GENDER DIFFERENCES IN THE MORPHOLOGICAL CHARACTERISTICS OF THE NASOPALATINE CANAL AND THE ANTERIOR MAXILLARY BONE - CBCT STUDY

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RODNE RAZLIKE U MORFOLOŠKIM KARAKTERISTIKAMA NAZOPALATINALNOG KANALA I PREDNJE MAKISLARNE KOSTI - CBCT STUDIJA

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ABSTRACT

The aim of this study was to investigate the gender differences in anatomical and morphometric characteristics of the nasopalatine canal–NPC and horizontal dimensions of the anterior maxilla by CBCT, which could be of interest for clinicians who perform implant surgery in this region. A retrospective quantitative study was conducted using CBCT images from the radiological database of the Department of Dentistry (Kragujevac) on a total of 113 participants (63 male and 50 female). The results of our study confirmed no gender difference in the distribution of NPC type, while the most frequent NPC type confirmed gender variations (cylindrical in females, funnel in males), but the lowest incidence of NPC type in both males and females was banana-type. The NPC length was significantly increased in males with no significant gender impact on medio-lateral (M-L) and antero-posterior (A-P) dimensions of the incisive foramen, as well as the A-P dimension of the nasal foramen. Linear regression analysis revealed the significant correlation between the M-L dimension of incisive foramen and the anterior maxilla diameter at all bone levels for males, and between the NPC length and the anterior maxilla diameter only in females at the level D. Also, both NPC type and gender significantly affected the correlations between the estimated parameters (females showed significant correlation only in funnel NPC type at the level D, while males showed significant correlation in both funnel NPC type at the level A, but also in hourglass-type at the level D). Those results imply significant gender impact in planning of various surgical interventions in the anterior maxilla region.

Keywords: nasopalatine canal – NPC, anterior maxilla, cone beam computed tomography – CBCT, morphometric analysis, gender difference.

SAŽETAK

Cilj ovog istraživanja je bio da se ispita uticaj rodne razlika na anatomske i morfometrijske karakteristike nazopalatinalnog kanala–NPC i horizontalne dimenzije prednje maksile pomoću CBCT, što može biti od interesa za kliničare koji realizuju implantološku hirurgiju u ovoj regiji. Retrospektivna kvantitativna studija je sprovedena uz korišćenje CBCT snimaka iz radiološke baze podataka Katedre za stomatologiju (Kragujevac) na ukupno 113 ispitanika (63 muškog i 50 ženskog pola). Rezultati naše studije potvrđuju da nije bilo rodne razlika u distribuciji tipa NPC, pri čemu je najčešći tip NPC pokazivao varijacije u zavisnosti od roda (cilindrični kod žena, levkasti kod muškaraca), ali je najmanje zastupljen tip NPC i kod muškog i ženskog roda bio tip banana. Dužina NPC je bila značajno veća kod muškaraca, bez značajnog uticaja roda na medio-lateralne (M-L) i antero-posteriorne (A-P) dimenzije incizivnog foramena, kao i na A-P dimenzije nazalnog foramena. Testiranje linearne regresije je pokazalo značajnu povezanost između M-L dimenzija incizivnog foramena i dijametra prednjeg dela maksile na svim nivoima za muškarce, i između dužine NPC i prednjeg dela maksile na nivou D kod žena. Takođe, i tip NPC i rod ispitanika su značajno uticali na korelacije između ispitivanih parametara (značajna korelacija samo kod levkastog tipa NPC na nivou D kod žena, dok je kod muškaraca značajna korelacija pokazana kod levkastog oblika NPC na nivou A, ali i kod oblika peščanog sata na nivou D). Ovi rezultati upućuju na značajan rodni uticaj na planiranje različitih hirurških intervencija u regionu prednje maksile.

Ključne reči: nazopalatinalni kanal - NPC, prednji deo maksile, kompjuterizovana tomografija konusnog zraka - CBCT, morfometrijska analiza, rodne razlike.

ABBREVIATIONS

CBCT - cone beam computed tomography

NPC - nasopalatine canal

A-P - anteroposterior

M-L - mediolateral

INTRODUCTION

Surgical procedures in the anterior maxillary region include surgical extraction of impacted teeth, implant placement, endodontic treatment, periodontal surgery, the enucleation of cysts, and orthognathic surgery (1). Clinicians, such as oral, maxillofacial and plastic surgeons, which perform surgical interventions in the mouth and surrounding structures, require more detailed insight into anatomy and variations of the NPC (2). This anatomical structure forms a relationship between the nasal and oral cavity and contains the nasopalatine nerve, the descending branch of the nasopalatine artery, fibrous connective tissue and salivary glands (3).

In order to prevent NPC damage during implant surgery, radiological diagnostic is crucial to assist surgeons in the evaluation of the morphological variations of the NPC (4). The current literature described several NPC shapes. Mardinger and coworkers have classified NPC into four types (banana-, hourglass-, cylindrical- and funnel-shaped) using sagittal cross-section slices at CBCT (5). The same classification was described by Guncu and coworkers (6). However, Liang and collaborators defined the NPC shape as conical and cylindrical (7), while Etoz and colleagues (8) classified six NPC types (tree branch, cylindrical, banana-like, funnel-like, cone-like, and hourglass). Saffi and collaborators (9) proposed the classification of sagittal NPC shape into four groups (cylindrical, funnel, hourglass, and spindle). Beside, the researchers also recommend the evaluation of the NPC location and extension for the planning procedures in implant surgery (10).

