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Assessment Of Condyle Fossa Relationship, Condylar Axis Angulation And Articular Eminence Morphology In Different Sagittal Malocclusions: A CBCT Study.

Abstract

Objectives
To assess and compare the condyle–fossa relationship, condylar axis angulation, and articular eminence morphology in orthognathic, retrognathic, and prognathic mandibles, and to evaluate gender differences using cone-beam computed tomography (CBCT).
Materials and Methods

This retrospective CBCT study included 48 subjects aged 18–30 years, equally distributed into three sagittal skeletal groups with equal male-to-female ratio. Classification was based on SNB angle, N–B (⊥HP), and Frankfort mandibular plane angle. Sagittal CBCT sections were used to measure anterior (S1), superior (S2), and posterior (S3) joint spaces. Condylar axis angulation was measured relative to the Frankfort horizontal plane. Articular eminence height and inclination were assessed using standardized landmarks. One-way ANOVA with Tukey post hoc test and independent sample t tests were applied ($P < .05$).
Results
No significant intergroup differences were found in S1, S2, S3 joint spaces or condylar axis angulation ($P > .05$). Articular eminence height and inclination differed significantly among groups ($P < .001$), with reduced values in the prognathic group. No significant gender differences were observed.
Conclusions
Sagittal skeletal pattern significantly influences articular eminence morphology, whereas the condyle–fossa relationship and condylar axis angulation remain relatively stable across sagittal malocclusions.

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I. INTRODUCTION

The temporomandibular joint (TMJ) is a highly specialized synovial articulation essential for mandibular function and craniofacial development. Its principal components—the mandibular condyle, glenoid fossa, and articular eminence—function in close coordination, and variations in their morphology or spatial relationships can influence occlusion, facial growth, and joint health. [1,2]

The mandibular condyle is a key site of adaptive growth, exhibiting functional responsiveness as a secondary cartilage. Variations in condylar height and axis angulation are associated with different facial growth patterns and sagittal malocclusions, making condylar angulation a valuable parameter for orthodontic diagnosis and growth assessment[2,3]. The articular eminence guides condylar translation during mandibular movements, and its height and inclination influence TMJ biomechanics and functional stability, with morphological variations related to masticatory loading and facial type.[4,5].

The condyle–fossa relationship reflects the spatial position of the condyle within the glenoid fossa and is critical for balanced joint biomechanics, while alterations may predispose to functional imbalance.[6] Functional appliance therapy induces adaptive condylar remodelling, necessitating corresponding changes in articular eminence morphology and joint spaces.[7] Cone-beam computed tomography (CBCT) enables accurate three-dimensional evaluation of these structures.[8] However, the combined assessment of the condyle–fossa relationship, condylar axis angulation, and articular eminence morphology across different sagittal malocclusions remains limited. Therefore, this study aimed to evaluate these parameters using CBCT in individuals with varying sagittal skeletal patterns.

II. MATERIALS AND METHODS

This retrospective CBCT-based study was conducted following approval from the Institutional Ethics Committee, and written informed consent was obtained from all participants prior to inclusion. Individuals with fully erupted permanent dentition up to the second molars and available pretreatment CBCT records were included. Subjects with a history of facial trauma, craniofacial anomalies, facial asymmetry, systemic disease, temporomandibular joint disorders, severe vertical growth patterns, previous orthodontic or surgical treatment, or condylar hyperplasia or hypoplasia were excluded.

All CBCT scans were obtained using a Planmeca 3D CBCT unit with participants seated in an upright position under standardized imaging conditions (90 kV, 8 mA; field of view 20.1 × 17.6 cm). Sagittal multiplanar reformation (MPR) images were analysed using Planmeca Romexis software (version 5.2.0).

A total of 48 subjects aged 18–30 years were included and equally distributed into three sagittal skeletal groups—orthognathic, retrognathic, and prognathic mandibles (n = 16 per group)—with an equal male-to-female ratio. The sample size was calculated to be 16 (male: female 1:1) in each group accounting up to a total of sample size of 48 according to Andhare [3] et al. Sagittal skeletal classification was based on SNB angle, N–B (⊥ HP), and Frankfort mandibular plane angle (FMA), measured on lateral cephalograms reconstructed from CBCT images. Only subjects with an average vertical growth pattern (FMA >15° and <30°) were included.

