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Sex Estimation through Morphometric Analysis of the Temporomandibular Joint

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Abstract

The present study evaluated through a morphometric analysis the temporomandibular joint (TMJ) to estimate sex. Participants in a database with archived tomographic images of patients who sought the Radiology Clinic of the Hospital Universitário Oswaldo Cruz/University of Pernambuco for face or skull tomography were evaluated. Gender was recorded while the participant underwent the tomographic exam and was indexed in the database. The tomographies were recorded in DICOM format and were evaluated using the OSIRIX HD Software. The morphology of the mandibular fossa, the joint eminence and the condyle were evaluated. The measures were analyzed statistically, and results with $p < 0.05$ were considered statistically significant. Both the length of the right and left mandibular condyle (Aco-pco) showed larger dimensions in the male group with a statistically significant result ($p = 0.003$). The measurements of the glenoid cavity also showed statistical significance with the male gender presenting a higher measurement standard than the female. There was a statistically significant association between Morphology of the left articular eminence and sex. Conclusion: Some linear measures of the JTM indicated the possibility of establishing sexual differentiation and showed that the values referring to the male group tend to be higher than those of the female sex. Further studies with larger sample numbers are needed to achieve scientific evidence.

Keywords

Temporomandibular Joint, Forensic Anthropology, Sexual Dimorphism

1. Introduction

The process of human identification plays a fundamental role in society, about legal, social, and personal aspects. This process consists of individualizing the person, using methods that will depend on each case, and whether the individual is alive or dead (Curi et al., 2016; Dong et al., 2015).

The first step in the human identification process is to build a biological profile, that is, to gather general characteristics such as ancestry, sex, age, height. These characters must be compared with ante-mortem data recorded or obtained through reports from family members or witnesses (Menon et al., 2011). The possibility of identifying the deceased has great repercussions, as it allows, for example, family members to experience grief and enables the resolution of issues such as life insurance, debt payments, remarriage, and child custody. In the criminal sphere, it is essential to identify the victim. Therefore, this must be a precise process based on scientific principles (Adserias-Garriga et al., 2018).

The forensic means have several methods for identifying the individual (Adserias-Garriga et al., 2018). Conclusive methods, such as fingerprinting, iris reading, DNA, are extremely important, but other inconclusive methods are also widely used, such as identification through anthropometric data. In situations where the individual is in an advanced state of putrefaction or when only bone fragments are available, many methods are no longer an option in this process and the evaluation of the skeleton often becomes the only alternative to obtain the identification of the corpse in question (Carneiro et al., 2017; Zheng et al., 2018).

Anthropometry is an essential method of anthropology to dimension the human body. These measurements are standardized and follow a scientific method to obtain reliable anthropometric values (Lobo et al., 2019). Measurements of the jaw, as well as the temporomandibular joint (TMJ), are important not only to address surgical or clinical issues, but also to cover forensic questions of age, sex estimation or to characterize different populations (Preissler et al., 2018; Coogan et al., 2018).

The temporomandibular joint is a synovial joint that has a fibrocartilaginous articular disc located between the eminence of the temporal bone and the mandibular condyle. This joint joins the mandible to the base of the skull, where the condyle lies in the glenoid cavity. Through this joint, it is possible to perform the movements of opening and closing the mouth, allowing adequate speech, and chewing (Coombs et al., 2019; Kim et al., 2017; Ilgüy et al., 2014).

The TMJ can suffer degeneration during the time of function due to overloads applied to the condyle region as well as hormonal changes. These dysfunctions can result in anatomical changes in the condyle, glenoid cavity, and articular eminence. In the general population, there is a prevalence of TMJ disorders in females. Thus, the possibility of changing the anatomical pattern of the mandibular condyle and articular fossa of the TMJ is questioned when comparing females and males. This difference may be important to establish an anthropometric pattern of the TMJ in terms of sexual dimorphism.

Therefore, the present study aimed to evaluate the forensic importance of the

Temporomandibular Joint (TMJ) for sex estimation through a morphometric analysis.

2. Methods

Research design

A cross-sectional study was carried out, considering that data on the variables of interest were collected at the same time; retrospective, as CT scans were analyzed from an image bank of patients who sought the radiology clinic of the Hospital Universitário Oswaldo Cruz (HUOC)/University of Pernambuco with a request for facial CT; and observational since the research intended to describe the distribution of certain aspects (PEREIRA, 1995). Using the OSIRIX HD Software, linear measurements of the glenoid cavity, articular eminence, and mandibular condyle on the right and left sides of the studied population were performed. These were also classified morphologically. This population was allocated into two groups: Group A (female) and Group B (male) for data analysis and comparison.

