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Do variations in craniofacial shape and size allow the identification of dental malocclusions?

Variações da forma e do tamanho craniofacial permitem identificar maloclusões dentárias?

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ABSTRACT

Based on the Angle's classification, to identify and compare changes in the shape and size of the craniofacial region in lateral teleradiographs of the face of individuals with dental malocclusions. This is a cross-sectional analytical study carried out using morphometric analysis of teleradiographs of adult individuals with Class I, II and III malocclusions. With the aid of conventional craniometric and cephalometric points, anatomical landmarks and semilandmarks were inserted. For the verification of the shape variation, MANOVA, canonical variable analysis, Mahalanobis and Procrustes distances, discriminant function and cross-validation were carried out. One-way ANOVA was also carried out for size, based on the size of the centroid. On the teleradiographs, significant differences ($p<0.05$) were found between the craniofacial shapes of the three groups, based on MANOVA. From the deformation grids, it was possible to observe variations in the mentonian and anterior maxillary regions. The variation in the shape of the structures was more pronounced in the teleradiographs of the Class III group. The measurements of the Mahalanobis and Procrustes distances were greater in the teleradiographs with Class II and III malocclusions, corroborating the results found by cross-validation. Size differences ($p<0.05$) were found, using the one-way ANOVA and Tukey's test, when comparing Class I individuals with the other groups. Geometric morphometrics helped us to identify variations in the shape and size of craniofacial structures. This technique, when applied to lateral teleradiographs, proved to be a promising auxiliary method for characterizing dental malocclusions, according to Angle's classification.

Keywords: Angle's Classification. Canonical Variates. Malocclusion. Multivariate analysis.

RESUMO

A partir da classificação de Angle, identificar e comparar alterações na forma e no tamanho da região craniofacial em telerradiografias laterais de face de indivíduos portadores de maloclusões dentárias. Trata-se de um estudo analítico transversal, realizado por meio da análise morfométrica de telerradiografias de indivíduos adultos portadores de maloclusões Classes I, II e III. Com o auxílio de pontos craniométricos e cefalométricos convencionais, marcos e semimarcos anatômicos foram inseridos. Para a verificação da variação da forma, realizou-se a MANOVA, análise de variável canônica, distância de Mahalanobis e Procrustes, função discriminante e validação cruzada. Também foi realizada a one-way ANOVA para o tamanho, com base no tamanho do centroide. Nas telerradiografias, foram encontradas diferenças significativas ($p<0,05$) entre as formas craniofaciais dos três grupos, a partir da MANOVA. A partir das grades de deformação, foi possível observar variações nas regiões mentoniana e anterior de maxila. A variação na forma das estruturas foi mais acentuada em telerradiografias do grupo com Classe III. As medidas das distâncias de Mahalanobis e de Procrustes foram maiores nas telerradiografias com maloclusões Classes II e III, corroborando com os resultados encontrados pela validação cruzada. Diferenças de tamanho ($p<0,05$) foram encontradas, a partir da one-way ANOVA e do teste de Tukey, ao comparar indivíduos Classe I com os demais grupos. A morfometria geométrica permitiu identificar variações da forma e do tamanho das estruturas craniofaciais. Essa técnica, quando aplicada às telerradiografias laterais, mostrou-se um método auxiliar promissor para caracterizar as maloclusões dentárias, segundo a classificação de Angle.

Palavras-chave: Análise multivariada. Classificação de Angle. Maloclusão. Variável canônica.

INTRODUCTION

Malocclusions are clinically significant variations of the normal growth and development of occlusions, characterized by deviations from normality of the dental arches, facial bones, or both. These changes imply several consequences for the functions of the stomatognathic system, and individuals' appearance and self-esteem (Bresolin, 2000).