The SNB angle was defined as the angle between the Sella–Nasion and Nasion–Point B lines and was used to classify mandibular sagittal position (<78° retrognathic, 78°–82° orthognathic, >82° prognathic). The N–B (⊥ HP) measurement represented the linear distance between Point B and a perpendicular dropped from Nasion to the horizontal plane, with gender-specific norms used for sagittal classification. In males, values < −12.0 mm indicated a retrognathic mandible, −12.0 to +1.4 mm an orthognathic mandible, and > +1.4 mm a prognathic mandible (mean −5.3 ± 6.7 mm). In females, values < −11.2 mm indicated a retrognathic mandible, −11.2 to −2.6 mm an orthognathic mandible, and > −2.6 mm a prognathic mandible (mean −6.9 ± 4.3 mm). The Frankfort mandibular plane angle (FMA) was defined as the angle between the Frankfort horizontal plane and the mandibular plane (Go–Gn). An FMA of 22°–28° represented an average growth pattern, and only subjects with FMA values between >15° and <30° were included in the study.

Subjects will be grouped into 3 categories based on their cephalometric measurements.

- Group 1 Orthognathic mandible
- Group 2 Retrognathic mandible
- Group 3 Prognathic mandible
- Assessment of Condyle–Fossa Relationship (Figure 1)

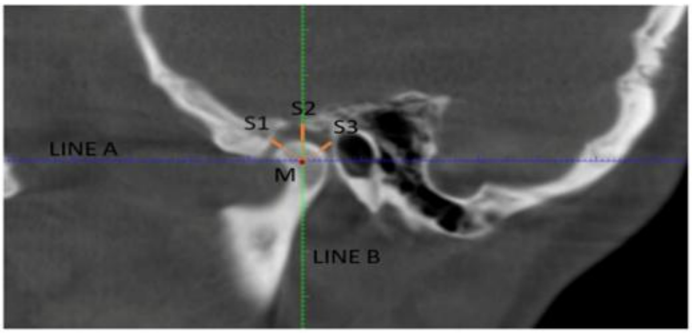

Figure 1. Assessment of condyle–fossa relationship on sagittal CBCT section.

Line A is drawn parallel to the Frankfort horizontal plane through the lowest point of the articular eminence. Line B is drawn perpendicular to Line A through the highest point of the glenoid fossa. The intersection of Lines A and B defines the midpoint of the glenoid fossa (M). The anterosuperior (S1), superior (S2), and posterosuperior (S3) joint spaces are illustrated.

- Assessment of condylar axis angulation (Figure 2)

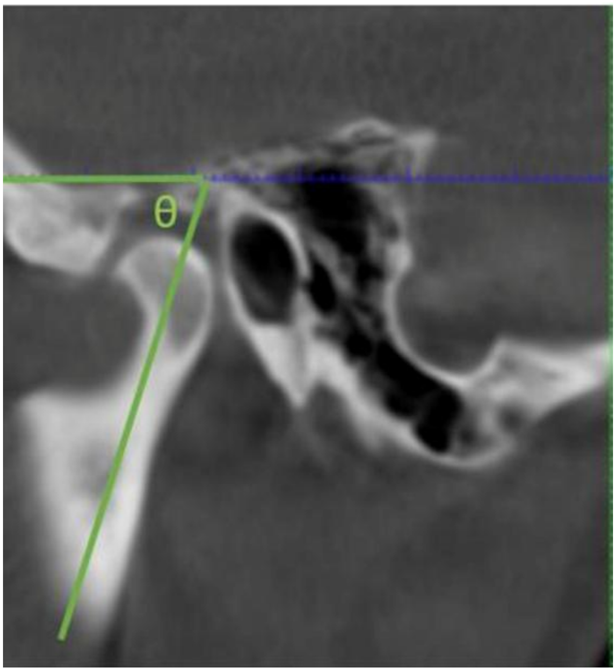

Figure 2. Assessment of condylar axis angulation on sagittal CBCT section.

A reference line is drawn parallel to the Frankfort horizontal plane, and a second line is constructed along the long axis of the mandibular condyle. The angle formed between these two lines represents the condylar axis angulation.