This study was approved by the Research Ethics Committee of UPE according to approval number 12112119.7.0000.5207 (**ANNEX 1**). This research was developed in accordance with resolution 466/2012-CNS/CONEP, concerning ethics in research involving human beings. The research was carried out in the city of Recife, State of Pernambuco. The population studied was made up of participants aged between 18 to 70 years, with an indication for performing a face or skull tomography at the HUOC. The sample size consisted of 88 patients, 44 female and 44 males for comparison between groups. CT scans that showed ankylosis of one or two TMJs were excluded from the study. presence of titanium plates or screws in the right or left TMJ region, tumors in one or two TMJs, artifact in the region to be analyzed, fractures or traumas in the right or left TMJ region.

All CT scans were measured by a single evaluator who was calibrated by a technician qualified to manipulate the software so that there was a standardization in all measurements in all tomographic images.

Research Procedure

The tomographic images stored in the database were performed on a 4-channel multislice/GE computed tomography scanner, with a slice thickness of 1.24 mm and an increment of 1 mm. CT scans were recorded in DICOM format and will be evaluated using OSIRIX Software.

The morphology of the mandibular fossa evaluated through the parasagittal section and classified according to Katsavrias (2006) as: 1) Triangular; 2) Trapezoidal; 3) Oval; 4) Round (**Figure 1**).

For the evaluation of the glenoid cavity and articular eminence, four reference points were demarcated for this study according to Katsavrias & Voudouris, (2004). These points are: Posterior fossa, Fp (the top of the post-glenoid process and when it is absent, the point most anterior of the squamotympanic suture), Ceiling of the fossa, Fr (the highest point of the fossa), Intermediate point of the