In addition to the analysis of the NPC (shape, location and dimensions), the horizontal maxillary bone diameter is the most important factor for successful implant therapy (11). It is not surprising that evaluation of the labiopalatal width of the alveolar ridge is necessary before dental implant placement (12). Accordingly, Al-Amery and coworkers used three different levels for the assessment of the horizontal anterior maxilla dimensions (13). On the other hand, Salemi and collaborators measured buccal bone thickness at four levels anterior to the NPC (14). All of mentioned characteristics of both the NPC and anterior maxilla have been reported to vary depending on gender, age, ethnicity and dental status (6, 15, 16).

The numerous complications during implant surgery in the anterior maxilla were described in a literature. Namely, osseointegration failure and short-term sensory disorder are the two most frequent adverse events that have been associated with the implant placement in this region. Implant contact with the neural tissue had been reported as a prediction factor for osseointegration failure. Furthermore, NPC perforation is often accompanied with the neurovascular bundle injury, bleeding during surgery, and the formation of the NPC cyst (2, 17, 18, 19). There are many radiological modalities available for analysis of the alveolar bone dimensions and surrounding anatomical structures that may be helpful in prevention of these complications (20, 21). However, CBCT

with 3D properties provides much more morphometric data for the implant placement planning than the two-dimensional radiographs (22, 23). Also, in recent years, the usage of CBCT had been widely spread for the estimation of anatomical and morphological NPC characteristics for numerous purposes (9, 24, 25).

Hence, the aim of this study was to investigate the gender differences in anatomical and morphometric characteristic of the NPC and horizontal dimensions of the anterior maxilla by CBCT, which could be of interest for clinicians who perform implant surgery in the region of the anterior maxilla.

MATERIALS AND METHODS

Patients' selection

A retrospective quantitative study was conducted using CBCT images from the radiological database of the Department of Dentistry, Faculty of Medical Sciences, University of Kragujevac. Radiographic images were obtained during six months (April to October 2020). The study protocol was approved by the Institutional review board of the Faculty of Medical Sciences, University of Kragujevac (approval ID 01-4376).

The inclusion criteria for involvement in this study were: patients over the age of 18, presence of both lateral and central incisors, and formal consent for usage of personal clinical data in scientific purposes. The exclusion criteria were established as: low image quality, patients with systemic diseases (such as hyperparathyroidism, Paget's disease, osteoporosis), maxillary osteonecrosis, as well as the pathological entities in the NPC surrounding region (nasopalatine duct cyst, tumors, impacted teeth, cleft lips, periodontal diseases of central and lateral incisors – radiographic bone level from cemento-enamel junction >3 mm). Patients with orthodontic braces, metal restoration, dental implants, bone grafting and spaced dentition were also excluded from this study. Therefore, a total of 113 participants fulfilled the inclusion criteria, 63 male and 50 female (an average age of 45.20 ± 2.14 and 41.06 ± 1.96 , respectively).

Imaging procedures

The CBCT images were obtained using an Orthophos XG 3D device (Sirona Dental Systems GmbH, Bensheim, Germany). Operating parameters were set - 85 kV/6 mA, exposure time - 14.3 s or 85 kV/10 mA, exposure time - 5.0 s, and a voxel size of 160 μ m or 100 μ m. The field of view was 8×8 cm for all CBCT images, and the Frankfort horizontal plane was perpendicular to the floor. GALAXIS software v1.9.4 (Sirona Dental Systems GmbH, Bensheim, Germany) was used to analyze images. The examiners analyzed the CBCT images using a monitor (23-inch Philips LED) with 1920x1080 screen resolution in a room with dim lightening.

Morphology and dimensions of nasopalatine canal and anterior maxilla

According to previously defined criteria (5), we classified the NPC into four groups (banana-, hourglass-, cylindrical- and funnel-type). The estimation of predefined NPC morphometric parameters was performed at different sections: anteroposterior (A-P) dimension of the nasal foramen, length of the NPC, A-P dimension of the incisive foramen, and mediolateral (M-L) dimension of the incisive foramen. We used sagittal CBCT slice for all morphometric analyzes of the NPC, except for the M-L dimension of incisive foramen, which was evaluated at axial CBCT slice (Figure 1). For the evaluation of the horizontal diameter of the anterior maxilla, we used sagittal CBCT slice, and measurement was obtained at four predefined levels, as shown in Figure 1. The values of all parameters were expressed in mm. All measurements were independently performed by two investigators (blind to the protocol), with high inter-rater reliability (Pearson's $r=0.95$). The mean value for each parameter was used for further analysis.

Figure 1. CBCT image analysis strategy.