The Angle classification is one of the most used instruments to record malocclusions (Foggiato et al., 2019). This method mainly considers the position of the first molar teeth, divided into three groups: Class I (neutrocclusion), Class II (distocclusion), which can still be subdivided into two types, and Class III (mesiocclusion) (Mageet, 2016; Foggiato et al., 2019). Analyses performed on conventional cephalometric radiographs, which combine linear and angular measurements or indices derived from such measurements, are also used in the complementary diagnosis of dental malocclusions (Freudenthaler, Čelar, Ritt & Mitteröcker, 2017).

However, these cephalometric measurements do not provide a detailed description of craniofacial morphology, since conventional tracings are limited to landmarks, straight lines, and angles. These deficiencies can be overcome by means of geometric morphometrics (GM), as it is a method based on Cartesian coordinates generated from anatomical landmarks (Freudenthaler et al., 2017; Kouli, Papagiannis, Konstantoni, Halazonetis & Konstantonis, 2019; Woon et al., 2019).

This technique consists in a statistical study of shape variation associated with causal factors. That is, in addition to quantifying the biological forms, the technique seeks to infer about the causes of such differences, which can play a significant role in the complementary diagnosis of pathologies, generating the interest of different areas of knowledge (Bookstein, 1997; Menezes & Sforza, 2010).

Therefore, in order to better understand the influence of malocclusions on facial morphology and phenotype, GM was used, as it is understood that this method has a better capacity to identify variations in the shape of facial structures, and can thus be used as an alternative approach to support the complementary diagnosis of these malocclusions.

Based on this assumption, the aim of this study was to identify and compare changes in the shape and size of the craniofacial region in face lateral cephalometric radiographs of individuals with dental malocclusions, based on the Angle's classification.

MATERIALS AND METHODS

This is a cross-sectional analytical study, carried out based on the use of geometric morphometrics in the face lateral cephalograms, obtained from the radiographic image bank of a private diagnostic imaging clinic in the city of Vitória da Conquista, Brazil. The study was approved by the Research Ethics Committee of the State University of Southwestern Bahia, Brazil, under number 28805020.7.0000.0055 (CAAE).

To compose the sample, radiographic images obtained from complete orthodontic documentation were used, randomly selected. All lateral cephalograms were obtained between 2017 and 2020 in the same digital cephalostat (Orthophos Plus DS®, Sirona Dental System, Bensheim, Germany).

In addition, the following exclusion criteria were considered: radiographs of patients with tooth loss or agenesis, teeth in intraosseous evolution (except third molars), evidence of previous orthognathic surgery, facial trauma, previous or ongoing orthodontic treatment, dental anomalies, and radiographs with poor image quality. Thus, 154 lateral cephalograms of individuals of both genders, aged between 18 and 56 years, were randomly selected, being sorted according to the Angle's classification (Mageet, 2016), from intraoral photographs contained in the respective orthodontic documentation.

In tpsUtil (Rohlf, 2010), the radiographic images were processed and a file with the TPS extension was generated. From this file, anatomical landmarks and semilandmarks were inserted using the tpsDig2 (Rohlf, 2015) program. In each of the teleradiographs, 14 points were selected, being five anatomical landmarks and nine anatomical semilandmarks (Figure 1), by a previously calibrated examiner.

The points were selected to ensure an adequate representation of the craniofacial morphology, and were distributed both on the face and on the skull base. Some of these reference points were chosen to correspond to those commonly used in traditional cephalometric systems in the assessment of lateral cephalograms, which are familiar to most dental surgeons, especially orthodontists, to determine malocclusion (Wellens, Kuijpers-Jagtman & Halazonetis, 2013). In addition, some of these reference points have been used in other studies (Woon et al., 2019; Ferreira, Nunes, Pithon, Maia & Casotti, 2020; Pereira, Silva, Assis, Casotti & Nunes, 2021). Table 1 describes the anatomical landmarks and semilandmarks used.

