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Relationship between the Volume of the Upper Airways and the Mandibular Angle Analyzed in Computed Tomography Scans

Relação do Volume das Vias Aéreas Superiores com o Ângulo Mandibular Analisadas em Tomografias Computadorizadas

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Abstract

Several variables can influence the treatment and outcome of orthognathic surgery, one of which is the angle of the mandibular ramus. The objective of this study is to analyze the upper airways (UA) of patients prior to orthognathic surgery, using cone-beam computed tomography (CBCT) and to correlate their volume with the angle of the mandibular ramus. DICOM (Digital Image Communication in Medicine) images of a radiology clinic were used, with a survey of 124 full face CBCT scans, from 2015 to 2018, and the measurement of the total volume in mm³ through software. To obtain the values of the angle of the mandibular ramus, images obtained from medical reports were used, through morphological evaluation. The values were tabulated and subsequently statistical analysis was performed using the ANOVA test to assess the differences between the mean airway volumes (mm³) according to gender, age and mandibular ramus angle. However, the angle of the ramus did not influence the volume of the UA, but a greater average of UA volume was observed in male individuals and in individuals over 34 years of age. There is no evidence that it is possible to measure or predict the volume of the UA by evaluating the angle of the mandibular ramus.

Keywords: Radiology. Cone-beam Computed Tomography. Orthognathic Surgery. Mandible. Pharynx.

Resumo

Diversas as variáveis podem influenciar no tratamento e resultado de uma cirurgia ortognática, uma delas é o ângulo do ramo mandibular. O objetivo deste trabalho é analisar as vias aéreas superiores (VAS) de pacientes previamente à cirurgia ortognática, por meio de tomografia computadorizada de feixe cônico (TCFC) e correlacionar o seu volume com o ângulo do ramo mandibular. Foram utilizadas imagens DICOM (Comunicação de Imagens Digitais em Medicina) de uma clínica radiológica, com o levantamento de 124 exames de TCFC de face total, do ano de 2015 até 2018 e feita a mensuração do volume total em mm³ através de um software. Para a obtenção dos valores do ângulo do ramo mandibular foram utilizadas imagens obtidas através dos laudos médicos, mediante avaliação morfológica. Os valores foram tabulados e posteriormente feita a análise estatística com o teste ANOVA para avaliar as diferenças entre as médias de volume das vias aéreas (mm³) de acordo com o gênero, a idade e o ângulo do ramo mandibular. Contudo, o ângulo do ramo não influenciou no volume das VAS, mas uma maior média de volume de VAS foi observada nos indivíduos do gênero masculino e nos indivíduos acima de 34 anos. Não há evidências de que se é possível mensurar ou ter previsibilidade do volume de VAS, avaliando o ângulo do ramo mandibular.

Palavras-chave: *Radiologia. Tomografia Computadorizada de Feixe Cônico. Cirurgia Ortognática. Mandíbula. Faringe.*

1 Introduction

The relationship between craniofacial morphology and respiratory function has been the focus of research since the 19th century[1]. Any change in the jaw and mandible can cause significant changes in airway volume. The upper airway (UA) is classified as a complex structure involving bones, cartilage and soft tissues[2] and is responsible for the main vital functions of the human organism[3] such as breathing, ingestion, swallowing and phonation[4]. The interest in studying the upper level of the airways has always been present in the orthodontia and has as its main objective to clarify the relationship between pharynx structures and the growth and development of the craniofacial complex[3].

Individuals can be classified according to Angle as standard I, II and III, short face or long face. Pattern I is identified by facial normality, II and III of positive and negative sagittal degree, respectively. In the long and short face patterns, the change is in the vertical direction[5]. Mouth breathing is the main etiological factor of the Long face Syndrome, or the Buccal Respirator Syndrome, making the facial structure long and narrow[6]. The Buccal Respirator Syndrome is characterized by an obstruction of the upper airways that leads the patient to the habit of breathing through the mouth, which has as consequences a postural adaptation, followed by changes in the dental arch and later in the face bones[7]. One of the characteristics of this syndrome is the presence of the lower third of the long face, resulting in a retrognathia appearance of the mandible, thus being important a correct evaluation to define, locate and quantify skeletal disharmony, which may be related to horizontal growth of the condyle and/or excessive posterior growth of the maxilla[8.] The knowledge of the morphology and functioning of the skeletal structures and of the soft tissue that make up the upper airspace is essential to understand the physiology and pathogenesis of its obstruction[9]. The correct evaluation is essential for patients suffering from respiratory problems and airway disorders[10] in order to obtain proper planning of orthodontic treatment or orthognathic surgery[11].