Sagittal cross-section with the region of interest (top); (a) A-P dimension of the incisive foramen, (b) level for the M-L measurement of the incisive foramen, (c) mid-length of the NPC, (d) A-P dimension of the nasal foramen, NCL (NPC

length), (A) horizontal diameter of the anterior maxilla from the buccal border of incisive foramen to the facial aspect of buccal bone plate, (B) horizontal diameter of the anterior maxilla from the buccal wall of the NPC to the facial aspect of buccal bone plate using a horizontal line from the palatal border of the incisive foramen, (C) horizontal diameter of the anterior maxilla from the buccal border at the midpoint level of the NCL to the facial aspect of buccal bone plate, (D) horizontal diameter of the anterior maxilla from the buccal border of nasal foramen to the facial aspect of buccal bone plate; **Axial cross-section with the region of interest (bottom);** (b) M-L diameter of the incisive foramen.

Statistical analysis

The data presented here was expressed as the means $\pm$ SEM. The parameters were initially submitted to Levene's test for homogeneity of variance and to the Shapiro-Wilk test of normality. Comparisons between groups were performed using independent t-test, Pearson's chi-squared test, and/or one-way ANOVA, followed by Scheffe's post hoc test. Pearson's coefficient of correlation was used to analyze relationships between parameters, and simple linear regression analyses were performed. A value of $p<0.05$ was considered to be significant. Statistical analysis was performed with the SPSS version 20.0 statistical package (IBM SPSS Statistics 20).

RESULTS

Results presented in Figure 2 confirmed no significant difference by means of distribution in the NPC type between male and female subjects (Pearson Chi-Square $F=1.742$, $df=3$, $p=0.628$). However, the distribution of the NPC type for both male and female subjects showed significant differences (Chi-Square $F=11.095$ and 9.040 , $p=0.011$ and 0.029 , respectively). The frequency of banana shape was the lowest for both estimated genders, but the highest incidence in male subjects was observed for funnel-type of the NPC (36.51%) while the most frequent NPC type in females was cylindrical (36%).

As presented in Figure 3, the dimensions at different sections of the nasopalatine canal and the horizontal diameter of the anterior maxilla were not significantly gender-dependent by means of both the mediolateral and anteroposterior dimension of the incisive foramen (Fig. 3A/1 and A/2, respectively). The similar situation was observed for the anteroposterior dimension of the nasal foramen (Fig. 3A/3). In contrast, the nasopalatine canal length (Fig. 3A/4) was significantly higher in male subjects ($p<0.01$). The horizontal diameter of the anterior maxilla was not significantly affected by means of gender difference at the levels of A, B, and C (Fig. 3B/1-3, respectively), but again male subjects showed significant augmentation in diameter of the anterior maxilla at the D level (Fig. 3B/4, $p<0.05$).

Figure 2. The frequency of the NPC type appearance.

Blue bars represents male subjects (n=63), pink bars represents female subjects (n=50).

Figure 3. The dimensions at different sections of the nasopalatine canal and the horizontal diameter of the anterior maxilla (mm).

A – different sections of NPC: A/1 - the mediolateral dimension of incisive foramen, A/2 – the anteroposterior dimension of the incisive foramen, A/3 –the anteroposterior dimension of the nasal foramen, A/4 – the nasopalatine canal length. B – horizontal diameter of anterior maxilla: B/1 – A level, B/2 – B level, B/3 – C level, B/4 – D level. Values are expressed as the mean $\pm$ SEM.

* Denotes a significant difference, $p < 0.05$, ** denotes a significant difference, $p < 0.01$.

The results presented in Figure 4 showed that there was no significant difference between the estimated parameters – the mediolateral and anteroposterior dimension of the incisive foramen (Fig. 4A and B, $df=7$, $F=1.818$ and 1.660 , respectively), as well as the anteroposterior dimension of the nasal foramen (Fig. 4C, $F=2.494$) and the NPC length (Fig. 4D, $F=2.031$) depending on NPC type. Also, there was no statistically significant gender difference in any estimated parameter for predefined NPC types.

The estimation of correlation between the dimension at different sections of the NPC and the anterior maxilla diameter at various levels (Table 1) showed that the M-L dimension of the incisive foramen significantly correlated with the anterior maxilla horizontal diameter at all levels for male

subjects, but only at level B and C for females, while no significant correlation between the A-P dimension of the incisive foramen and the anterior maxilla horizontal diameter was observed. As shown in Table 1, the A-P dimension of the nasal foramen significantly correlated with the anterior maxilla horizontal diameter at all levels for male subjects, but only at level D for females. In contrary, NPC length analysis showed no significant correlation with the anterior maxilla horizontal diameter in male subjects, while females showed significant correlation at D level.

The horizontal diameter of the anterior maxilla at all estimated levels (A-D, Fig. 5A-D, respectively) was significantly affected neither by the NPC type nor gender.

Figure 4. The dimensions of the NPC up to the NPC type in sagittal cross-section (in mm).

A – M-L dimension of the incisive foramen; B – A-P dimension of the incisive foramen;
C – A-P dimension of the nasal foramen; D – NPC length. Values are expressed as the mean $\pm$ SEM.

Figure 5. The horizontal diameter of the anterior maxilla at different levels according to the NPC type in sagittal cross-section (in mm).

