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Analysis of the 3D Contour of the Human Face and its Relationship with Age: a Study in CT Scans

Henrique Tonelli[1], Alexandre Rodrigues Freire[1], Isabela Lesse de Paula[1], Beatriz Carmona Ferreira-Pileggi[1], Felippe Bevilacqua Prado[1], Ana Cláudia Rossi[1]

[1]Faculdade de Odontologia de Piracicaba, Universidade Estadual de Campinas (UNICAMP), Piracicaba, São Paulo, Brasil

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ABSTRACT

Introduction: the aim of the present study was to evaluate the three-dimensional contour of the face through morphometric analysis of three facial angles in computed tomography scans of human skulls in different age categories from a Brazilian sample.

Methods: the sample consisted of 123 CT scans that were divided into three groups according to the age. The Mimics 18.0 software (Materialise, NV, Belgium) was used to perform the segmentation of the images of each CT scan. Using the 3D reconstructions of the CT scans, the angular measurements were obtained for the evaluation of the orbital, pyriform and maxillary angles. A significance level of 5% was considered. Descriptive statistics were performed for each measurement in each age category and sex. Two-way ANOVA was performed, with multiple comparisons by Tukey's test.

Results: in females, there was a tendency for the pyriform angle to increase from the young (57.52º) to the middle-aged group (60.39º) and decrease from the middle-aged (60.39º) to the elderly group (53.60º) (p= 0.0216).

Conclusion: considering the Brazilian sample evaluated, female's skulls showed more aging changes in the angular dimensions than males mainly in the pyriform angle of the face. There is a need to know how the face is remodeled in the process of aging and to understand this bony remodeling is important for application in facial analysis for execution of surgical and aesthetic procedures.

Keywords: Face; Bone; Anatomy; Age; Rejuvenation.

Introduction

The traditional concept of facial aging revolves around the changes that occur in the soft tissue, with atrophy of elasticity, which leads to tissue loss. Facial rejuvenation techniques have focused on reversing these changes by repositioning and redecorating the tissues, with an emphasis on lifting vectors. Although these techniques are effective to a greater extent, they do not necessarily produce a completely harmonic and naturally rejuvenated appearance since the bone aging process is associated[1].

Bone aging occurs in specific underlying areas, thus contributing to the significant changes reflected in the face, resulting in soft tissue atrophy[2]. It is conceptually important to notice that, in most individuals who present with a pre-aged face, the facial skeleton may be inherently inadequate. To effectively circumvent this problem, and harmonically rejuvenate a face, it is necessary to understand the dynamics of the skeletal aging process[3].

With the application of three-dimensional analysis of computed tomography (CT), more accurate studies on the understanding of skeletal aging were allowed. Khan and Shaw[4], through tomographic sections of 60 patients, explored the most affected areas of the skull in this process. This study allowed us to conclude that bone aging includes selective resorptions in specific sites of the skeletal structure, such as the piriform aperture, the maxilla, and the periorbital region[4]. The same authors found that the piriform aperture has a greater loss of bone margin when compared to other areas of the face, occurring mostly in the nasal floor and, therefore, with an increase in its width, which is the critical area for support for the greater alar cartilages and external nasal valves[5]. There is clinical evidence that suggest the nasal profile changes secondarily due to underlying changes in nasal and maxillary bone remodeling[6].

Loss of maxillary bone projection occurs from adulthood at a slower rate than the piriform aperture. Alterations in this area contribute, medially, to tissue fall, and, laterally, the changes are manifested as loss of malar projections, reflecting in a greater depth of the nasolabial fold[5]. This process differs from the orbital cavity, which shows an increase in both height and width with age. However, resorption occurs unevenly and at specific sites. The superomedial and inferolateral aspects of the orbital rim yield more to resorption, although these changes occur at different stages. While changes in the inferolateral margin of the orbit occur earlier, close to middle age, and especially in males, changes in the superomedial quadrant can

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only be seen at more advanced ages[4]. In contrast, the central part of the lower and upper margins is more stable, with little or no resorption occurring with age[7].

The understanding of the bone aging process and its repercussions on soft tissues dates back decades, but without a definitive conclusion. The intervention only in soft tissues, however, does not necessarily lead to an optimal cosmetic result for all patients[8]. Thus, there is a need to know how the face is remodeled in the face of aging and to understand this remodeling morphologically and morphometrically for application in facial analysis, which precedes the execution of surgical and aesthetic procedures on the face.

