Anatomical evaluation of the nasopalatine canal using CBCT (Cone Beam Computed Tomography): Method validation in open source software

Avaliação anatômica do canal nasopalatino por meio de TCFC (tomografia computadorizada de feixe cônico): Validação de método em programa de código aberto

Evaluación anatómica del canal nasopalatino mediante CBCT (tomografía computarizada de haz cónico): validación del método en un programa de código abierto

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Abstract

Objective: Development and validation (using open source software) of a method for volumetric and linear assessment of the nasopalatine channel (NPC) using cone beam computed tomography (CBCT). Materials and methods: This was an observational, cross-sectional study of 276 CBCTs. Acquisition was performed on a Prexion 3D computerized tomography scanner (manufacturer), using voxels of 0.08 mm and 0.14 mm, (with FOV at 5 and 12 cm). The images were compiled and divided in accordance with gender and the dental

condition of the maxilla. Evaluation took place on a MacBook Pro computer using the Horos Project program (Version 3.3.5). Linear measurements and NPC volumetric evaluations were performed after correcting the orientation axes (sagittal and axial). The *length* and *ROI volume* tools were used. Results: The average age for men was 60.15 ± 11.94, for women it was 59.95 ± 10.63. Respectively, for men and women, the average NPC volume values were: 68.59 mm^3 and 59.37 mm^3 (p = 0.032), for length they were 10.08 mm and 8.84 mm (p = 0.000). Of the dentate participants, the NPC averages for volume for men and women were: 71.01 mm^3 and 57.18 mm^3 (p = 0.007), for length they were 10.26 mm and 9.14 mm (p = 0.001). In the edentulous, the average NPC lengths were 9.79 mm (men) and 8.37 mm (women) (p = 0.005). Conclusion: For linear and volumetric nasopalatine channel assessment, the post-processing method used in the Horos software was considered precise and easy-to-use.

Keywords: Cone-beam computed tomography; Maxilla; Anatomic variation; Validation study.

Resumo

Objetivo: Desenvolvimento e validação de um método para avaliação volumétrica e linear do canal nasopalatino (CNP) através de tomografia computadorizada por feixe cônico (TCFC) em software de código aberto. Materiais e métodos: Trata-se de estudo observacional, transversal de 276 TCFC. A aquisição foi realizada por um tomógrafo computadorizado Prexion 3D (fabricante), com voxel de 0,08 mm e 0,14 mm, e FOV de 5 cm e 12 cm. As imagens foram compiladas e divididas segundo sexo e estado dentário da maxila. A avaliação ocorreu num computador MacBook Pro através do programa Horos Project (Versão 3.3.5). Foram realizadas mensurações das medidas lineares e avaliação volumétrica do CNP após correção dos eixos de orientação (axial e sagital). Foram usadas as ferramentas *length* e *ROI volume*. Resultados: A média de idade para homens foi 60,15 ± 11,94 e mulheres 59,95 ± 10,63. Para homens e mulheres, os valores médios do CNP para volume e comprimento foram: 68,59 mm^3 e 59,37 mm^3 (p = 0,032), 10,08 mm e 8,84 mm (p = 0,000). Entre os participantes dentados, as médias do CNP de volume e comprimento para homens e mulheres foram: 71,01 mm^3 e 57,18 mm^3 (p = 0,007), 10,26 mm e 9,14 mm (p = 0,001). Apenas entre os edêntulos, o comprimento médio do CNP foi 9,79 mm (homens) e 8,37 mm (mulheres) (p = 0,005). Conclusão: O método de pós-processamento usado no software Horos foi considerado como uma ferramenta precisa e de fácil utilização para a avaliação linear e volumétrica do canal nasopalatino.

Palavras-chave: Tomografia computadorizada por feixe cônico; Maxila; Variação anatômica; Estudo de validação.

Resumen

Objetivo: Desarrollo y validación de un método para la evaluación volumétrica y lineal del canal nasopalatino (CNP) utilizando tomografía computarizada de haz cónico (TCFC) en software de código abierto. Materiales y métodos: Este es un estudio observacional de corte transversal de 276 TCFC. La adquisición se realizó mediante un escáner de tomografía computarizada 3D Prexion (fabricante), con vóxeles de 0,08 mm y 0,14 mm, y FOV de 5 cm y 12 cm. Las imágenes se recopilaron y dividieron según el sexo y el estado dentario del maxilar. La evaluación se realizó en una computadora MacBook Pro utilizando el programa Horos Project (Versión 3.3.5). Las medidas de las medidas lineales y la evaluación volumétrica del CNP se realizaron después de corregir los ejes de orientación (axial y sagital). Se utilizaron herramientas de longitud y volumen de ROI. Resultados: La edad promedio de los hombres fue de 60,15 ± 11,94 y las mujeres de 59,95 ± 10,63. Para hombres y mujeres, los valores promedio de CNP para volumen y longitud fueron: 68,59 mm3 y 59,37 mm3 (p = 0,032), 10,08 mm y 8,84 mm (p = 0,000). Entre los participantes dentados, los promedios de volumen y longitud del CNP para hombres y mujeres fueron: 71,01 mm3 y 57,18 mm3 (p = 0,007), 10,26 mm y 9,14 mm (p = 0,001). Solo entre los edéntulos, la longitud media del CNP fue de 9,79 mm (hombres) y 8,37 mm (mujeres) (p = 0,005). Conclusión: El método de posprocesamiento utilizado en el software Horos fue considerado como una herramienta precisa y fácil de usar para la evaluación lineal y volumétrica de canal nasopalatino.

