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Mandibular assessment of panoramic radiographs for sex identification

Análise do dimorfismo sexual através de índices radiomorfométricos em radiografias panorâmicas

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ABSTRACT

Sex determination plays a crucial role in the post-mortem identification of human remains. One effective approach for obtaining sex-related data is to use measurements of anatomical structures such as the mandible. This study aimed to evaluate the potential of mandibular radiomorphometric indices from panoramic radiographs (PRs) for the identification of sexual dimorphism. The study sample included 300 PRs of individuals aged 51 to 80 years from the northeastern region of Brazil. Four linear measures and three numerical indices were analyzed with

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Inkscape® version 1.0.1 for Windows by two blinded evaluators. After statistical analysis, the results showed that the linear measurements obtained from PRs are a reliable method for sex identification. However, the calculated indices of these measurements exhibited lower efficacy for the same purpose. Therefore, PRs proved to be a valuable method for sexual identification through mandibular assessment.

Indexing terms: Mandible. Radiography, panoramic. Sex characteristics.

RESUMO

A determinação do sexo é um dado importante para a identificação post-mortem de um indivíduo ou de restos mortais humanos. Uma maneira de adquirir dados quanto ao sexo é utilizar mensurações de estruturas como a mandíbula. O objetivo principal deste estudo é avaliar a utilização de índices radiomorfométricos de mandíbulas para a identificação de dimorfismo sexual, através de radiografias panorâmicas. O estudo foi realizado em exames radiográficos panorâmicos de 300 indivíduos entre 51 e 80 anos, residentes do Nordeste brasileiro. Foram analisadas quatro medidas lineares e três índices numéricos no software Inkscape® versão 1.0.1 para Windows, por dois avaliadores cegos. Após análise estatística, os resultados demostraram que as medidas lineares obtidas se configuram como um método seguro para a identificação sexual. Entretanto, os índices obtidos através destas medidas demostraram menor eficiência para o mesmo fim. Logo, as radiografias panorâmicas podem ser utilizadas como método eficaz para a obtenção da caracterização sexual através da mandíbula.

Termos de indexação: Mandíbula. Radiografia panorâmica. Caracteres sexuais.

INTRODUCTION

Sexual dimorphism refers to morphological differences that exist between males and females [1]. In anthropological examinations for forensic purposes, determining characteristics such as sex, species, ethnic group, age, and height is crucial, as these factors help establish an individual's biological profile, contributing to their identification. The procedures for determining an individual's profile are complex as they involve many factors, and differences can be observed in both soft dental tissues and bones. Facial bones are extremely durable structures and may be the only viable remains after a long post-mortem period or in situations of extreme destruction [1].

The initial step in the identification process is determining the sex, as it serves as the foundation upon which subsequent estimations of age and stature are built. Therefore, sexual dimorphism better directs the search for necessary data and samples for more precise determination. Identification based on morphological measurements yields more accurate results, and these methods can also be used for sex determination based on cranial and mandibular measurements [2].

An individual's bone structure is subject to several variables, including genetics, pathologies, environmental factors, diet, growth, and aging, which collectively lead to variations in bone volume and density between the sexes [3]. Research consistently indicates that male mandibles tend to exhibit significantly larger linear measurements compared to those of females. This trend extends to the overall size of the male skull and mandible, which are generally larger [4,5]. The mandible, in particular, is a crucial point of study due to its distinctive evolutionary changes, resulting in notable differences in shape and size between the sexes. Moreover, its compact and durable bone structure makes it an ideal choice for analysis, as it can often remain intact even in the aftermath of mass disasters and over extended periods [6,7].

Sex estimation can be accomplished through the metric method, which entails taking bone measurements. This method can be applied using imaging techniques like PRs, utilizing indices and formulas to ensure reproducibility and contribute to the validation of results [6,8].

Panoramic radiography is a radiological technique that captures a comprehensive image of the mandible and surrounding structures in a single exposure. Its significance extends to dentistry and forensic science, where it plays a pivotal role [9]. PR stands out as a non-invasive diagnostic method applicable to both living and deceased individuals. The precision of digital PR in delivering anatomical measurements has made it an invaluable tool in forensic science. Moreover, it offers several advantages, including cost-effectiveness, reduced radiation exposure compared to methods such as computed tomography, shorter chair time for patients, and decreased workload for operators, as images can be promptly evaluated after acquisition [10]. Furthermore, PR allows for fine-tuning through contrast and brightness adjustments and offers the option of image enlargement, ensuring a precise and reproducible means of measuring specific points [11].

