Morphometric analysis of temporomandibular joint using cone beam computed tomography

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SUMMARY

The morphometric analysis of the temporomandibular joint (TMJ) using cone-beam computed tomography (CBCT) provides valuable insights into joint morphology and potential sex-based variations, which are critical for clinical and forensic applications. Seventy subjects (35 males, 35 females) aged from 18 to 30 years underwent CBCT imaging. Mandibular fossa and condylar morphology were classified qualitatively. Quantitative measurements included three linear parameters (distance from posterior fossa to articular eminence apex, vertical distance from fossa roof to articular eminence apex, and distance between intermediate point and apex of articular eminence) and one angular parameter. Statistical analysis was performed using Student's t-test and Chi-square test. Results revealed no significant gender differences in qualitative classifications of mandibular fossa and condyle. Morphological features predominantly included round fossa (60-64%) and flattened condyles (40-52%). Notably, significant sexual dimorphism emerged in the vertical distance from fossa roof to articular eminence apex and articular eminence angle, with males consistently demonstrating larger measurements. Statistical significance was observed bilaterally, with p-values ranging from 0.001 to 0.033 for these parameters. The findings underscore that, while qualitative TMJ morphological classifications do not show gender predilection, specific quantitative morphometric parameters exhibit meaningful sexual dimorphism. These population-specific reference data hold substantial potential for advancing TMJ disorder diagnosis and for supporting forensic identification procedures, offering a nuanced understanding of joint structural variations across sexes.

Key words: Temporomandibular joint – Cone-beam computed tomography – Morphology – Temporomandibular joint disorders – Oral radiology

INTRODUCTION

The distinctive anatomical configuration of the TMJ predisposes it to various functional and pathological conditions, collectively termed temporomandibular disorders (TMDs). As one of

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Submitted: March 7, 2025. **Accepted:** May 22, 2025

https://doi.org/10.52083/KMSR5053

the body's most actively utilized joints, the TMJ is susceptible to congenital anomalies, developmental aberrations, traumatic injuries and pathological conditions. TMDs manifest primarily through pain, joint sounds, and restricted jaw mobility, significantly compromising life quality . These disorders are categorized as either intracapsular, affecting joint structures directly, or extracapsular, involving surrounding musculature. The unique biomechanics of the TMJ necessitate specialized therapeutic approaches for intracapsular conditions such as disc displacement and degenerative joint disease (Hatcher, 2022).

Morphometric analysis has emerged as a valuable methodological approach for examining TMJ anatomical variations and pathological changes. By establishing normative data, morphometrics facilitates differentiation between normal anatomical variance and pathological structural alterations. This approach provides insights into sex- and age-related morphological differences, crucial for accurate diagnosis and personalized treatment planning in orofacial pain, orthodontics, prosthodontics, and maxillofacial surgery. Furthermore, TMJ morphometrics holds forensic significance in sex determination and individual identification, particularly when other anatomical markers are unavailable.

The use of Cone Beam Computed Tomography (CBCT) has enhanced TMJ morphometric analysis by providing three-dimensional visualization of complex structures with lower radiation exposure compared to conventional CT (Ajmal et al., 2023). In the context of TMDs, CBCT allows excellent examination of bony components, including condylar morphology and articular surfaces. This high-resolution imaging modality is particularly valuable for evaluating hard tissue structures and can help detect subtle morphological changes in the TMJ that might not be apparent through clinical examination or conventional radiography alone.

The increasing prevalence of TMDs, attributed to modern lifestyles, necessitates accurate diagnostic methodologies (Sfeir et al., 2025). Our study aims to conduct comprehensive morphometric analysis of the TMJ using CBCT to characterize joint morphology, specifically examining sex-based differences with implications for clinical practice and forensic science. By providing detailed data on individual anatomical variations, this investigation seeks to enhance diagnostic precision, treatment planning, and forensic identification techniques, ultimately contributing to improved management of TMDs and more effective treatment protocols, particularly for complex cases requiring surgical intervention.

