Prevalence and Anatomical Variations of the *Canalis Sinuosus* in a Lithuanian Population Using Cone-Beam Computed Tomography: a Retrospective Study

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ABSTRACT

Objectives: The aim of this retrospective study was to examine the prevalence of the *canalis sinuosus*, its anatomical variations, and the relationship between its opening sites and the anterior teeth in the Lithuanian population.
Material and Methods: A retrospective cross-sectional analysis of cone-beam computed tomography (CBCT) scans including the full maxillary arch of adult patients was performed. The *canalis sinuosus* (CS) presence, distribution, opening diameter, and distances to surrounding anatomical landmarks were measured and compared by side, sex, and age groups using CS 3D Imaging software (Carestream Inc.).
Results: Among 200 CBCT scans, CS was identified in 73% of subjects (365 canals), with bilateral presentation in 63% and predominantly palatal openings (96.7%). Most canals measured < 1 mm (88.7%) and median CS diameter was significantly greater on the right than on the left (0.78 [SD] vs. 0.7 [SD] mm; $P = 0.034$). Males exhibited significantly larger CS diameters and greater CS-nasal cavity floor and CS-buccal cortical bone distances bilaterally ($P < 0.05$). CS was most frequently located in the central and lateral incisor regions. No significant association was observed between CS location and sex or between age groups and CS dimensions or location; however, unilateral occurrence was more frequent in the age group of 18 to 30 years ($P = 0.002$).
Conclusions: The *canalis sinuosus* is a frequent anatomical structure in the anterior maxilla, most often presenting bilaterally with palatal openings. Sex-related differences were observed, whereas age showed no significant effect on canal dimensions.

Keywords: cone-beam computed tomography; maxilla; maxillary nerve; sinonasal tract.

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INTRODUCTION

The maxilla plays a critical role in both functional and aesthetic aspects of the craniofacial complex. Its anterior region is particularly important due to its proximity to vital neurovascular structures and its frequent involvement in dental rehabilitation [1]. The *canalis sinuosus* (CS) is a winding intraosseous canal originating from the infraorbital nerve. It passes posterior to the infraorbital foramen, runs anterolaterally along the anterior wall of the nasal cavity, then curves sharply downward near the pyriform aperture, and continues toward the palate, exiting through an accessory foramen. Measuring about 55 mm along the maxilla, the CS has a thin bony covering, making it vulnerable to injury. It carries the anterosuperior alveolar nerve along with accompanying vessels and may show accessory channels in the anterior palate. The neurovascular branches within the CS supply the incisor and canine region and surrounding soft tissues [2,3]. The CS was first described and named by Jones in 1939 [4] from its double curved course. Although recognized as a normal anatomical structure [3,5-9], descriptions of the CS and its variations remain rare in anatomical texts and scholarly literature [3,5,6,8,10-12]. Knowledge about CS is essential for surgical procedures, yet it often remains unrecognized by clinicians until they encounter complications [13].

In a study by Lopes-Santos et al. [14], which aimed to assess the level of knowledge of dentists and dental students regarding the CS, the authors reported that 65.3% of respondents failed to diagnose CS in any CBCT examination. Furthermore, only 29.5% of the participants demonstrated awareness of this anatomical structure, indicating a generally low level of knowledge and recognition of the structure.

Limited knowledge of CS inevitably creates additional challenges in radiographic diagnosis and may result in inaccurate diagnoses. CS has been reported to present as concerning radiolucencies and mimic resorptive defects periapically [15-17].

Unawareness of CS might also lead to iatrogenic complications during or after treatment, such as neurovascular injuries [18,19]. It is considered a risk factor for complications during implantology procedures [3,20,21]. Dental implants interrupting or compressing the CS can cause pain [13,20,22-25], paraesthesia [13,20,25], dysesthesia [22], haemorrhage [12], trigeminal neuralgia [25], nasal bleeding, subnasal swelling [26].

Thorough knowledge of the anatomy of the surgical site is essential in oral surgery. Taking into consideration that the morphology of the anatomical structures of the maxilla is individual and that surgeries in this region are becoming increasingly frequent, it is essential to thoroughly study these structures when planning treatment and operating in this area [8,27-29].

One of the most commonly used diagnostic methods in oral surgery is cone-beam computed tomography (CBCT). It is helpful for evaluating and planning surgical procedures in the maxillary region. Due to the reported variability of the CS in the maxillary anterior region, conventional two-dimensional radiographs fail to reliably detect these variations [30]. CBCT is considered the gold standard for assessing the CS, as it provides detailed images at lower radiation doses than helical CT and allows accurate measurements, visualization, and multiplanar reconstruction [7,9,25,28,31-34]. The use of CBCT imaging was justified in accordance with European guidelines [35,36].