The aim of this study was to evaluate the three-dimensional contour of the face through the morphometric analysis of three facial angles in computed tomography scans of human skulls in different age categories from a Brazilian sample.

Materials and Methods

The present research was analyzed and approved by the Ethics Committee from FOP/UNICAMP (CAAE protocol: 63135522.1.0000.5418).

Sample

In the sample, 123 computed tomography scans of dry human skulls were used (57 females and 66 males; age range from 18 to 80 years; with Brazilian nationality from the Southeast region of Brazil) from the Biobank "Prof. Dr. Eduardo Daruge" from the Faculdade de Odontologia de Piracicaba – Universidade Estadual de Campinas (UNICAMP).

The sample was divided into three groups according to the age categories defined by Shaw and Kahn (2007):

1) Young (25 to 44 years old): n= 30;
2) Middle age (45 to 64 years old): n= 42;
3) Elderly ((≥65 years old): n= 51.

The tomographic images were obtained in an Aisteion Multislice 4 CT System device (Toshiba Medical Systems Corporation – Japan), for the skull protocol: 100 MA, 120KV, with 1mm slices.

Only tomography scans were included that showed a skull with preserved and intact anatomical structures, without macroscopic deformities, fractures, or any other pathological or surgical change. CT scans of individuals with any anatomical abnormalities in the region of interest, surgeries, traumas, or any signs of bone remodeling, as well as individuals with implants, plates, screws, or any other metallic artifact close to the region, were excluded.

Image processing

The Mimics 18.0 software (Materialise, NV, Belgium) was used to perform the segmentation of the images of each computed tomography scan. Segmentation consisted of selecting the pixels of the bone structure in each tomographic section. This selection was defined by evaluating a threshold of scale values to obtain voxels, whose values are in a range according to the bone components of interest. The 3D reconstruction was performed to enable the visualization of these components and each three-dimensional surface was exported in virtual stereolithography (STL) to perform the surface evaluation. Each skull was standardized in right laterality and parallel to the Frankfurt Horizontal Plane.

Angular measurements

The 3D reconstructions of the CT scans were imported into the Mimics 18.0 software (Materialise, NV, Belgium), in which angular measurements (in degrees) were obtained for evaluation and characterization of the orbital, pyriform, and maxillary angles (Fig. 1). The orbital angle is defined as the angle formed between a horizontal line from the sella turcica to the nasion landmark and a line from the center of the supraorbital margin to the infraorbital margin. The pyriform angle is defined as the angle formed between a horizontal line parallel to the line running from the sella turcica to the nasion landmark, at the level of the inferior margin of the nasal bone, and a line from the inferior margin of the nasal bone to the inferolateral angle of the piriform aperture. The maxillary angle is defined as the angle formed between a horizontal line parallel to the line running from the sella turcica to the nasion landmark, at the level of the inferior margin of the zygomatic arch, and a line passing through the zygomaticomaxillary suture[7]. The values obtained by the software were tabulated for statistical analysis.

Statistical analysis

After collecting all the data, they were tabulated in the Microsoft Office Excel® package. Statistical analysis was performed using GraphPad Prism v.8 software (San Diego, CA, USA). The normality of the sample was checked by Shapiro-Wilks. A significance level of 5% was considered. Descriptive statistics were performed to obtain the mean and standard deviation (SD) for

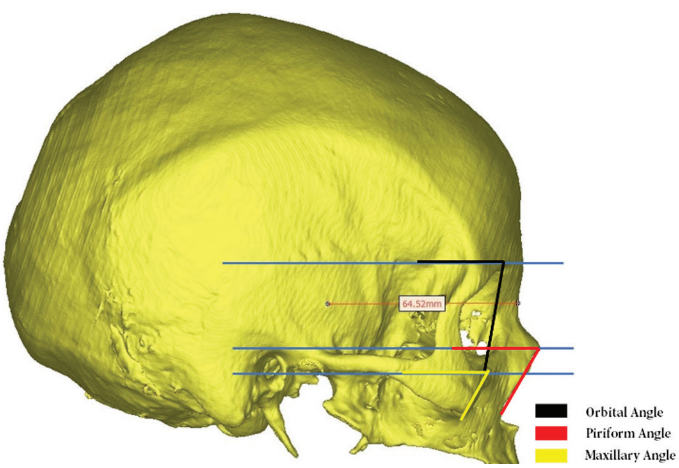

Figure 1. Delimitation of the orbital, pyriform and maxillary angles measured in the three-dimensional reconstruction of the skull.

each measurement (orbital, pyriform, and maxillary angles), in each age category and gender. Two-way ANOVA was performed, with multiple comparisons by Tukey's test (young versus middle-aged, middle-aged versus elderly, and young versus elderly) for each measure evaluated.