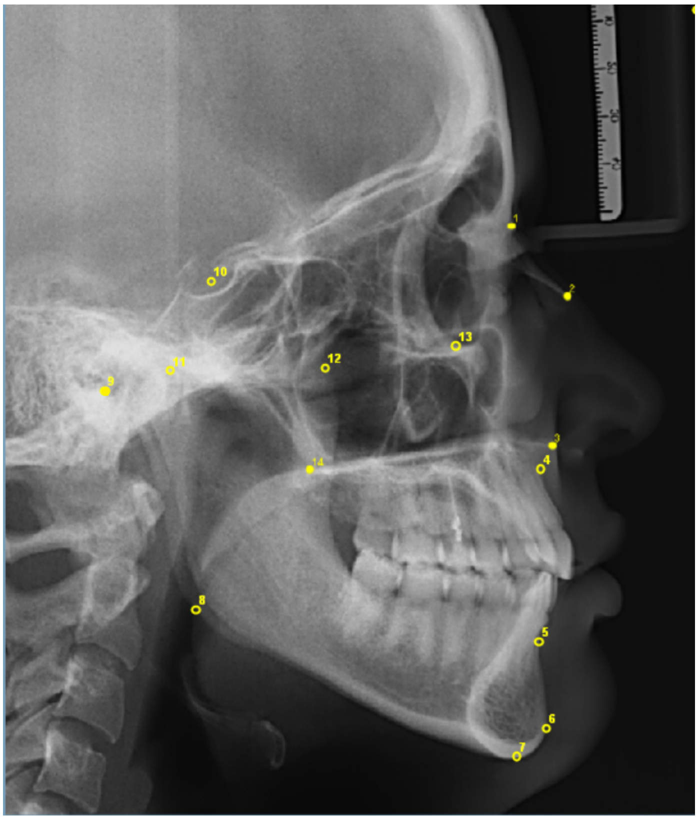
In order to assess the calibration of the examiner responsible for identifying the anatomical landmarks and semilandmarks in the radiographic images, 30 teleradiographs were randomly selected, in which the anatomical points were marked by the same operator in duplicate, with an interval of three days between markings, in order to rule out and test the effect of measurement error, as proposed by Palmer (1994).

The verification of the operator's calibration was confirmed by the Procrustes ANOVA test using the MorphoJ software (Klingenberg, 2015). This analysis made it possible to verify that the variation occurred as a function of the studied object (radiographic images), rather than the meter, as suggested by Palmer (1994). After this calibration process in the 154 selected teleradiographs, the anatomical points were marked, followed by the GM analyses.

With the aim of optimizing the position of the semilandmarks in relation to the average shape, alignment was carried out in the tpsRelw program (Rohlf, 2003). In this process, the Procrustes' least squares method was used, thus turning the semilandmarks into reliable anatomical landmarks (Mitteroecker & Gunz, 2009). Subsequently, from the coordinates generated by the landmarks of each of the teleradiographs, the Procrustes superimposition was performed. This step was responsible for converting the original data into shape coordinates, eliminating position, direction, and scale effects (Mitteroecker & Gunz, 2009).

Figure 1

Lateral teleradiography of the face with 14 reference points used for morphometric analysis. Anatomical landmarks (closed points) and anatomical semilandmarks (hollow points).



Source: The authors.

Regression analysis was performed to examine the impact of allometry on development, that is, the shape variation as a function of size was evaluated, considering the size of the centroid. Multivariate analysis of variance (MANOVA), canonical variable analysis (CVA), Mahalanobis and Procrustes distances, as well as the application of discriminant function and cross-validation were conducted to assess the variation in the shape of the structures, using the MorphoJ software (Klingenberg, 2015).

Finally, the assessment of size disparities was conducted using the PAST software (Hammer, Harper & Ryan, 2001), based on the size of the centroid. This is calculated as the square root of the sum of the distances of the squares obtained from the anatomical landmarks and their centroids (Klingenberg, 2011). With the purpose of verifying whether there were generalized variations in the size of individuals (Pereira, Silva, Assis, Casotti & Nunes, 2021), ANOVA and Tukey's test were applied.