The use of PR has its limitations, including image overlap, tooth distortions, ghost images, and enlargements [12]. Nevertheless, PR remains widely accessible and cost-effective, leading to its frequent use in combination with radiomorphometric indices (RIs) in various scientific studies, particularly in areas such as osteoporosis and osteogenesis imperfecta [13]. Radiomorphometric indices are instrumental in quantitatively and qualitatively assessing bone morphology through the application of several indices to radiographic images [14]. However, there is a noticeable scarcity of literature regarding the use of RI for sexual dimorphism assessment, underscoring the urgent need for more research on this topic.

METHODS

Study design

This was an observational and cross-sectional study with a descriptive approach, employing quantitative methods. It followed the guidelines outlined by the STROBE initiative (Strengthening the Reporting of Observational Studies in Epidemiology), translated into Portuguese by Malta and colleagues in 2010 [15].

Ethical aspects

This study was conducted in accordance with ethical principles governing research involving human subjects and received approval from the Research Ethics Committee of the Federal University of Ceará (approval number 3,693,553).

Participants

The study used PRs from participants who met specific eligibility criteria, which included individuals of both sexes evenly distributed across age groups of 51-60, 61-70, and 71-80 years.

Examinations with incomplete data, poor image quality, distortion, insufficient contrast or density, or the presence of artifacts obstructing the proper visualization of the mandibular ramus, foramen, notch, condyle, and coronoid process were excluded.

Variables

Sex represented the outcome variable. Quantitative variables included linear measurements D1, D2, D3, and D4, as well as indices of the mandibular notch (MNI), coronoid process (CPI), and height of the mandibular condyle (HMCI).

Data sources/Measurements

The PRs included in the study were obtained using four different panoramic X-ray devices, namely: Kodak K 9000 3D (Kodak Dental Systems, Carestream Health, Toronto, Canada), Eagle X 3D PAN/TELE (Dabi Atlante, Ribeirão Preto, SP, Brazil), VATECH PaX 400-C (Vatech Global, Gangnam Gu, South Korea), and Kodak K 8000 (Kodak Dental Systems, Carestream Health, Toronto, Canada). All examinations were performed with kilovoltage settings ranging from 65 to 75 kVp and milliamperage settings of 8 to 12 mA, with an exposure time of 23 seconds, varying according to patient characteristics (weight and density).

The images were exported in uncompressed JPEG format, and measurements on the images were sequentially performed on the right and left sides by two calibrated and blinded evaluators. For the analyses, the software Inkscape® version 1.0.1 for Windows (https://inkscape.org/pt-br/) was used. Inkscape® is a professional-quality, free, and open-source vector graphics editor [16].

In addition to individual linear measurements, this study also evaluated ratios between measurements of the mandibular ramus, based on a prior study [17]. The measurements included in the analysis were as follows:

D1: Vertical distance from the lowest point of the mandibular notch image to the highest point of the upper border of the mandibular foramen image.

D2: Vertical distance from the lowest point of the mandibular notch image to the image of the lower border of the mandibular ramus, passing through the center of the mandibular foramen.

D3: Vertical distance from the highest point of the coronoid process image to the highest point of the upper border of the mandibular foramen image.

D4: Vertical distance from the highest point of the mandibular condyle image to the highest point of the upper border of the mandibular foramen image.

To standardize measurements, a rectangle was created with its upper side tangent to the lowest point of the mandibular notch image. The rectangle's sides aligned with the lateral edges of the mandibular ramus, and its base touched the lower border of the mandibular ramus image at the center. A straight line was then drawn, touching the upper border of the mandibular foramen image. All vertical lines formed 90° angles, and horizontal lines were set at 0° angles. The study's measurements were based on the positions of these lines (figure 1).