MATERIALS AND METHODS

Study design and setting

This descriptive morphometric analysis of the temporomandibular joint (TMJ) utilizing Cone Beam Computed Tomography (CBCT) was conducted at the Department of Oral Medicine and Radiology, JSS Dental College and Hospital, Mysuru, India (August 2023-July 2024). The study protocol received ethical approval (IEC #44/2023).

Study population

Based on previously reported TMJ morphometric differences between sexes (Melo et al., 2022), sample size was calculated as 35 males and 35 females (80% power, 5% significance level). Subjects were selected using systematic consecutive sampling until the target was reached.

Inclusion and exclusion criteria

CBCT scans performed for various diagnostic purposes (implant planning and orthodontic assessment) were included. Scans with developmental anomalies, pathologies affecting the TMJ, previous surgical interventions, fractures, dental implants, participants with partial edentulism or technical artifacts in the TMJ region were excluded.

Morphometric assessment

TMJ morphometry evaluation included both qualitative classifications and quantitative measurements:

Qualitative assessment:

- Mandibular fossa morphology was classified as triangular, trapezoidal, oval, or round (Fig. 1).

- Condylar shape was categorized as convex, round, flattened, or angled (Fig. 2).

Quantitative assessment:

Four reference points were established (Fig. 3A):

- Posterior-most point of the fossa (Fpost) - the top of the post-glenoid process and, when it is absent, the point most anterior of the squamotympanic suture.
- Superior-most point of the fossa (Froof) - Highest point of the fossa.
- Intermediate point of the articular eminence (AEmp) - the midpoint between the roof of the fossa and the height of the articular eminence.
- Articular eminence height point (Aetop) - Height of the eminence joint.

Using the reference points, three linear measurements were recorded (Fig. 3B):

- Distance between Fpost and Aetop
- Vertical distance from Froof to Aetop
- Distance between AEmp and Aetop

Articular eminence angle was measured using Froof, Aetop, and Fpost points (Fig. 3C).

All measurements were performed using Planmeca Romexis CBCT imaging software (version 5.3.5) with accuracy of 0.01 mm for linear measurements and 0.1 degree for angular measurements.

Statistical analysis

Data analysis was performed using SPSS version 23.0. After confirming normal distribution (Shapiro-Wilk test), Student's t-test was employed for comparing quantitative measurements between groups, while Chi-square test was used for qualitative variables. Statistical significance was established at $p < 0.05$.

RESULTS

The study population comprised 70 subjects aged between 18 and 30 years (35 males and 35 females) who met the established inclusion criteria. The age range was specifically selected considering that temporomandibular joint morphology typically undergoes significant changes after 30 years of age due to physiological remodelling

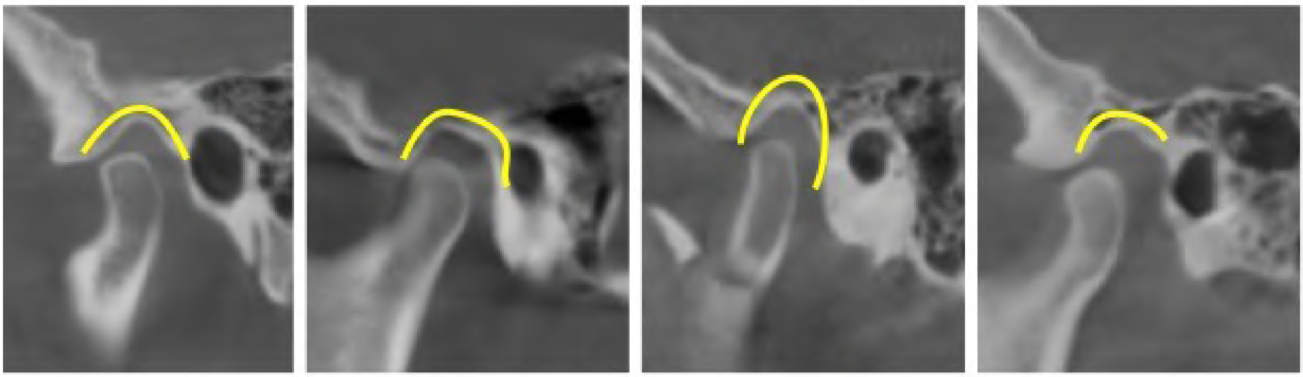

Fig. 1.- Morphological variants of mandibular fossa.