Also, according to Klingenberg (2011), the size of the centroid is the square root of the sum of the squared distances of a set of reference points from its centroid or, equivalently, the square root of the sum of the variances of the reference points about this centroid in the X and Y directions. This parameter is used in geometric morphometrics, because it is approximately uncorrelated with all shape variables when the reference points are distributed around average positions by independent noise of the same small variation at each reference point and in all directions. This is a measure of size used to scale a configuration of reference points so that they can be plotted as a point in Kendall shape space. The denominator of the formula for the Procrustes distance between two sets of reference point configurations is the product of their centroid sizes.

Table 1
Description of anatomical landmarks and semilandmarks used in the morphometric analysis.

Anatomical landmark	Description	Classification
1	Anterior region of the frontonasal suture.	Anatomical landmark.
2	Lower border of nasal bone.	Anatomical landmark.
3	Anterior nasal spine.	Anatomical landmark.
4	Greater concavity in the anterior portion of the maxilla.	Anatomical semilandmark.
5	Greater concavity in the anterior portion of the mental symphysis.	Anatomical semilandmark.
6	Most anterior region of the anterior contour of the mental symphysis.	Anatomical semilandmark.
7	Most anterior and inferior region of the mental symphysis.	Anatomical semilandmark.
8	Lower and posterior region of the mandible.	Anatomical semilandmark.
9	External acoustic meatus.	Anatomical landmark.
10	Center of the Turcian cell.	Anatomical semilandmark.
11	Most superior point of the condyle.	Anatomical semilandmark.
12	Most superior point of the coronoid process.	Anatomical semilandmark.
13	Lowermost region of the lower limit of the orbit.	Anatomical semilandmark.
14	Posterior nasal spine.	Anatomical landmark.

Source: The authors.

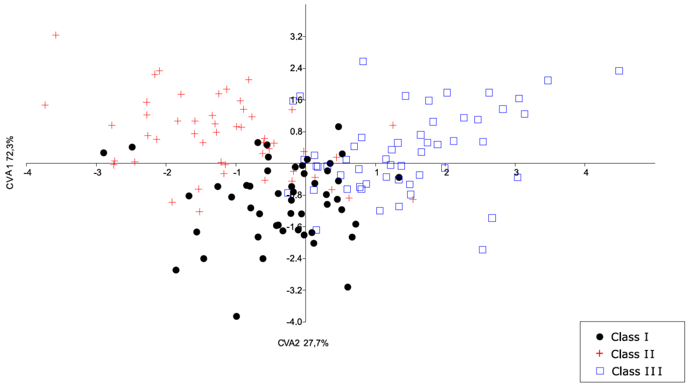
RESULTS AND DISCUSSION

A total of 154 lateral teleradiographs of the face of individuals aged between 18 and 56 years, with a mean age of 25.4 years (SD±6.52) was assessed. Of this total, 101 (65.6%) were women and 53 (34.4%) were men. As for occlusion, using the Angle's classification as a reference, 32.5% (n=50) of the teleradiographs showed individuals with neutrocclusion (Class I), 32.5% (n=50) distoclusion (Class II) and 35.5% (n=54) mesiocclusion (Class III).

The regression analysis carried out to verify the presence of the allometry effect showed insignificant values ($p>0.05$). In other words, there was no interference from the size of the anatomical structures on the shape. Significant differences ($p<0.05$) between the craniofacial shapes of the three groups were revealed by MANOVA.

After the CVA, it was observed that the first two canonical variates accumulated 100% difference in the lateral view between the groups. The first explains 72.3%, separating the Class III individuals from the Class II group, while the second one explains 27.7%, separating Classes I and II (Figure 2).