In the lateral cephalometric analysis, made from conventional X-ray, only the height and depth of the pharynx are evaluated, and the transverse analysis is not possible, that is, the width of the same[9], in addition to presenting deficiencies as distortion, enlargement and superposition of structures that limit VAS investigations[12]. The use of conical beam computed tomography (CFCT) represents a valuable diagnostic tool in the airway study when compared to conventional radiographic plane[2]. In addition to making treatment planning more efficient[13], he revolutionized dental X-ray allowing the visualization of airways and volumetric images in three dimensions (3D), they can be compared using real measurements in a ratio of 1 to 1 with less magnification and distortion[14].

The increase in pharyngeal airspace can be achieved in a reversible way through the use of removable devices; or permanent, with surgery[9]. Orthognathic surgery not only improves the esthetic appearance of patients with facial deformities, but also alters the function and physiology of occlusion, communication and breathing, affecting several related anatomical structures[15]. However, there are several variables that can influence the treatment and final result of an orthognathic surgery, one of them is the angle of the mandibular branch. The objective of this study is to evaluate the airways by means of CFCT and to relate its total volume (mm^3) to anatomical variables, emphasizing the angle of the mandibular branch, gender and age, in addition to the construction of three-dimensional VAS models, testing the hypothesis that it is possible to relate the volume of the airways according to the angle of the mandibular branch.

2 Material and Methods

2.1 Universe of research

This is a cross-sectional database analysis study of a dental radiology clinic in the city of Passo Fundo, with the survey of 244 full-face TCFC exams in DICOM format, dating from 2015 to 2018. After the inclusion and exclusion criteria were assessed, the large group was divided into female and male groups to correlate volume with angle, where a comparison was made between them, and later, another comparison was made within each group in relation to the mean age and angle of the mandibular branch.

2.2 Inclusion and exclusion criteria

All examinations of total face of patients between 15 and 60 years of age, of both genders, with the value related to the angle of the bilateral mandibular branch, were included in the study. The excluded examinations were those of young people under 15 years of age and elderly people over 60 years of age, repeated exams or with absence of the archives in DICOM format, absence of the angle values of the mandibular branch, exams that present morphological alterations, neoplastic or traumatic injuries that could create bias in research and examinations that show signs of previous bone correction surgery.

2.3 Acquisition of tomographic taking

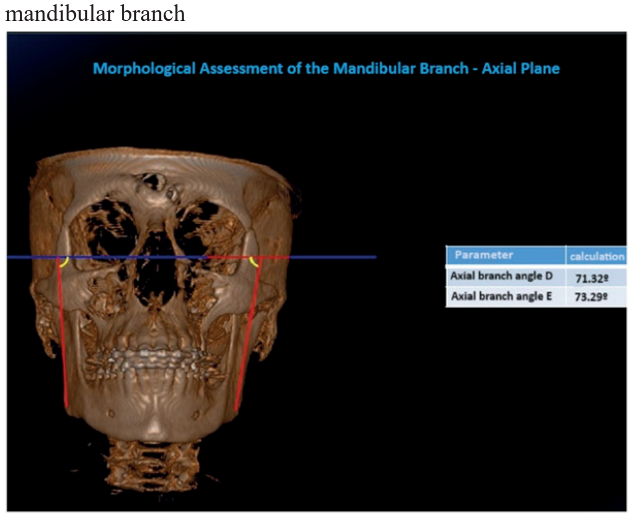
All the TCFC tests were performed with total face in the same radiological clinic, using the same equipment and configurations, with the acquisition parameters at 120 kVp, 37.1 mA, 17.8 seconds, volume size rendered at 17 x 23 cm and 0.3 mm^3 voxel resolution, through the ICAT *Imaging Sciences International LLC, Hatfield, PA*, *USA device*.

2.4 Image manipulation and analysis

The volumetric measurements of the DICOM files were obtained by different examiners. All examinations were analyzed according to the sagittal relationship between maxilla and mandible, expressed by the ANB angle, formed by the intersection of the cephalometric lines NA and NB, determined by the N (nasio), A (sub spinal) and B (supramental) points. To analyze the reliability of the operators, a reliability test (*Kappa* = 0.75 test) was applied until there were no statistically significant differences between the values obtained.