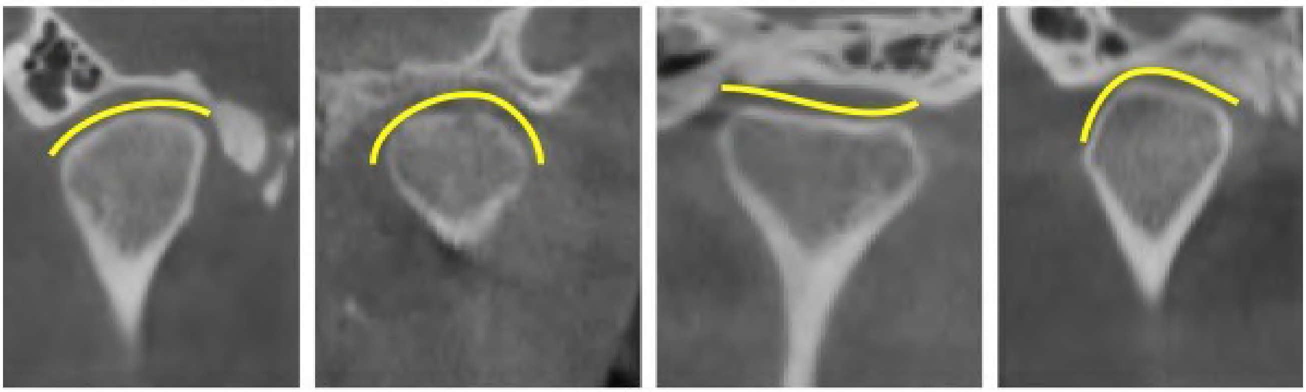

Fig. 2.- Morphological variants of mandibular condyle.

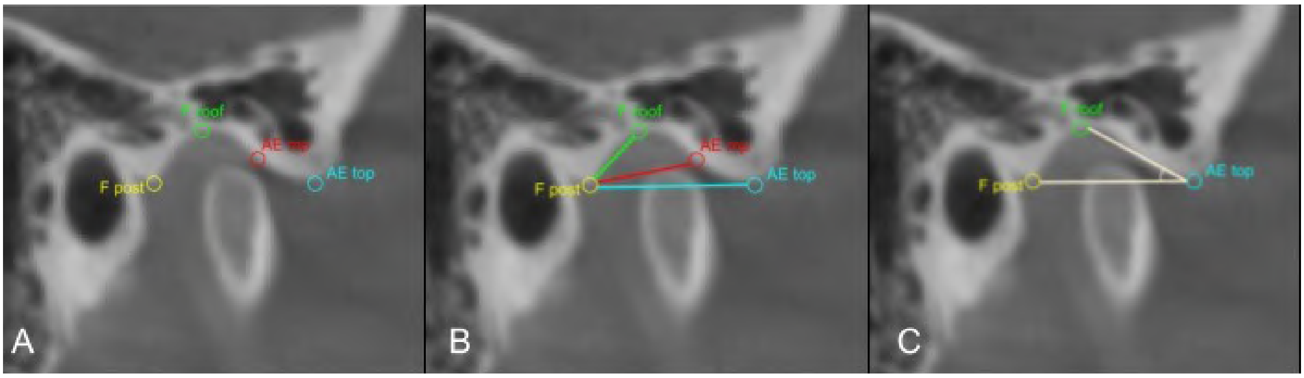

Fig. 3.- A - Reference points established for quantitative measurements of TMJ; B - Linear measurements that were employed in the study; C - Measurement of angle using the three reference points.