Given the current lack of literature on CS in the Lithuanian population, gaining a better understanding of its prevalence and morphology can help reduce the risk of perioperative complications that could lead to surgical failure or other negative outcomes, as well as improve diagnostic accuracy by enabling clinicians to better differentiate anatomical variations from pathological findings.

Therefore, the aim of this retrospective study was to examine the prevalence of the *canalis sinuosus*, its anatomical variations, and the relationship between its opening sites and the anterior teeth in the Lithuanian population using cone-beam computed tomography, as well as to assess potential sex- and age-related differences.

MATERIAL AND METHODS

Ethical approval

The study was conducted at the Department of Maxillofacial Surgery, Lithuanian University of Health Sciences, Lithuania between May 1, 2025, and June 1, 2025.

All data were obtained only from patients who consented to the use of their anonymized health information for scientific purposes.

The study protocol was approved by the Bioethics Center of Lithuanian University of Health Sciences, Lithuania (Protocol No. 2025-BEC2-0702).

Study design

The study was conducted as a retrospective cross-sectional analysis of diagnostic CBCT scans. The retrospective analysis was performed on a random sample of patients (n = 3014) who underwent CBCT imaging between January 1, 2016, and January 1, 2025.

Subject sample

The sample size was determined using the G*Power 3 software (Heinrich-Heine University; Düsseldorf, Germany), with a power of 90% and $\alpha = 0.05$. The effect size was estimated based on a combination of pilot data and Cohen's recommendations. The minimum required sample size was determined to be 184 patients.

Inclusion criteria

The inclusion criteria included CBCT scans of patients aged 18 years or older, with full maxillary arch coverage, obtained from individuals treated in Lithuania.

Exclusion criteria

Exclusion criteria in this study included non-permanent dentition, prior surgery, trauma, and pathological lesions (cysts, tumours, etc.) in the anterior maxillary region, developmental aberrations (such as cleft palate, supernumerary teeth, etc.) or missing teeth in the anterior maxillary region, ongoing orthodontic treatment, dental implants and dental restorations containing radiopaque materials that would obscure anterior maxilla visualisation and evaluation, scans with radiographic artefacts, indistinct or CBCT scans with excessive slice thickness.

Examination process

Six teeth were examined in the scan of every patient (central incisors, lateral incisors, and canines) in both quadrants. The study recorded the following parameters: gender, age, CS distribution (left/right, bilateral/unilateral), opening diameter of CS, distance between CS at the opening of the alveolar ridge crest (ARC) and buccal cortical bone (BCB), nasal cavity floor (NCF), and nasopalatine canal (NPC). The measurement landmarks of the CS are presented in the corresponding planes in Figure 1.

Study area

The study comprised patients from all regions of Lithuania, not solely from Kaunas. Consequently, the sample represents the Lithuanian population rather than participants from a single city.

Collection tools

All CBCT images were obtained using Carestream CS 9000 3D scanner (Carestream Health, Marne-la-Vallée, France), with an isotropic voxel size of 200 µm, a field of view of diameter 12 x 15 cm, and exposure parameters of 74 kV, 10 mA, and 32.4 s. CS 3D Imaging Software version 3.5.18 (Carestream Inc.; New York, USA) was used for data observation.

Observation procedure

The patients' CBCT scans were randomly assigned identification numbers, and their gender and age were recorded.
Radiographic images were evaluated by two observers (A.B. and E.J.). All images were evaluated on

Figure 1. A = the canalis sinuosus (CS) course identified in the coronal section (blue arrows).
B = axial view of the maxillary arch, with the white arrow indicating the diameter of the CS opening.
C = sagittal section showing measurements from the CS opening: the yellow line represents the distance to the nasal cavity floor, the green line represents the distance to the buccal cortical bone, and the red line represents the distance to the alveolar ridge crest.

15.6-inch laptop with a screen resolution of 1920 x 1080 pixels (Lenovo IdeaPad S340 - Lenovo Ltd.; Beijing, China) in a room with standardized conditions of low environmental noise and dimmed light. All scans were acquired and stored in Digital Imaging and Communications in Medicine (DICOM) format. Default values were retained for all parameters to ensure methodological reproducibility. Grayscale mapping was assigned according to tissue category as follows: skin (S) = 0, flesh (F) = 0, bone (B) = 4, dentin (D) = 40, enamel (E) = 100, and amalgam (A) = 100. CBCT cases were utilized for calibration preceding the image analysis which was subsequently excluded from the study. Inter-rater reliability was assessed by calculating Cohen's kappa (κ) for 30 randomly chosen CBCT images. To determine intra-rater reliability for the radiographic parameters, κ values were calculated by re-evaluating 30 randomly selected CBCT images after an 8-week interval. In case of any disagreement, an experienced oral surgeon (P.D.) was involved in the discussions to reach a consensus.