Subsequently, ratios were calculated between the linear measurements to ensure proportionality and eliminate potential influences from differences between panoramic devices. This calculation yielded the following indices:

1. Mandibular notch index (MNI): D2/D1
2. Coronoid process index (CPI): D3/D1
3. Height of the mandibular condyle index (HMCI): D4/D1

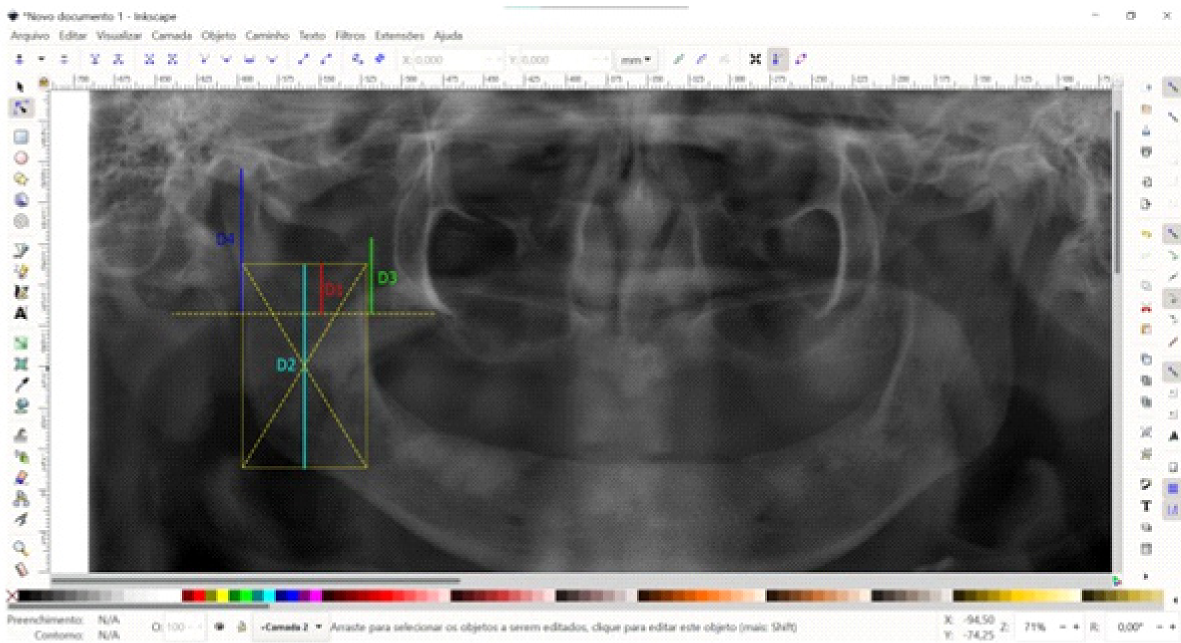

Figure 1. Enlarged RP with mandibular branch on the right side showing the measurements permormed on the software Inkscape®.

Bias control

To minimize potential sources of measurement bias, the evaluation was performed by two calibrated and blinded evaluators who had been previously trained by experts with experience in oral and maxillofacial radiology. Patient data were concealed at the time of analysis by a researcher who did not participate in the study’s measurements. To avoid visual fatigue of the evaluators, the sample was limited to a maximum of 30 PRs per day. Additionally, pixel units of measurement were used to account for variations in image magnification across different panoramic devices. Consequently, this study adopted a comparative approach and did not aim to assess patients’ actual measurements in centimeters [16].

Evaluator training involved two analyses with the same measurements, conducted by both evaluators at a 15-day interval, using 20 PRs randomly selected from those not pertaining to the main sample. Satisfactory intra-examiner reliability (ICC>0.8) and inter-examiner reliability (ICC>0.9) were achieved before subsequent evaluations.

The assessments occurred in a controlled environment with 15.6-inch monitors over consecutive days to minimize interpretation variations. Following the assessments, a precision study involved three consecutive measurements on a randomly selected sample from the study (n=15 for each age group) to ensure measurement reproducibility [18].

Sample size

Based on the study by AKAY, who found a significant difference in the lower Right-PMI measurement between males and females (0.32±0.06 vs. 0.36±0.07, respectively), it was determined that a minimum of 42 PRs per age group was required to achieve a sample with 80% power and 95% confidence (t-test). In this study, a sample of 50 PRs per sex was chosen for each selected age group.