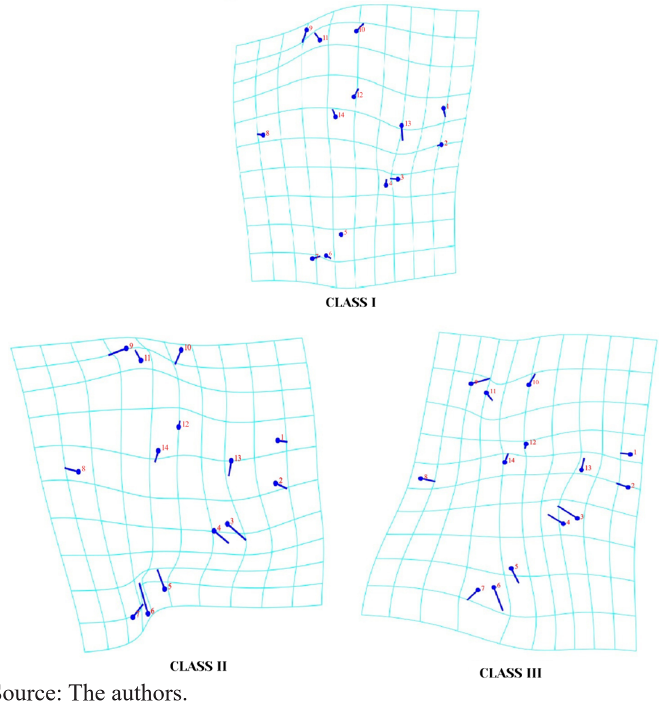
Figure 2
Scatter plot indicating differences in the craniofacial shape of individuals with Class I, II and III malocclusions, based on the analysis of canonical variates.



Source: The authors.

To visualize the differences in the shape of the analyzed structures, the deformation grid was used, which has as its principle the interpolation of surfaces or deformed images (Gunz & Mitteroecker, 2013). By analyzing these deformation grids, it was possible to visualize the differences in shape in the face structures between the groups (Figure 3).

Figure 3
Deformation grid indicating the variation in the shape of structures between Classes I, II and III individuals.



Source: The authors.

Based on the deformation vectors, in individuals with distoclusion (Class II), greater compression was observed in the chin region indicated by points 5, 6 and 7, as well as in the region of the external acoustic meatus and condyle head corresponding to points 9 and 11, respectively. In addition, an expansion area in the region of the mandibular angle, signaled by the deformation of point 8 was observed. Likewise, the expansion of the anterior region of the maxilla, expressed by points 3 and 4, was clear. These findings indicated a tendency to mandibular retrognathism in this group.

Still considering the deformation grid, it was found that in the group with mesiocclusion (Class III) the regions of greatest variation were like those of Class II, however, the behavior of these variations was the opposite in the same points mentioned above, indicating mandibular prognathism. Furthermore, a variation in maxillary inclination was observed among individuals classified as Class II and Class III, as can be seen through landmarks 3 and 14. As to individuals with neutrocclusion (Class I), distinct variations were identified in relation to the observations in the other groups, showing no tendency to retrognathism or maxillomandibular prognathism.

Significant differences ($p<0.01$) were obtained through the analysis of the discriminant function with 10,000 permutations. In the cross-validation, we could observe that, in Class I and Class II groups, 68% of the individuals were correctly classified within each group. On the other hand, among the Class I and Class III groups, the value found was 73%. Between Class II and Class III, 80% of the cases were correctly classified.

The Mahalanobis and Procrustes distance measurements, with 10,000 permutations, also showed statistically significant differences ($p<0.01$) between the groups. In addition, it was demonstrated that the greatest distances were between individuals with Class II and Class III malocclusions, corroborating the cross-validation outcome (Table 2).

Table 2

Procrustes and Mahalanobis distances, after 10,000 permutations, shown on the upper and lower diagonals, respectively.