A – horizontal diameter of the anterior maxilla – A level; B – horizontal diameter of the anterior maxilla – B level;
C – horizontal diameter of the anterior maxilla – C level;
D – horizontal diameter of the anterior maxilla – D level. Values are expressed as the mean $\pm$ SEM.

As shown in Table 2, the M-L dimension of the incisive foramen at level A and B significantly correlated with the horizontal diameter of the anterior maxilla at level A and B for banana and funnel NPC types in male subjects, while the significant correlation in females was observed only in the hourglass NPC type, with no significant correlation for either gender in the cylindrical NPC type. Again, female subjects showed the significant correlation between the M-L dimension of incisive foramen and the horizontal diameter of anterior maxilla at level C in the hourglass type. The significant correlation between those parameters in male subjects was observed in the cylindrical NPC type, but both gender statistics confirmed significant correlation at the level C of the anterior maxilla only in funnel NPC type. The analysis performed at level C of the anterior maxilla showed no significant correlation in either gender.

Interestingly, the significant correlation between the A-P dimension of the incisive foramen and the anterior maxilla diameter was observed only in female subjects at the level A and B for the hourglass, and level B for the cylindrical NPC type (Table 3), while males did not show any significant correlation between those parameters at all levels.

As shown in Table 4, A-P dimension of the nasal foramen significantly correlated with the anterior maxilla diameter at levels A, B, and C only for the funnel NPC type in male subjects, while no significant correlations with the NPC type in females. On the other hand, female subjects expressed significant correlation between the A-P dimension of the nasal foramen and the anterior maxilla diameter at level C for the hourglass type, and level D for the cylindrical NPC type.

Results presented in Table 5 showed that there was no significant correlation between the NPC length at all estimated levels and the anterior maxilla diameter for banana and cylindrical NPC types in both populations. At the same time, the significant correlation was confirmed between the NPC length and the anterior maxilla diameter at the level D for the hourglass type, and level A for the funnel NPC type in male subjects. Finally, the significant correlation for female participants was confirmed only between the NPC length and the anterior maxilla diameter at the level D for the funnel NPC type.

Table 1. The correlation between the dimension at different sections of the NPC and the anterior maxilla diameter at various levels (significant correlations are bolded, blue fields represent significant correlations only for male subjects, pink fields represent significant correlations only for female subjects, gray fields represent significant correlations for both gender).

The sections of the NPC	Gender	The levels of anterior maxilla horizontal diameter			
		A level	B level	C level	D level
The M-L dimension of incisive foramen	Male	$R^2 = 0.2223$ $p = 9.61 \times 10^{-5}$	$R^2 = 0.309$ $p = 2.25 \times 10^{-6}$	$R^2 = 0.2788$ $p = 8.7 \times 10^{-6}$	$R^2 = 0.0908$ $p = 0.016$
	Female	$R^2 = 0.027$ $p = 0.254$	$R^2 = 0.0903$ $p = 0.034$	$R^2 = 0.1872$ $p = 0.002$	$R^2 = 0.0443$ $p = 0.142$
The A-P dimension of incisive foramen	Male	$R^2 = 0.0064$ $p = 0.532$	$R^2 = 0.0538$ $p = 0.067$	$R^2 = 0.0036$ $p = 0.641$	$R^2 = 0.001$ $p = 0.804$
	Female	$R^2 = 0.0015$ $p = 0.791$	$R^2 = 0.0054$ $p = 0.612$	$R^2 = 1 \times 10^{-7}$ $p = 0.998$	$R^2 = 0.0013$ $p = 0.804$
The A-P dimension of nasal foramen	Male	$R^2 = 0.0727$ $p = 0.033$	$R^2 = 0.1011$ $p = 0.011$	$R^2 = 0.2882$ $p = 5.7 \times 10^{-6}$	$R^2 = 0.0788$ $p = 0.026$
	Female	$R^2 = 0.0328$ $p = 0.208$	$R^2 = 0.0033$ $p = 0.690$	$R^2 = 0.0336$ $p = 0.203$	$R^2 = 0.1827$ $p = 0.002$
The NPC length	Male	$R^2 = 0.0048$ $p = 0.590$	$R^2 = 0.0005$ $p = 0.856$	$R^2 = 0.0015$ $p = 0.766$	$R^2 = 0.0036$ $p = 0.462$
	Female	$R^2 = 0.0003$ $p = 0.901$	$R^2 = 0.002$ $p = 0.760$	$R^2 = 0.0012$ $p = 0.814$	$R^2 = 0.100$ $p = 0.025$

Table 2. The correlation between the M-L dimension of the incisive foramen and anterior maxilla diameter at various levels depending on the canal type at the sagittal cross-section (significant correlations are bolded, blue fields represent significant correlations only for male subjects, pink fields represent significant correlations only for female subjects, gray fields represent significant correlations for both gender).

