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Symmetry and Correlation Analysis of Mandibular Condyles and Mandibular Rami Landmarks: a Morphometric Study in Dry Human Mandibles

Matheus Corrêa da Silva[1], Marcus Vinícius Silva Weigel-Gomes[1], Olavo Barbosa de Oliveira Neto[2], Cristiano Manoel[3], Alexandre Rodrigues Freire[3], Fernando José Camello de Lima[2]

[1]Dental School, Federal University of Alagoas, Maceió, AL, Brazil
[2]Institute of Health and Biological Sciences, Federal University of Alagoas, Maceió, AL, Brazil
[3]Department of Morphology, Anatomy Division, Piracicaba Dental School - State University of Campinas, Piracicaba, SP, Brazil

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ABSTRACT
Introduction: the aim os the study was to compare and correlate measures of angles and axes of homolateral and contralateral mandibular condyles and mandibular rami landmarks.
Methods and Methods: Linear measures and angles from sixty dry human mandibles of individuals from both sexes, with no distinction regarding ethnicity, were obtained using the software Image J and statistically processed for comparison and correlation analysis.
Results: three hundred sixty-four correlations were processed considering all homolateral and contralateral variables and the following was found: 76 (20,88%) correlations presented significant results, none of which with perfect correlation or with absence of correlation; 23 (6,32%) weak correlations (12 positive and 11 negative); 25 (6,87%) moderate correlations (16 positive and 9 negative); 20 (5,49%) strong correlations (10 positive and10 negative); and 08 (2,20%) very strong correlations (04 positive and 04 negative). Significant differences were not found between the right and left sides for measures regarding contralateral mandibular variables.
Conclusion: tnalyzed structures presented symmetry and exhibited a positive correlation when there was a plausible synergistical muscle action and a negative correlation when there was a plausible antagonistic action. Future clinical studies with a long follow-up should be considered to assess the role of this muscles on mandibular morphology and on TMDs.
Keywords: Mandibular condyle; Mandibular ramus; Coronoid process; Mandibular angle; Symmetry.

Introduction

Stress and strain areas are created in different regions of the bone when it receives mechanical load, resulting in bone deposition and resorption as a part of the remodeling process[1]. Since the bone adapts to mechanical loads to obtain the best morphology/resistance relation, it is understood that the skeletal shape is determined mostly by received forces, which was demonstrated in a clinical study[2].

The analysis regarding morphometrical asymmetries of mandibular condyles of both sides, as well as between themselves and mandibular rami landmarks, may contribute in the understanding of a possible participation of the masticatory muscles on mandibular modeling, especially as a predictor of Temporo-Mandibular Disorders (TMDs)[3,4], or even as an aggravating factor of the pathological condition. One must highlight that it can start even during childhood, where the skeleton is still growing [5], which facilitates the formation of asymmetries between the mandibular condyles in adults, although asymptomatic. However, therapeutic results may be limited by this condition[6,7,8].

The importance of the masticatory muscles and the interferences that they cause on mandibular morphology should also be considered as they can also occur in non-syndromic individuals with good dental occlusion[9,10], in individuals with different types of malocclusion[11,12], or even non-significant asymmetries can be found in individuals with unilateral crossed bite[13].

Hence, morphometric data regarding the mandibular condyle and mandibular ramus anatomical structures may provide more data for a safe exam of the mandible, regardless of clinical signs of dental occlusion[9,11,12,13]. Thus, diagnosis and treatment plans tend to be more accurate on different levels of prevention and treatment of TMDs[2].

The present study may provide new data for dentists and physical therapists regarding the anatomical basis for the diagnosis and treatment of TMDs. Hence, the aims of this study were to compare and correlate measures of axes and angles of mandibular condyles and mandibular rami landmarks, both unilaterally and contralaterally.

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Materials and Methods

Ethical Considerations and Sample

According to the Brazilian Federal Law 8.501 (November 30, 1992), and after institutional approval, an *ex vivo* cross-sectional anatomical study was performed using 60 dry human mandibles, which pertained to the Anatomy Divisions of the Institute of Health and Biological Sciences (Federal University of Alagoas, Maceió, Alagoas, Brazil) and the Piracicaba Dental School (University of Campinas, Piracicaba, São Paulo, Brazil).