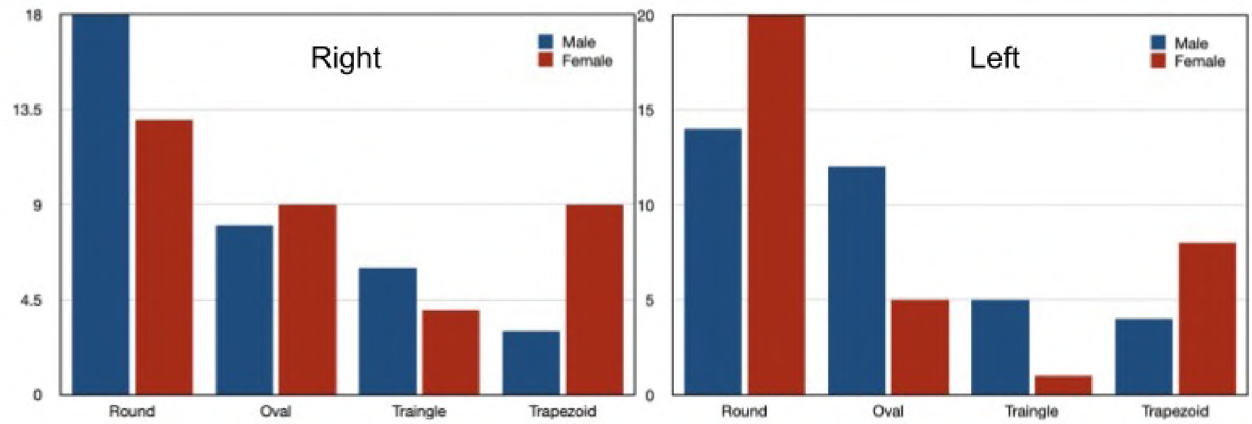

Fig. 4.- Graphical representation of morphological patterns observed in right and left mandibular fossa.

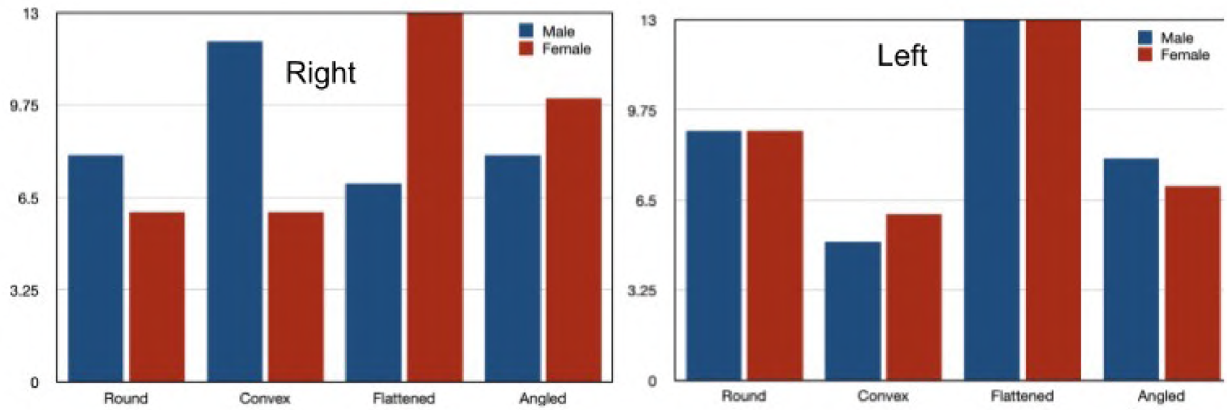

Fig. 5.- Graphical representation of morphological patterns observed in right and left mandibular condyle.

and potential degenerative changes. The mean age of the study population was 24.56 ± 2.33 years. There was no statistically significant difference in age distribution between male and female groups ($p > 0.05$), ensuring age homogeneity for comparative analysis.