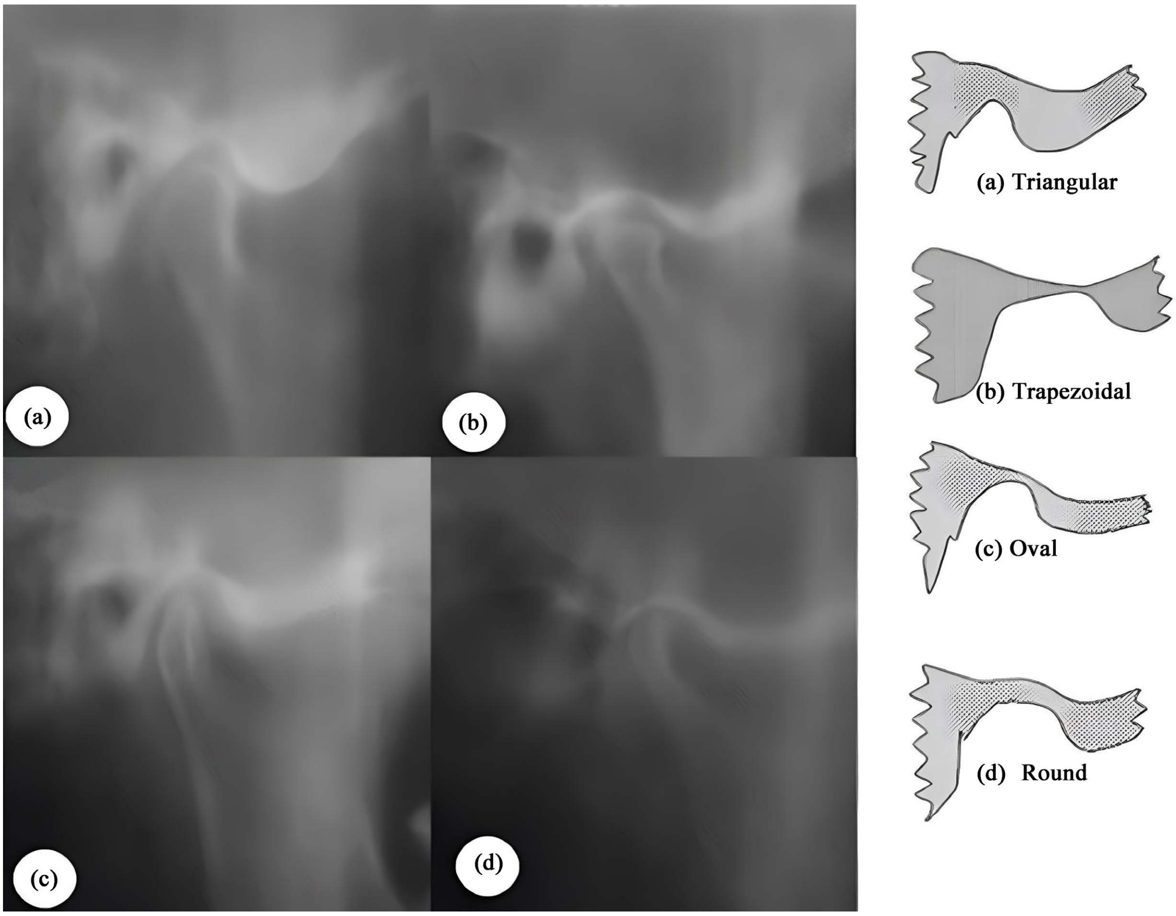

Figure 1. Classification of glenoid fossa morphology. (a) Triangular; (b) Trapezoidal; (c) Oval; (d) Round (Katsavrias 2006).

articular eminence, AEmp (the midpoint between the roof of the fossa and the height of the articular eminence), Height of the eminence joint, Aetop (**Figure 2**). From these points measurements were demarcated.

Three linear measurements were performed from the pre-established points and an angle that corresponds to the angle to the articular eminence (**Figure 3**). These are:

Linear measurements:

- Fpost-Aetop;
- Ffoof-Aetop;
- AEmp-Aetop.

Angle:

- Froof.AEtop.Fpost.

All measurements were performed by the measurement program integrated into the software with a measurement accuracy of 0.1 mm. The four measures listed below (**Figure 3**) agree with Kinzinger et al. (2018).

For assessment of the mandibular condyle according to condyle condyle calculations with Schlueter et al. (2008). This linear measure was demarcated from two points. These are: Aco (most anterior point of the mandibular condyle in a

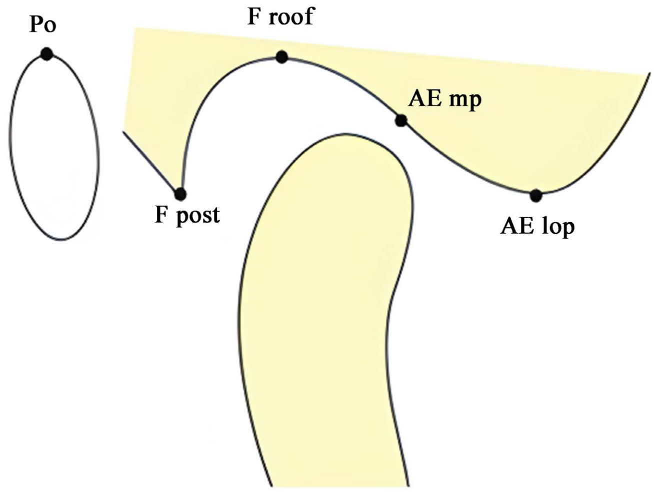

Figure 2. Five specific points of reference according to Katsavrias & Voudouris (2004), (Kinzinger et al., 2018).

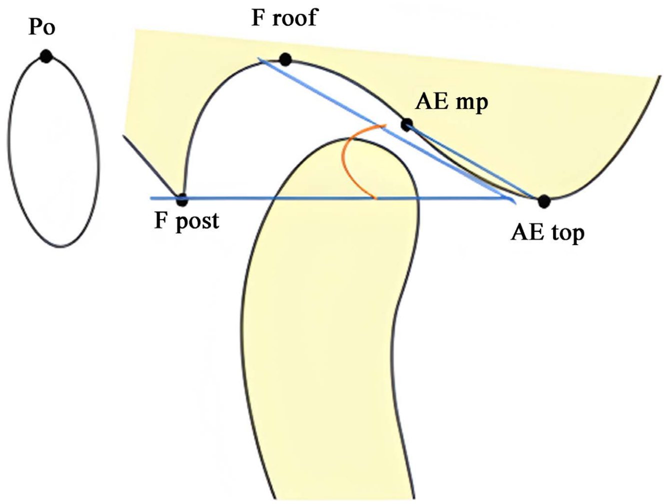

Figure 3. Angle formed between the Frof-AEtop line and the AEtop-Fpost and linear measurements (Kinzinger et al., 2018).

parasagittal view) and Pco (most posterior point of the mandibular condyle in a parasagittal view) (**Figure 4**).