Mandibles from individuals of both sexes, with no distinction regarding ethnicity or dental occlusion, were eligible. Mandibles had to be in an overall good state of conservation, specially the mandibular ramus landmarks, the mental tubercle, and the inferior margin of the mandibular body. In addition, mandibles had to show signs of third molars eruption or extraction, or any other morphological bone feature indicative of adult individuals[14].

Mandibles from non-adult individuals and mandibles with no anatomical integrity of studied structures were excluded from the sample.

Variables

Measures were obtained from images taken using a digital camera considering the superior, posterior, right, and left views using the software Image J (National Institutes of Health, Bethesda, Maryland, USA). A focal distance of 10cm was respected for all image acquisitions.

The following variables were measured:

1-Antero-medial angle of the condyle (AMAgCd): angle formed by the linear axis between the medial and lateral condyle poles and the median axis that passes through the mental tubercle;

2-Anterior angle of the condyle (AAgCd): angle formed by the axis between the most anterior and posterior points of the mandibular condyles and the axis of the posterior margin of the mandibular ramus;

3-Supero-medial angle of the condyle (SMAgCd): angle formed by the linear axis between the medial and lateral mandibular condyles and the axis of the posterior margin of the mandibular ramus;

4-Antero-posterior length of the condyle (APLCd): length formed by the linear axis between the most anterior and posterior points of each mandibular condyle;

5-Latero-medial length of the condyle (LMLCd): length formed by the linear between the medial and lateral poles of each mandibular condyles;

6-Vertical length of the condylar process (VLCd): length formed by the linear axis that passes through the higher point of the condyle until it reaches a horizontal line that passes through the most concave point of the sigmoid notch;

7-Antero-posterior length of the condylar process' base (APLCdP): length formed by the linear axis, parallel to the horizontal plane, that passes through the most concave point of the sigmoid notch and runs until the most posterior point of the condylar process;

8-Vertical length of the coronoid process (VLCr): length formed by the linear axis that passes through the higher point of the coronoid process until it reaches a horizontal line that initiates on the most concave point of the sigmoid notch;

9-Antero-posterior length of the coronoid process (APLCr): length formed by the linear axis, parallel to the horizontal plane, that runs from the most concave point of the sigmoid notch to the most anterior point of the coronoid process;

10-Angle of the mandibular angle (AgMAg): angle formed between the linear axis of the posterior margin of the mandibular ramus and the linear axis of the inferior margin of the mandibular body;

11-Superior inclination angle of the mandibular ramus (SAgMR): angle formed between the vertical linear axis, perpendicular to the horizontal plane, that runs from the mandibular angle region and the axis of the posterior margin of the mandibular ramus;

12-Posterior inclination angle of the mandibular ramus (PAgMR): angle formed between the linear axis that passes through the lateral pole of the mandibular condyle and the coronoid process (in a superior view) and the antero-posterior axis that runs parallel to the median line drawn over the mental tubercle;

13-Vertical length of the mandibular ramus (VLMR): length formed by the linear axis drawn from the most superior point of the mandibular condyle that touches the posterior margin of the mandibular ramus until it reaches a line that runs backwards from the inferior margin of the mandibular body;

14-Antero-posterior length of the mandibular ramus (APLMR): length formed by the linear axis that passes through the coronoid notch and runs backwards until it reaches the posterior margin of the mandibular ramus (Figure 1).