The qualitative analysis of mandibular fossa and condyle morphology revealed no statistically significant gender differences (chi-square tests, $p > 0.05$ for all comparisons) (Table 1). For the mandibular fossa, the most common types were round (right: 31/52, 60%; left: 34/53, 64%) and oval (right: 17/52, 33%; left: 17/53, 32%), with no significant gender distribution differences (right: $p = 0.234$; left: $p = 0.087$) [Figure 4]. Among condyles,

Table 1. Qualitative analysis with chi-square test for mandibular fossa and condyle.

Mandibular Fossa					
	Type	**Male**	**Female**	**Total**	**p value**
RIGHT	Round	18	13	31	0.234
	Triangle	6	4	10	
	Trapezoid	3	9	12	
	Oval	8	9	17	
LEFT	Round	14	20	34	0.087
	Triangle	5	2	7	
	Oval	12	5	17	
	Trapezoid	4	8	12	
Condyle					
RIGHT	Round	8	6	14	0.230
	Angle	8	10	18	
	Flattened	7	13	20	
	Convex	12	6	18	
LEFT	Flattened	13	13	26	0.984
	Angled	8	7	15	
	Round	9	9	18	
	Convex	5	6	11	

flattened (right: 20/50, 40%; left: 26/50, 52%) and angled (right: 18/50, 36%; left: 15/50, 30%) were predominant, again without significant gender associations (right: p = 0.230; left: p = 0.984) (Fig. 5). These findings suggest that morphological variations in mandibular fossae and condyles are not significantly influenced by sex.

The descriptive statistics for mandibular parameters (Table 2) revealed gender-specific differences in certain measurements. On the left side, males exhibited higher mean values for "F roof to AE top" (13.286 vs. 12.429 mm) and the "angle between F roof, F top, and F post" (30.311° vs. 26.867°), while "F post to AE top" and "AE mp to AE top" showed minimal differences (17.241 vs. 17.043 mm; 5.877 vs. 5.848 mm) (Figs. 6, 8). On the right side, males again had larger mean values for "F roof to AE top" (13.378 vs. 11.657 mm) and the angular parameter (28.787° vs. 25.839°), with "F post to AE top" and "AE mp to AE top" showing negligible gender variation (17.333 vs. 16.541 mm; 5.789 vs. 5.816 mm) (Figs. 7, 8). Coefficients of variation indicated moderate variability across parameters, particularly for angular measurements.

The independent samples t-tests (df=68) revealed significant differences between groups for specific parameters on both the left and right sides. On the left side, significant differences were observed in "F roof to AE top" (p = 0.014) and the "angle between F roof, F top, and F post" (p = 0.033). On the right side, significant differences were found in "F roof to AE top" (p = 0.001) and the same angular parameter (p = 0.031). Conversely, "F post to AE top" (left: p = 0.660; right: p = 0.139) and "AE mp to AE top" (left: p = 0.888; right: p = 0.906) showed no significant differences. These results indicate that variations in "F roof to AE top" distance and the specified angular measurement are statistically significant, whereas the other parameters are not influenced by the grouping variable (Table 3).

DISCUSSION

In the complex landscape of temporomandibular joint (TMJ) research, morphometric analysis emerges as a crucial investigative tool, particularly given the intricate nature of growth modification theories and the multifaceted biological mechanisms involved in TMJ development. The

Table 2. Descriptive statistics for quantitive analysis of TMJ parameters.

Parameters		Group	Mean	SD	SE	Coefficient of varation
LEFT	F post to AE top	Male	17.241	1.209	0.204	0.070
		Female	17.043	2.354	0.398	0.138
	F roof to AE top	Male	13.286	1.398	0.236	0.105
		Female	12.429	1.428	0.241	0.115
	AE mp to AE top	Male	5.877	0.881	0.149	0.150
		Female	5.848	0.882	0.149	0.151
	Angle between F roof, F top and F post	Male	30.311	8.133	1.375	0.268
		Female	26.867	4.589	0.776	0.171
RIGHT	F post to AE top	Male	17.333	1.906	0.322	0.110
		Female	16.541	2.483	0.420	0.150
	F roof to AE top	Male	13.378	2.065	0.349	0.154
		Female	11.657	2.258	0.382	0.194
	AE mp to AE top	Male	5.789	1.005	0.170	0.174
		Female	5.816	0.870	0.147	0.150
	Angle between F roof, F top and F post	Male	28.787	6.942	1.173	0.241
		Female	25.839	3.779	0.639	0.146

Table 3. Independent samples T-Test.