Results

The mean age at the young age group was 37.67 years (SD, 4.393), ranging from 30 to 44 years for males; and 36.90 years (SD, 5.195) with a range of 30 to 43 years for females. Males in the middle-aged group had a mean age of 54.88 years (SD, 5.465) with a range of 45 to 64 years, and female individuals had a mean age of 54.58 years (SD, 7.391) ranging from 45 to 64 years. The mean age in the elderly age group was 74.67 years (SD, 6.334), ranging from 65 to 87 years for males; and 73.91 years (SD, 7, 801), ranging from 65 to 100 for females.

Orbital Angle

In general, the Two-way ANOVA test showed a significant difference when comparing the orbital angle between males and females (P= 0.0224), while, when comparing between ages, no significant differences were detected (P= 0.1687).

The mean orbital angle measurement in males was 73.42 degrees for the young age group, 71.21 degrees for the middle-aged group, and 71.64 degrees for the elderly group. The average measurement of the orbital angle in females was 75.88 degrees for the young age group, 74.46 degrees for the middle-aged group, and 72.99 degrees for the elderly group (Table 1). Multiple comparisons by Tukey's test performed in both sexes between the means of each age category did not show significant differences (Fig.2). Despite this, there was a tendency for the orbital angle to decrease from the young to the middle-aged group and from the middle-aged to the elderly group in both sexes.

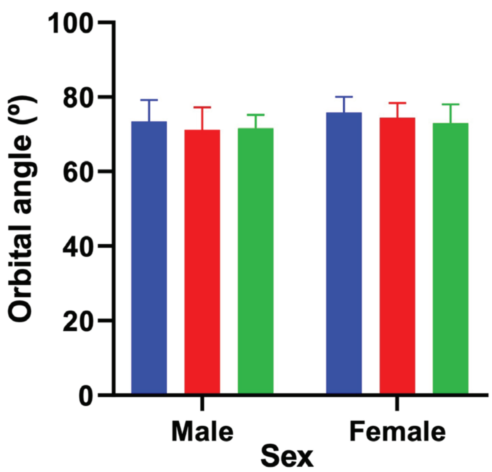

Figure 2. Means of orbital angle (in degrees) by sex in each age category (young, middle-aged, and elderly). For males - young versus middle-aged: P= 0.3304; middle-aged versus elderly: P= 0.9584; and young versus elderly: P= 0.5424. For females - young versus middle-aged: P= 0.7889; middle-aged versus elderly: P= 0.6665; and young versus elderly: P= 0.2586. Blue column: Young group; Red column: Middle-aged group; Green column: Elderly group.

Pyriform Angle

In general, the Two-way ANOVA test showed a significant difference when comparing the pyriform angle between males and females (P= 0.076), while, when comparing between ages, no significant differences were detected (P= 0.1687).

The mean measurement of the pyriform angle in males was 55.15 degrees for the young age group, 53.23 degrees for the middle-aged group, and 53.13 degrees for the elderly group. The mean measurement of the pyriform angle in females was 57.52 degrees for the young age group, 60.39 degrees for the middle-aged group, and 53.60 degrees for the elderly group. In females, there was a tendency for the pyriform angle to increase from the young to the middle-aged group and decrease from the middle-aged to the elderly group (Table 1). The multiple comparisons by Tukey's test performed in both sexes between the averages of each age category showed significant differences in females when comparing middle age with the elderly (P=0.0216). For the other comparisons, there were no significant differences (Fig. 3).

Table 1. Mean (SD) angular measurements (in degrees) by sex in each age category.