- Assessment of articular eminence height and inclination (Figure 3)

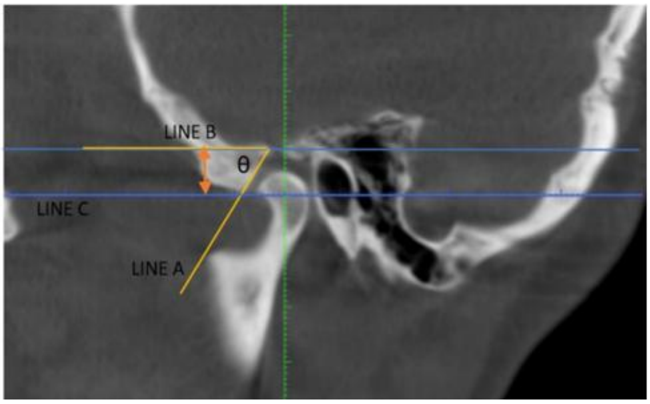

Figure 3. Assessment of articular eminence height and inclination on sagittal CBCT section

Line A: Best-fit line along the posterior surface of the articular eminence (anterior surface of the fossa).
Line B: Line through the deepest point of the fossa, parallel to the Frankfort horizontal plane.
Line C: Line through lowest point of the articular eminence, parallel to the Frankfort horizontal plane.
Articular eminence inclination: Angle between Line A and Line B.
Articular eminence height: Distance between Line B and Line C, perpendicular to FH plane.

Data were analysed using IBM SPSS Statistics (Version 23). Normality was assessed with the Shapiro–Wilk test. As the data were normally distributed, parametric tests were applied. Descriptive statistics were expressed as mean ± standard deviation.

Intergroup differences among sagittal malocclusion groups were evaluated using one-way ANOVA with Tukey's post hoc test. Sex-based comparisons were performed using independent t tests. Statistical significance was set at $p < 0.05$.

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III. RESULTS

Comparison of temporomandibular joint morphological parameters among different sagittal skeletal patterns

The anterior (S1), superior (S2), and posterior (S3) joint spaces showed comparable mean values across orthognathic, prognathic, and retrognathic groups, with no statistically significant intergroup differences (Table 1, Figure 4).

Table 1: Comparison of temporomandibular joint morphological parameters among different sagittal skeletal patterns

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean Lower Bound	95% Confidence Interval for Mean Upper Bound	Sum of Squares	Mean Square	F	Sig.
S1	Orthognathic	16	2.365	0.553	0.127	2.098	2.631	.698	.349	1.437	.247
	Prognathic	16	2.297	0.395	0.091	2.106	2.487				
	Retrognathic	16	2.572	0.521	0.130	2.294	2.850				
S2	Orthognathic	16	3.369	0.895	0.205	2.938	3.801	2.088	1.044	1.314	.278
	Prognathic	16	3.504	1.022	0.234	3.012	3.997				
	Retrognathic	16	3.024	0.699	0.175	2.652	3.397				
S3	Orthognathic	16	2.514	0.669	0.154	2.191	2.836	2.048	1.024	2.027	.142
	Prognathic	16	2.955	0.822	0.188	2.559	3.351				
	Retrognathic	16	2.866	0.609	0.152	2.542	3.191				
Condylar angulation	Orthognathic	16	71.274	3.337	0.766	69.665	72.882	126.518	63.259	2.400	.101
	Prognathic	16	74.186	5.016	1.151	71.768	76.603				
	Retrognathic	16	74.750	6.787	1.697	71.133	78.367				
AE height	Orthognathic	16	6.912	0.852	0.195	6.501	7.322	29.537	14.769	24.179	.000*
	Prognathic	16	5.230	0.666	0.153	4.909	5.551				
	Retrognathic	16	6.558	0.821	0.205	6.121	6.996				
AE Inclination	Orthognathic	16	59.053	5.873	1.347	56.222	61.884	1009.461	504.730	23.308	.000*
	Prognathic	16	49.166	4.033	0.925	47.222	51.110				
	Retrognathic	16	56.791	3.565	0.891	54.891	58.690				