Palabras clave: Tomografía computarizada de haz cónico; Maxila superior; Variación anatómica; Estudio de validación.

1. Introduction

The routine of cone beam computed tomography (CBCT) in dentistry has allowed Dental Surgeons to improve their exam imaging, to ensure a detailed view of underlying structural relationships. With 3D images, decision making is simplified and recognition of bone defects from different angles becomes easier (Shukla et al., 2017).

The Nasopalatine Canal (NPC) also identified as Incisor Canal (IC) is part of the forward region of the maxilla, and it is located in the midline of the palate, establishing a bone

connection between the oral and nasal cavities. Planning operating procedures in this area must be based on detailed understanding of the anatomical structure (Friedrich et al., 2015).

Conducting nasopalatine nerves, arteries and vessels, the NPC is one of the most important anatomical structures in the antero-maxillary region. Since the anterior region of the maxilla is more vulnerable to both trauma and tooth loss, knowledge concerning its morphology, dimensions and development of NPC is needed (Sekerci et al., 2014).

The anatomical variability of the canal depends on gender, age, presence or absence of teeth, population group, and imaging technique (Panjnoush et al., 2016). Though there are few studies analyzing its structure in relations of volumetric measurements, variations in NPC volume in relation to morphology are becoming more evident (Acar & Kamburoğlu, 2015).

Given that linear measurements are often limited, and can even mask relevant changes (Costa et al., 2019), volumetric calculation of the NPC attempts to visualize dimensional change with less morphological distortion. The objective of the current study was development and validation of a linear - volumetric NPC evaluation method using CBCT in open source software.

2. Methodology

2.1 Sample selection

The study was previously submitted to the Research Ethics Committee of the Health Sciences Center of the Federal University of Paraíba, in accordance with resolution 466/12 of the National Health Council - CNS/MS, in which approval was obtained under the Protocol number 3,320,684. A cross-sectional observational study of 276 CBCTs was performed (Figure 1) whose data were collected from radiological clinics between the months of January to December 2018.

Figure 1. Schematic illustration of the sample separation into groups by gender (male and female) and dental condition (dentate and dentulous).
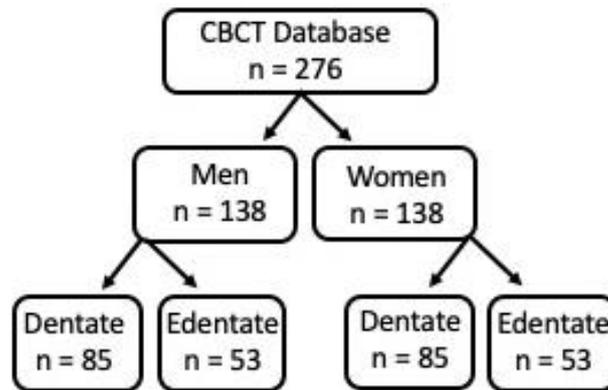
Source: Authors.

The sample size was defined by non-parametric analysis using two-way ANOVA (2x2) in a calculation performed in EXCEL software (Soumya et al., 2019). Given the individualities of the study, the magnitude of effect considered was the average value of 0.25. From this, a total sample size of 128 participants was calculated. In the current study, the value was increased, enabling an increase in power, as well as a decrease in the degree of uncertainty.

The study included healthy individuals, aged 40 to 90 years (mean 60.1 ± 11.3), who underwent maxillary CBCT exams as a complementary exam for dental treatment planning; all included CBCTs were performed with a FOV of 5 cm and 12 cm.

Participants were excluded if their exams lacked information concerning any variable; or upon presenting CBCT images with artifacts making it difficult to detect reference points for measurement; or presenting an impacted tooth in the anterior region of the maxilla, or presenting pathologies that might seriously affect alveolar bone and palatine canal dimensions, such as a nasopalatine duct cyst (NPDC), or any pathology caused by metabolic, developmental, or inflammatory factors.

The anatomical variations of the NPC were measured according to gender and age for dentate and edentulous participants. NPC measurements were compared between females and males (Table 1), between toothed male and female participants (Table 2), and between edentulous male and female participants (Table 3). Toothed participants were considered individuals presenting dental elements 12, 11, 21, and 22 (Demiralp et al., 2018). Edentulous participants lacked these teeth.

2.2 Obtaining tomographic images

Tomographic images were obtained using Prexion 3D computerized tomography (Prexion Inc. - USA) with a section thickness/voxel size of 0.08 mm and 0.14 mm. The working regime adopted was 90 kVp and 4 mA, and the exposure time was 37 s. For all images, a 5 cm and 12 cm field of view (FOV) was selected.

The acquisition of CBCT images was performed uniformly after the initial scan, with an axially oriented cutting plane, and leveled to the incisal of the teeth/alveolar process (edentulous maxilla). The initial volumetric study - data in RAW format, was obtained using 360/720 simultaneous images by x-ray tube rotation (Hi and Hi/Hi resolution protocols), sequentially saved in the tomography workstation for further processing and use of image processing protocols.