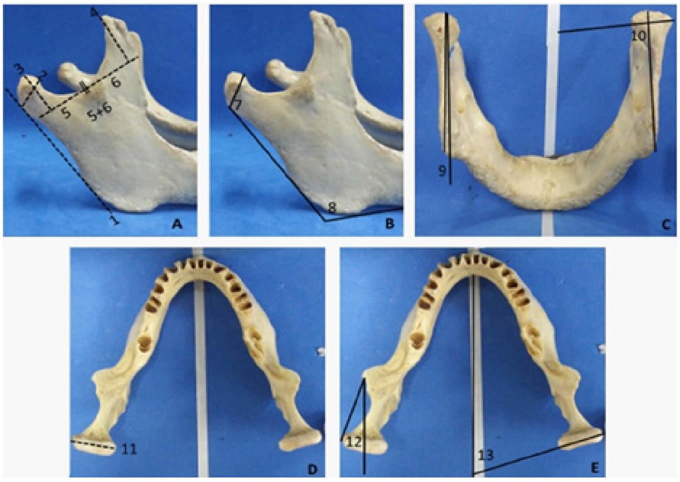

Figure 1. Traces performed to obtain lengths and angles. a) 1- VLMR, 2- APLCd, 3- VLCd, 4- VLCr, 5- APLCdP, 6-APLCr, 5+6- APLMR; b) 7- AAgCd, 8- AgMAg; c) 9- SAgMR, 10-SMAgCd; d) 11- LMLCd; e) 12- PAgMR and 13- AMAgCd.

Statistical Analysis

The Lilliefors test was performed to assess the sample distribution. The Student's t test or the Wilcoxon's test were performed to test the null hypothesis in cases of normal and non-normal distributions, respectively.

Linear correlation analysis was conducted to compare measures of different variables of the same side (i.e. right side versus right side and left side versus left side) and of different sides (right side versus left side). Correlation levels were set as previously described[15]. The Pearson's or Spearman's correlations tests were used for linear correlation analysis depending on the result of the Lilliefors normality test.

The statistical software Bioestat 5.3 (Instituto Marimauá, Brazil) was used to perform the Lilliefors test. The remaining analyzes were conducted on GraphPad Prism 6.01 (GraphPad, San Diego, California, USA). This research set its significance level at 5% and its confidence interval at 95%.

Results

The fourteen studied variables had their right and left sides compared in pairs (Table 1). Considering the standard deviations, 100% of symmetry was shown through the absence of statistical differences of the same variable compared on opposite sides. However, only six of the fourteen outcomes (42,86%) showed significant results (p<0.05), which were the following: antero-posterior length of the condyle (APLCd), vertical length of the condylar process (VLCd), antero-posterior length of the condylar process' base (APLCdP), angle of the mandibular angle (AgMAg); posterior inclination angle of the mandibular ramus (PAgMR); antero-posterior length of the mandibular ramus (APLMR).

Of the 364 correlations that were performed considering all homolateral and contralateral variables, 76 (20,88%) presented significant results, and, of these, there was no perfect correlation or absence of correlation. There were 23 (6,32%) weak correlations (12 positive and 11 negative), 25 (6,87%) moderate correlations (16 positive and 9 negative), 20 (5,49%) strong correlations (10 positive and 10 negative), and eight (2,20%) very strong correlations (four positive and four negative).

Very strong correlations occurred as follows (Table 2): the antero-medial angle of the condyle (AMAgCd) with the supero-medial angle of the condyle (SMAgCd), both homolaterally and contralaterally; similarly, homolateral and contralateral very strong correlations occurred between the anterior angle of the condyle (AAgCd) and the angle of the mandibular angle (AgMAg).

The AMAgCd also showed a strong correlation with the posterior inclination angle of the mandibular ramus (PAgMR). However, this particular correlation occurred only between the right side of the AMAgCd and both sides of the PAgMR. For the remaining strong correlations, a situation where one variable was correlated to other variable for both sides of both variables was not identified (Table 3).

Table 1. Paired comparisons between contralateral variables. SD = standard deviation.