Parameters		t	df	p
LEFT	F post to AE top	0.442	68	0.660
	F roof to AE top	2.536	68	0.014
	AE mp to AE top	0.141	68	0.888
	Angle between F roof, F top and F post	2.182	68	0.033
RIGHT	F post to AE top	1.495	68	0.139
	F roof to AE top	3.327	68	0.001
	AE mp to AE top	-0.118	68	0.906
	Angle between F roof, F top and F post	2.206	68	0.031

importance of precise morphometric measurements becomes evident when considering the delicate interplay of factors such as viscoelastic forces, skeletal adaptations, and neuromuscular components that contribute to TMJ remodelling.

While various hypotheses attempt to explain TMJ growth patterns —from the growth relativity hypothesis highlighting the balance of six major factors to the functional matrix theory emphasising soft tissue influences to the ratchet hypothesis focusing on the condyle's adaptive capabilities— the ability to quantify these changes through robust morphometric methods provides an objective foundation for understanding these theoretical frameworks (Owtad et al., 2013). This scientific approach allows dental practitioners to better comprehend the natural course of TMJ development and its response to functional demands, ultimately contributing to more informed clinical decision-making in general dentistry. The application of morphometric analysis becomes particularly relevant when evaluating the complex three-dimensional changes that occur in the TMJ during growth and adaptation, offering valuable insights that enhance our understanding of both normal development and potential therapeutic interventions.

The selection of participants aged between 18 and 30 years in our study strategically captured TMJ morphology during optimal structural stability while controlling for age-related variations. This age range follows the completion of major developmental changes, with articular eminence achieving full height by an age between 18 and 20 (Katsavrias and Dibbets, 2001) and eminence inclination reaching its peak in ages between 21 and 30 ages (Sülün et al., 2001). Our approach is further validated by research showing progressive posterior positioning of condyles with advancing age (Chen et al., 2022) and significantly increased condylar morphological changes in individuals over 40 years (90%) compared to those under 40 (64%) (Mathew et al., 2011), effectively minimizing the influence of age-related degenerative changes in our morphometric analyses.

The present study's findings regarding mandibular fossa morphology demonstrate interesting patterns when compared with historical and contemporary research. While Oberg et al. (1971) initially established a basic classification system with four categories focusing on concavity levels on autopsy models, subsequent research has evolved to more specific shape-based classifications based on radiographs. The current study revealed that round morphology was predominant on both sides (31% right, 34% left), followed by oval shape (17% bilaterally). This distribution differs notably from the findings by Katsavrias (2006) in Class II Division 2 malocclusion subjects, where oval shapes were markedly more prevalent (58.3%) and round shapes were surprisingly rare (7.3%). More recent research by Kinzinger et al. showed varying results across imaging modalities, with CT scans revealing 52% round fossae, while MRI showed 48% oval fossae, highlighting potential methodology-dependent variations in morphological assessment (Kinzinger et al., 2018a, b). The present study's findings align more closely with