The morphology of the articular eminence was classified into 4 types according to the criteria of Kurita et al. (2000) (**Figure 5**):

1) Flat: flattened eminence;

2) Sigmoid: posterior slope of the eminence in a sigmoid curve;

3) Boxed: deep fossa and eminence with accentuated posterior slope;

4) Deformed: morphology of the irregular eminence not fitting into any of the three categories above.

Statistical analysis

A database was generated and analyzed in the SPSS statistical package version 13.0 (Statistical Package for the Social Sciences), with subsequent verification of typing consistency. After the Kolmogorov-Smirnov analysis, Student's t (normal

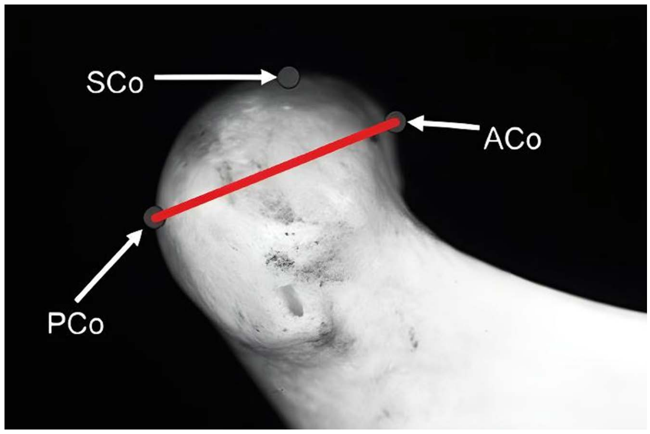

Figure 4. Line from the Pco point to the Aco point demarcating the length of the condyle Schlueter et al. (2008).

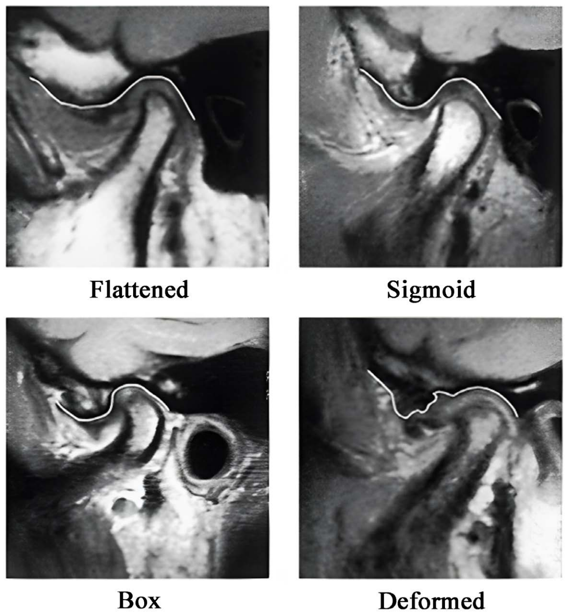

Figure 5. Morphological classification of TMJ according to Kurita et al. (2000). TMJ images in MRI demonstrating the classification: Flattened (flattened), Sigmoid (sigmoid), Box (in box), deformed (deformed) (Tsuruyama et al., 2006).

distribution) or Mann-Whitney (not normal distribution) tests were used to compare whether there was a statistically significant difference between the sexes in the measures studied. To verify the best mathematical model to discriminate the sexes and determine which of the measures is most relevant, the stepwise Discriminant Analysis model was used. In all statistical tests, a significance level of 5% ($p < 0.05$) was adopted.

3. Results

Eighty-eight tomographic images were selected for the present study, 44 (50%) belonging to females and 44 (50%) males, to enable comparison between the groups.

Table 1 shows the difference in the measurements of the right and left TMJs,

Table 1. General data.