Variables	Mean	SD	p-value	Test
APLMR (right)	37,36	4,00	0,0325*	t test
APLMR (left)	37,16	4,41		
APLCr (right)	22,42	3,03	0,0947	t test
APLCr (left)	23,22	2,64		
VLCr (right)	20,82	3,27	0,6220	t test
VLCr (left)	20,65	3,64		
APLCdP (right)	19,18	2,80	0,0064*	Wilcoxon's test
APLCdP (left)	18,21	2,45		
VLCd (right)	8,80	2,48	0,0237*	t test
VLCd (left)	8,34	2,31		
APLCdP (right)	8,59	1,68	0,0172*	Wilcoxon's test
APLCdP (left)	7,96	1,91		
VLMR (right)	58,37	6,95	0,3986	t test
VLMR (left)	58,91	7,13		
LMLCd (right)	20,04	4,26	0,4366	t test
LMLCd (left)	19,74	4,19		
AgMAg (right)	127,42	7,58	0,0325*	t test
AgMAg (left)	128,69	7,88		
AAgCd (right)	51,26	10,13	0,8508	t test
AAgCd (left)	51,38	9,16		
SAgMR (right)	13,07	5,46	0,2464	Wilcoxon's test
SAgMR (left)	12,38	5,19		
SMAgCd (right)	85,03	9,11	0,5293	t test
SMAgCd (left)	84,44	10,12		
PAgMR (right)	17,59	4,52	0,0041*	t test
PAgMR (left)	15,77	4,75		
AMAgCd (right)	73,86	6,70	0,1381	t test
AMAgCd (left)	75,00	7,01		

* = indicates a significant result.

Table 2. Correlations between different homolateral and contralateral variables. R = correlation coefficient; CI = confidence interval.

Variables in Correlation		r	CI	p-value
AMAgCd (right)	SMAgCd (left)	0,71	0,51 0,83	< 0,0001
AMAgCd (right)	SMAgCd (right)	0,70	0,50 0,83	< 0,0001
AMAgCd (left)	SMAgCd (right)	0,70	0,50 0,83	< 0,0001
AMAgCd (left)	SMAgCd (left)	0,74	0,55 0,85	< 0,0001
AAgCd (right)	AgMAg (left)	-0,84	-0,91 -0,72	< 0,0001
AAgCd (right)	AgMAg (right)	-0,89	-0,94 -0,79	< 0,0001
AAgCd (left)	AgMAg (right)	-0,84	-0,90 -0,71	< 0,0001
AAgCd (left)	AgMAg (left)	-0,93	-0,96 -0,87	< 0,0001

Table 3. Strong correlations between different homolateral and contralateral variables. R = correlation coefficient; CI = confidence interval.

Variables in Correlation		r	CI	P-value
AMAgCd (right)	PAgMR (left)	-0,50	-0,70 -0,22	0,0005
AMAgCd (right)	PAgMR (right)	-0,58	-0,75 -0,33	< 0,0001
LMLCd (Left)	VLCd (Right)	0,42	0,13 0,64	0,0032
LMLCd (left)	VLCd (Left)	0,44	0,15 0,66	0,0021
LMLCd (left)	AgMAg (left)	-0,40	-0,63 -0,11	0,0047
PAgMR (right)	SMAgCd (right)	-0,45	-0,67 -0,17	0,0016
PAgMR (left)	SMAgCd (right)	-0,42	-0,64 -0,12	0,0034
SAgMR (left)	AAgCd (right)	-0,46	-0,68 -0,17	0,0012
SAgMR (left)	AAgCd (left)	-0,44	-0,67 -0,15	0,0019
SAgMR (left)	AgMAg (right)	0,47	0,18 0,68	0,0011
SAgMR (left)	AgMAg (left)	0,45	0,16 0,67	0,0015
AAgCd (right)	VLCd (right)	0,50	0,23 0,70	0,0004
AAgCd (left)	VLCd (right)	0,50	0,22 0,70	0,0005
VLCd (right)	AgMAg (left)	-0,52	-0,72 -0,26	0,0002
VLCd (right)	AgMAg (right)	-0,47	-0,68 -0,19	0,0288
VLCd (left)	AgMAg (left)	-0,40	-0,63 -0,10	0,0050
APLCd (right)	APLMR (right)	0,40	0,11 0,63	0,0048
APLCd (left)	APLMR (right)	0,50	0,21 0,70	0,0005
VLCr (left)	APLCr (left)	0,42	0,13 0,65	0,0030
APLCr (left)	APLMR (left)	0,52	0,26 0,72	0,0002

Discussion

Despite small individual differences regarding contralateral measures of lengths and angles of the mandibular ramus, it was statistically shown that all analyzed variables presented bilateral symmetry, which overcame our initial expectation of 5% of asymmetry.

