INVESTIGATION

Pattern of shape variation of the mandibular dental arch in a sample from the Metropolitan Region of Chile

Patrón de variación de la forma del arco dentario mandibular en una muestra de la Región Metropolitana de Chile

Padrão de variação na forma do arco dentário mandibular em uma amostra da Região Metropolitana do Chile

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Abstract

Objectives: Describe the pattern of shape variation of the mandibular dental arch in a sample from the Metropolitan Region through an observational, cross-sectional study.
Methods: 18 landmarks on 134 standardized photographs of dental casts were digitized, and a Procrustes analysis was performed.
Results: The size of the centroid in men was significantly larger than in women. Discriminant analysis with gender cross-validation did not show significant differences in the shape components. The variation pattern in the shape of the dental arches is mainly explained by PC1 (50.1% of the total variation, anteroposterior variation) and PC2 (13.3%, transverse variation).
Conclusions: Given the morphological continuity that is observed when performing a statistical analysis of the variation pattern in shape and size of the arch applying geometric morphometric tools, the use of preformed templates for determining the shape of the dental arch should be reconsidered.

Keywords (MeSh): dental arch; orthodontics; analysis, principal component.

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Resumen

Objetivos: Describir el patrón de variación de la forma de la arcada dentaria mandibular en una muestra de la Región Metropolitana mediante un estudio observacional, transversal.

Métodos: Se digitalizaron 18 puntos de referencia en 134 fotografías estandarizadas de modelos de yeso y se realizó un análisis de Procusto para obtener los componentes de variación de la forma y el tamaño (tamaño del centroide= cs).

Resultados: El tamaño de centroide en hombres es significativamente mayor que en mujeres. El análisis discriminante con validación cruzada no mostró diferencias significativas en los componentes de la forma según el sexo. Las diferencias en la forma de los arcos dentales, explicada por los dos primeros componentes de la forma correspondió al 73.4% de la varianza total (PC1= 50,14%, en el eje anteroposterior y PC2= 13,31% en el eje transversal).

Conclusiones: De acuerdo con los resultados del presente estudio, se debe replantear el uso de plantillas preformadas en la determinación de la forma del arco dentario, dada la continuidad morfológica que se observa al realizar un análisis estadístico del patrón de variación en forma y tamaño del arco, como queda en evidencia al utilizar herramientas de morfometría geométrica.

Palabras clave (MeSh): arco dentario; ortodoncia; análisis, componente principal.

Resumo

Objetivos: Descrever o padrão de variação da forma do arco dentário mandibular em uma amostra populacional da Região Metropolitana, através de um estudo observacional transversal.

Métodos: 18 pontos anatómicos em 134 fotografias padronizadas de moldes de gesso foram digitalizados e foi realizado uma análise Procrustes.

Resultados: O tamanho do centróide nos homens é significativamente maior do que nas mulheres. A análise discriminante com validação cruzada de gênero não mostrou diferenças significativas nos componentes da forma. O padrão de variação na forma das arcadas dentárias é explicado principalmente por PC1 (50,1% da variação total, variação anteroposterior) e PC2 (13,3%, variação transversal).

Conclusões: Dada a continuidade morfológica que se observa ao realizar uma análise estatística do padrão de variação da forma e tamanho da arcada, aplicando ferramentas morfométricas geométricas, o uso de templates pré-formados para determinação da forma da arcada dentária deve ser reconsiderado.

Palavras-chave (MeSh): arcada dentária; ortodontia; análise, componente principal.

Introduction

The study of dental arches has been relevant in fields such as anthropology and dentistry, and it has aimed at characterizing populations and establish normal ranges. In orthodontics, particularly in the therapeutic field, this study is of key importance, as one of its primary goals is to enhance the stability, functionality, and aesthetics of dental arches [1,2].

The shape of the dental arch refers to the geometry established by relating the alveolar process and the underlying basal bone with both intraoral and perioral forces [3,4]. The alveolar process can be influenced by nutritional, functional, and systemic factors, which may alter the size, shape, and volume of this structure [5,6,1].