Variables	Mean ± SD	Median (Q1; Q3)	Minimum maximum
Fpost—Aetop right	1.80 ± 0.41	1.74 (1.49; 2.06)	1.10 - 2.82
Fpost—Left Aetop	1.76 ± 0.42	1.77 (1.44; 2.02)	1.00 - 2.65
Froof—Aetop right	1.24 ± 0.36	1.24 (1.00; 1.42)	0.43 - 2.11
Froof—Left Aetop	1.19 ± 0.35	1.22 (0.91; 1.42)	0.43 - 2.10
AEmp—Aetop right	0.65 ± 0.24	0.60 (0.51; 0.77)	0.20 - 1.51
AEmp—Left Aetop	0.65 ± 0.22	0.67 (0.46; 0.81)	0.30 - 1.31
Angle Frof-Aetop line and right Aetop-Fpost	51.87 ± 15.03	48.50 (40.25; 61.75)	26.00 - 87.00
Angle Frof-Aetop line and left Aetop-Fpost	50.95 ± 13.58	48.00 (42.00; 56.75)	26.00 - 87.00
Right Pco-Aco	0.61 ± 0.21	0.55 (0.44; 0.78)	0.32 - 1.21
Pco-Aco left	0.61 ± 0.23	0.54 (0.43; 0.80)	0.23 - 1.23
	n	**%**	
Right glenoid fossa morphology			
1—triangular	19	22.6	
2—trapezoidal	21	25.0	
3—oval	23	27.4	
4—round	21	25.0	
Left glenoid fossa morphology			
1—triangular	20	23.8	
2—trapezoidal	26	31.0	
3—oval	18	21.4	
4—round	20	23.8	
Right articular eminence morphology			
1—flat	25	29.7	
2—sigmoid	26	31.0	
3—box	21	25.0	
4—deformed	12	14.3	
Left articular eminence morphology			
1—flat	20	23.8	
2—sigmoid	23	27.4	
3—box	27	32.1	
4—deformed	14	16.7	

Source: Authors' data.

as well as the difference in the morphology of the glenoid cavity and articular eminence. It can be noted that there was no significant difference in the variation of measurements when comparing the right side with the left side of the TMJ. There were no great variations in the morphological classification when comparing the groups of the right and left TMJs, it is observed that both sides followed the same metric and morphological pattern.

When analyzing Table 2, it is observed that when separating the female and male groups, there is a change in the metric pattern. Both the length of the right and left mandibular condyle (Aco-pco) showed greater dimensions in the male group, with a statistically significant result ($p = 0.003$).

The measurements of the glenoid cavity also showed statistical significance with males presenting a higher measurement pattern than females. There was no statistical difference for the measurements "Frof-Aetop line angle and the right Aetop-Fpost" and "Frof-Aetop line angle and the left Aetop-Fpost".

According to the morphological classification of the TMJ, it was observed that there was only a statistically significant association between morphology of the left articular eminence and sex, as shown in Table 3. Most female patients had a flattened (28.6%) and sigmoid (38.1%) eminence. Most males (42.9%) had a box-shaped eminence.

4. Discussion

The temporomandibular joint (TMJ) undergoes anatomical changes over time due to its constant use and constant overloads on it. It is classified as a triaxial bicondylar synovial joint, where its movement necessarily requires movement on both the right and left sides. Sometimes greater degeneration is observed on one side due to several mechanical factors that can act more on one of the TMJs,

Table 2. Gender comparison numerical variables.

Variables	Sex		p-value
	Masculine Mean ± SD	Feminine Mean ± SD	
Fpost—Right Aetop	1.91 ± 0.36	1.68 ± 0.42	0.007*
Fpost—Aetop left	1.91 ± 0.36	1.61 ± 0.42	0.001*
Froof—Right Aetop	1.35 ± 0.33	1.13 ± 0.35	0.003*
Froof—Aetop left	1.31 ± 0.33	1.06 ± 0.33	0.001*
AEmp—Right Aetop	0.72 ± 0.19	0.57 ± 0.25	0.004*
AEmp—Aetop left	0.75 ± 0.19	0.56 ± 0.22	<0.001*
Angle line Frof-Aetop and the right Aetop-Fpost	55.00 ± 14.56	48.74 ± 15.02	0.056*
Angle line Frof-Aetop and the left Aetop-Fpost	53.29 ± 12.55	48.62 ± 14.32	0.116*
Right Pco-Aco	0.67 ± 0.19	0.56 ± 0.22	0.003**
Pco-Aco left	0.68 ± 0.21	0.53 ± 0.22	0.003*

(*) t Student test (**) Mann-Whitney test. Source: Authors' data.

Table 3. Gender comparison in morphology.

variables	Sex		p-value
	male n (%)	female n (%)	
Morphology glenoid fossa right			
1—triangular	7 (16.7)	12 (28.6)	0.353*
2—trapezoidal	12 (28.6)	9 (21.4)	
3—oval	14 (33.3)	9 (21.4)	
4—round	9 (21.4)	12 (28.6)	
Morphology glenoid fossa left			
1—triangular	8 (19.0)	12 (28.6)	0.052*
2—trapezoidal	10 (23.8)	16 (38.1)	
3—oval	14 (33.4)	4 (9.5)	
4—round	10 (23.8)	10 (23.8)	
Morphology articular eminence right			
1—flat	12 (28.6)	13 (31.0)	0.891*
2—sigmoid	12 (28.6)	14 (33.3)	
3—box	12 (28.6)	9 (21.4)	
4—deformed	6 (14.2)	6 (14.3)	
Morphology articular eminence left			
1—flat	8 (19.0)	12 (28.6)	0.037*
2—sigmoid	7 (16.7)	16 (38.1)	
3—box	18 (42.9)	9 (21.4)	
4—deformed	9 (21.4)	5 (11.9)	

(*) t Student test. Source: Authors' data.

whether right or left (Preissler et al., 2018).