	Class I	Class II	Class III
Class I	0	0.0196*	0.0319*
Class II	1.8062*	0	0.0430*
Class III	2.1573*	2.6309*	0

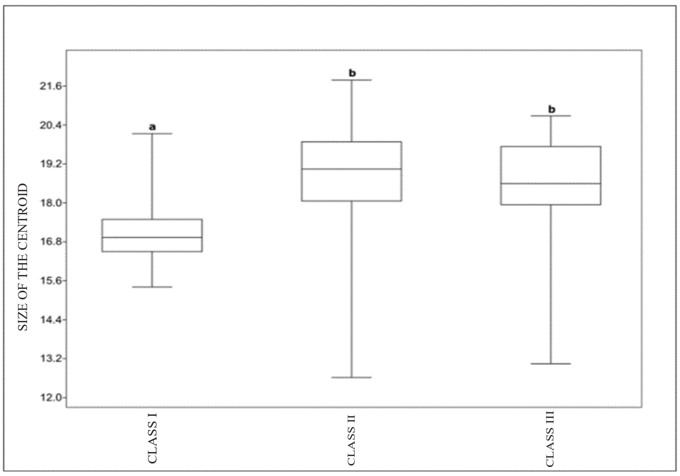
*$p<0.01$.

Source: The authors.

Statistically significant differences in size ($p<0.05$) were found by means of ANOVA and Tukey's test when comparing individuals with neutrocclusion (Class I) with the other groups, since they tended to have smaller craniofacial structures (Figure 4).

Figure 4

Boxplot showing the analysis of the centroid size, indicating the variation between Class I, II and III individuals.



Source: The authors.

Note. *Tukey Test: [a, b] different letters indicate statistical difference between groups ($p<0.05$).

GM is a statistical tool that stems from the advances in multivariate statistics and computer technology, with the aim of investigating the shape and size of organisms and biological structures, allowing the identification of morphological changes associated with variables (Mitteroecker, Gunz, Windhager & Schaefer, 2013).

Moreover, as inferred by other studies (Sigirli & Ercan, 2013; Nunes, Jesus, Casotti & Araújo, 2018; Pinto, Carmo, Sales, Nunes & Casotti, 2020; Pereira et al., 2021), this technique presents great potential for investigating the effects of environmental factors, diseases, and systemic conditions on organisms, as it helps to identify shape peculiarities, through statistical analysis, based on anatomical landmarks (Altemus & Epps, 1974).

The use of GM to identify malocclusions in a Brazilian population differentiates this investigation from previous studies. Through this technique, the shape and size of the craniofacial complex can be retrieved and described in detail, without being subjected to a fragmented analysis of angles and proportions, which is considered a problem inherent to conventional cephalometry (Kouli, Papagiannis, Konstantoni, Halazonetis & Konstantonis, 2019).

Based on the results of the present study, it was observed that GM is a sensitive technique for the identification of craniofacial alterations found among the different groups of malocclusions, corroborating previous studies carried out with some specific populations (Freudenthaler et al., 2017; Woon et al., 2019). The absence of an allometric effect can probably be explained by the fact that the images analyzed belonged to individuals who were over 18 years of age, characterized by the progressive deceleration of craniofacial growth (Eto & Mazzieiro, 2005).

The use of GM in lateral facial teleradiographs has shown to be a promising method for the characterization of dental malocclusions. This technique helped to correlate these malocclusions with craniofacial morphology. These findings corroborate the results obtained by Woon et al. (2019), whose study used GM in the evaluation of malocclusions by means of cephalometric tracings in an adult population in Malaysia. According to these authors, the shape of the craniofacial skeleton is clearly associated with the classification of malocclusion, with considerable variations. They also report that GM is a promising alternative technique for the complementary diagnosis of malocclusions.

