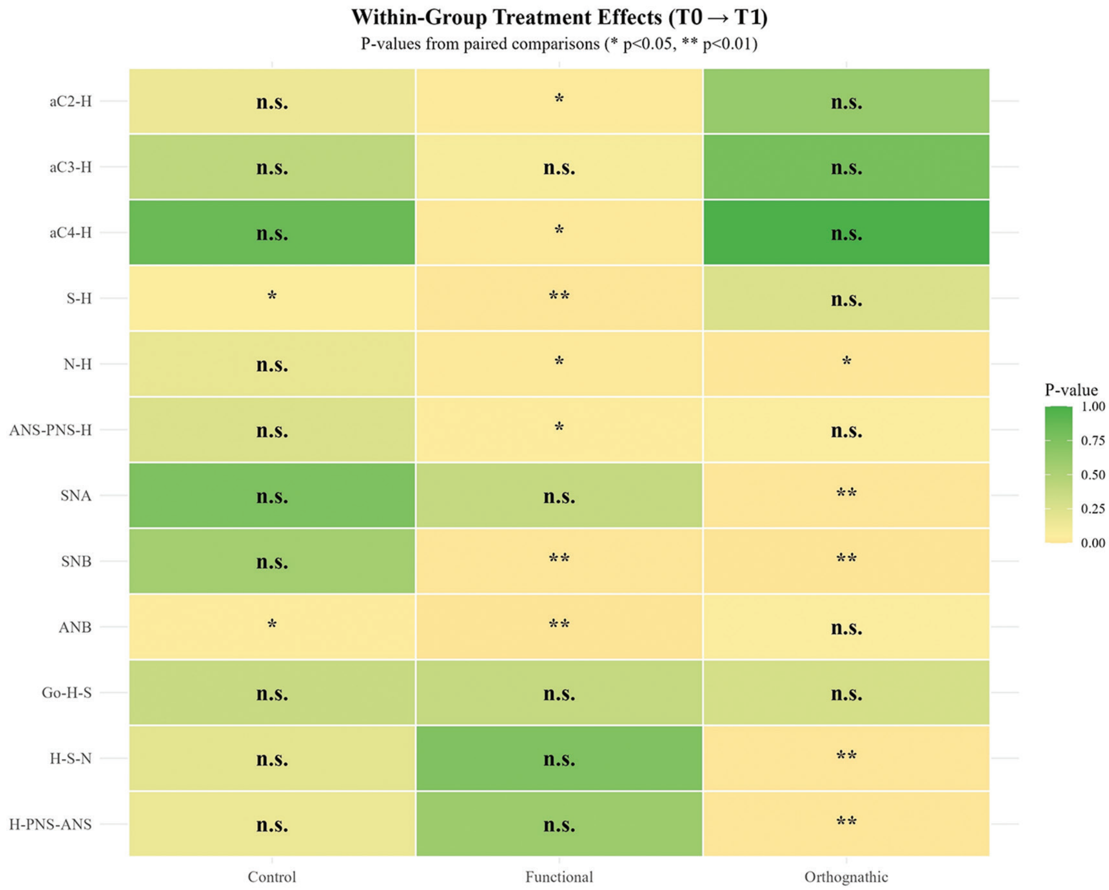

Figure 6. Heatmap illustrating within-group treatment effects (T0-T1) for all linear and angular variables in the control, functional treatment, and orthognathic surgery groups. Statistical significance is denoted as follows: *p<0.05; **p<0.01; n.s., not significant.

DISCUSSION

The aim of the present study was to evaluate the effects of mandibular advancement achieved through functional treatment and orthognathic surgery on hyoid bone position and to compare the resulting changes with those observed in an untreated control group. Accordingly, the null hypothesis of the study was that there would be no statistically significant differences in positional changes of the hyoid bone among the three groups. Because significant differences were identified in several measurements, the null hypothesis was rejected.