Angle (°)	Young (SD)	Middle-aged (SD)	Elderly (SD)
Orbital			
Male	73.42 (5.799)	71.21 (5.976)	71.64 (3.556)
Female	75.88 (4.158)	74.46 (3.932)	72.99 (5.078)
Pyriform			
Male	55.15 (8.503)	53.23 (5.241)	53.13 (8.627)
Female	57.52 (8.596)	60.39 (6.817)*	53.60 (7.419)*
Maxillary			
Male	47.66 (7.435)	47.44 (6.269)	50.05 (6.418)
Female	47.75 (4.858)	45.03 (3.465)	48.84 (5.879)

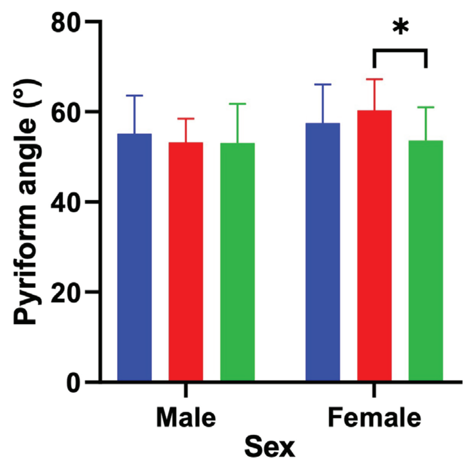

Figure 3. Fig 3. Means of the pyriform angle (in degrees) by gender in each age category (young, middle-aged, and elderly). For males - young versus middle-aged: P= 0.6769; middle-aged versus elderly: P= 0.9989; and young versus elderly: P= 0.6938. For females - young versus middle-aged: P= 0.6397; middle-aged versus elderly: P= 0.0216; and young versus elderly: P= 0.3155. *Statistical difference (decreased from the middle-aged to the elderly group). Blue column: Young group; Red column: Middle-aged group; Green column: Elderly group.

Maxillary Angle

In general, the Two-way ANOVA test did not show a significant difference when comparing the maxillary angle between males and females (P= 0.3364), nor when comparing ages (P= 0.0694).

The mean maxillary angle measurement in males was 47.66 degrees for the young age group, 47.44 degrees for the middle-aged group, and 50.05 degrees for the elderly group. The mean maxillary angle measurement in females was 47.75 degrees for the young age group, 45.03 degrees for the middle-aged group, and 48.84 degrees for the elderly group (Table 1). Multiple comparisons by Tukey's test performed in both sexes between the means of each age category did not show significant differences (Figure 4). Despite this, there was a tendency for the maxillary angle to increase from the middle-aged to the elderly group in both sexes.

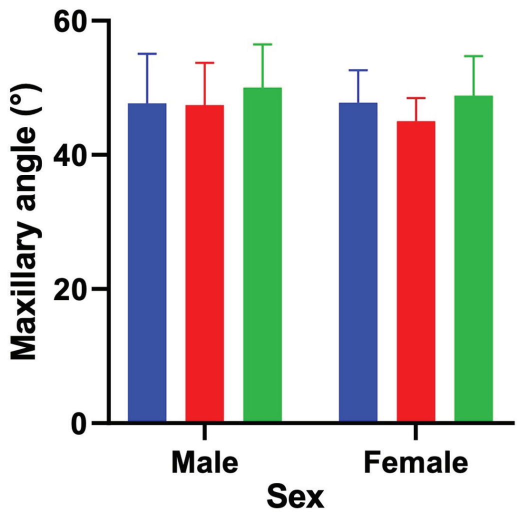

Figure 4. Means of maxillary angle (in degrees) by gender in each age category (young, middle-aged, and elderly). For males - young versus middle-aged: P= 0.9923; middle-aged versus elderly: P= 0.3419; and young versus elderly: P= 0.4656. For females - young versus middle-aged: P= 0.5481; middle-aged versus elderly: P= 0.1560; and young versus elderly: P= 0.8731. Blue column: Young group; Red column: Middle-aged group; Green column: Elderly group.

Discussion

The areas most affected by the reduction of skeletal projection correspond to the areas of the face that are most affected by the stigmas of aging, such as the piriform aperture, orbital cavity, and maxillary region. The reabsorption of these areas develops with the retrusion of their respective periosteum[9]. Consequently, the location of ligament and muscle insertions through the periosteum also ends up moving[3]. As a result, these structures end up losing the mechanical advantages of their effectiveness in the tissue they act on[10].

Some of the changes that occur with age in the regions of the face involves tissue loss, glabella protrusion, expansion of supraorbital wrinkles, lateral translation of the orbit, and increase in nose and chin dimensions[4].