2.3 Validation Method - Analysis and evaluation of tomographic images

After acquiring the axial images, they were stored natively in a universal DICOM format (*Digital Imaging Communication in Medicine*) and transmitted via a network environment in a Gigabit Ethernet protocol to an independent workstation (Macbook pro mid 2015 - MacOs Mojave), containing free open source software Horos - Horos Project (Version 3.3.5 - Annapolis, MD), where the CBCTs were analyzed. Horos is based on OsiriX[TM] and other open source medical image libraries, and is available under the GNU Public License (LGPL-3.0) (Vellone et al., 2020).

The data reconstruction algorithms were adjusted using the MIP (Max Intensity Projection) tool, where a 1.0 mm cut thickness (reformatting) was assigned (Shyu et al., 2015). This adjusement was done in order to allow more fast and reliable analysis and identification of anatomical landmarks. The slices were reformatted to place the NPC in the vertical position in coronal view, and the palate or floor of the nose in a horizontal position in a sagittal view (the CBCT orthogonal orientation) (Gönül et al., 2016).

After correcting the orientation axes, the dimensions of the NPC were measured in mm using the reformatted sagittal CBCT images. The following landmarks were selected for standardized measurements (Figure 2) for the NPC evaluation and linear analysis. Using the *length* tool, the following structures were measured in mm: (L1) diameter of the nasal foramen (NF) - if the NPC presented more than one NF, the average of the foramens found was calculated; (L2) diameter of the incisor foramen (IF) -if the NPC had more than one IF,

the mean of the foramens found was calculated; (L3) length of the NPC along its slices (between the NF midpoint and the IF midpoint); (L4) the NPC midpoint width, between the incisor and nasal foramen. On the axial slice, using the same *length* tool, the NF (L5) diameter was measured. If there was more than one NF, the mean of the foramens found was calculated. In this same section, the number of nasal foramen or Stenson foramen (SF) was obtained (Bornstein et al., 2011; Gil-Marques et al., 2020) (Figure 2 A and B).

Figure 2. (A) Linear measurements in sagittal CBCT section (mm). L1 - diameter of the NF (nasal foramen). L2 - IF diameter (incisor foramen). L3 - length of the NPC (nasopalatine channel). L4 - NPC midpoint width. (B) Linear measurement in axial section of CBCT (mm). L5 - diameter of the NF (nasal foramen).
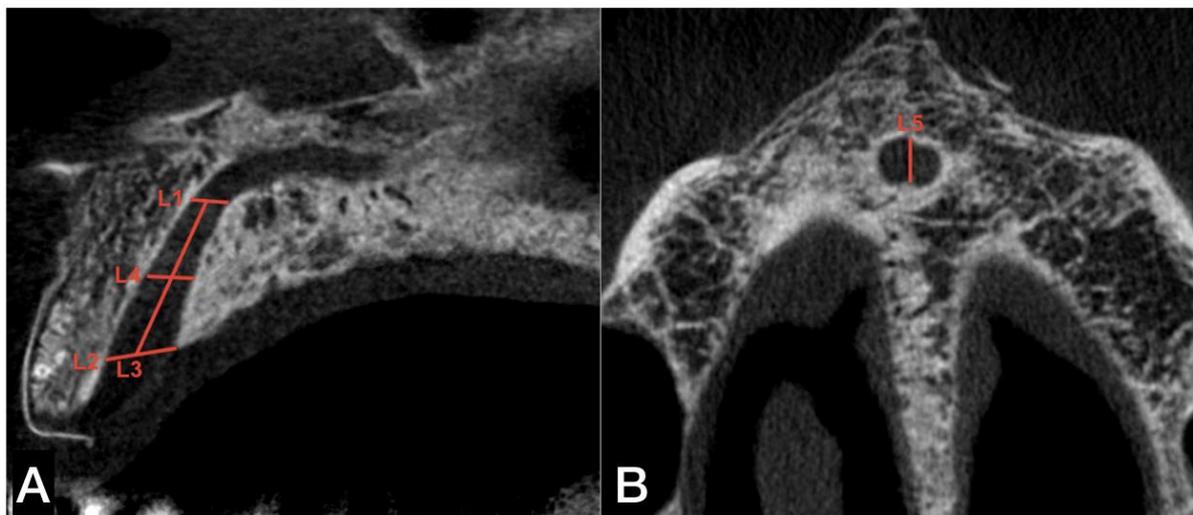
Source: Research data.

The routine for evaluating the NPC volume calculation was obtained using the *ROI* command (Vellone et al., 2020). Initially, the operator performed manual tracing (pencil tool) around the entire perimeter of the NPC in the axial plane, calculating the area (mm^2) of this structure in each tomographic section. This was initiated in the nasal foramen and ended in the incisive foramen, so that the entire distance of the NPC was included, covering all of the images of the tomographic section in an alternating way. After the NPC was completely delimited, the *Generate Missing ROIs* command was used, such that the NPC perimeters not performed by the examiner, were generated by the Horos software itself (Figure 3 A-D).