In the present study, the orthognathic surgery group exhibited significantly greater pre-treatment aC2-H, aC3-H, aC4-H, S-H, N-H, and ANS-PNS-H values than the functional treatment and control groups. These measurements represent distances between the hyoid bone and superior or anterior craniofacial reference points. In contrast, no significant differences were observed among the groups for the SNA, SNB, ANB, Go-H-S, H-S-N, or H-PNS-ANS measurements. However, all intergroup differences disappeared after treatment, and the positional parameters of the hyoid bone were comparable across the groups. The greater pre-treatment hyoid distances observed in the orthognathic surgery group suggest a more posterior-inferior hyoid position in these patients. This can be attributed to the generally older age of patients in this group and the progressive development of compensatory head-neck posture. Indeed, there is evidence that the hyoid bone tends to shift inferiorly and slightly posteriorly with age, and this positional adaptation develops in accordance with mandibular growth and respiratory requirements.[19]

The untreated control group exhibited only minor changes over time, including a slight increase in the S-H distance and a small decrease in ANB. These findings are consistent with natural craniofacial changes associated with growth and development. In a longitudinal study conducted by Ochoa and Nanda[20] on individuals aged 6 to 20 years, the ANB angle decreased until approximately 14 years of age. The limited magnitude of these changes and the absence of significant differences in the remaining parameters indicate that the positional stability of the hyoid bone was largely preserved in the control group. Matsuda et al.[21] reported that the hyoid bone shifts posteriorly and inferiorly with advancing age in individuals aged 22-84 years, and is pronounced in males over 60 years of age. Furthermore, cone-beam computed tomography-based studies conducted in subjects aged 6-18 years have demonstrated that significant changes in hyoid position may occur after puberty, in parallel with craniofacial growth.[22] In the present study, the limited changes observed in the control group may be attributed to the relatively short follow-up period. Furthermore, the retrospective design of the study restricted the duration of follow-up and may have limited the ability to detect more pronounced growth-related changes.

Functional treatment led to significant increases in aC2-H, aC4-H, S-H, N-H, and ANS-PNS-H, which represent the distances from the hyoid bone to cervical reference points. In addition, the change in the SNA angle was not significant, while the SNB angle showed a significant increase, indicating anterior repositioning of the mandible following functional treatment. The significant decrease in the ANB angle also suggested a marked improvement in the skeletal Class II relationship. Zhou et al.,[23] Ulusoy et al.,[9] and Hourfar et al.[24] have reported that the hyoid bone assumes a more inferior and anterior position after functional treatment, which is consisting with our findings as well. Anterior advancement of the mandible through functional therapy leads to anterior displacement of the hyoid bone via muscular attachments.[9,23-27] Furthermore, the eruption of the second molars and growth-related increases in lower facial height contribute to inferior positioning of the hyoid bone by promoting clockwise rotation of the mandible.[11] Sambale et al.[11] reported significant anterior movement of the hyoid bone following functional appliance therapy, as indicated by increased distances from the aC2, aC3, and aC4 reference points. However, unlike the present findings, they also reported a superior displacement of the hyoid bone. This discrepancy may be attributed to methodological differences in the cephalometric reference points. In the previous study, hyoid position was assessed primarily by the perpendicular distance from the hyoid bone to the mandibular plane; in our study, hyoid position was evaluated using the S-H and N-H planes. Nevertheless, Sambale et al.[11] also observed a trend toward increasing S-H and N-H distances in their study. Overall, the changes in SNA, SNB, and ANB are consistent with craniofacial responses reported for the activator and similar functional appliances.[28,29] These findings support the ability of functional treatment to enhance sagittal mandibular development and improve skeletal Class II relationships. Moreover, this treatment-related skeletal response appears biomechanically consistent with the anterior positional changes observed in the hyoid bone.