The correlation between the M-L dimension of incisive foramen and anterior maxilla diameter on different levels	Gender	The NPC type at the sagittal cross-section			
		Banana	Hourglass	Cylindrical	Funnel
The M-L dimension of incisive foramen vs. A level	Male	$R^2 = 0.8776$ p = 0.019	$R^2 = 0.135$ p = 0.134	$R^2 = 0.0123$ p = 0.672	$R^2 = 0.3015$ p = 0.007
	Female	$R^2 = 0.519883$ p = 0.169	$R^2 = 0.4546$ p = 0.032	$R^2 = 0.0504$ p = 0.672	$R^2 = 0.0005$ p = 0.935
The M-L dimension of incisive foramen vs. B level	Male	$R^2 = 0.8946$ p = 0.015	$R^2 = 0.0641$ p = 0.311	$R^2 = 0.0273$ p = 0.526	$R^2 = 0.4272$ p = 0.001
	Female	$R^2 = 0.7471$ p = 0.059	$R^2 = 0.6061$ p = 0.008	$R^2 = 0.0944$ p = 0.215	$R^2 = 0.2092$ p = 0.065
The M-L dimension of incisive foramen vs. C level	Male	$R^2 = 0.7564$ p = 0.0553	$R^2 = 0.2071$ p = 0.058	$R^2 = 0.2285$ p = 0.030	$R^2 = 0.2049$ p = 0.030
	Female	$R^2 = 0.4326$ p = 0.228	$R^2 = 0.6925$ p = 0.003	$R^2 = 0.0016$ p = 0.874	$R^2 = 0.4137$ p = 0.005
The M-L dimension of incisive foramen vs. D level	Male	$R^2 = 0.0094$ p = 0.876	$R^2 = 0.1275$ p = 0.146	$R^2 = 0.1387$ p = 0.141	$R^2 = 0.0062$ p = 0.722
	Female	$R^2 = 0.0032$ p = 0.928	$R^2 = 0.0362$ p = 0.598	$R^2 = 0.1404$ p = 0.125	$R^2 = 0.0324$ p = 0.489

Table 3. The correlation between the A-P dimension of the incisive foramen and the anterior maxilla diameter at various levels depending on the canal type at the sagittal cross-section (significant correlations are bolded, blue fields represent significant correlations only for male subjects, pink fields represent significant correlations only for female subjects, gray fields represent significant correlations for both gender).

The correlation between the A-P dimension of nasal foramen and anterior maxilla diameter on different levels	Gender	The NPC type at the sagittal cross-section			
		Banana	Hourglass	Cylindrical	Funnel
The A-P dimension of nasal foramen vs. A level	Male	$R^2 = 0.5001$ p = 0.182	$R^2 = 0.0042$ p = 0.855	$R^2 = 0.0094$ p = 0.711	$R^2 = 0.2443$ p = 0.016
	Female	$R^2 = 0.4523$ p = 0.214	$R^2 = 0.0602$ p = 0.494	$R^2 = 0.0116$ p = 0.670	$R^2 = 6 \times 10^{-5}$ p = 0.075
The A-P dimension of nasal foramen vs.	Male	$R^2 = 0.6757$ p = 0.088	$R^2 = 0.0324$ p = 0.475	$R^2 = 0.0528$ p = 0.359	$R^2 = 0.2772$ p = 0.009

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		Banana	Hourglass	Cylindrical	Funnel
B level	Female	$R^2 = 0.1552$ $p = 0.518$	$R^2 = 0.1011$ $p = 0.370$	$R^2 = 0.0004$ $p = 0.937$	$R^2 = 0.009$ $p = 0.717$
The A-P dimension of nasal foramen vs. C level	Male	$R^2 = 0.7152$ $p = 0.071$	$R^2 = 0.2715$ $p = 0.027$	$R^2 = 0.2028$ $p = 0.069$	$R^2 = 0.3381$ $p = 0.004$
	Female	$R^2 = 0.3094$ $p = 0.330$	$R^2 = 0.1200$ $p = 0.327$	$R^2 = 0.0052$ $p = 0.775$	$R^2 = 0.0883$ $p = 0.247$
The A-P dimension of nasal foramen vs. D level	Male	$R^2 = 0.0074$ $p = 0.890$	$R^2 = 0.0575$ $p = 0.338$	$R^2 = 0.1558$ $p = 0.117$	$R^2 = 0.1492$ $p = 0.069$
	Female	$R^2 = 0.0782$ $p = 0.649$	$R^2 = 0.3954$ $p = 0.051$	$R^2 = 0.3125$ $p = 0.016$	$R^2 = 0.0799$ $p = 0.272$

Table 4. The correlation between the A-P dimension of the nasal foramen and the anterior maxilla diameters at various levels depending on the canal type at the sagittal cross-section (significant correlations are bolded, blue fields represent significant correlations only for male subjects, pink fields represent significant correlations only for female subjects, gray fields represent significant correlations for both gender).

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	Female	$R^2 = 0.4523$ $p = 0.214$	$R^2 = 0.0602$ $p = 0.494$	$R^2 = 0.0116$ $p = 0.670$	$R^2 = 6 \times 10^{-5}$ $p = 0.075$
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	Female	$R^2 = 0.3094$ $p = 0.330$	$R^2 = 0.1200$ $p = 0.327$	$R^2 = 0.0052$ $p = 0.775$	$R^2 = 0.0883$ $p = 0.247$
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Table 5. The correlation between the nasopalatine canal length and anterior maxilla diameters at various levels depending on the canal type at the sagittal cross-section (significant correlations are bolded, blue fields represent significant correlations only for male subjects, pink fields represent significant correlations only for female subjects, gray fields represent significant correlations for both gender).