Statistical analysis

The data were presented as mean ± standard deviation and assessed for normality using the Kolmogorov-Smirnov test. Comparison between the right and left sides was performed using the Wilcoxon test for non-parametric data. The mean values between the right and left sides underwent ROC curve analysis to establish a cutoff point indicative of sexual dimorphism. After the categorization of these cutoff points, sensitivity, specificity, positive predictive values, negative predictive values, and accuracy were calculated. All analyses were conducted with a 95% confidence level using SPSS v20.0 software for Windows.

Study limitations

The study's results are not generalizable to the entire Brazilian population as it does not encompass all ethnic and racial groups. Larger and more comprehensive studies are necessary to obtain data representative of the entire country.

RESULTS

The linear measurements D1, D2, D3, and D4 yielded significant results ($p < 0.05$) for differentiating between sexes. Notably, D3 (distance from the top of the coronoid process to the highest point of the mandibular foramen) and D4 (distance from the top of the condyle to the highest point of the mandibular

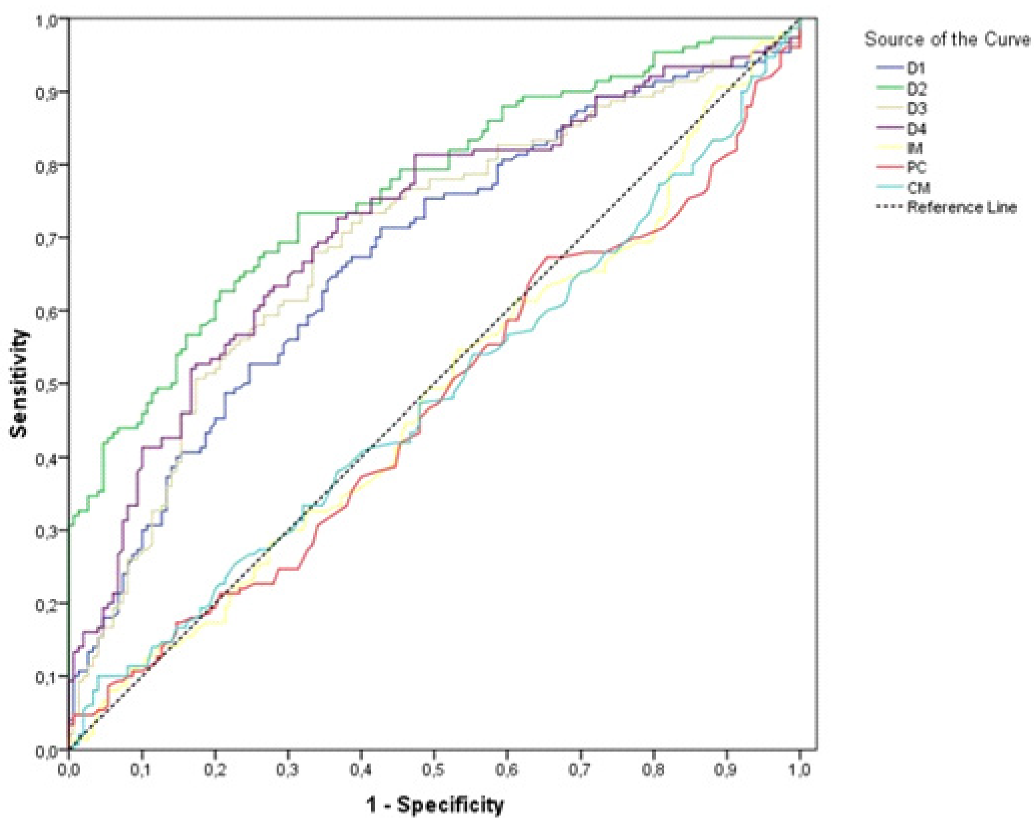

Figure 2. ROC curve of gender predictive parameters.

foramen) exhibited the most significant sex differentiation ($p < 0.001$). Regarding radiomorphometric indices, MNI exhibited statistical significance ($p = 0.011$), while CPI and HMCI did not differ significantly between sexes. Sexual dimorphism was examined for all variables studied.

The ROC curve analysis of predictor parameters for sex demonstrated that linear measurements D1 to D4 were the most sensitive for distinguishing between sexes, while MNI, CPI, and HCMI indices were not significant (figure 2 and table 1). These measurements exhibited significant values ($p < 0.001$) for sex differentiation and established cutoff values, with lower values associated with the female sex. The tests showed sensitivity, specificity, and accuracy for sexual dimorphism, with high positive and negative predictive values (>60%) [table 3].