Figure 3. (A-D) Sequence of NPC (nasopalatine canal) perimeter delimitation using the pencil tool in the axial section. NF (A) and IF (B) represent the beginning and end of the measurements, respectively. Cutting thickness of 1.0 mm. (E) Volumetric measurement of the CBCT NPC, using the ROI VOLUME tool of the Horos software (volume measured in mm^3).
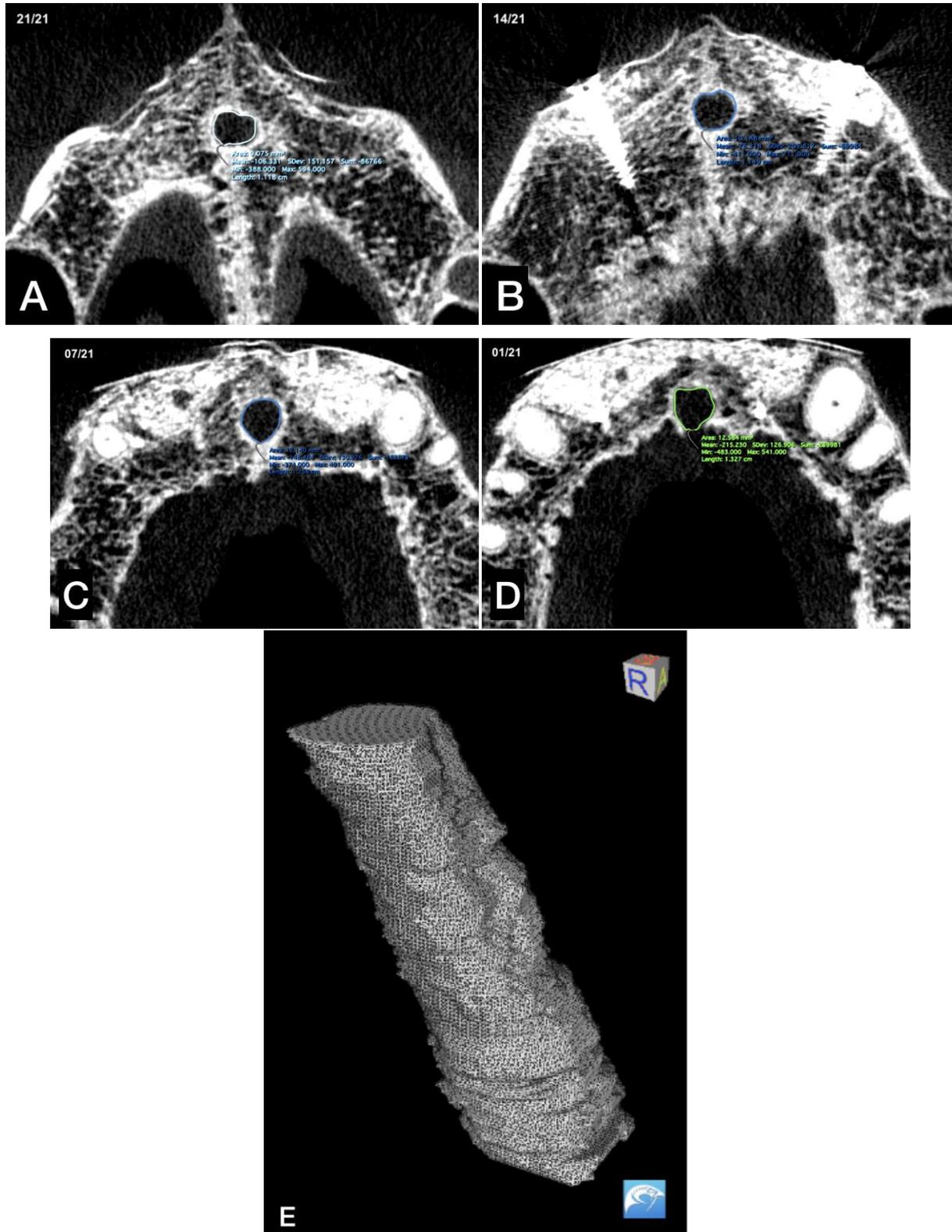
Source: Research data.

Soon afterwards, the *ROIS* were joined using the *ROI VOLUME (COMPUTE VOLUME)* command, for volumetric calculation of the anatomical site in question. In this way, cubic information was obtained, encompassing the NPC in its entirety (Figure 3 E).

Calculations and analyses were performed by a single previously trained examiner. The examiner's calibration was performed by a radiologist through four separate sessions in which training was conducted through theoretical discussion and CBCTs exercises with the linear and volumetric measurement of CNP. For intra-examiner calibration, reexamination was performed on 20% of the sample at the beginning of data collection for NPC anatomical landmark identification and measurements (Cicchetti, 1994). All evaluations were performed individually and sequenced under controlled light in an environment free of external stimuli. In order to improve the quality of the images, adjustments such as contrast, brightness, and zoom were performed; and to avoid measurement errors due to researcher visual fatigue, a maximum of 10 images per session were evaluated.

2.4 Statistical analysis

Data analysis was executed using the IBM SPSS Statistics version 25 for Windows. Two-way ANOVA analysis was used to define the sample size. The intra-class correlation coefficient was applied for intra-examiner validation. For normal continuous variables, the independent T parametric test was applied. The non-parametric Mann-Whitney test was applied to continuous and non-normal variables. Analysis of the discrete variables was performed using the X^2 test. Pearson's correlation between dependent and independent variables was also used. Data were expressed as mean ± standard deviation, and as frequencies and percentages. For statistical significance, values of $p < 0.05$ were considered.