Various methods have been employed to study the shape of the dental arch. These include templates featuring predetermined geometric shapes, whereby arches are categorized based on their resemblance to such templates [2,7,8,9]. More intricate approaches include functions such as the catenary curve, the cubic spline function, conic sections, polynomial functions including the quadratic polynomial and the sixth-degree polynomial, Euclidean distance matrices, Fourier series, and the beta function [4, 10].

A wide variety of preformed archwires are available in the orthodontic industry for use in patient treatment. The orthodontist selects and uses the preformed archwire shape that best suits each clinical case. Although this practice is very popular among clinicians, it overlooks the natural variation in dental arches within the population, as it conforms their shape to a pre-existing one [11]. In view of these shortcomings, geometric morphometrics has been applied by some authors in the study of dental arch shape variation [5,12].

This morphological analysis tool has been primarily employed in the study of human populations by physical anthropologists and, more recently in dental practice to examine the dento-skeletal pattern of shape and size variation [13,14,15,16]. This tool was developed for carrying out the statistical analysis of shape variation enabling the description, analysis, and comparison of the morphology of biological objects by differentiating the effect of shape variation from size variation, which is geometric in nature (centroid size = square root of the sum of the square distances from each landmark to the centroid point) [17,18,19,20,21,22]. Thus, the form of a biological object is determined by both its size and the spatial or geometric relationship of the anatomical landmarks that comprise it [23].

Currently, the use of geometric morphometrics for the study of shape and size variation in the maxillofacial territory is undergoing a phase of expansion, with several publications already utilizing this morphological analytical tool [10,14,15,16]. With this in mind, this study aims to describe the pattern of variation in the shape of the mandibular dental arch using geometric morphometrics standard pipeline in a population sample from the Metropolitan Region of Chile. Our null hypothesis states that changes in the shape of the mandibular dental arch occur solely by chance, regardless of factors such as the size of the dental arch or the sex of the individuals. This way, more precise information regarding its variability can be obtained, contributing to improve the orthodontic practice through personalized treatment.

Materials and Methods

This is an observational, cross-sectional study employing random sampling. The sample comprised 134 plaster models of the mandibular arch (67 women and 67 men), housed at the Center for Quantitative Analysis in Dental Anthropology (CA2) of the Faculty of Dentistry, Universidad de Chile. Inclusion criteria were as follows: well-preserved models from individuals with no history of surgical nor orthodontic treatment, complete dental arch (excluding third molars), fully erupted second molars, absence of cusp wear, no dental anomalies in size and/or shape, absence of evident asymmetries in the mandibular dental arch, and a Little's irregularity index [24] equal to or less than 3 mm. Sample size was calculated using an F test for overall MANOVA effects (total N= 128, alpha= 0.05, statistical power= 0.8, n groups= 2, effect size= 0.0625, Pillai's trace= 0.0588, G*Power program, v. 3.1.9.6).

Standardized photographs were taken of each plaster model using a "Nikon" D3400 18-55 f/3.5-5.6G camera. The standardization of photographic registering involved employing a tripod to maintain camera stability at a consistent height and distance (50 cm) for all photos. Eighteen anatomical landmarks were digitized on each photograph based on the corresponding homology map (Table 1, Figure 1). These landmarks were digitized using the TPSDig2 program (v. 2.30; Rohlf, 2017), yielding an *x*, *y* matrix of landmark coordinates. Subsequently, the landmark coordinates were subjected to a generalized Procrustes Analysis (GPA) using the MorphoJ software, following a standardized geometric morphometrics pipeline [20,17].

Table 1. Definition of Landmarks in the Homology Map

Landmark	Definition
1	Distobuccal cusp of the lower right second molar.
2	Mesiobuccal cusp of the lower right second molar.
3	Midbuccal cusp of the lower right first molar.
4	Mesiobuccal cusp of the lower right first molar.
5	Buccal cusp of the lower right second premolar.
6	Buccal cusp of the lower right first premolar.
7	Cusp of the lower right canine
8	Midpoint of the mesiodistal distance of the lower right lateral incisor.
9	Midpoint of the mesiodistal distance of the lower right central incisor.
10	Midpoint of the mesiodistal distance of the lower left central incisor.
11	Midpoint of the mesiodistal distance of the lower left lateral incisor.
12	Cusp of the lower left canine.
13	Buccal cusp of the lower left first premolar.
14	Buccal cusp of the lower left second premolar.
15	Mesiobuccal cusp of the lower left first molar.
16	Midbuccal cusp of the lower left first molar.
17	Mesiobuccal cusp of the lower left second molar.
18	Distobuccal cusp of the lower left second molar.