To obtain the values of the angle of the mandibular branch, images contained in the patients' reports were used, through morphological evaluations, already presenting the previous values of the right and left angles. The angles are formed by the intersection of the axial plane and the tangential plane to the lateral portion of the mandibular branch (Figure 1).

Figure 1 - Reference points for the angle measurements of the mandibular branch



Source: authors.

2.5 Software for analysis

The files in DICOM format were analyzed by ITK-NAP application version 3.6.0, an integration between the NAP and ITK tools (*Insight Toolki*) by *Cognitica Corporation* under NIH / NLM PO 467-MZ-202446-1 (*US National Institutes of Health*), with validation study supported by NIH/ NIBIB P01 EB002779, NIH (*Conte Center*) MH064065, and UNC (*Neurodevelopmental Disorders Research Center, Developmental Neuroimaging Core*) a free 3D anatomical segmentation processor of medical images[16].

2.6 Data analysis

The defined values were tabulated in the *Excel* 2010 program of the *Microsoft Office* 2010 package, and then analyzed in the SPSS software. The Levene test was performed to verify the homogeneity of variances, and after that, the variance analysis was performed (ANOVA) to relate the volume of the upper airways to the angle of the mandibular branch, with a significance level of 95%, estimating the variables of interest and their respective confidence intervals.

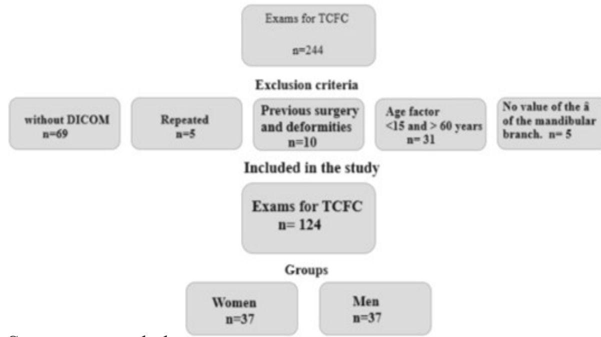
2.7 Ethical issues

The project was submitted to the Research Ethics Committee of University of Passo Fundo (approved under opinion number 3.414.871 / 914903119.8.0000.5342) and only after being authorized, data collection was started. The agreement to participate in the study was obtained by means of a letter to the clinic supplying the exams. Because it is a study performed through individual image examinations, it offered no risk to the participants, and remained anonymous.

3 Results and Discussion

The sample consisted of 124 patients. In relation to gender, 87 (66.4%) individuals were women. In relation to age, the mean total age (±SD) of the sample was 35.4 (±10.15) years, with a minimum age of 15 years and a maximum age of 58 years (Figure 2). The mean age (±SD) among women was 33.5 (±9.3) years, being the younger age 15 years and the older age 58 years. As for men, the mean age (±SD) was 40 (±10.7) years, being the lowest age in the 19-year-old group and the highest age of 56 years.

Figure 2 – Flowchart of inclusion criteria and final number of participants



Source: research data.

In relation to the volume of the upper airways, the mean sample was 22847.4 mm^3 (±SD 7192,8mm^3; min: 7658.3mm^3; max.:45837.1mm^3). Regarding the volume of the airways of women, the mean observed was 22027.36 mm^3 (±SD 6782.524 mm^3; min:7658 mm^3; max: 43489 mm^3). In the male group, the mean volume was 24775.48 mm^3 (±SD 7833.456 mm^3; min:13381 mm^3; max: 45837 mm^3).

In relation to the angle of the mandibular branch, the mean sample was 71.6 0 (±DP8,50^o; min:50.20^o; max:96,40^o). In the female gender, the angular measurement was 72,03^0 (±SD 8.10^0; min:50,20^0; max:96,40^0). In men, the mean angulation was 70,53^0 (±SD 9,25^0; min:50,3^0; max:94,6^0).

The ANOVA test was performed to evaluate the differences between the mean airway volume (mm^3) according to gender, age and angle of the mandibular branch (Table 1). The angle of the branch did not influence the volume of the airways. However, the highest mean airway volume was found in male individuals (MD± SD: 24775.5 ±7833,5mm^3; p=0.049) and in individuals over 34 years of age (MD± SD**:** 24485.8mm^3 ± 7385.5mm^3; p=0.017).