3. Results

Applying the intra-class correlation coefficient, the result found was significant agreement in the analysis for all variables (Table 1). No significant associations were found between the NPC linear measurements and age, and between NPC volume and age (Table 2).

It was observed that the male participants presented higher averages than female participants for the following variables: NPC volume, IF diameter and NPC length. The average age for men and women was respectively 60.15 ± 11.94 and 59.95 ± 10.63. The volume of the NPC had an average value of 63.99 ± 35.22 mm^3, with values ranging between

9.03 mm^3 (min.) and 229.30 mm^3 (max.). This variable was statistically significantly higher for men, with an average value of 68.59 ± 36.59 mm^3. While women presented an average NPC volume equal to 59.37 ± 32.28 mm^3 (p = 0.032). A significant difference was observed between the mean diameter of the incisor foramen, which was greater for men (3.61 mm) than for women (3.35 mm) (p = 0.026). Gender had a significant effect on the average length of the NPC, which was greater in men (10.08 mm) than in women (8.84 mm) (p = 0.000). The average diameter of the NF was greater in females on the sagittal slice and was equivalent to males on the axial slice. Gender was not related to the diameter of the nasal or NPC midpoint width, and the mean of each variable was higher for the female participants (Table 3).

As for the number of NF, up to 4 openings were observed at the level of the nasal floor. The presence of two foramen (47.1%) was the most frequent finding for males. While for females, an equivalent frequency was found for one (44.9%) and two (43.5%) NF. There wasn't association between gender and number of NF (p = 0.05) (Table 6).

In the group of participants with dentate maxilla, the variables presenting the highest averages for male subjects were: NPC volume, IF diameter, NPC length, NPC midpoint width, and NF diameter on the sagittal and axial slices. In this group, the average age for males was 57.95 ± 11.40 and for females 59.04 ± 10.67. The average NPC volume in this group was 64.1 ± 2.57 mm^3, with a minimum and maximum of 11.1 mm^3 and 229.30 mm^3. For this group, there was a statistically difference between genders and average NPC volume, which ranged from 57.18 ± 25.79 mm^3 (women) to 71.01 ± 38.63 mm^3 (men) (p = 0.007). In this same group, gender also had a significant effect on the average NPC length, being 9.14 mm (for women) and 10.26 mm (for men) (p = 0.001) (Table 4).

Regarding the number of NF in dentate patients, it was detected that the presence of two foramen was more prevalent in both male (52.9%) and female (48.2%) patients. No association was found between sex and the number of NF in dentate patients (p = 0.27) (Table 6).

For participants with edentulous maxilla, the variables presenting the highest averages among male patients were: age, NPC volume, IF diameter and NPC length. The average age was higher in males than in females, with respective values equal to 63.68 ± 12.06 and 61.42 ± 10.49. The average volume of the NPC was 63.81 ± 3.69 mm^3, with values ranging between 9.03 mm^3 (min.) to 166.90 mm^3 (max.), yet with no statistical significance between male and female, whose mean values were respectively 64.72 ± 33.05 mm^3 and 62.89 ± 42.69 mm^3. In edentulous patients, a statistically difference was observed for NPC length and sex (p = 0.005), with mean values being 9.79 mm (men) and 8.37 mm (women) (Table 5).

Regarding the number of NF in the edentulous patients group, an association with gender was found where the most prevalent presence of just one foramen was observed for female patients (60.4%), while male patients had an equivalent prevalence for one foramen (41.5%) or two foramens (37.7%) (p = 0.042).

Table 1. Intra-class correlation coefficient.

Variable	ICC
V	0,94
L1	0.96
L2	0,94
L3	0,98
L4	0,93
L5	0,95

V represents the NPC volume. L1 represents the diameter of the NF (sagittal slice). L2 represents IF diameter (sagittal slice). L3 represents the length of the NPC (sagittal slice). L4 represents the NPC midpoint width (sagittal slice). L5 represents the NF diameter (axial slice). ICC means intra-class correlation.

Source: Authors.

Table 2. Correlation between NPC measurements and patient age.

Variable	V	L1	L2	L3	L4	L5
Age						
r	-0,027	-0,051	0,022	-0,070	0,022	-0,094
P Value	0,653	0,397	0,717	0,245	0,710	0,118

V represents the NPC volume. L1 represents the diameter of the NF (sagittal slice). L2 represents IF diameter (sagittal slice). L3 represents the length of the NPC (sagittal slice). L4 represents the NPC midpoint width (sagittal slice). L5 represents the NF diameter (axial slice).

Source: Authors.

Table 3. Comparison of NPC measurements by gender.