The CBCT analysis methodology was adapted based on the study by Rao et al. [37]. A threshold of 0.3 mm for the CS diameter was chosen because it represents the minimal reliably detectable canal diameter on CBCT images, allowing accurate identification while excluding very small openings that are unlikely to be clinically significant.

The examination started with identifying the intraosseous canals in the anterior maxillary region with an upward tract to the CS. Bilateral/unilateral distribution was then noted with axial, coronal, and sagittal slices. Number of intraosseous canals was recorded. The CBCT images were analysed in three steps: first, the presence of CS, the number, and the distribution (on the left sides or the right) were observed; secondly, the palatal opening diameter was measured at the endpoint on the alveolar ridge crest where the CS canal opens (only CS structures with openings on the palatal side of the alveolar ridge crest were recorded). Finally, the three-dimensional position of the CS was recorded (the distance from the palatal opening of CS to BCB, NCF, ARC, and NPC) (Figure 1).

Measurement method

The CS diameter was measured after identifying the palatal opening on the alveolar ridge crest in the coronal section. Using the axial cursor, positioned perpendicular to the long axis of the CS canal, the buccolingual and mesiodistal diameters were measured at the opening in the axial section. The average value was then recorded. Next, the distance from the canal opening to NPC was recorded. The three-dimensional position of the CS was recorded in the axial section by placing the CBCT measurement software cursor at the palatal opening of the CS on the alveolar ridge crest. The sagittal section direction was adjusted to ensure the section was perpendicular to the dental arch, and the distance between the opening and the long axis of the nasopalatine canal was measured. Subsequently, in the sagittal section, the distances from the canal opening to NCF, BCB, and ARC were measured and recorded (Figure 1).

Statistical analysis

The research data was collected and systematically recorded in an Excel database. The data obtained were analysed using IBM SPSS Statistics, version 29.0.2.0 (IBM Corp.; Armonk, NY, USA). Depending on the distribution of continuous variables, either Student's t-test or the Mann-Whitney U test was applied to compare the five continuous measurements (the distance between the CS and the nasal cavity floor, the distance between the CS and the nasopalatine canal, the distance between the CS and the buccal cortical bone, the distance between the CS and the alveolar ridge crest, and the diameter of the CS) with respect to sex and side.

Pearson's chi-square test was used to examine differences in the presence of canal opening location, CS count, and unilateral/bilateral openings according to side, sex, and age group. When more than 25% of expected cell counts were < 5, Fisher's exact test was applied instead of the chi-square approximation.

Comparisons of the four distance measurements and CS diameter across age groups were performed using the Kruskal-Wallis H test, as the data were not normally distributed.

When statistically significant differences were detected, post-hoc pairwise comparisons with Bonferroni adjustment were conducted to identify specific intergroup differences.

$P < 0.05$ was considered statistically significant.

RESULTS

Both inter- and intra-rater agreement for categorical data were evaluated using Cohen's kappa. Inter-rater reliability was 0.83, indicating high agreement between observers. Intra-rater reliability for the 30 radiographic parameters was 0.87 for each observer (A.B. and E.J.), indicating consistent evaluations when assessed individually.

A total of 1432 patients' maxillary CBCT scans were collected between January 1, 2016, and January 1, 2025. The minimum required sample size was determined to be 184 patients. Based on the study's inclusion and exclusion criteria, a total of 200 patients' CBCT scans were selected for final evaluation (Figure 2).

The study population comprised 78 males (39%) and 122 females (61%). The mean age of the participants was 43.87 (SD 13.91) years (ranged from 18 to 82 years). The distribution of patients by age group was as follows: 30 (15%) patients were between 18 to 30 years old (group 1), 76 (38%) were between 31 to 43 years old (group 2), 53 (26.5%) were between 44 to 56 years old (group 3), 41 (20.5%) were older than 56 years old (group 4).

Presence and lateral distribution of CS

Of the 200 subjects examined, 73% presented a CS. A total of 365 CS canals were identified. Among these, 63% were bilateral and 37% were unilateral, demonstrating that bilateral presentation was more frequent. Most CS openings were directed toward the palate (96.7%), whereas only a small proportion opened toward the nasopalatine canal (2.5%) or the alveolar process (0.8%).

CS diameter

In the anterior maxilla, 324 canals (88.7%) had a diameter < 1 mm, whereas 41 canals (11.3%) measured ≥ 1 mm. Evaluation of CS diameter revealed that the right side had a significantly larger diameter compared with the left side (P = 0.034). The median canal diameter was 0.78 mm (0.35 to 1.4) on the right and 0.7 mm (0.22 to 1.65) on the left side (Table 1).

Tooth-specific CS distribution

The most frequently observed location of the CS was in the left central incisor region (18.8%), followed by the right lateral (18.1%), and left lateral (17.8%) incisor regions. The least frequent location was the intercentral region. No statistically significant side-related differences in opening location were detected (Table 1).