Table 1 - Mean values (±SD; min; max) of airway volumes (mm^3) according to gender, age and angle of mandibular branch, Passo Fundo, RS/Brazil. (n=124)

Variable	n	Mean (±SD)	Min	Max	*p*
Sex					0.049
Male	37	24775.5mm^3 (7833.5mm^3)	13380.9mm^3	45837.1mm^3	
Female	87	22027.4mm^3 (6784.5mm^3)	7658.3mm^3	43489.1mm^3	
Age					0.017
Up to 34 years	66	21407.5mm^3 (6750.5mm^3)	7658.3mm^3	43189.9mm^3	
Over 34 years	58	24485.8mm^3 (7385.5mm^3)	13380.9mm^3	45837.1mm^3	
Angle					0.357
Up to 71.2º	61	23454.5mm^3 (7104.2mm^3)	12428.4mm^3	45837.1mm^3	
Above 71. 2º	63	22259.5mm^3 (7285.8mm^3)	7658.3mm^3	43849.0mm^3	

Source: research data.

Comparing the mean angles of the mandibular branch with the groups according to sex, it is noted that in both genders, both female and male, which present the angle value of the mandibular branch up to 71.2, they have a higher airway volume, but with significant differences low (Table 2).

Table 2 - Mean values of airway volumes (mm³) according to the and angle of mandibular branch according to sex, Passo Fundo, RS/ Brazil. (n=124)

Variable	N	Angle of the Mandibular Branch. (Categorized)	Means	Standard Deviation	*p*
Sex					0.393
Female	42	Up to 71.2º	22568.78mm³	6948.541mm³	
	45	More than 71. 2º	21522.04mm³	6666.714mm³	
Male	20	Up to 71.2º	25845.78mm³	7306.163mm³	
	17	More than 71. 2º	23516.31mm³	8459.405mm³	

Source: research data.

Deficiencies such as distortion, enlargement, and structure overlap are common in two-dimensional images, which limit investigations of the upper airways[12], and TCFC represents a valuable diagnostic tool in the airway study when compared to conventional radiography, changing the entire form of diagnosis and planning[2]. The present study aimed to analyze the volume of the airways through the HRCT prior to the orthognathic surgery, correlating its total volume with the gender, age and angle of the mandibular branch.

A study conducted by Schendel *et al.*[11], where airway growth was evaluated by means of TCFC in 1,300 class I patients, aged 6 years old to aging, dividing the groups with a 20-year interval, it showed that the size and length of the airways increase up to 20 years, then remain relatively equal until 50 years, when they start to decrease dramatically, without varying according to the sex of the patients. This decrease throughout life is explained by the muscular flaccidity that is inevitable over the years.

Alves Jr *et al.*[17] assessed children aged 8 to 10 years, who underwent HRCT for orthodontic reasons, and concluded that patients with mandibular deficiency presented lower airway volume compared to those with a balanced development of maxilla and mandible, with no statistical difference between genders.

The results of Schendel *et al.*[11] and de Alves Jr *et al.*[17] disagree with Chiang *et al.*[18] who found significant differences according to the gender of the patients, where the female sex showed a significant increase in VAS from 8 to 18 years of age while the male sex increased the volume in a subtle manner from 8 to 10 years of age and in a more expressive way from 11 to 18 years of age. However, this difference between the sexes may have occurred due to the difference in the volume measurement forms, so we emphasize the importance of following all previously determined reference points in order to obtain more reliable results. In the present study, because it is a cross-sectional analysis, we collected data in a single moment of time, not allowing the evaluation of the images in two moments such as Chiang *et al.*[18].

The results obtained in the present study showed that the highest mean airway volume was found in males and individuals over 34 years of age, but did not change according to the angle of the mandibular branch. In the literature, there are no reports of other studies evaluating the relationship of the volume of the upper airways with the angle of the mandibular branch.

Studies that have related VAS volume to facial patterns are the most common. Zheng *et al.*1 , observed the variability in the upper airways of individuals with different anteroposterior skeletal patterns by evaluating the volume and area of the most restricted cross-section of the pharyngeal airways, and found results that varied with the different skeletal patterns, concluding that the airway volume of class I and class III individuals was significantly higher than that of patients with skeletal class II pattern, and no significant difference was found between class I and class III groups.

Claudino *et al.*[3] assessed the size and morphology of the pharyngeal cavity in adolescents, aged 13 to 20 years, and concluded that the class II adolescents presented lower mean values (lower pharyngeal, velopharynx and oropharynx portion) than the class III group, and velopharynx morphology significantly less uniform than class I and class III groups. A negative correlation was observed between the value of BNA (angle between the nasio, point A and point B) and the volume of the airways in the lower portion of the pharynx and the velopharynx (both genders) and in the oropharynx (only in male individuals).