Variable	Men (n=138)	Women (n=138)	Total (n=276)	P Value
Age	60.15 ± 11.94	59.95 ± 10.63	60.05 ± 11.28	0.098
V (mm^3)	68.59 ± 36.59	59.37 ± 32.28	63.28 ± 35.21	0.032*
L1 (mm)	2.31 ± 1.07	2.39 ± 1.09	2.36 ± 1.08	0.523
L2 (mm)	3.61 ± 1.1	3.35 ± 1.11	2.48 ± 1.11	0.026*
L3 (mm)	10.08 ± 2.44	8.84 ± 2.31	9.46 ± 2.45	0.000*
L4 (mm)	1.98 ± 0.81	2.1 ± 1.03	2.04 ± 0.93	0.637
L5 (mm)	2.43 ± 1.19	2.42 ± 1.26	2.42 ± 1.23	0.956

V represents the NPC volume. L1 represents the diameter of the NF (sagittal slice). L2 represents IF diameter (sagittal slice). L3 represents the length of the NPC (sagittal slice). L4 represents the NPC midpoint width (sagittal slice). L5 represents the NF diameter (axial slice). Data are expressed as mean ± standard deviation. * Differences between groups statistically significant (p <0.05). Source: Authors.

Table 4. Comparative statistical analysis of dented participants by gender.

Variable	Men (n=85)	Women (n=85)	P Value
Age	57.95 ± 11.40	59.04 ± 10.67	0.437
V (mm^3)	71.01 ± 38.63	57.18 ± 25.79	0.007*
L1 (mm)	2.35 ± 1.09	2.31 ± 1.01	0.803
L2 (mm)	3.54 ± 1.05	3.28 ± 0.97	0.093
L3 (mm)	10.26 ± 2.23	9.14 ± 2.29	0.001*
L4 (mm)	1.99 ± 0.85	1.97 ± 0.82	0.89
L5 (mm)	2.49 ± 1.17	2.33 ± 1.16	0.372

V represents the NPC volume. L1 represents the diameter of the NF (sagittal slice). L2 represents IF diameter (sagittal slice). L3 represents the length of the NPC (sagittal slice). L4 represents the NPC midpoint width (sagittal slice). L5 represents the NF diameter (axial slice). Data are expressed as mean ± standard deviation. * Differences between groups statistically significant (p <0.05). Source: Authors.

Table 5. Comparative statistical analysis of edentulous participants by gender.

Variable	Men (n=53)	Women (n=53)	P Value
Age	63.68 ± 12.06	61.42 ± 10.49	0.327
V (mm^3)	64.72 ± 33.05	62.89 ± 42.69	0.806
L1 (mm)	2.27 ± 1.05	2.54 ± 1.21	0.222
L2 (mm)	3.73 ± 1.19	3.48 ± 1.31	0.298
L3 (mm)	9.79 ± 2.75	8.37 ± 2.29	0.005*
L4 (mm)	1.98 ± 0.76	2.31 ± 1.30	0.111
L5 (mm)	2.33 ± 1.22	2.56 ± 1.42	0.363

V represents the NPC volume. L1 represents the diameter of the NF (sagittal slice). L2 represents IF diameter (sagittal slice). L3 represents the length of the NPC (sagittal slice). L4 represents the NPC midpoint width (sagittal slice). L5 represents the NF diameter (axial slice). Data are expressed as mean ± standard deviation. * Differences between groups statistically significant (p <0.05). Source: Authors.

Table 6. Frequency and percentage of nasal foramen by gender.

Number NF	n (1)	% (1)	n (2)	% (2)	n (3)	% (3)	n (4)	% (4)	P Value
Men (n=138)	46	33,3	65	47,1	23	16,7	4	2,9	0,05
Women (n=138)	62	44,9	60	43,5	16	11,6	-	-	0,05
Men Dentate (n=85)	24	28,2	45	52,9	13	15,3	3	3,5	0,27
Women Dentate (n=85)	30	35,3	41	48,2	14	16,5	-	-	0,27
Men Edentulous (n=53)	22	41,5	20	37,7	10	18,9	1	1,9	0,042*
Women Edentulous (n=53)	32	60,4	19	35,8	2	3,8	-	-	0,042*

FS representa foramina nasal. n representa tamanho amostral. * Differences between groups statistically significant (p < 0,05). Source: Authors.

4. Discussion

Since diagnostic and radiographic methods evolve, measurement of anatomic structures became more precise and important. Use of imaging softwares (dicom viewers) are mandatory in accomplishing this task. In this regard, open source programs are an important tool in daily routine of health professionals (Haak et al., 2016). The NPC presents anatomical variation with different morphologies and dimensions (Acar & Kamburoğlu, 2015; Al-Amery et al., 2015; Bornstein et al., 2011; Etoz & Sisman, 2014; Gönül et al., 2016; Güncü et al., 2013; Hakbilen & Magat, 2018; Jain et al., 2016; Kajan et al., 2015; Khojastepour et al., 2017; Safi et al., 2016), and is the most important anatomical structure of the anterior maxillary region (Gil-Marques et al., 2020). Imprudent operations can damage the NPC

neuro-vasculature, resulting in paresthesia, hemorrhage, and osseointegration failure (Khojastepour et al., 2017). Improvements in anatomical knowledge can result in the reduction of both risks and damages in pre-maxilla region surgeries.

