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Morphometric Comparisons and Correlations of the Mandibular Fossa and Articular Eminence of the TMJ: a Study on Dry Human Skulls

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ABSTRACT

Introduction: the Temporomandibular Joint (TMJ) is classified both morphologically and functionally as condylar and biaxial, and it plays a critical role in human activities such as chewing, swallowing, and verbal communication. The bones of the TMJ exhibit morphological plasticity, which allows them to remodel in the first years of life, during which the articular eminence (AE) and the mandibular fossa (MF) acquire a characteristic "S" shape in response to stimuli from the maxillomandibular complex. The present research aims to obtain measurements of the linear and angular lengths of AE and MF structures of TMJs.

Methods: after calibrating the measurements using Image J software, morphometries of TMJ AE and MFs were evaluated in a sample of 73 photographed dry skulls, obtained through sample size calculation, and outcomes related to the analyzed structures were measured. The collected data were organized and analyzed using the Shapiro-Wilk normality test, and subsequently, comparison and correlation tests were performed.

Results: one AE outcome and eight outcomes associated with MF had a non-normal distribution. Three significant comparisons were obtained, all of which were related to MF. Of a total of 276 obtained correlations, 30.79% presented significant results, of which 7.61% had $r \geq 0.6$, and 1.09% had $r \geq 0.8$. All assessed outcomes, when correlated with their contralateral counterpart, returned significant results.

Conclusion: comparison between both sides of the same outcome in AE structures resulted in non-significant symmetries between them, while MF showed a higher prevalence of significant symmetry between the analyzed structures. Strong significant positive and negative correlations were found between the analyzed structures, and outcomes on the same side had stronger correlations. Strong correlations were also found between AE and MF outcomes, especially between IaMedLatMF-R and IaMedLatCAE-R outcomes. Very strong correlations were obtained between MF and AE mediolateral angulations analysis on the same side, but contralateral correlations involving both outcomes were weak.

Keywords: Temporomandibular Joint; Morphology; Symmetry.

Introduction

The Temporomandibular Joints (TMJs) are two condylar and bi-axial synovial joints, each composed of an articular capsule, capsular and extra-articular ligaments, mandibular condyle, articular disc, and the mandibular fossa (MF) of the temporal bone. The MF is anteriorly delimited by the articular tubercle, a linear and transverse structure located medially to the posterior margin of the zygomatic process of the temporal bone. At its most lateral end, the articular tubercle projects a bone structure with downward convexity called the Articular Eminence (AE), which provides viability to different mandibular movements and contributes to chewing, phonetic, and swallowing functions in humans[1-4].

The temporal portion of the TMJ changes considerably since the embryonic and postnatal period, when the TMJ changes its morphology from roughly flat to a characteristic "S" shape, strongly influenced by musculoskeletal growth and development. This causes the MF and AE to undergo a remodeling process that will define its final topography, with proportional dimensions relative to the facial ones, and maintain a strong relationship with forces performed by the masticatory muscles[5-11]. Approximately 50% of the morphometric maturation of the temporal part of the TMJs is completed after two years old[12].

TMJ remodeling in the extrauterine period can still be influenced by the presence of other factors such as varied maxillomandibular growth patterns. These patterns can generate maxillary and/or mandibular prognathism or retrognathism. In addition to morphological and functional changes

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in the dental arches, these factors can contribute to TMJ bone modeling and provide morphometric changes. These changes occur mainly in MF depth and AE height and inclination[7,13–15]. Behavioral issues such as having a preferential chewing side generate different muscle tensions with different repercussions on both TMJs. This causes repetitive and asymmetrical movements which can be predictors of morphological asymmetries in TMJ structures such as MF and AE[15].

The susceptibility of MF to undergo bone remodeling, providing variations in its measurements, can influence the dynamics of the articular disc, contributing to the appearance of pathologies such as Temporomandibular Disorders (TMDs). However, in the literature, data on TMJ morphometric variations for TMD cases still require further studies[16,17].

Regarding this, the present study aims to increase knowledge about the morphometric characteristics of AE and MF of the TMJ, allowing for the recognition of normal patterns based on anatomical parameters and creating concrete elements for a correct diagnosis, prognosis, and treatment plan of TMDs. This study provides data from an anatomical morphometric pattern that will contribute to data for future research, as well as adjust therapeutic approaches mainly performed by dentists and physiotherapists.