The assessed tests displayed accuracy across all age groups included in the study (51 to 80 years), with the 61-70 years age group showing the highest accuracy values, exceeding 70% for all linear measurements (table 4).

Table 1. Mean values from the radiographic study of the mandible.

	Side			
	R	**L**	**P-Value**	**Mean**
Measurement				
D1	48.72±11.02	49.66±10.85	**0,003**	49.19±10.36
D2	171.48±25.99	172.44±25.99	**0,046**	171.96±25.53
D3	93.56±17.82	96.36±18.67	**<0,001**	94.96±17.43
D4	108.43±19.43	110.83±19.31	**<0,001**	109.63±18.67
MNI	3.63±0.57	3.57±0.55	**0,011**	3.60±0.50
CPI	1.96±0.33	1.98±0.32	**0,502**	1.97±0.30
MCHI	2.29±0.40	2.29±0.38	**0,722**	2.29±0.36

Note: *p<0,05, Wilcoxon signed-ranks test (mean ± SD). R = right; L = left.

Table 2. Area under the ROC curve and cut-off point obtained in the study.

	p-Value	**AUC (Mean ± SD, CI95%)**	**Cut off point**
Measurement			
D1	**<0,001**	0.675±0.031(0.614-0.736)	48
D2	**<0,001**	0.765±0.027(0.712-0.819)	170
D3	**<0,001**	0.694±0.031(0.634-0.754)	95
D4	**<0,001**	0.716±0.030(0.657-0.774)	110
MNI	**0,581**	0.482±0.033(0.416-0.547)	-
CPI	**0,351**	0.469±0.033(0.403-0.534)	-
MCHI	**0,581**	0.482±0.033(0.416-0.547)	-

Note: AUC = area under ROC curve.

Table 3. Cutoff values between sexes, sensitivity, specificity, positive predictive value (VPP), negative predictive value (NPV) and accuracy of the tests.

	Sex						
	Female	Male	Sensitivity	Specificity	PPV	NPV	Accuracy
D1							
≤ 48	91	49	67,3%	60,7%	63,1%	65,0%	64,0%
>48	59	101					
D2							
≤ 170	96	40	73,3%	64,0%	67,1%	70,6%	68,7%
>170	54	110					
D3							
≤ 95	100	53	64,7%	66,7%	66,0%	65,4%	65,7%
>95	50	97					
D4							
≤ 110	101	50	66,7%	67,3%	67,1%	66,9%	67,0%
>110	49	100					

Note: PPV = positive predictive value; NPV = negative predictive value.

Table 4. Values distributed by age group.

1 of 2

	Sex						
	Female	Male	Sensitivity	Specificity	PPV	NPV	Accuracy
51-60 years							
D1							
≤48	29	20	60,0%	58,0%	58,8%	59,2%	59,0%
>48	21	30					
D2							
≤ 170	33	19	62,0%	66,0%	64,6%	63,5%	64,0%
>170	17	31					
D3							
≤ 95	36	24	52,0%	72,0%	65,0%	60,0%	62,0%
>95	14	26					
D4							
≤ 110	29	21	58,0%	58,0%	58,0%	58,0%	58,0%
>110	21	29					
61-70 years							
D1							
≤ 48	38	16	68,0%	76,0%	73,9%	70,4%	72,0%
>48	12	34					

Table 4. Values distributed by age group.

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	Sex						
	Female	Male	Sensitivity	Specificity	PPV	NPV	Accuracy
D2							
≤ 170	37	9	82,0%	74,0%	75,9%	80,4%	78,0%
>170	13	41					
D3							
≤ 95	38	13	74,0%	76,0%	75,5%	74,5%	75,0%
>95	12	37					
D4							
≤ 110	42	15	70,0%	84,0%	81,4%	73,7%	77,0%
>110	8	35					
71-80 years							
D1							
≤ 48	24	13	74,0%	48,0%	58,7%	64,9%	61,0%
>48	26	37					
D2							
≤ 170	26	12	76,0%	52,0%	61,3%	68,4%	64,0%
>170	24	38					
D3							
≤ 95	26	16	68,0%	52,0%	58,6%	61,9%	60,0%
>95	24	34					
D4							
≤ 110	30	14	72,0%	60,0%	64,3%	68,2%	66,0%
>110	20	36					

Note: PPV = positive predictive value; NPV = negative predictive value.