Previous studies regarding the morphological asymmetry between mandibular condyles indicated that existing differences between sides are not necessarily related to dental occlusion, since people with class I occlusion, and with no temporomandibular disorders, may present asymmetries between contralateral mandibular condyles[14,16]. On the other hand, other studies showed that this asymmetry occurred in individuals with different bite classes, as well as in teenagers with posterior unilateral crossed bites and non-syndromic individuals[15,17,18], even that this posterior unilateral cross bite may coexist with non-significant asymmetries between mandibular condyles[19]. Thus, not living aside dental occlusion, one must focus on the morphological features of bone structures of TMJ and the muscular activity related to this region acting as bone modelling factor not necessarily related to dental occlusion.

Several anatomical structures may induce the appearance of landmarks on bone topography and morphology. Of these, one must highlight the skeletal muscles, and, among these, the masticatory muscles (masseter, temporal, medial pterygoid, and lateral pterygoid muscles), which insert on mandibular ramus structures[14,16]. The strains that these muscles cause on the mandible cause the formation of landmarks and, in addition, contribute to the normal growth and modelling of the general morphology of this bone. This assumes particular importance during childhood and adolescence, when plasticity and bone growth are most intense[3,14].

Considering the areas of insertion of masticatory muscles on the mandibular ramus and the direction of their muscle fibers, as well as the strains that they cause during mandibular movements, one must notice that these muscles participate on the morphological definition of the mandible, especially during the skeleton growth phase [3,4,5]. According to this principle, the anatomical features of the condylar process may be associated to the lateral pterygoid muscle, the mandibular angle to the masseter and medial pterygoid muscles, and the coronoid process to the temporal muscle[3].

The morphometric results from the present study indicate a predominant coherence of strong and very strong correlations when variables of the mandibular ramus are correlated to masticatory muscles performing synergistic and antagonistic roles during movements of opening, closing, protrusion, retrusion, right latero-protrusion, and left latero-protrusion. Theoretically, in this context, positive correlations are related to muscles acting synergistically, and negative correlations are related to muscles acting antagonistically.

AMAgCd and SMAgCd, both influenced by the lateral pterygoid muscles, presented a very strong positive correlation, both unilaterally and bilaterally, which is coherent considering the action of these muscles, especially during opening and protrusion, when both sides act synergistically. However, for right or left latero-protrusion, when only one of the lateral pterygoid muscles will be effectively contracting, the positive correlation may be explained by the balance of movements that occur on both sides of the mandible during the bone growth period, which is corroborated by our results that also showed symmetry between bilateral variables. Other possible explanation may be the fact that latero-protrusive movements are acquired later on in life than opening, closing, protrusion, and retrusion during childhood[5,19,17].

A very strong negative correlation, both unilaterally and bilaterally, was shown for AAgCd and AgMAg, which are influenced, respectively, by the lateral pterygoid muscle for mouth opening and by the masseter muscle for mouth closing. This negative correlation becomes relevant for the antagonistic action between the masseter muscle and the homolateral lateral pterygoid muscle for latero-protrusion; hence, a contralateral synergism occurs. Another explanations for these results are: the balance of movements that occur for both sides, which, as previously discussed in the present study, were considered statistically symmetrical; the proper and balanced function of both sides of the mandible during the bone growth phase; and the fact the latero-protrusive movements are developed later on than the other movements (opening, closing, protrusion, and retrusion) [5,19,17,18].

Strong correlations were found in 20 combination of variables, in both sides (10 negative and 10 positive correlations). Plausible muscle actions[1,2] involved were: the action of lateral pterygoid muscles (eight); the relationship between the lateral pterygoid and masseter muscles (four); the relationship between the medial pterygoid and masseter muscles (two); the relationship between the medial and lateral pterygoid muscles (two); the action of the lateral pterygoid muscle related to the temporal and masseter muscles (two); the relationship between the contralateral temporal muscles (one); and the relationship between the temporal and masseter muscles (one).