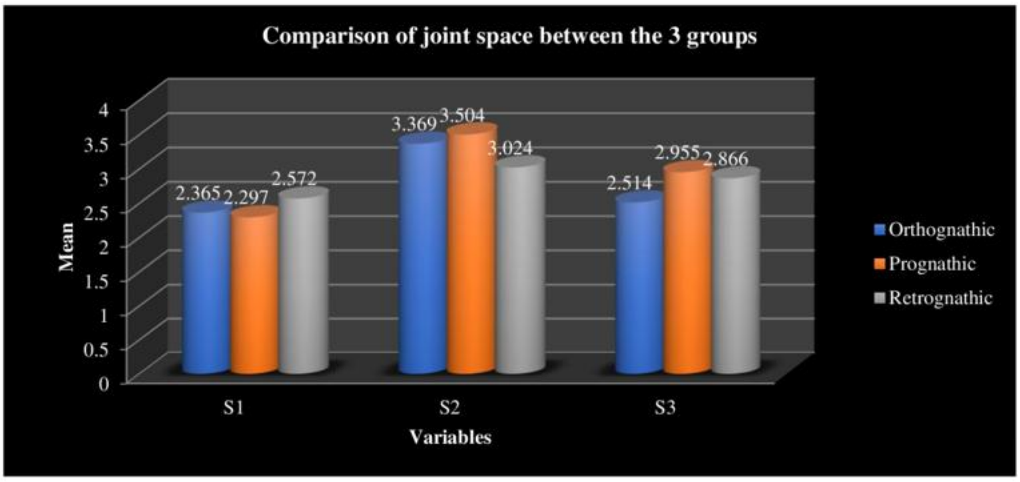

Figure 4. Comparison of temporomandibular joint (TMJ) fossa relationship among orthognathic, retrognathic, and prognathic groups.

Mean S1 values were 2.365 ± 0.553 mm (orthognathic), 2.297 ± 0.395 mm (prognathic), and 2.572 ± 0.521 mm (retrognathic) ($p = 0.247$). Mean S2 values were 3.369 ± 0.895 mm, 3.504 ± 1.022 mm, and 3.024 ± 0.699 mm, respectively ($p = 0.278$). Mean S3 values were 2.514 ± 0.669 mm (orthognathic), 2.955 ± 0.822 mm (prognathic), and 2.866 ± 0.609 mm (retrognathic), with no significant difference among groups ($p = 0.142$).

Condylar axis angulation was lowest in the orthognathic group (71.274 ± 3.337°) compared with the prognathic (74.186 ± 5.016°) and retrognathic groups (74.750 ± 6.787°); however, the difference was not statistically significant ($F = 2.400$, $p = 0.101$) (Table 1, Figure 5).

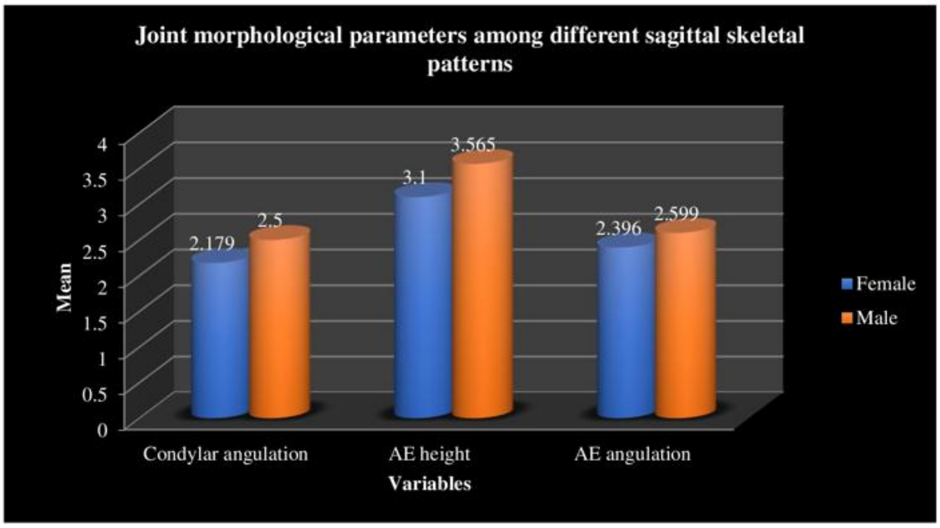

Figure 5. Comparison of condylar axis angulation, articular eminence inclination, and articular eminence height among orthognathic, retrognathic, and prognathic groups.