For anatomical examination of the NPC, previous studies have used imaging exams obtained from spiral computed tomography (Güncü et al., 2013; Tözüm et al., 2012) and computed micro-tomography (*micro CT*) (Fukuda et al., 2015). CBCT's three-dimensional imaging can accurately reveal anatomical appearances and variations in the NPC (Soumya et al., 2019). In the studies mentioned, morphological evaluations used measurements of the distance between two points in the sagittal and axial planes. For surgical planning, the sagittal plane is the most widely studied (Fernández-Alonso et al., 2014). In addition to linear assessments in the sagittal and axial planes using images obtained by CBCT, in this paper, volumetric calculations of the NPC were also performed, thus presenting a simultaneous three-dimensional analysis. NPC volume analysis does not change with the tomographic plane studied, this ensures greater morphological precision (Demiralp et al., 2018), and can reduce trans-operative accidents, including problems.

During post-processing, tomographic images can be analyzed using different software, which can be either free, or free to copy (A. L. F. Costa et al., 2016). In the current study, the DICOM images were reconstructed using the free software Horos, available for download on the internet. The HOROS PROJECT has the same virtual environment as the OsiriX[TM] Software (open source PixMeo Sarl) (Vellone et al., 2020), which is easy to use, offers advanced post-processing, and presents useful image protocols, generating versatile DICOM visualizations, and offering regular updates (Santos Junior et al., 2013). We observed the same characteristics in Horos, which in addition to presenting an accessible graphical interface, allows operator interaction, with a high degree of control of the structure to be analyzed during volumetric and linear studies.

Using the 3D-Doctor software (Able Software Corp, Lexington, MA, USA), measuring the segmentation of the digital image based on vectors it is possible to perform cubic NPC measurements (Acar & Kamburoğlu, 2015; Demiralp et al., 2018). The NPC volumetric calculation in the current study was performed using the *ROI* tool in the Horos software. The technique is based on manual segmentation of the 3D image, and has been shown to be reliable and reproducible (Vellone et al., 2020), thus Horos software was selected over other available public domain free software. As reported in the literature, gender and the presence (or not) of teeth in the anterior region of the maxilla significantly influence NPC size (Acar & Kamburoğlu, 2015; Demiralp et al., 2018; Gönül et al., 2016; Hakbilen &

Magat, 2018; Jain et al., 2016; Kajan et al., 2015; Khojastepour et al., 2017; Safi et al., 2016). In this study, a linear and volumetric evaluation method based on NPC changes related to gender, age, and dental status is presented. Volumetric evaluations allow objective quantifiable measurements to be made; for calculating graft material, and evaluating conditions for emptying the vascular-nervous bundle in extremely atrophic cases; providing information for design of managerial models, and for preoperative planning and post-surgical result evaluation (Breakey et al., 2017).

It was observed that the NPC volume differed by gender (p = 0.032), being higher in men than in women. This variable was also significant in relation to gender for Demiralp et al., (2018) and Acar & Kamburoğlu, (2015), respectively reporting average values of 123.38 mm^3 and 72.96 mm^3 (in men) and 94.74 mm^3 and 55.17 mm^3 (in women). Analyzing the participants separately, the average volume of the NPC was higher in dentate men than in dentate women, showing differences between groups (p = 0.007), a similar finding was reported by Demiralp et al., (2018).

It is likely the volumetric difference of the NPC between men and women is related to greater bone dimensions, and to the greater NPC distance in men. Data from the current study for the edentulous group revealed that although the average NPC volume in men was greater than that in women, no statistical difference was found between the sexes. This may be related to the negligible interference of gender in bone resorption and remodeling of anatomical structures surrounding the NPC after tooth extraction.

Similar to Acar & Kamburoğlu, (2015), there wasn't correlation between the average NPC volume and participant age. It is believed that aging causes loss of bone structure and changes in the degree of resorption, and consequently, changes in NPC volume, but these differences were not noticeable in the current study. Other studies have evidenced that NPC volume increases with age in patients over 50 years old (Costa et al., 2019), and that average NPC volume increases significantly with age (p = 0.009) yet only in edentulous participants (Demiralp et al., 2018). In this paper, there wasn't correlation between mean NPC volume and incisor or nasal foramen diameters, unlike results found in other studies (Acar & Kamburoğlu, 2015; Demiralp et al., 2018), where increases in the NPC volume were related to thinner buccal bone plates and to higher values for nasal and incisor foramen diameters. We note that these differences are related to differing image post-processing techniques.

It has been described in the literature that the average measurement of the NPC varies between 7.9 mm to 16.3 mm (Al-Amery et al., 2015; Cazar Almache et al., 2019). In the current study, the average length of the NPC was 9.46 mm, being statistically higher in men

than in women (p <0.05). This is in agreement with other studies reporting longer and wider channels in male patients (Güncü et al., 2013; Rao et al., 2018). Thakur et al., (2013) stated that the greater NPC length in men can be attributed to the greater cranial-caudal dimension of the face as compared to women. The average length of the NPC found in this paper was statistically significant by sex for edentulous participants, noting that the average is smaller for the women in this group (Hakbilen & Magat, 2018). Bornstein et al., (2011) has reported a decrease in NPC dimensions, when accompanied by an increase in bone resorption. Other studies however, report no association between average NPC length and gender (Panjnoush et al., 2016; Soumya et al., 2019) or dental condition (Panjnoush et al., 2016; Thakur et al., 2013). Despite the edentulous participants being older, no correlation was observed between NPC length and age in the present study.