Materials and Methods

In accordance with Federal Law nº. 8.501 of November 30, 1992, and the National Research Ethics Committee (CAAE: 66287517.7.0000.5208), only dry skulls that were legally eligible for study purposes were used, with prior authorization from the Department of Anatomy of the Federal University of Pernambuco (UFPE).

The sample, obtained through sample calculation based on the hypothesis of 95% symmetry between contralateral MFs and AEs, 95% confidence interval, and standard error of 5%, consisted of 73 dry human skulls stored in the Laboratory of Anthropology and Forensic Osteology (LAOF) in the Anatomy Department of the Federal University of Pernambuco (UFPE).

Dry human skulls, without distinction of sex, ethnicity, and height, were included, but the skulls needed to present evidence of upper third molar eruption, totally or partially, or evidence of their previous extraction. Additionally, the skulls should also have bone integrity of the structures in both the MFs and AEs of the right and left TMJs. Skulls in which anatomical characteristics of non-adult individuals could be identified were excluded, such as the presence of fontanelles, deciduous or mixed dentition, and synchondrosis still open at the base of the skull.

These skulls were photographed from three different views: bottom view (B), right side view (R), and left side view (L). The focal length for the camera (Sony Cyber-Shot, Japan) was 10 centimeters from the most projected part of the skull and next to a graph paper for morphometric calibration of the measurement software (ImageJ)[18], in which the measurements of the studied outcomes were taken. These images were stored on a computer HD (Toshiba Canvio Basics, AM, Brazil), and each skull was enumerated in a sequence from 1 to 73, with each captured image identified by the skull number and the letter of the cranial view. For example, 1B, 1R, 1L; 2B, 2R, 2L; ... 73L.

The following outcomes were bilaterally obtained and morphometrically analyzed in the lateral and basal views of the skulls:

- Inclination angle of the posterior slope of the TMJ AE (IaPsAe) tangent to the posterior edge of the AE with the Frankfurt Horizontal Plane (FHP).
- Inclination angle of the anterior slope of the TMJ AE(IaAnAe) tangent to the anterior margin of the AE with the FHP.
- Inclination angle between the anterior and posterior slopes of the TMJ AE(IaPsAnAe) tangent to the posterior margin of the AE with another plan tangent to the anterior margin of the structure.
- Height of the TMJ AE (HAe), measured as the linear distance perpendicular to the FHP, measured between the lower portion of the AE to the upper margin of the zygomatic arch.
- Mediolateral length of the anterior limit of the MF (MedLatLeAnMF), measured between the anterolateral and anteromedial limits of the MF.
- Mediolateral length of the posterior limit of the MF(MedLatLePsMF), measured between the posterolateral and posteromedial limits of the MF.
- Medial-lateral length of the central aspect of the MF (MedLatLeCeMF), measured between the medial and lateral limits of the MF, with the measurement taken halfway between these two limits.
- Anteroposterior length of the lateral limit of the MF (AnPsLeLatMF), measured between the anterolateral and posterolateral limits of the MF.
- Anteroposterior length of the medial limit of the MF (AnPsLeMedMF), measured between the anteromedial and posteromedial limits of the MF.
- Anteroposterior length of the central aspect of the MF(AnPsLeCeMF), measured between medial and lateral limits of the MF, with the measurement taken halfway between these two limits.
- Inclination angle between the mediolateral ends of the MF (IaMedLatMF) in relation to the median plane drawn along the longitudinal suture of the palate.
- Medial-lateral inclination angle of the articular eminence crest (IaMedLatAEC) in relation to the median plane drawn along the longitudinal suture of the palate.

Each outcome measurement was renamed according to the respective analyzed side of the skull, such as IaPsAe-L and HeAe-R, for better understanding and organization of the measurement results. This resulted in a total of 24 analyzed outcomes per skull. Initially, two researchers (V.H.S.L. and N.N.Q.S.) calibrated the measurements for 20% of the sample's skulls (15 randomly selected skulls), and the results were compared using a 95% Confidence Interval (CI). If the average measurements fell within the CI between researchers, definitive measurements were conducted and all of the sample's skull outcomes were measured individually by a single researcher. However, if measurements fell outside of the CI, the researchers discussed their definitions for that outcome measurement and repeated their measurements.