The synergistic action of the bilateral lateral pterygoid muscles for opening and protrusion movements may be corroborated by the following strong positive correlations: LMLCd versus VLCd and AAgCd versus VLCd. The antagonistic action between the contralateral lateral pterygoid muscles during latero-protrusive movements may be corroborated by the following negative correlations: PAgMR versus SMAgCd and AMAgCd versus PAgMR.

The antagonistic action between the contralateral masseter and lateral pterygoid muscles for latero-protrusive movements for mastication in one side of the dental arch may be explained by the negative strong correlations between LMLCd versus AgMAg and VLCd versus AgMAg.

The strong positive correlation SAgMR versus AgMAg, may explain the synergistic action between the masseter and medial pterygoid muscles for mouth closing. On the other hand, the negative strong correlation SAgMR versus AAgCd may demonstrate the antagonistic action between the lateral pterygoid muscles (for mouth opening) and the medial pterygoid muscles (for mouth closing).

A strong positive correlation occurred for variables associated to areas of insertion of the temporal muscle with other masticatory muscles that act synergistically. Variables VLCr versus APLCr indicated the bilateral action of temporal muscles on mouth closing and retrusion, and APLCr versus APLMR indicated the correlation between the temporal muscle acting synergistically with the masseter muscle and with the contralateral temporal muscle.

The strong positive correlation found between variables APLCdP versus APLMR may indicate that, among antagonistic muscles (e.g. lateral pterygoid muscle) acting on mandibular retrusion and depression, and the temporal muscle acting on mandibular retrusion and elevation, a strain compensation occurs, that is, a given movement will stimulate an opposite movement in the same way but in different directions.

Considering the results from the present study, it is plausible to consider the importance in preventing TMDs occurrence since childhood, during the breastfeeding phase and when introducing a solid diet for children[1,3,4]. Attention to the jaw posture should be given during day and night, avoiding unilateral chewing and parafunctional activities, such as grinding or clenching teeth and biting nails[1,2]. Altogether, these can cause muscle overload and asymmetrical muscle strain, which by its turn may cause morphological changes on the mandible during the skeletal growth phase that may become permanent on the adult individual[20].

Future studies should compare symmetrical versus asymmetrical patients regarding mandibular ramus landmarks. The diagnosis should be given using computed tomography and electromyography of the masticatory muscles during mandibular movements.

Conclusion

It was shown that the analyzed mandibular ramus landmarks exhibited symmetry, often with positive correlation levels when are modeled by muscles in synergistic actions, and negative correlation levels when are modeled by muscles in antagonistic actions. This shows that there is a plausible interference of masticatory muscles on mandibular morphology by means of modelling caused by different strains generated by these muscles.

Short conclusion

It was shown that the analyzed mandibular ramus landmarks exhibited symmetry, often with positive correlation levels when are modeled by muscles in synergistic actions, and negative correlation levels when are modeled by muscles in antagonistic actions.

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Mini Curriculum and Author's Contribution

1. Matheus Corrêa da Silva, DDS: accountable for obtention of the images and editing, measurement of the mandibles, as well as writing the introduction, method, results. Orcid: 0000-0003-0087-0041

2. Marcus Vinícius Silva Weigel-Gomes, Undergraduated student: accountable for reading the scopus of Journal of Anatomy, conducting the submitting process, writing discussion and conclusion. Orcid: 0000-0001-6858-5015

3. Olavo Barbosa de Oliveira Neto, DDS; MSc; PhD: accountable for obtention of the images, reviewer of the method and statistical analisis. Orcid: 0000-0003-1280-659

4. Cristiano Manoel, MSc.: accountable for helping the method design and obtention of the imagens. Orcid: 0000-0003-1280-659X

5. Alexandre Rodrigues Freire, DDS; MSc; PhD: accountable for mandible selection and helping the method design. Orcid: 0000-0003-1280-659

6. Fernando José Camello de Lima, DDS; MSc; PhD: accountable for the conception of the research, review of method, orientation and final reviewer. Orcid: 0000-0003-1593-7747

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Corresponding author
Fernando José Camello de Lima
E-mail: fernando.camello@hotmail.com