The variation in the shape of the facial structures was more marked in individuals with Class III malocclusion, thus allowing them to be distinguished from the other groups. This implies that morphology seems to play a more significant role in this group, endorsing what had already been found in a study by Freudenthaler et al. (2017), carried out in a Caucasian population, in which the GM was used to assess, from lateral teleradiographs of the face, Class I, II and III malocclusions and anterior open bite. Also, according to these authors, among the structures assessed, the position and shape of the mandible contributed to differences between Class II and Class III groups, while the maxillary shape showed less variation. In addition, they highlighted a greater correlation of craniofacial morphological alterations in Class III individuals.

In the meantime, differences in the shape, size and inclination of the maxilla and mandible help to explain the variation of the individuals' craniofacial phenotypic characteristics and malocclusions (Profitt & Fields, 1999). Corroborating this, in this study we observed differences in the maxillary inclination of Class II and Class III individuals in relation to Class I. In addition, the other maxillomandibular alterations also contributed to differentiating and characterizing the craniofacial phenotype of the groups. Furthermore, in the population group analyzed in this study, the largest Mahalanobis and Procrustes distances were observed from the radiographic images of individuals with Class II and III malocclusions.

Regarding the size of the anatomical structures evaluated from the teleradiographs, it was observed that individuals classified as Class I tended to have smaller craniofacial structures when compared to Class II and III. This suggests that the craniofacial shape is not the only factor responsible for the emergence of these malocclusions. Similar findings have also been described in the literature, in studies conducted with other populations (Uribe, Vela, Kummet, Dawson & Southard, 2013; Uribe et al., 2014; Freudenthaler et al., 2017; Woon et al., 2019). Thus, it can be inferred that craniofacial size has a probable influence on dental malocclusions. This finding should prompt further investigations, which will allow a better understanding of the mechanisms that interfere with dental malocclusion.

The limitations of this work include the lack of ethnic classification of the individuals, the use of two-dimensional images (lateral teleradiographs of the face) and the fact that it is a cross-sectional study, which makes it impossible to establish cause and effect relationships between the variables. Despite this, it is important to highlight that these limitations did not interfere with the results obtained.

The results of this study made it possible to verify that GM allows the identification of variations in the shape and size of facial structures associated with different malocclusions. By means of this technique, it was possible to verify the origin, direction, and location of the morphological alterations, thus helping significantly to the understanding of how such alterations occur at the bone level. These findings confirm that this technique can be seen as a powerful tool to identify morphological changes in the face.

CONCLUSION

The GM allowed the identification of variations in the shape and size of craniofacial structures in lateral teleradiographs of the face of both genders with Class I, II and III malocclusions. The alterations observed were located mainly in the chin region and in the anterior region of the maxilla. Shape variation tends to play a more significant role in mesiocclusion (Class III). Thus, the use of GM for the analysis of these images of teleradiographs of young adults with dental malocclusions proved to be a promising auxiliary method capable of individually characterizing the different malocclusions proposed by Angle, it also allows the identification of the places where the variations in the shape of the facial structures occurred.

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CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest.

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AUTHOR CONTRIBUTIONS

Conceptualization: A. P. S., C. A. C. *Data curation*: A. P. S., R. C. D. V. A., C. A. C., L. A. N. *Formal analysis*: A. P. S., L. A. N., C. A. C. *Funding acquisition*: C. A. C. *Investigation*: A. P. S., L. A. N., C. A. C. *Methodology*: A. P. S., L. A. N. *Project administration*: C. A. C. *Resources*: L. A. N., R. C. D. V. A. *Software*: L. A. N., A. P. S. *Supervision*: L. A. N., R. C. D. V. A., P. E. S. M., H. J. M., C. A. C. *Validation: A. P. S., L. A. N., H. J. M., P. E. S. M., C. A. C. Visualization: A.* P. S., L. A. N., C. A. C. *Writing the initial draft*: A. P. S., C. A. C. *Revision and editing of writing*: A. P. S., L. A. N., H. J. M., P. E. S. M., C. A. C.

PEER REVIEW

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