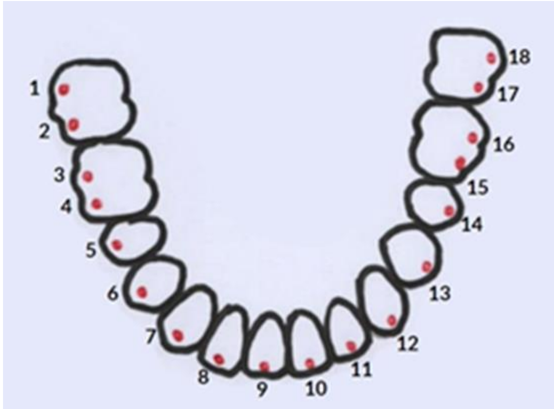

Figure 1: Homology map used in the study

Results

Intraobserver Error Calculation

The main author (FV) conducted the digitization of the 22 anatomical landmarks for 30 individuals, consisting of 15 females and 15 males. This process was repeated with the same individuals after a week. Subsequently, a Principal Component Analysis was performed separately for each group, using the shape components (PC1, PC2, ..., PCn) as linear variables in a one-way ANOVA (n= 60). The analysis only included the principal components that contributed to a cumulative variance corresponding to 90% of the total variance. Levene's test rejected the hypothesis of equal variances (p= 3.18E-19), leading to the application of the nonparametric Kruskal-Wallis test. This test revealed no statistically significant differences between the first and second measurements [H (Ji^2): 1.714, Hc (corrected range): 1.714, p (equal groups): 0.944], confirming the absence of statistically significant observer bias in the measurements.

Sexual Dimorphism Analysis

Although, as anticipated, the centroid size (CSize) of men is significantly larger than that of women ($CSize_{men}$ = 10.71 +/- 0.56; $Csize_{women}$ = 10.28 +/- 0.55; t = 4.54, p = 1.271 E-05), there were no significant differences in the shape components concerning sex (discriminant analysis with cross-validation, correctly classified women = 62.7%; correctly classified men = 64.2% for expected values above 80%).

Pattern of Shape Variation Analysis

The observed pattern in the first two principal components of shape indicates anteroposterior contraction and expansion in PC1 (50.14% of the variance), while PC2 (13.31% of the variance) shows a pattern of transverse contraction and expansion of the dental arch (Fig. 2).

In PC1, the landmarks exhibiting the greatest anteroposterior variation correspond to the buccal cusps of the second molar and the central incisors, while in PC2 they correspond to the buccal cusp of the second premolar and the distobuccal cusp of the second molar (Fig. 3).

Discussion

To investigate the variation of mandibular dental arch shape in a sample from the Metropolitan region of Santiago, Chile, a cross-sectional study was conducted using the standard geometric morphometrics pipeline. According to our findings, the centroid size of the mandibular arches is significantly larger in males compared to females. This difference is attributed to mesiodistal coronal size dissimilarity between the sexes, as previously reported (25, 26, 27, 28). However, as demonstrated in this study, when analyzing the arch shape itself independently from size, no statistically significant differences were observed between males and females. Other studies employing the same geometric morphometrics approach have also reported the absence of sexual dimorphism in dental arches (10, 11, 12).

Our main finding reveals a significant variability in the shape of the mandibular arch around the consensus shape, which is positioned at the center of the distribution graph, resembling the "ovoid" shape of preformed templates. This may explain why other authors, using preformed templates, have concluded that the most prevalent shape in the populations they studied is the ovoid shape (30).