The correlation between NPC length and anterior maxilla diameter on different levels	Gender	The NPC type at the sagittal cross-section			
		Banana	Hourglass	Cylindrical	Funnel
NPC length vs. A level	Male	$R^2 = 0.5000$ $p = 0.182$	$R^2 = 0.0657$ $p = 0.651$	$R^2 = 0.0022$ $p = 0.858$	$R^2 = 0.2551$ $p = 0.014$
	Female	$R^2 = 0.4606$ $p = 0.208$	$R^2 = 0.0268$ $p = 0.651$	$R^2 = 0.0292$ $p = 0.498$	$R^2 = 0.0077$ $p = 0.738$
NPC length vs. B level	Male	$R^2 = 0.6587$ $p = 0.095$	$R^2 = 0.0569$ $p = 0.340$	$R^2 = 0.0078$ $p = 0.736$	$R^2 = 0.1649$ $p = 0.054$
	Female	$R^2 = 0.2089$ $p = 0.439$	$R^2 = 0.0001$ $p = 0.993$	$R^2 = 0.0130$ $p = 0.652$	$R^2 = 0.0042$ $p = 0.806$
NPC length vs. C level	Male	$R^2 = 0.3954$ $p = 0.256$	$R^2 = 0.0778$ $p = 0.262$	$R^2 = 0.0001$ $p = 0.979$	$R^2 = 0.1580$ $p = 0.060$
	Female	$R^2 = 0.533$ $p = 0.161$	$R^2 = 0.0121$ $p = 0.762$	$R^2 = 0.0110$ $p = 0.678$	$R^2 = 0.0083$ $p = 0.728$
NPC length vs. D level	Male	$R^2 = 0.1125$ $p = 0.581$	$R^2 = 0.3829$ $p = 0.006$	$R^2 = 0.0083$ $p = 0.727$	$R^2 = 0.0052$ $p = 0.743$
	Female	$R^2 = 0.6497$ $p = 0.099$	$R^2 = 0.2256$ $p = 0.165$	$R^2 = 0.0413$ $p = 0.419$	$R^2 = 0.428$ $p = 0.004$

DISCUSSION

A growing interest for a variety of surgical protocols in dentistry implies the necessity for upgraded planning of such interventions. One of the most complex issues that employs regions in oral and maxillofacial surgery is focused on the anterior maxilla. Therefore, the development of methodology for better knowledge of morphometric properties of the NPC and faster acquisition may be substantially important. In order to establish the methodology that could be helpful by means of duration in surgical interventions planning, we performed the estimation of the morphometric analysis of the NPC and the anterior maxilla, based on the NPC type classification, according to gender.

The results of our study confirmed no gender difference in the distribution of the NPC type. Our results are in line with studies by Guncu (6) and Thakur and coworkers (20). However, as shown in Figure 2, the frequency of appearance for different NPC types did not follow equal distribution for both male and female subjects. Interestingly, the most

frequent NPC type confirmed gender variations (cylindrical in females, funnel in males), but the lowest incidence of the NPC type in both male and female participants was the banana-type of the NPC. This is also in accordance with Guncu and collaborators (6).

The analysis of the dimensions at different sections of the NPC showed no significant gender impact on M-L and A-P dimensions of the incisive foramen, as well as the A-P dimension of the nasal foramen. In contrast, the NPC length was significantly increased in male participants. The results for the NPC length and the A-P dimension of the nasal foramen are in accordance with previous report of Kajan and collaborators (26), but they found statistical difference in the A-P dimension of incisive foramen between male and female. However, the study of Soumya and coworkers showed that gender did not have an impact on any of the estimated dimensions of the NPC sections (16). The observed differences could be attributed to different methodologies applied. Furthermore, analysis of the horizontal diameter of the anterior maxilla at different levels also showed the gender impact

manifested as significant augmentation of distance between the nasal foramen and cortical layer of the anterior maxilla in male subjects, with no significant difference at the lower parts of the anterior maxilla. Our results are in line with research groups of Salemi (14) and Gonul (27). However, our findings are not in accordance with the results presented by Lopez (1) and Hakbilen and colleagues (28). A potential explanation could be found in obvious differences in population characteristics, age of participants, total number of subjects, and/or predefined inclusion/exclusion criteria. Also, there was a substantial variability in methodology (number and definition of NPC sections, as well as the classification of NPC types).

According to the results obtained in this study none of the parameters (the dimensions of NPC up to NPC type in sagittal cross-section) was significantly different according to gender (Fig. 4). However, we are not able to compare the results obtained in this study with other published material due to lack of literature data.