Articular eminence height differed significantly among groups (Table 1, Figure 5), with the highest values in the orthognathic group (6.912 ± 0.852 mm), followed by the retrognathic group (6.558 ± 0.821 mm), and the lowest in the prognathic group (5.230 ± 0.666 mm) ($F = 24.179$, $p < 0.001$). Post hoc analysis showed significantly greater height in the orthognathic and retrognathic groups compared with the prognathic group ($p < 0.001$), with no significant difference between the orthognathic and retrognathic groups ($p = 0.384$).

Articular eminence inclination also showed a highly significant intergroup difference (Table 1, Figure 5), being greatest in the orthognathic group (59.053 ± 5.873°), followed by the retrognathic group (56.791 ± 3.565°), and lowest in the prognathic group (49.166 ± 4.033°) ($F = 23.308$, $p < 0.001$). The prognathic group demonstrated significantly lower inclination than both the orthognathic and retrognathic groups ($p < 0.001$), while the difference between the orthognathic and retrognathic groups was not significant ($p = 0.332$).

Independent samples *t*-tests showed no significant gender differences in any temporomandibular joint morphological parameters across orthognathic, prognathic, and retrognathic mandible groups. Anterior, superior, and posterior joint spaces (S1, S2, S3), condylar axis angulation, articular eminence height, and articular eminence inclination were comparable between males and females within each sagittal skeletal pattern ($p > 0.05$). These results indicate that TMJ morphology is influenced more by sagittal skeletal pattern than by gender.

IV. DISCUSSION

CONDYLE–FOSSA RELATIONSHIP

The temporomandibular joint (TMJ) is essential for mandibular function, and the condyle–fossa relationship is critical for joint health and long-term treatment stability. As direct clinical assessment of condylar position is not feasible, radiographic evaluation of joint spaces is widely accepted as an indirect method, as reported by Dalili et al.[9] Cone-beam computed tomography (CBCT) enables reliable three-dimensional assessment of anterior (S1), superior (S2), and posterior (S3) joint spaces across different sagittal skeletal patterns.

In the present study, no statistically significant differences were observed in anterior, superior, or posterior joint spaces among orthognathic, prognathic, and retrognathic mandibular patterns. Although prognathic mandibles demonstrated a tendency toward reduced anterior and increased posterior joint space, these variations did not reach statistical significance, supporting the concept of adaptive remodelling of the TMJ.

Similar trends have been reported in CBCT-based studies. Alhammadi et al.[10] and Jeon et al.[11] observed increased anterior joint space in skeletal Class II subjects and reduced anterior joint space in Class III subjects. However, Arieta-Miranda et al.[12] concluded that although spatial differences existed among sagittal skeletal patterns, they were not clinically significant, which is consistent with the findings of the present study.

A consistent joint space distribution pattern (S2 > S3 > S1) was observed across all sagittal groups, with no statistically significant intergroup differences. This suggests that sagittal skeletal discrepancy alone exerts a limited influence on the condyle–fossa relationship when confounding factors are controlled. Gender-based analysis also revealed no statistically significant differences in joint spaces, in agreement with findings reported by Dalili et al.[9] and Lobo et al.[13]

Overall, the findings of the present study, together with those of Dalili et al.[9], Alhammadi et al.[10], Arieta-Miranda et al.[12], and Lobo et al.[13], support the concept that the TMJ possesses a high capacity for adaptive remodelling, enabling relatively stable condyle–fossa relationships across different sagittal skeletal patterns and between genders.

CONDYLAR AXIS ANGULATION

Anteroposterior jaw discrepancies arise from variations in maxillomandibular size, shape, and position, influencing occlusion and facial profile and resulting in sagittal malocclusions, as described by Hegde et al.[14]. Longitudinal evidence suggests that condylar growth direction and axis angulation play a crucial role in sagittal skeletal development. Baccetti, Franchi, McNamara, and Tollaro[15] reported that untreated Class II malocclusion is characterized by a downward and backward inclination of the condylar axis, leading to posterior mandibular rotation, reduced mandibular growth, and progressive retrusion. In contrast, Tollaro et al.[16] demonstrated an upward and forward orientation of the condylar axis in Class III patients undergoing growth modification therapy, highlighting the role of condylar angulation as an indicator of mandibular growth direction and skeletal adaptation.