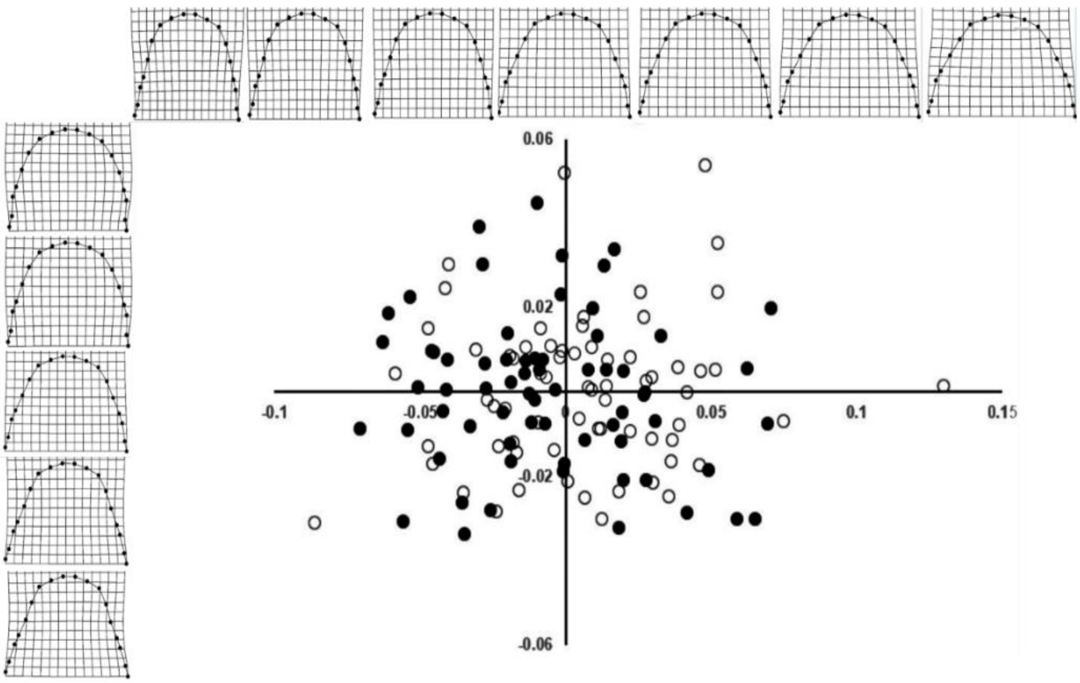

Figure 2: Shape Variation According to Principal Components 1 and 2 (PC1 = 50.14%, PC2 = 13.31%). The figures show the anteroposterior variation of the arch in the horizontal axis or PC1. The vertical axis (PC2) illustrates the transverse variation of the arch. Additionally, the absence of differences with respect to sex (females in white circles, males in black circles) is clearly observed.