Linear regression analysis (Table 1) revealed the significant correlation between the M-L dimension of the incisive foramen and the anterior maxilla diameter at all bone levels for male subjects, while this relation in female participants was present only in the mid part of the anterior maxilla (level B and C). A similar finding was observed for the A-P dimension of the nasal foramen, where again significant correlation was confirmed in male subjects, but the A-P dimension of the nasal foramen correlated significantly with the anterior maxilla diameter only at the highest evaluated level (level D) in females. The opposite finding was achieved concerning the relationship between the NPC length and alveolar bone thickness. Namely, the significant correlation between the NPC length and the anterior maxilla diameter was observed only in female participants at the level D. Furthermore, the horizontal diameter of the anterior maxilla at different levels according the NPC type in sagittal cross-section showed no significant difference according to gender (Fig. 5).

The correlation between the M-L dimension of the incisive foramen and the anterior maxilla diameter at various levels depending on the canal type at the sagittal cross-section was variously affected by gender (Table 2). In male subjects, significant correlation between the M-L dimension of the incisive foramen and lower parts of the alveolar ridge (level A and B) was observed in the banana- and funnel-type of NPC, while with the higher regions of the anterior maxilla (level C) significant correlation was present in the cylindrical- and funnel-type of NPC. In contrast, females expressed significant correlation between the M-L dimension of the incisive foramen and the anterior maxilla thickness only in the hourglass-type of NPC at the levels A, B, and C, as well as the funnel NPC type at the level C.

The linear regression analysis revealed significant correlation between the A-P dimension of the incisive foramen and the anterior maxilla diameter only for females with the hourglass-type at levels A and B, and for the cylindrical-type

of NPC at level B, with no significant correlations for male participants.

Furthermore, the estimation of interconnection between the A-P dimension of the nasal foramen and anterior maxilla diameters at different levels depending on the canal type at the sagittal cross-section confirmed that no significant correlation for either gender in the banana NPC type. At the same time, male subjects showed significant correlation between the A-P dimension of the nasal foramen and buccal bone in the funnel NPC type at all levels except the highest (D level), and the hourglass-type at the level C. Unlike for males, female participants confirmed significant correlation between the A-P dimension of nasal foramen and anterior maxilla thickness in the cylindrical-type of NPC at the highest level (level D).

Finally, the linear regression analysis for the relationship between the NPC length and the anterior maxilla diameters at various levels depending on the canal type revealed that in female subjects significant correlation was present only in the funnel NPC type at the level D. In contrast, male participants showed significant correlation in both the funnel NPC type at level A, but also in the hourglass-type at the level D.

Unfortunately, we are not able to compare the mathematical analysis that gives an insight into the relationship between the anterior maxilla dimensions and morphometric characteristics of the NPC according to the NPC type, since to our knowledge this interconnection was not yet evaluated. Thus, it is even more not possible to estimate the gender impact on those relationships. However, our principle intention was to allow the more accurate data for morphometric quantification in order to achieve advanced planning of various surgical interventions in the anterior maxilla region. Future investigations on this topic, accompanied with the standardized methodology for evaluation, will allow more reliable information for clinical practice.

REFERENCES

1. López JP, Boix P, Sanchez PA, Boracchia A. Morphological Characterization of the Anterior Palatine Region Using Cone Beam Computed Tomography. *Clin Implant Dent Relat Res*. 2015; e459-64.
2. Bahşi I, Orhan M, Kervancıoğlu P, Yalçın ED, Aktan AM. Anatomical evaluation of nasopalatine canal on cone beam computed tomography images. *Folia Morphol (Warsz)*. 2019; 78(1): 153-162.
3. Peñarrocha M, Carrillo C, Uribe R, García B. The nasopalatine canal as an anatomic buttress for implant placement in theseverely atrophic maxilla: a pilot study. *Int J Oral Maxillofac Implants*. 2009; 24(5): 936-942.
4. Costa EDD, Nejaim Y, Martins LAC, Peyneau PD, Ambrosano GMB, Oliveira ML. Morphological Evaluation of the Nasopalatine Canal in Patients With Different Facial Profiles and Ages. *J Oral Maxillofac Surg*. 2019; (4): 721-729.