The N-H measurement, representing the distance between the hyoid bone and anterosuperior reference structures, decreased significantly after orthognathic surgery. Likewise, significant reductions were observed in the H-S-N and H-PNS-ANS angular measurements. In contrast, both SNA and SNB angles increased significantly after surgical intervention, confirming skeletal advancement of the jaws. Altogether, these findings indicate that orthognathic surgery causes hyoid bone displacement predominantly in the superior direction. However, the decrease in N-H measurement suggested limited anteroposterior involvement and a slight posterior displacement rather than a pronounced anterior shift. Therefore, the overall pattern of hyoid movement following surgery can be interpreted as a predominantly superior repositioning, accompanied by rotational adaptations. Consistent with this interpretation, no significant changes were observed in the aC2-H, aC3-H, and aC4-H measurements, which further support limited anterior displacement of the hyoid bone. Karslı and Altuğ[30] investigated changes in hyoid bone position following mandibular advancement surgery in patients with skeletal Class II malocclusion, and found that the hyoid bone exhibited superior displacement after bimaxillary surgery involving maxillary impaction combined with mandibular advancement. The findings of the present study regarding superior hyoid movement are consistent with their results. This may be explained by the fact that most patients in the orthognathic surgery group underwent bimaxillary surgery, with maxillary impaction representing a common surgical component that likely promoted counterclockwise mandibular rotation. Therefore, the superior hyoid displacement observed in the present study may be associated with the upward repositioning of the maxilla. Consistent with this explanation, reductions in the H-S-N and H-PNS-ANS angles suggest counterclockwise adaptation of the hyoid bone relative to mandibular repositioning.

We also compared the time- and treatment-related changes among the three groups to determine whether these treatment approaches produced distinguishable effect sizes in hyoid bone position. No significant intergroup differences were observed in the effect sizes of the linear and angular variables representing hyoid bone position. Thus although both treatment modalities produced significant changes in hyoid position, neither showed superiority in terms of overall magnitude of change. From a clinical perspective, the hyoid bone was predominantly displaced anteriorly after functional treatment, whereas superior displacement was more pronounced in the orthognathic surgery group. Therefore, although the direction of hyoid movement differed between treatment modalities, the overall magnitude of positional change appeared comparable. Anterior of the hyoid displacement is generally associated with forward movement of the tongue base and a potential increase in upper airway dimensions, whereas superior repositioning may reflect adaptive changes related to mandibular rotation and maxillary impaction. However, since airway dimensions and functional respiratory parameters were not directly assessed in the present study, further investigations are required to determine which pattern of hyoid movement may be clinically more advantageous. Changes observed in the control group were limited and were interpreted as physiological adaptations related to growth and development. Nevertheless, the magnitude of change did not differ significantly among the three groups. Since no study had simultaneously compared the outcomes of functional treatment and orthognathic surgery with an untreated control group, direct comparison with earlier studies was not possible.

However, our findings highlight the potential clinical relevance of functional orthopedic treatment, as it appears capable of producing hyoid adaptations comparable in magnitude to those observed after orthognathic surgery. Since functional treatment is applied during the growth period and avoids the morbidity associated with surgical intervention, its ability to induce measurable hyoid positional changes may represent a significant therapeutic advantage.

Study Limitations

This study has several limitations. First, the retrospective design limit complete control over patient selection and treatment heterogeneity. The number of patients in the orthognathic surgery group was relatively small, resulting in slight imbalance among the groups. Additionally, age and growth status were not fully matched, particularly between the growing functional and control groups and the skeletally mature surgical group. All evaluations were performed using lateral CEPH. Although orthognathic surgical procedures predominantly involved bimaxillary surgery, the extent of maxillary impaction and mandibular advancement varied among individuals, potentially influencing hyoid position and reducing treatment homogeneity. Furthermore, vertical facial pattern, a factor known to influence hyoid bone position, was not specifically controlled. Future studies should adopt prospective designs, utilize three-dimensional imaging modalities, investigate more homogeneous surgical samples, and include broader age ranges to better clarify treatment- and age-related effects on hyoid bone position.

CONCLUSION

Functional treatment led to significant antero-inferior displacement of the hyoid bone, whereas superior displacement was more pronounced following orthognathic surgery. Both treatment modalities resulted in significant skeletal changes, as reflected by improvements in SNB and ANB measurements. Only limited changes in hyoid position were observed in the untreated control group. Although the direction of hyoid displacement differed between functional treatment and orthognathic surgery, the overall magnitude of treatment-related change was comparable between the two approaches. In conclusion, neuromuscular and postural adaptation mechanisms activated by mandibular advancement may guide the hyoid bone toward a common equilibrium position, regardless of the treatment modality.