The 24 outcomes related to the analyzed anatomical structures among the sample skulls (73) were measured to assess the normal distribution of the data through the Shapiro-Wilk test. Comparison tests analyzed both sides of the same outcome (i.e., IaPsAnAe-R and IaPsAnAe-L). When both outcomes presented a normal distribution, the Paired t Test was used for comparison purposes. When a single outcome presented non-normal data distribution, the Wilcoxon test was used for comparison purposes.

Correlation tests (r) analyzed different outcomes and sides to identify positive or negative correlations among them. Pearson correlation test was used in case of normal data distribution for both assessed outcomes, otherwise, the Spearman correlation test was used for analysis. The correlation parameters were applied, regardless of number signs[19].

- Poor correlation ($0.1 \leq r < 0.3$);
- Weak correlation ($0.3 \leq r < 0.6$);
- Moderate correlation ($0.6 \leq r < 0.8$);
- Very strong correlation ($0.8 \leq r < 1$).

For statistical processing, the eighth version of the GraphPad Prism program was used, and a significance level of 5% and a confidence interval of 95% were assumed in all situations.

Results

The researchers were calibrated in all analyzed outcomes, although a second calibration step was necessary for the outcome AnPsLeLatMF-L.

Normality

Data distribution was normal for 15 of the 24 outcomes. The outcomes IaPsAnAe-R, AnPsLeMedMF-L, AnPsLeMedMF-R, AnPsLeLatMF-L, AnPsLeLatMF-R, AnPsLeCeMF-L, AnPsLeCeMF-R, MedLatLeCeMF-L and MedLatLeCeMF-R showed non-normal distribution.

Comparison

Out of the 12 performed comparison tests, five addressed AE structures, showing 100% non-significant symmetries among the compared anatomical structures. Among the remaining seven comparisons, four (33.33%) showed non-significant symmetries, while three (25%) presented significant symmetries, which addressed the following outcomes: MedLatLePsMF, AnPsLeLatMF, and AnPsLeCeMF. Values and further details regarding the comparison of the analyzed outcomes in this study are summarized in Table 1.

Correlation

Out of 276 correlation tests performed among all analyzed outcomes, 85 showed significant results, which subdivided into 62 positive and 23 negative correlations, with modules classified as:

- Poor correlation - 18 correlations;
- Weak correlation - 46 correlations;
- Moderate correlation - 18 correlations;
- Very strong correlation - 3 correlations.

Data regarding significant outcomes correlations with modules "moderate," "very strong," and "perfect" are listed in Tables 2 and 3. All the obtained correlations, regardless of significance or module results, are listed in supplementary Appendix 1.

Regarding AE vs. AE correlations, IaPsAnAe is negatively interrelated with IaPsAe, IaAnAe, and HeAe on the same side. The correlations' strength ranged between moderate and very strong. When correlating the same outcome on opposite sides, positive correlations were found between measurements in all cases. Among these outcomes, those with the lowest correlation were associated with AE: IaMedLatAEC, IaAnAe, IaPsAe, and IaPsAnAe.

When it comes to MF vs. MF correlations, MedLatLeCeMF correlates moderately and positively with the outcomes MedLatLeAnMF and MedLatLePsMF when both are analyzed on the same side. MedLatLeCeMF-L correlates moderately with MedLatLeAnMF-R, while the correlation between MedLatLeCeMF-R and MedLatLeAnMF-L remains poor.

Regarding AE vs. MF correlations, IaMedLatMF and IaMedLatAEC present very strong and positive correlations when both are analyzed on their same side (left or right). Correlations between both outcomes on opposite sides returned weaker values.

Discussion

Out of a total of 73 skulls measured, 1752 measurements were obtained, which were submitted, in the statistical analysis, to a total of 12 comparison tests and 276 correlation tests. All the comparison results evidenced AE and MF symmetries between both sides of the analyzed

Table 1. Means, confidence interval and results of the comparison tests performed for each assessed outcome.