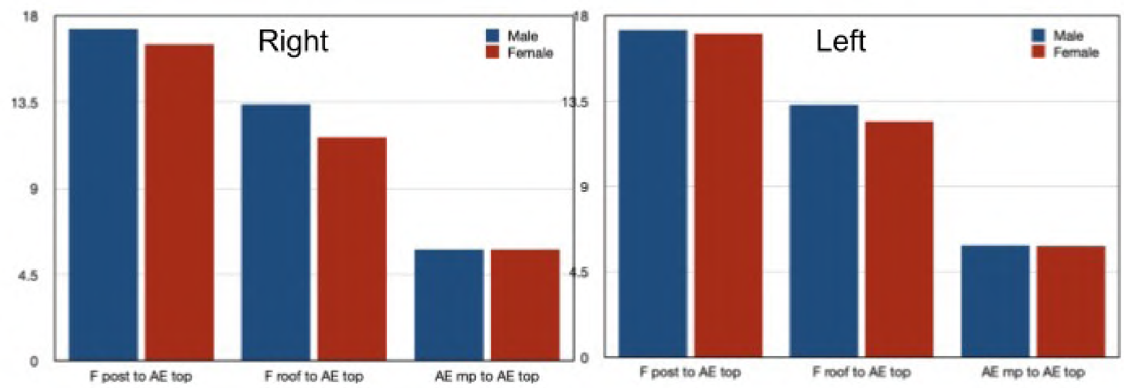

Fig. 6.- Linear parametric analysis of right and left TMJ.

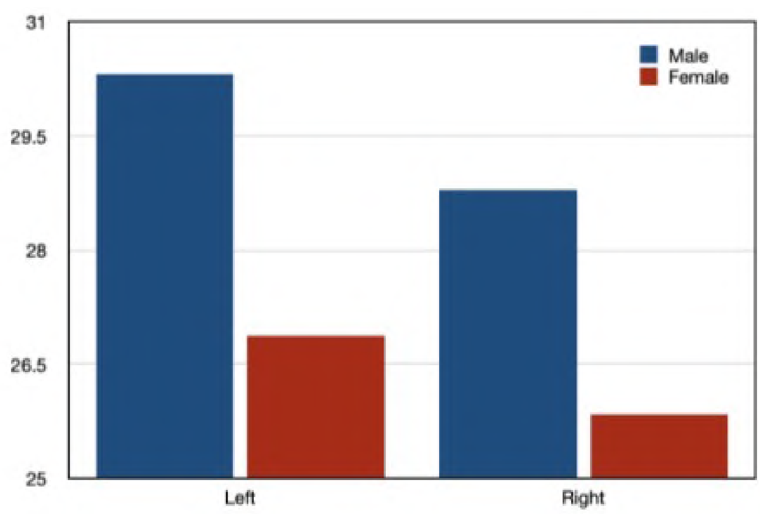

Fig. 7.- Angle between F roof, F top, and F post in right and left TMJ.

Melo et al.'s research on the general population, which demonstrated a more balanced distribution across all morphological categories (approximately 22-31% for each shape type) (Melo et al., 2022). This comparison suggests that mandibular fossa morphology may exhibit population-specific variations like ethnicity and food patterns; and the current study's distribution pattern appears to represent a more generalised population trend rather than the skewed distributions observed in specific malocclusion groups or earlier research cohorts. The relatively balanced distribution observed in the present study, with no single shape type exceeding 34%, supports the concept of natural morphological variation in mandibular fossa anatomy.

The foundational understanding of condylar morphology stems from Osborn et al., who identified varied shapes in dried skulls (Osborn and Baragar, 1992), evolving significantly as documented in Hedge et al. (2013) systematic review highlighting variations with age, gender, facial type, and functional load. The progression from Yale's initial three-category classification to current comprehensive understanding through high-resolution CT imaging demonstrates the field's evolution (Yale et al., 1966). Population-specific findings reveal intriguing variations, with Thai studies reporting round morphology as most prevalent (70.63%) (Arayapisit et al., 2023), while Indian studies showed a more balanced distribution between round and angled forms (Sahithi et al., 2016), with which our findings align more closely, due to shared population characteristics. However, variations exist compared to Turkish studies finding convex forms most common (42.6%), especially in young females (54.4%) (Tassoker et al., 2017), potentially due to different classification methodologies, imaging techniques, and genetic or environmental factors. Mohamed et al. further correlate angled condyles with anterior disc displacement, suggesting morphological variations may have clinical implications beyond anatomical interest (Mohamed et al., 2023).