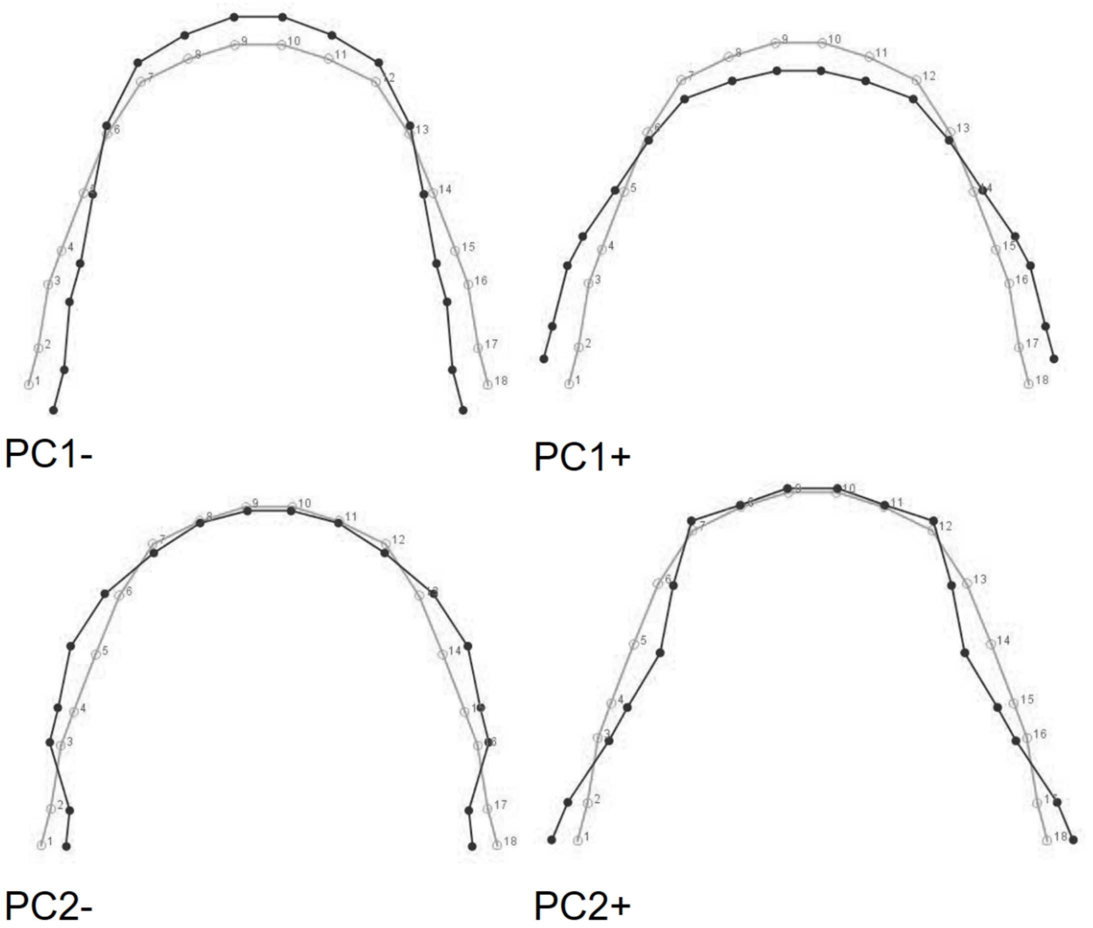

Figure 3: The above images depict overlays of the consensus configuration (in gray) with the extremes of variation (in black) in Principal Component 1 (PC1-, PC+). Primarily, differences in the sagittal dimension –attributed to variations in the position of the incisors– are observed. The lower images depict overlays of the consensus configuration (in gray) with the extremes of variation (in black) in Principal Component 2 (PC2-, PC+). The position of the second premolar and second molar accounts for the most significant variation observed along this axis.

Therefore, determining when a shape ceases to be "ovoid" and becomes classified as "round," "square," or "triangular" becomes arbitrary [(31, 32)]. This fact is acknowledged in research employing the aforementioned definitions [(33)]. According to our results, these shapes, supposedly represented in the mandibular arches of the population, are definitely not observed in the pattern of shape variation revealed by geometric morphometrics, which is primarily explained by differences in the positions of the second molars, incisors, and second premolars. When using preformed templates for arch form studies, researchers must determine which template most accurately matches the shape of the dental arch under examination. Based on this assessment, they make a classification judgment by assigning a specific shape. As noted, we find this classification criterion to be arbitrary, as it fails to consider the natural variability in the shape of dental arches. The main challenge in orthodontic practice arises from the use of preformed arch wires, particularly the elastic or superelastic alloy arch wires offered to orthodontists by commercial manufacturers. In clinical practice, orthodontists select the preformed archwire that best fits the arch form of a particular patient. In a study of preformed archwires, only one out of ten commercial brands showed a close match to the average obtained [10]. We believe that ideally, these preformed archwires should be customized from the outset of treatment, even those that are elastic or superelastic, to conform to the shape of the patient's dental arch. Failure to do so could potentially introduce a factor of instability or relapse [34].

In summary, there is significant variability in the shape of the mandibular arch around the consensus shape, resembling the "ovoid" form of preformed templates. Other shapes such as round, triangular, and square are deviations from the consensus shape and are primarily influenced by differences in the positions of the second molars and incisors. Consequently, geometric morphometrics reveals morphological continuity along both axes, thus not being able to precisely classify the dental arch as ovoid, square, round, or triangular.

Conclusion

According to the findings of this study, the use of preformed templates in determining dental arch form should be reconsidered, given the observed morphological continuity in arch shape and size variation revealed through statistical analysis applying geometric morphometric tools.

Data Availability

The entire dataset supporting the findings of this study was provided in this article.

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b) Adquisición de datos
c) Análisis de datos
d) Discusión de resultados
e) Redacción y corrección del manuscrito
f) Aprobación de la versión final del manuscrito

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MI has contributed to c, d, e, f
AD has contributed to a, c, d, e, f
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