Shokri *et al.*[10] made important discoveries when they concluded that the three skeletal classes of adult patients differed significantly in airway volume, and found significant differences in airway volume and mean area between class II and III patients, the minimum axial area and morphology in class III patients were larger than in class I and class II patients. Each increase of one unit in the ANB angle reduced the volume of the airways by 0.261 units. The effect of the ANB angle on airway volume was statistically significant and it was shown that the increase of one unit in the angle decreased airway volume in 453,509 units, in conclusion, the total airway volume and mean airway area of class III patients were larger than those of class II. Although many studies report the relationship between airway volume and facial pattern, the present study did not correlate this variable during the analyzes.

Other studies compared only pattern III with pattern I, such as Hong *et al.*[14] who concluded through his study that the volume of the upper part of the pharyngeal space was higher in patients with Class III skeletal malocclusion, and the increase in the volume of the upper part of the pharyngeal airways showed significant correlations with the anterior position of the mandible. Alhammadi *et al.*[4], showed that due to an inherent inverse jaw positioning in Class II skeletal malocclusion, there is a decrease in the spaces of the upper airways of the pharynx. This decrease is partially compensated by an increase in the most restricted area of the pharyngeal airways. Conversely, the vertical positioning of the mandible in class II skeletal malocclusion significantly increases the spaces of the upper airways of the pharynx. The study by Hong *et al.*[14] and de Alhammadi *et al.*[4] agree that the volume of the upper part of the pharyngeal space may be increased in patients with Class III skeletal malocclusion and decreased in patients with Class II skeletal malocclusion.

For correction of facial profiles class II and III, orthognathic surgeries may be chosen, but remembering that they tend to cause alterations not only in the patient's esthetics, but also in the functional aspect. Lee *et al.*[15] evaluated factors that influence the airways space after mandibular setback surgeries and setback of both maxillary muscles in facial pattern III patients and showed that the posterior impact of maxilla on maxilla and mandible surgery had an effect on volume preservation total pharyngeal airways (TPV). A change in body mass index (BMI) was an important predictor of decreased TPV in patients submitted to jaw surgery and that posterior maxillary impaction can be a reliable option to compensate for the reduction of pharyngeal airways after mandibular reversion surgery. Postoperative weight gain may increase the risk of postoperative pharyngeal airway reduction. Therefore, these factors need to be considered before and after surgery.

Irani *et al.*[19] saw that after the surgery of mandibular regression, the volume of the pharyngeal airways and posterior dimensions were decreased. Patients submitted to mandibular setback surgery should be evaluated for obstructive sleep apnea and the proposed treatment plan according to the risk of possible airway involvement. HART *et al.*20 in a similar study, found the same results and made important analyzes in which they found that the optimal control of airway volume is through mandible management in the horizontal direction and in the vertical posterior movement of the maxilla in all patients and that both surgeon and orthodontist should plan for ideal way these movements to control gains or losses in airway volume as a result of orthognathic surgery, in order to have the best results**.**

Jacobtone *et al.*[21] also evaluated class III patients after bimaxillary correction, but found different results, even when evaluating CFCT and lateral cephalometries. Its results were that the orthognathic surgery did not cause a decrease in airway space. This may have occurred due to the small number of individuals who participated in the research and different reference points from researchers from other studies.

The objective of performing a complete analysis of VAS through 3D models was achieved in the present study, the technique allows the segmentation of the airways, manipulation of tomographic images according to the software and its available programs, and more reliable results can be obtained. even with the manual segmentation method, individualizing the evaluation of each patient. The main advantages of the VAS evaluation method, applied in the present study, is that having access to DICOM images, it is possible to perform numerous evaluations, apply slices, segmentations, different contrasts, visualization of 3D image models by ITK- Snap, a quality software, free of charge and easy to access, contributing to the interpretation and evaluation of TCFC.

4 Conclusion

The analysis of the VAS volume through the CFCT is interesting for a correct diagnosis and surgical planning of the patients, mainly through the development of the three-dimensional models, where it allows an individualized evaluation, observing the areas of greater or lesser constriction and without any interference from surrounding structures.

Furthermore, we conclude that it is not possible to relate the volume of the airways according to the angle of the mandibular branch, and that it is not possible to measure or have predictability of the airway volume by evaluating the angle of the mandibular branch, and it is not a variable that needs to be evaluated for the diagnosis and planning of orthognathic surgeries.

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