Analyzed Outcomes	Mean	95% Confidence Interval	Comparison Test	P value	Symmetry
IaPsAe-L	36,15	34,53; 37,78	Paired Student t	0,0829	Yes
IaPsAe-R	37,48	35,98; 38,99			
IaAnAe-L	16,18	14,31; 18,04	Paired Student t	0,4969	Yes
IaAnAe-R	15,44	13,61; 17,27			
IaPsAnAe -L	128	124,80; 131,20	Wilcoxon	0,2327	Yes
IaPsAnAe -R	122	115,20; 128,80			
HeAe-L	0,8574	0,818; 0,897	Paired Student t	0,2713	Yes
HeAe-R	0,8718	0,835; 0,91			
IaMedLatAEC-L	76,33	74,94; 77,72	Paired Student t	0,2026	Yes
IaMedLatAEC-R	75,32	73,94; 76,71			
MedLatLeAnMF-R	1,681	1,63; 1,732	Paired Student t	0,8752	Yes
MedLatLeAnMF-L	1,683	1,635; 1,732			
MedLatLePsMF-R	1,472	1,423; 1,521	Paired Student t	0,0293*	Yes
MedLatLePsMF-L	1,517	1,468; 1,566			
AnPsLeMedMF-R	1,076	0,787; 1,365	Wilcoxon	0,9271	Yes
AnPsLeMedMF-L	1,076	0,782; 1,37			
AnPsLeLatMF-R	0,851	0,623; 1,08	Wilcoxon	< 0.0001*	Yes
AnPsLeLatMF-L	0,776	0,580; 0,972			
AnPsLeCeMF-R	0,780	0,620; 0,940	Wilcoxon	0,0136*	Yes
AnPsLeCeMF-L	0,746	0,601; 0,890			
MedLatLeCeMF-R	2,072	2,088; 2,546	Wilcoxon	0,8503	Yes
MedLatLeCeMF-L	2,088	1,561; 2,615			
IaMedLatMF-R	77,58	76,17; 78,99	Paired Student t	0,8636	Yes
IaMedLatMF-L	77,72	76,23; 79,2			

R – Right, L – Left, * - Significant P value. Outcome's acronyms are previously described in methods section.

Table 2. Significant correlation results of the TMJ morphometries.

Analyzed Outcomes		Correlation Tests	P value	Correlation Results	95% Confidence Interval
IaMedLatMF-R	IaMedLatAEC-R	Pearson	<0.0001	0,948	0,918; 0,967
IaMedLatMF-L	IaMedLatAEC-L	Spearman	<0.0001	0,931	0,890; 0,957
IaAnAe-R	IaPsAnAe-R	Spearman	<0.0001	-0,65935	-0,775; -0,501
IaAnAe-L	IaPsAnAe-L	Pearson	<0.0001	-0,82871	-0,890; -0,739
IaPsAnAe-R	HeAe-R	Spearman	<0.0001	-0,67816	-0,788; -0,526
IaPsAnAe-L	HeAe-L	Pearson	<0.0001	-0,61219	-0,738; -0,445
IaPsAe-R	IaPsAnAe-R	Spearman	<0.0001	-0,73365	-0,827; -0,601
IaPsAe-L	IaPsAnAe-L	Pearson	<0.0001	-0,73152	-0,823; -0,603
MedLatLeAnMF-R	MedLatLeCeMF-R	Spearman	<0.0001	0,72672	0,592; 0,822
MedLatLeAnMF-R	MedLatLeCeMF-L	Spearman	<0.0001	0,61994	0,449; 0,747
MedLatLeAnMF-L	MedLatLeCeMF-L	Spearman	<0.0001	0,71027	0,569; 0,811
MedLatLePsMF-R	MedLatLeCeMF-R	Spearman	<0.0001	0,60256	0,427; 0,735
MedLatLePsMF-L	MedLatLeCeMF-L	Spearman	<0.0001	0,72868	0,594; 0,823

R- Right, L- Left. Outcome's acronyms are previously described in methods section.

Table 3. Significant correlation results enrolling same outcomes but analyzed in opposite sides: Correlation results do not suffer any alterations when outcomes analysis order is changed.