Various methodologies have been proposed for assessing condylar angulation. Two-dimensional cephalometric analysis, as described by Hegde et al.[14], provides indirect inference based on cranial base and mandibular parameters, whereas CBCT allows direct three-dimensional evaluation of condylar orientation and its spatial relationship to the glenoid fossa, as reported by Arieta-Miranda et al.[12]. CBCT-based investigations by Alhammadi et al.[10] and Gauthami et al.[17] further demonstrated that vertical growth pattern significantly influences condylar position and angulation, underscoring its relevance in orthodontic diagnosis and treatment planning.

The present study evaluated condylar axis angulation relative to the Frankfort horizontal plane in sagittal view among orthognathic, prognathic, and retrognathic mandibles with an average growth pattern. Condylar axis angulation was marginally lower in the orthognathic group compared with the prognathic and retrognathic groups; however, these differences were not statistically significant. This finding indicates that sagittal skeletal discrepancy alone does not exert a substantial influence on condylar axis angulation when vertical growth pattern is controlled.

In agreement with previous cephalometric and CBCT studies by Arieta-Miranda et al.[12], sagittal skeletal pattern demonstrated only a limited influence on condylar orientation, with differences that were statistically small and clinically insignificant. Gender-based analysis in the present study revealed no statistically significant differences in condylar axis angulation across all sagittal mandibular patterns, supporting CBCT observations by Andhare et al.[3], who reported minimal gender-related influence on condylar orientation. Overall, these findings suggest that condylar axis angulation is primarily governed by growth pattern and functional adaptation rather than sagittal skeletal relationship or gender.

ARTICULAR EMINENCE HEIGHT AND INCLINATION

Articular eminence morphology is clinically significant because of its role in governing temporomandibular joint biomechanics and exhibits marked functional adaptability to masticatory forces. It transitions from a relatively flat configuration at birth to a progressively steeper posterior slope with growth and increasing functional demand, reflecting adaptive remodelling in response to mandibular movements and loading patterns, as described by Ingervall and Thilander[18].

In the present study, articular eminence morphology was significantly influenced by sagittal skeletal pattern. Both articular eminence height and inclination were reduced in individuals with a prognathic mandible, whereas the orthognathic group demonstrated the greatest eminence height and steepest inclination. These findings suggest that anterior mandibular positioning and altered functional loading in prognathic individuals may induce adaptive flattening and shortening of the articular eminence, facilitating condylar translation and reducing intra-articular stress. The absence of statistically significant differences between orthognathic and retrognathic groups further indicates a more pronounced adverse effect on eminence morphology in prognathic skeletal patterns.

These findings are consistent with CBCT-based studies by Arieta-Miranda et al.[12], Lobo et al.[13], and Alhammadi et al.[10], who reported reduced articular eminence height and inclination in skeletal Class III malocclusion. Similarly, Aung Thet Khine et al.[19] observed greater articular eminence height in skeletal Class II subjects and comparatively reduced dimensions in Class III patients, supporting the role of sagittal skeletal pattern in articular eminence adaptation.

In contrast, Moscagiuri et al.[20] reported no significant association between articular eminence inclination and sagittal skeletal class in normodivergent adults. This discrepancy may be attributed to methodological differences, as their study evaluated only articular eminence inclination, whereas the present study assessed both eminence height and angulation across clearly defined sagittal mandibular patterns.

With respect to gender differences, the present study demonstrated only minimal and statistically insignificant variations in articular eminence height and inclination between males and females, consistent with findings reported by Sümbüllü[21]. These results suggest that articular eminence morphology is influenced predominantly by skeletal pattern and functional adaptation rather than gender.

V. CONCLUSION

• When vertical growth pattern is controlled, sagittal skeletal pattern has minimal influence on the condyle–fossa relationship and condylar axis angulation.
• Anterior, superior, and posterior joint spaces remain stable across orthognathic, retrognathic, and prognathic mandibles, indicating adaptive TMJ remodelling.
• Articular eminence height and inclination are significantly associated with sagittal mandibular pattern.
• Prognathic mandibles exhibit a flatter and shorter articular eminence compared with other groups.
• No significant gender-related differences are observed in TMJ morphology.
• Articular eminence morphology is a sensitive indicator of sagittal skeletal pattern and is relevant for orthodontic diagnosis and treatment planning.

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