From a review of the literature, it is apparent that our knowledge of the aging process of the facial skeleton has increased. For the continuous study, in our research, 123 skulls of male and female sex were included for analysis independently, allowing us to detect differences for each sex. Were included three age categories, which we hope will allow us to identify and track the aging process more precisely. The use of tomography allowed a more accurate 3-D reconstruction, thus increasing our accuracy in obtaining measurements and comparing them with past literature. According to results of the present study, it was found that each angle of the face suffers from changes at different levels and times. First, we observed a tendency for the orbital angle to decrease from the young to the middle-aged group and from the middle-aged to the elderly group in both sexes, resulting in larger orbital cavities. This is due to the resorption of the inferolateral region of the orbital cavity being the most affected of all, and the superior region being the least resorbed. As the inferior region undergoes selective resorption, the angle tends to decrease in conjunction with bone aging. Our results agree with the findings by Shaw and Khan[5], who concluded that there is continuous resorption of the orbital cavity and loss of tissue volume and projection, resulting in a loss of support in the area, thus helping in a fall and accumulation of soft tissue in the lateral region of the orbit, called the "tissue hood". These changes can play a key role in leading to a more aged appearance. On the other hand, the present study found a tendency for the maxillary angle to increase from the middle-aged group to the elderly, in both sexes.

In the present study, the pyriform angle showed significant differences both between sexes and between ages in the female group. This shows that each sex demonstrates its skeletal changes at different levels, and, in females, there was a tendency for the pyriform angle to increase from the young to the middle-aged group, but there was a significant difference when noticing the decrease in the middle-aged group for the elderly group, demonstrating that the adult phase is where the most significant changes occur in this region. This occurs due to the aging process initially affecting the nasal floor more than any other structure in the piriform aperture region, with resorption in the posteroinferior direction, resulting in an increase in the angle. This is noted in soft tissue evaluation by determining the position of the alar base relative to the medial canthus. When the alar base is positioned posterior to the medial corner, the facial profile appears more aged. As it remodels superiorly, the alar base is pulled superiorly, resulting in a decrease in the angle. This suggests that facial bones that support the jaws recede with age, causing a generalized increase in volume. The reason that leads us to believe that females suffer more than males involves the study by Barlett *et al.*[11], who through cephalometry studies, concluded that female skulls have a greater increase in all lengths and depth of the middle third with increasing age, compared with males. In other words, females are more prone to selective resorptions than males[12].

We know that females are more prone to these changes, but males are not exempt. Our research aims to help and continuously study the areas of the face where we suffer the greatest variations and alterations, aiming to help better and more sophisticated aesthetic procedures based not only on the clinic but on biological aging.

Conclusion

In conclusion, considering the Brazilian sample evaluated, the female's skulls showed more aging changes in the angular dimensions than males mainly in the pyriform angle of the face.

Acknowledgements

The authors state that every effort was made to follow all local and international ethical guidelines and laws that pertain to the use of human cadaveric donors in anatomical research[13].

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Mini Curriculum and Author's Contribution

1. Henrique Tonelli – DDS, MSc. Contribution: Effective scientific and intellectual participation for the study; Data acquisition; wrote the manuscript; critical review and final approval. ORCID: 0000-0002-0303-2337

2. Alexandre Rodrigues Freire - DDS, MSc, PhD, Assitant Professor. Contribution: Effective scientific and intellectual participation for the study; data analysis; wrote the manuscript; critical review and final approval. ORCID: 0000-0002-0175-0896

3. Isabela Lesse de Paula – Undergraduate student. Contribution: Effective scientific and intellectual participation for the study; Data acquisition; critical review and final approval. ORCID: 0000-0003-2342-9910

4. Beatriz Carmona Ferreira-Pileggi - DDS; PhD student. Contribution: Effective scientific and intellectual participation for the study; data analysis; wrote the manuscript; critical review and final approval. ORCID: 0000-0001-6845-7881

5. Felippe Bevilacqua Prado - DDS, MSc, PhD, Associate Professor. Contribution: Wrote the manuscript; critical review and final approval. ORCID: 0000-0001-5636-6915

6. Ana Cláudia Rossi – DDS; PhD, Associate Professor. Contribution: Effective scientific and intellectual participation for the study; data analysis; wrote the manuscript; critical review and final approval. ORCID: 0000-0002-8718-4898

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Corresponding author
Ana Cláudia Rossiu
E-mail: anarossi@unicamp.br