Analyzed Outcomes		Correlation Tests	P value	Correlation Results	Confidence Interval
IaPsAe-R	IaPsAe-L	Pearson	<0.0001	0,522	0,332 to 0,671
IaAnAe-R	IaAnAe-L	Pearson	<0.0001	0,557	0,373 to 0,698
IaPsAnAe-R	IaPsAnAe-L	Spearman	<0.0001	0,642	0,478 to 0,763
HeAe-R	HeAe-L	Pearson	<0.0001	0,773	0,661 to 0,852
IaMedLatAEC-R	IaMedLatAEC-L	Pearson	0,000619	0,391	0,177 to 0,570
MedLatLeAnMF-R	MedLatLeAnMF-L	Pearson	<0.0001	0,759	0,641 to 0,842
MedLatLePsMF-R	MedLatLePsMF-L	Pearson	<0.0001	0,672	0,522 to 0,781
AnPsLeCeMF-R	AnPsLeCeMF-L	Spearman	<0.0001	0,779	0,665 to 0,857
AnPsLeLatMF-R	AnPsLeLatMF-L	Spearman	<0.0001	0,717	0,579 to 0,815
AnPsLeMedMF-R	AnPsLeMedMF-L	Spearman	<0.0001	0,772	0,655 to 0,853
MedLatLeCeMF-R	MedLatLeCeMF-L	Spearman	<0.0001	0,701	0,557 to 0,804
IaMedLatMF-R	IaMedLatMF-L	Pearson	0,00014	0,429	0,221 to 0,600

R- Right, L- Left. Outcome's acronyms are previously described in methods section.

skulls, exceeding the 95% symmetries hypothesis among the analyzed anatomical structures between both sides of the skulls. When analyzing AE and MF comparisons, a higher percentage of significant results were found in the latter comparisons. The comparison results oppose the study of Jasinevicius *et al.* (2015)[15], which advocates for 10% symmetry regarding the MF and AE between sides. This fact can be justified by factors such as ethnicity differences between samples, the measurement process, and different anatomical references used for outcomes establishment.

The positive and very strong correlations obtained between the IaMedLatMF-R and IaMedLatAEC-R outcomes are justified by the modeling of the MF and the AE by the mandible condyle, which, when redistributing the forces arising from the physiological movements of the mandible, molds the anatomical structures of the temporal bone[8, 20].

The negative correlation between IaPsAe, IaAnAe, and IaPsAnAe can be explained by the geometric rule that affirms that three rays that form a triangle have angles of an inversely proportional nature since the triangle's internal angles sum is 180º. A similar situation occurs between the outcomes HeAe and IaPsAnAe since the outcome HeAe is associated with the height of the previously mentioned polygon.

The three outcomes related to the mediolateral length of the mandibular fossa - bilateral MedLatLeAnMF, MedLatLeCeMF, and bilateral MedLatLePsMF - are closely interrelated to the condylar morphology, as they are part of the diffusion site of forces guided by the mandible. This fact can be corroborated by the study of Sá *et al.* (2017)[20], which indicated morphometric changes in the MF in the case of temporomandibular disorders, which tend to impair this physiological diffusion of forces.

A significant positive correlation was also observed between the outcomes MedLatLeAnMF-R and MedLatLeCeMF-L, indicating a proportional relationship between them. Although the correlation between the same outcomes on the opposite sides (MedLatLeAnMF-L and MedLatLeCeMF-R) was similarly significant, it was classified as weak because the value of r was below 0.6 (r=0.54). This event can be explained by the fact that the correlation between the outcomes MedLatLeAnMF-R and MedLatLeCeMF-L occurs moderately, and its r value is very close to 0.6 (the limit between moderate correlation and weak correlation), having much of its confidence interval encompassing weakly correlated values.

Thus, the symmetry observed between the temporal components of the temporomandibular joint is expected and justifies correlations between outcomes from opposite sides involving the structures, such as the moderate correlation previously specified, due to the already documented late remodeling of the TMJ temporal portion due to external factors such as mechanical factors and primary dentition development[8,22,23].

Conclusion

The comparison of the same contralateral outcomes presented in the AE resulted in non-significant symmetries between the structures, while the MF outcomes showed a higher prevalence of symmetry between the analyzed structures. There were strong and significant positive and negative correlations between the AEs, with outcomes from the same side showing stronger correlations. When analyzing outcomes regarding AEs and MFs, correlations of the same characteristic were also found, especially between the IaMedLatMF-R and IaMedLatAEC-R outcomes. There were significant and moderate morphometric correlations between the MF outcomes assessed on the same side and opposite sides. There were very strong and significant positive correlations between IaMedLatMF and IaMedLatAEC on the same side, but contralateral correlations involving both structures were weak.

Ethics Statement

The authors state that every effort was made to follow all local and international ethical guidelines and laws that pertain to the use of human cadaveric donors in anatomical research[24].

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