5. Mardinger O, Namani SN, Chaushu G, Schwartz AD. Morphologic Changes of the Nasopalatine Canal Related to Dental Implantation: A Radiologic Study in Different Degrees of Absorbed Maxillae. *J Periodontol*. 2008; 79 (9): 1659–1662.
6. Güncü GN, Yıldırım YD, Yılmaz HG, Galindo-Moreno P, Velasco-Torres M, Al-Hezaimi, K, Al-Shawaf R, Karabulut E, Wang, H.L, Tözüm TF. Is there a gender difference in anatomic features of incisive canal and maxillary environmental bone? *Clin Oral Implants Res*. 2013; 24 (9): 1023–1026.
7. Liang X, Jacobs R., Martens W, Hu Y, Adriaenssens P, Quirynen M, Lambrichts I. Macro- and micro-anatomical, histological and computed tomography scan characterization of the nasopalatine canal. *J Clin Periodontol*. 2009; 36 (7): 598–603.
8. Etoz M, Sisman Y. Evaluation of the nasopalatine canal and variations with cone-beam computed tomography. *Surg Radiol Anat*. 2014; 36 (8): 805–812.
9. Safi Y, Moshfeghi M, Rahimian S, Kheirkhahi M, Manouchehri, ME. Assessment of Nasopalatine Canal Anatomic Variations Using Cone Beam Computed Tomography in a Group of Iranian Population. *Iran J Radiol*. 2017; 14(1): e13480.
10. Buser D, Chappuis V, Belser UC, Chen S. Implant placement post extraction in esthetic single tooth sites: When immediate, when early, when late? *Periodontology* 2000. 2016; 73(1): 84–102.
11. Mounir M, Beheiri G, El-Beialy W. Assessment of marginal bone loss using full thickness versus partial thickness flaps for alveolar ridge splitting and immediate implant placement in the anterior maxilla. *Int J Oral Maxillofac Surg*. 2014; 43(11): 1373–1380.
12. Kan JYK, Rungcharassaeng K, Deflorian M, Weinstein T, Wang HL, Testori T. Immediate implant placement and provisionalization of maxillary anterior single implants. *Periodontology* 2000. 2018; 77(1): 197–212.
13. Al-Amery SM, Nambiar P, Jamaludin M, John J, Ngeow WC. Cone beam computed tomography assessment of the maxillary incisive canal and foramen: considerations of anatomical variations when placing immediate implants. *PLoS One*. 2015; 10(2): e0117251.
14. Salemi F, Moghadam FA, Shakibai, Z, Farhadian M. Three-dimensional Assessment of the Nasopalatine Canal and the Surrounding Bone Using Cone-beam Computed Tomography. *J. Periodontol. Implant Dent*. 2016; 8(1): 1–7.
15. Panda M, Shankar T, Raut A, Dev S, Kar AK, Hota S. Cone beam computerized tomography evaluation of incisive canal and anterior maxillary bone thickness for placement of immediate implants. *J Indian Prosthodont Soc*. 2018; 18(4): 356–363.
16. Soumya P, Koppolu P, Pathakota, KR, Chappidi V. Maxillary Incisive Canal Characteristics: A Radiographic Study Using Cone Beam Computerized Tomography. *Radiol Res Pract*. 2019; 2019: 6151253.
17. Peñarrocha D, Candel E, Guirado JLC, Canullo L, Peñarrocha M. Implants Placed in the Nasopalatine Canal to Rehabilitate Severely Atrophic Maxillae: A Retrospective Study with Long Follow-up. *J Oral Implantol*. 2014; 40(6): 699–706.
18. McCrea SJJ. Aberrations Causing Neurovascular Damage in the Anterior Maxilla during Dental Implant Placement. *Case Rep Dent*. 2017; 2017: 5969643.
19. Mraiwa N, Jacobs R, Van CJ, et al. The nasopalatine canal revisited using 2D and 3D CT imaging. *Dentomaxillofac Radiol*. 2004; 33(6): 396–402.
20. Canto G. Comparative analysis of imaging techniques for diagnostic accuracy of peri-implant bone defects: a meta-analysis. *Oral Surg Oral Med Oral Pathol Oral Radiol*. 2017; 124(4): 432–440.e5.
21. Wanner L, Ludwig U, Hövener JB, Nelson K, Flügge T. Magnetic resonance imaging-a diagnostic tool for postoperative evaluation of dental implants: a case report. *Oral Surg Oral Med Oral Pathol Oral Radiol*. 2018; 125(4): e103-e107.
22. Sahota J, Bhatia A, Gupta M, Singh V, Soni J, Soni R. Reliability of Orthopantomography and Cone-beam Computed Tomography in Presurgical Implant Planning: A Clinical Study. *J Contemp Dent Pract*. 2017; 18(8): 665–669.
23. Jacobs R, Salmon B, Codari M, Hassan B, Bornstein MM. Cone beam computed tomography in implant dentistry: recommendations for clinical use. *BMC Oral Health*. 2018; 18(1): 88.
24. Alkanderi A, Al Sakka Y, Koticha T, Li J, Masood F, Suárez-López Del Amo F. Incidence of nasopalatine canal perforation in relation to virtual implant placement: A cone beam computed tomography study. *Clin Implant Dent Relat Res*. 2020; 22(1): 77–83.
25. Thakur AR, Burde K, Guttal K, Naikmasur VG. Anatomy and morphology of the nasopalatine canal using cone-beam computed tomography. *Imaging Sci Dent*. 2013; 43(4): 273–281.
26. Kajan ZD, Kia J, Motevasseli S, Rezaian SR. Evaluation of the nasopalatine canal with cone-beam computed tomography in an Iranian population. *Dent Res J (Isfahan)*. 2015; 12(1): 14–19.
27. Gönül Y, Bucak A, Atalay Y, Beker-Acay M, Çalışkan A, Sakarya G, Soysal N, Cimbar M, Özbek M. MDCT evaluation of nasopalatine canal morphometry and variations: An analysis of 100 patients. *Diagn Interv Imaging*. 2016; 97(11): 1165–1172.
28. Hakbilen S, Magat G. Evaluation of anatomical and morphological characteristics of the nasopalatine canal in a Turkish population by cone beam computed tomography. *Folia Morphol (Warsz)*. 2018; 77(3): 527–535.