Ethics

Ethics Committee Approval: Ethical approval for the study was obtained from the İnönü University Scientific Research Ethics Committee (approval no: 2025/8835, date: 02.12.2025).

Informed Consent: Informed consent was waived due to the retrospective nature of the study.

Footnotes

Author Contributions: Surgical and Medical Practices – F.O., H.G.O.; Concept - F.O.; Design - F.O., H.G.O., T.K.; Data Collection and/or Processing - F.O., H.G.O.; Analysis and/or Interpretation - F.O., H.G.O., T.K.; Literature Search - F.O., H.G.O., T.K.; Writing - F.O., H.G.O., T.K.

Conflict of Interest: No conflict of interest was declared by the authors.

Financial Disclosure: The authors declared that this study received no financial support.

Supplementary Table: https://d2v96fxpocvxx.cloudfront.net/beb8919b-f013-4ea1-b1c8-40332e840fe1/content-images/fb8f50ab-c5dd-4f8e-bdb6-db6ba7e3a387.pdf

REFERENCES

1. Graber LW, Vanarsdall Jr RL, Vig KW, Huang GJ. Orthodontics: current principles and techniques. first SA Edn. Haryana: *Elsevier Health Sciences*; 2016:928. [CrossRef]
2. McNamara JA Jr. Components of class II malocclusion in children 8-10 years of age. *Angle Orthod.* 1981;51(3):177-202. [CrossRef]
3. Proffit WR, Fields Jr HW, Sarver DM. *Contemporary Orthodontics*. 5th ed. Elsevier India; 2012. [CrossRef]
4. Baccetti T, Franchi L, Toth LR, McNamara JA Jr. Treatment timing for twin-block therapy. *Am J Orthod Dentofacial Orthop.* 2000;118(2):159-170. [CrossRef]
5. Godiawala RN, Joshi MR. A cephalometric comparison between class II, division 2 malocclusion and normal occlusion. *Angle Orthod.* 1974;44(3):262-267. [CrossRef]
6. Soheilifar S, Momeni MA. Cephalometric comparison of position of the hyoid bone in class i and class ii patients. *Iran J Orthod.* 2017;12(1):1-4. [CrossRef]
7. Lin YC, Lin HC, Tsai HH. Changes in the pharyngeal airway and position of the hyoid bone after treatment with a modified bionator in growing patients with retrognathia. *J Clin Exp Med.* 2011;3(2):93-98. [CrossRef]
8. Bavbek NC, Tuncer BB, Turkoz C, Ulusoy C, Tuncer C. Changes in airway dimensions and hyoid bone position following class II correction with forsus fatigue resistant device. *Clin Oral Investig.* 2016;20(7):1747-1755. [CrossRef]
9. Ulusoy C, Canigur Bavbek N, Tuncer BB, Tuncer C, Turkoz C, Gencturk Z. Evaluation of airway dimensions and changes in hyoid bone position following class II functional therapy with activator. *Acta Odontol Scand.* 2014;72(8):917-925. [CrossRef]
10. Samaha CJ, Tannous HJ, Salman D, Ghafari JG, Amatoury J. Role of surgical hyoid bone repositioning in modifying upper airway collapsibility. *Front Physiol.* 2022;13:1089606. [CrossRef]
11. Sambale J, La Garde V, Koehler U, Korbmacher-Steiner HM. The role of the hyoid bone in mandibular advancement: insights from functional appliance therapy in patients with skeletal class II - a prospective cohort study. *Head Face Med.* 2025;21(1):76. [CrossRef]
12. Jo JH, Park JW, Jang JH, Chung JW. Hyoid bone position as an indicator of severe obstructive sleep apnea. *BMC Pulm Med.* 2022;22(1):349. [CrossRef]
13. Kohno A, Kitamura Y, Kato S, et al. Displacement of the hyoid bone by muscle paralysis and lung volume increase: the effects of obesity and obstructive sleep apnea. Sleep. 2019;42(1):zsy198. [CrossRef]