These data differ from Güncü et al., (2013) and Tözüm et al., (2012), in which edentulous patients were the oldest (p = 0.0001). Some studies have claimed that there is a negative correlation between NPC size and age (Fernández-Alonso et al., 2014; Gönül et al., 2016; Jain et al., 2016). In another study using 79 CBCTs, NPC length increased with increasing age (Soumya et al., 2019). Bornstein et al., (2011) reported that the age of patients had an important effect on NPC distance, with average values generally decreasing with increasing age. Other studies have stated that there isn't significant correlation between NPC length and age for either sex (Acar & Kamburoğlu, 2015; Al-Amery et al., 2015; Etoz & Sisman, 2014; Hakbilen & Magat, 2018; Panjnoush et al., 2016; Safi et al., 2016; Thakur et al., 2013).

In this study, the IF diameter varied between 0.62 mm and 7.45 mm, with a statistically difference between genders (p = 0.026), corroborating the findings of other studies whose mean IF diameters in men were significantly greater than in women (Acar & Kamburoğlu, 2015; Demiralp et al., 2018; Kajan et al., 2015; Khojastepour et al., 2017; Panjnoush et al., 2016; Rao et al., 2018; Safi et al., 2016; Tözüm et al., 2012). In a study by Güncü et al., (2013) there was significance for IF diameter by sex only for dentate participants (p <0.0001). Other studies have found no statistical differences for IF diameter by sex, although the value was higher for male participants (Bornstein et al., 2011; Gönül et al., 2016; Hakbilen & Magat, 2018; Jain et al., 2016; Soumya et al., 2019; Thakur et al., 2013). In the p study, age did not significantly affect the IF diameter, similar to other investigations (Acar & Kamburoğlu, 2015; Etoz & Sisman, 2014; Gil-Marques et al., 2020; Gönül et al., 2016; Hakbilen & Magat, 2018; Thakur et al., 2013). Khojastepour et al., (2017) and Soumya

et al., (2019) found a positive correlation for IF diameter by patient age, increasing significantly with age, whether toothed or in edentulous maxilla.

The mean value of the NF diameter of the participants in the current study wasn't correlated with age, as found in other studies (Acar & Kamburoğlu, 2015; Gil-Marques et al., 2020; Gönül et al., 2016; Güncü et al., 2013; Hakbilen & Magat, 2018; Tözüm et al., 2012). The literature reports a higher average NF diameter in males than in females with a statistically difference (Acar & Kamburoğlu, 2015; Etoz & Sisman, 2014; Gönül et al., 2016; Khojastepour et al., 2017; Rao et al., 2018; Safi et al., 2016; Tözüm et al., 2012) or absence of statistical significance (Al-Amery et al., 2015; Bornstein et al., 2011; Demiralp et al., 2018; Güncü et al., 2013; Hakbilen & Magat, 2018; Jain et al., 2016; Kajan et al., 2015; López Jornet et al., 2015; Panjnoush et al., 2016; Thakur et al., 2013). In this research, in an isolated investigation of the edentulous participants as to gender, a greater mean diameter for the NF was found in females, with no statistical difference. This observed distinction might be related to individual or racial diversity within the sample group. It was also found in the current study that the mean diameter of the IF was greater than that of the NF, without significant correlation; corroborating other studies (Bornstein et al., 2011; Gil-Marques et al., 2020; López Jornet et al., 2015).

Concerning variations that occur at the level of the nasal floor, the literature reports that the number of foramen can vary from one to six (Sicher, 1962), with the most frequent values being one and two (Etoz & Sisman, 2014; Fernández-Alonso et al., 2014; Jain et al., 2016; Song et al., 2009; Thakur et al., 2013). This corroborates the current study, in which the highest prevalences found were one and two NF for the entire sample. Thakur et al., (2013) reported that the largest NF diameters were found in NPCs with a single opening in the nasal fossa, but without a statistically difference.

This paper demonstrates the NPC as a dynamic structure, with great variability. Clinically, this study reveals that the variations found in the NPC, whether volumetric or linear, are related to sex, age, and to the presence of teeth. Surgical implants are the broadest accepted method to rehabilitate tooth loss in anterior maxilla, but it is a challenging task due to its aesthetic and functional requirement. NPC can occupy up to 58% of buccal bone plate width (Khojastepour et al., 2017), so it is advisable to carry out volumetric calculation of the canal and the study of NPC dimension/location and its attached structures, to ensure greater anatomical measurement accuracy for correct position of upper incisor implants.

However, certain factors may interfere with the accuracy of NPC measurements, such as mouse sensitivity, selection of the correct reference point, and the observer's ability. In this

context, we recommend that future studies be performed to increase the degree of anatomical detail and intraosseous characteristics for NPC and those different methods of image post-processing be studied in volumetric analysis while using other open source software.

5. Conclusions

In morphological terms for the NPC, the anatomical differences encountered emphasized the role of volumetric and linear evaluation. There was a difference between genders, in which men had higher values for the volume and length of the NPC, and for the diameter of the IF. The number of FN varied between edentulous individuals, with a higher prevalence of a single opening for women. The post-processing technique used in the Horos software presents a fast, easy-to-use tool that has the benefits of precision with a high degree of control and reproducibility. For these reasons, the NPC anatomical evaluation method developed in this paper can be applied for preoperative planning of surgical procedures in anterior maxilla.

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