In our study, measurements, and morphology of the right and left side of the TMJ of 84 patients were evaluated and compared, however, there was no significant variation between both sides. This result may indicate that despite the possibility of anatomical variability comparing each side of the TMJs, they tend to follow the same anatomical pattern with similar dimensions. However, even so, we cannot affirm or conclude that this difference cannot be significant due to the sample size of our study. Few studies compare the right and left sides of the TMJ, and it is not possible to conclude whether there is a significant difference from one side to the other.

In a study carried out by Kim et al. (2017), to verify the sex-dependent mechanical properties of the mandibular condyle, the condyles evaluated were randomly chosen, 11 on the right side and 5 on the left side. Thus, it is not possible to verify whether one side of the condyles has a greater or lesser influence in this study. Another study by Coombs et al. (2019) evaluated through a sagittal overlap of the right and left condyles a possible relationship between TMJ morphometric characteristics and sex differentiation. The authors therefore considered both sides similar for morphometric evaluation. Therefore, it is considered that both sides of the same patient tend to follow the same anatomical dimensions and morphology.

Dong et al. (2015) show in their study carried out in a Chinese population that several osteometric patterns of the mandible can be used as a reliable indicator of sexual dimorphism and suggest that the measurements performed in computed tomography can be a very valuable source of data for Anthropology forensics.

In our study, when analyzing the linear measurements and angles of the TMJ, separating the female and male groups, we observed a statistically significant difference, indicating that males tended to have greater anatomical proportions to the detriment of females. Only the right and left eminence angles did not show statistical significance, but all other measurements were statistically significant. These findings may further add to the already existing importance of the mandible as an indicator for sexual differentiation.

Other authors corroborate this result, indicating that the male TMJ tends to have larger measurements when compared to females. Coogan et al. (2018) through a tomographic evaluation of mandibular condyles, concluded that male condyles were on average larger than female condyles with complex differences in microstructural characteristics. The authors also concluded that the height and slope of the eminence are influenced by sex and age.

Coombs et al. (2019) indicated that intrinsic sex-specific differences in temporomandibular morphometry included increased medial condylar length and mediolateral disc lengths in men and greater anteroposterior disc lengths in women.

Regarding the TMJ morphology, our study observed a statistically significant association between the morphology of the left articular eminence and sex. The study showed that the majority of female patients had a flattened (28.6%) and sigmoid (38.1%) eminence. The majority of males (42.9%) had a box-shaped eminence. The flattened and sigmoid eminence may be related to the fact that joint degenerations and TMJ dysfunctions are more common in females. The question to be raised is whether the morphological difference can influence the higher prevalence of TMD in females or whether the higher prevalence of these degenerative dysfunctions should lead to anatomical changes in these joints. This question cannot be answered without further research with this focus. On this matter, Coogan et al (2018) were able to determine sex-dependent differences in mandibular condyle morphology, the study concluded that the anatomical differences in both sexes can, in turn, alter the biomechanics of the joint and favor the appearance of TMJ dysfunctions. But, further studies with a larger data also including skeletons in the sample could be performed to prove this statement.

Our study indicated a possible correlation of linear TMJ measurements and articular eminence morphology with sexual differentiation in a population from the Northeast of Brazil. Therefore, we emphasize the need to carry out more studies with different population groups and larger samples, as well as other methodological types of studies that perform, for example, the morphometric evaluation in dry skulls in order to reach a higher level of scientific evidence in this sense and this way to add to forensic anthropology one more possibility of sexual differentiation.

5. Conclusion

Some linear measurements of the TMJ indicated the possibility of establishing sexual differentiation and showed that the values for the male group tend to be higher than those for the female sex. Regarding the morphological classification, only the morphology of the articular eminence indicated a significant result to assess sexual dimorphism. More studies with larger sample numbers are needed to reach scientific evidence.

Data Availability

All data generated or analyzed during this study are included in this published article.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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