DISCUSSION

Radiomorphometric indices are used to assess bone morphology, both qualitatively and quantitatively in imaging examinations. These indices involve the application of various metrics to radiographic images, with a primary focus on measuring cortical bone, which is more readily distinguishable in radiographs compared to trabecular bone [14].

This methodology holds significant importance in forensic research, especially in cases where the identification of skull fragments based on dental arches is unlikely. In such instances, sex determination is essential to promptly rule out multiple hypotheses but also contribute to the development of a biological profile of human remains, thus moving closer to a compatible identification [14].

In a study conducted by Saloni et al. in 2020, an accuracy rate of 77.6% was achieved in sex identification using alternative indices. This underscores the practicality of sex determination through radiomorphometric indices of the mandibular ramus, mirroring the outcomes of our study. In our investigation, the overall accuracy of linear measurements D1-D4 was found to be 66.35% [2].

In the present research, several measurements of parameters related to the mandibular ramus, condyle, and coronoid process were examined and utilized to predict the biological sex of the individual depicted in the panoramic image. The findings indicated that the values obtained were notably greater in males compared to females, and this difference was statistically significant ($P < 0.001$). These results align with the current literature, which suggests that male bones typically exhibit larger dimensions than female bones [2,19]. The accuracy of the predictions exceeded 60% for all linear measurements analyzed. However, the radiomorphometric indices used did not differ significantly between both sexes, except for the MNI, which showed statistical significance ($p=0.011$).

Moreover, in a study by More, Vijayvargiya, and Saha in 2017, as well as in the present study, PRs were used to assess differences in condyle and ramus height, with significant results being observed in the measurement of these parameters [20]. In our study, we found that these parameters were significantly different between the sexes ($p<0.001$). As suggested in the study by Saloni and colleagues, areas of bone remodeling have the highest potential for sexual dimorphism [2].

Nevertheless, the measurements that exhibited the most pronounced sexual dimorphism were D3 (distance from the highest point of the coronoid process to the highest point of the mandibular foramen) and D4 (distance from the highest point of the condyle to the highest point of the mandibular foramen), both with $p < 0.001$. In a study conducted by Satish in 2017 [6], the parameter displaying the highest sexual dimorphism was the height of the mandibular ramus, followed by the width of the mandibular angle.

Consistent with the findings of this study, the mandibular ramus and condyle exhibit greater sexual dimorphism, primarily because of their association with the most substantial morphological size changes during growth [2]. Consequently, measurements of the mandibular ramus can serve as reliable indicators for sex determination [6]. Additionally, our analysis revealed that the coronoid process also significantly differs between sexes.

In the study conducted by Pokhel in 2013 using similar metric methods to those employed in our study, a minimum accuracy of 60.3% was achieved for sex determination using the mandible. In line with these findings, our research underscores the mandible's potential effectiveness in distinguishing an individual's sex, with the height of the mandibular ramus and the distance from the highest point of the mandibular condyle to the highest point of the upper border of the mandibular foramen emerging as the most accurate measures for sex estimation, yielding accuracies of 68.7% and 67%, respectively [21].

CONCLUSION

Linear measurements taken from the mandibular condyle, ramus, and coronoid process proved to be effective in discerning sexual dimorphism, particularly within the age group of 61-70 years. In general, females exhibited smaller measurements. Notably, the radiomorphometric indices used in our analysis did not exhibit significant differences between the sexes.

Collaborators

The authors AL Santos and KTS Pinheiro were responsible for the radiographic examinations, the formal analysis and conceptualization of the statistical results, and the writing of the present manuscript. LM Kurita and

EC Ribeiro contributed as advisors throughout the research, in addition to designing the research project, obtaining funding from UFC (Federal University of Ceará) and FUNCAP (Cearense Foundation for Scientific and Technological Development), and supervising each stage of the study. PGB Silva contributed to data curation and statistical analysis, as well as designing the relevant images for data interpretation. FWG Costa and ASW Aguiar conducted the final review of the manuscript, including necessary considerations and corrections during the writing of the paper.

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