This study represents the first investigation of these specific TMJ parameters for sex estimation in an Indian subpopulation, with only one previous study by Melo et al. examining similar parameters in a Brazilian population using computed tomography (Melo et al., 2022). The analysis revealed varying patterns of sexual dimorphism across different TMJ measurements. While the F roof to AE top measurements demonstrated significant bilateral sexual dimorphism (left: p=0.014; right: p=0.001) aligning with Melo et al.'s findings, other parameters showed population-specific variations. Notably, the angle between F roof, F top, and F post exhibited significant dimorphism bilaterally (p=0.033 left, p=0.031 right) in the present study, contrasting with Melo et al.'s borderline findings. However, the F post to AE top and AE mp to AE top measurements showed no significant sexual differences in the current study, diverging from Melo et al.'s results (Melo et al., 2022). These variations highlight the importance of population-specific standards in forensic anthropology, as the manifestation of sexual dimorphism in TMJ structures appears to vary across different population groups, likely due to complex interactions between genetic, hormonal, and environmental factors during development.

The morphometric variations of the temporomandibular joint (TMJ) have profound clinical implications that span across multiple areas of dental and maxillofacial practice. When interpreting diagnostic images, clinicians must recognise that TMJ morphology naturally varies with age, progressing from round to oval condylar shapes in developing patients (Karlo et al., 2010), while also understanding that specific morphometric patterns can indicate pathology, such as increased horizontal condylar angles being associated with disc displacement without reduction (Crusoé-Rebello et al., 2003; Kurita et al., 2003). This knowledge becomes particularly crucial in treatment planning, whether for surgical intervention or prosthetic rehabilitation following tooth loss (which can lead to decreased condylar height and increased width) (Ahmed et al., 2020), or orthodontic treatment where the articular eminence's inclination (normally between 30 and 60°) plays a vital role in determining mandibular movement patterns (Katsavrias and Halazonetis, 2005). Additionally, Costen syndrome, characterized by symptoms such as otalgia, tinnitus, and vertigo resulting from TMJ dysfunction, presents distinct morphometric features detectable on CBCT imaging, including flattening of the mandibular condyle, reduced joint space, and sclerotic changes in the articular surfaces, providing clinicians with valuable diagnostic criteria when evaluating suspected cases of this condition (Effat, 2024).

Our study's primary limitations include the cross-sectional data collection, which prevents assessment of TMJ morphological changes over time. The sample size may not represent all regional variations within the Indian subpopulation. CBCT limits soft tissue assessment of the TMJ. Future studies should focus on longitudinal assessment using non-ionising imaging. Research priorities include: investigating age-related morphological variations in the Indian subpopulation; examining TMJ morphometry and disc displacement using combined CBCT-MRI analysis; and expanding the study across different ethnic groups within India. Research exploring the correlation between TMJ parameters and internal disorders requires further investigation, particularly focusing on gender-specific variations, as literature indicates significant differences between male and female patients.

CONCLUSION

The present study elucidates significant sexual dimorphism in specific temporomandibular joint morphometric parameters, particularly the vertical distance from the roof of the mandibular fossa to the articular eminence apex and the angular measurement between reference points, while revealing no appreciable gender differences in qualitative morphological classifications. These findings contribute valuable population-specific data for the Indian subcontinent, with implications across diagnostic, therapeutic, and forensic domains. The observed morphometric variations underscore the complex interplay of genetic, hormonal, and environmental factors influencing TMJ development and highlight the necessity for population-specific reference standards. Despite methodological limitations inherent in cross-sectional CBCT-based assessment, this investigation establishes a foundation for future longitudinal studies incorporating multimodal imaging to explore age-related variations, structure-function relationships, and pathological correlations within the temporomandibular joint complex.

AUTHOR'S CONTRIBUTION

VSC, KP- Conception, Study Design, Critical review; VSC, SCJ, RB - Data collection, Manuscript writing; VSC, KP - Data analysis, Manuscript revision.

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