14. Sambale J, Birk R, Koehler U, Hildebrandt W, Korbmacher-Steiner HM. An interdisciplinary approach: presentation of the pediatric obstructive sleep apnea diagnostic examination form (POSADEF). *Diagnostics (Basel)*. 2024;14(15):1593. [CrossRef]

15. Li Y. Early orthodontic treatment of skeletal class II malocclusion may be effective to prevent the potential for OSAHS and snoring. *Med Hypotheses*. 2009;73(4):594-595. [CrossRef]

16. Restrepo C, Santamaría A, Peláez S, Tapias A. Oropharyngeal airway dimensions after treatment with functional appliances in class II retrognathic children. *J Oral Rehabil*. 2011;38(8):588-594. [CrossRef]

17. Faul F, Erdfelder E, Lang AG, Buchner A. G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behav Res Methods*. 2007;39(2):175-191. [CrossRef]

18. Oğuz F, Oğuz HG, Bütün M. Evaluating craniofacial structures in patients with congenital missing teeth. *Folia Morphol (Warsz)*. 2025. [CrossRef]

19. King EW. A roentgenographic study of pharyngeal growth1. *Angle Orthod*. 1952;22(1):23-37. [CrossRef]

20. Ochoa BK, Nanda RS. Comparison of maxillary and mandibular growth. *Am J Orthod Dentofacial Orthop*. 2004;125(2):148-159. [CrossRef]

21. Matsuda Y, Ito E, Kimura Y, Araki K. Hyoid bone position related to gender and aging using lateral cephalometric radiographs. *Orthod Waves*. 2018;77(4):226-231. [CrossRef]

22. Jiang YY, Xu X, Su HL, Liu DX. Gender-related difference in the upper airway dimensions and hyoid bone position in Chinese Han children and adolescents aged 6-18 years using cone beam computed tomography. *Acta Odontol Scand*. 2015;73(5):391-400. [CrossRef]

23. Zhou L, Zhao Z, Lu D. [The analysis of the changes of tongue shape and position, hyoid position in class II, division 1 malocclusion treated with functional appliances (FR-I)]. *Hua Xi Kou Qiang Yi Xue Za Zhi*. 2000;18(2):123-125. Chinese. [CrossRef]

24. Hourfar J, Lisson JA, Kinzinger GSM. Changes of epiglottis and hyoid bone position after orthodontic treatment with cast splint fixed functional appliances. *Clin Oral Investig*. 2021;25(3):1525-1534. [CrossRef]

25. Jiang C, Yi Y, Jiang C, Fang S, Wang J. Pharyngeal airway space and hyoid bone positioning after different orthognathic surgeries in skeletal class II patients. *J Oral Maxillofac Surg*. 2017;75(7):1482-1490. [CrossRef]

26. Jena AK, Singh SP, Utreja AK. Effectiveness of twin-block and mandibular protraction appliance-IV in the improvement of pharyngeal airway passage dimensions in class II malocclusion subjects with a retrognathic mandible. *Angle Orthod*. 2013;83(4):728-734. [CrossRef]

27. Yassaei S, Sorush M. Changes in hyoid position following treatment of class II division1 malocclusions with a functional appliance. *J Clin Pediatr Dent*. 2008;33(1):81-84. [CrossRef]

28. Türkkahraman H, Sayin MO. Effects of activator and activator headgear treatment: comparison with untreated Class II subjects. *Eur J Orthod*. 2006;28(1):27-34. [CrossRef]

29. Pakshir H, Mokhtar A, Darnahal A, Kamali Z, Behesti MH, Jamilian A. Effect of bionator and farmand appliance on the treatment of mandibular deficiency in prepubertal stage. *Turk J Orthod*. 2017;30(1):15-20. [CrossRef]

30. Karslı N, Altuğ AT. Pharyngeal airway space changes after single mandibular and two-jaw surgery in patients with skeletal class II malocclusion. *Turk J Orthod*. 2024;37(3):182-192. [CrossRef]