The measurements of the CS and related anatomical distances are presented in Table 2. Significant sex-related differences were detected for CS-NCF, CS-BCB, and CS diameter on both sides. On the right side, males presented greater CS-NCF and CS-BCB distances and a larger CS diameter than females (P = 0.049, P < 0.001, and P = 0.006, respectively). On the left, these measurements were likewise significantly greater in males (P = 0.005, P < 0.001, and P = 0.005, respectively). No significant differences were found for CS-ARC or CS-NPC on either side (P > 0.05).

As presented in Table 3, the CS was most frequently located in the central incisor and lateral incisor regions in both males and females on each side. Chi-square analysis showed no significant association between CS location and sex on either the right or left side (P = 0.895 and P = 0.214, respectively).

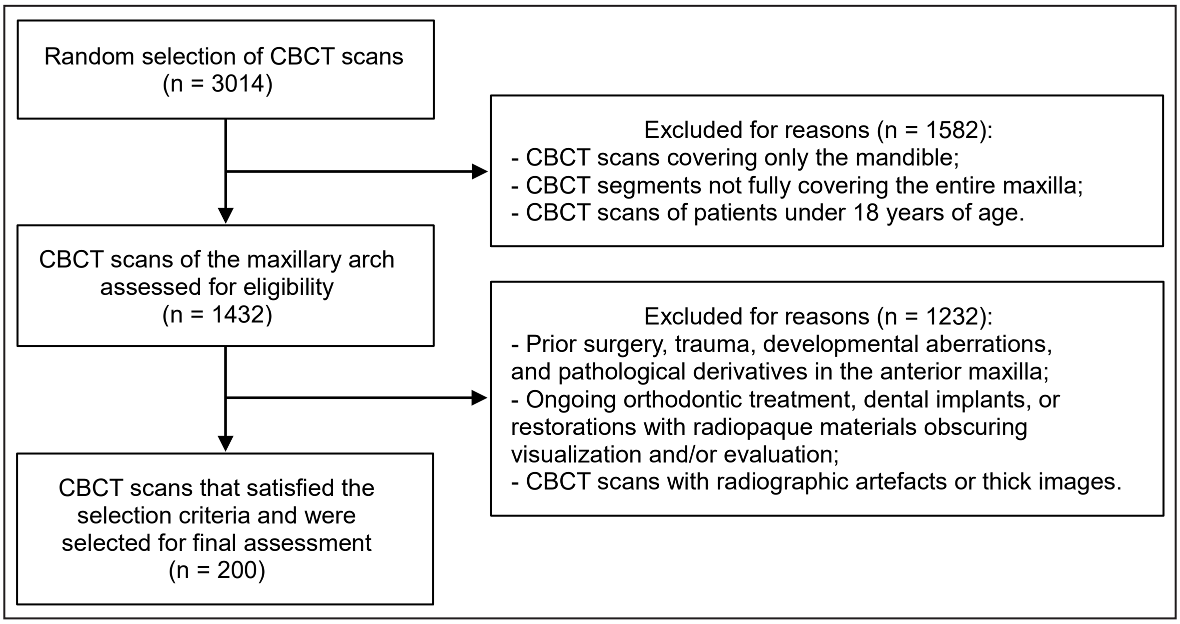

Figure 2. Selection flowchart.
CBCT = cone-beam computed tomography; n = number.

Table 1. Distribution of the *canalis sinuosus* (CS) diameter in the anterior maxilla and comparison of the four measurements and CS location between right and left sides

Measurements		Right side	Left side	P-value
Diameter of CS (mm)	Mean (SD)	0.76 (0.02)	0.72 (0.02)	0.034[b]*
	Median (min; max)	0.78 (0.35;1.4)	0.7 (0.22;1.65)	
Location (number [%])	Intercentral	4 (1.1)	4 (1.1)	0.992[a]
	Central incisors	61 (16.7)	68 (18.8)	
	Central-lateral incisors	24 (6.6)	20 (5.5)	
	Lateral incisors	66 (18.1)	65 (17.8)	
	Lateral incisors-canine	10 (2.7)	14 (3.8)	
	Canine	14 (3.8)	15 (4.1)	
CS-NCF (mm)	Mean (SD)	15.33 (0.26)	15.71 (0.25)	0.539[b]
	Median (min; max)	15.9 (4.5; 24)	16 (5.5; 28.8)	
CS-BCB (mm)	Mean (SD)	7.47 (0.09)	7.24 (0.09)	0.118[b]
	Median (min; max)	7.4 (5.1; 12.5)	7.2 (4.9; 12.2)	
CS-ARC (mm)	Mean (SD)	7.59 (0.25)	7.02 (0.22)	0.13[b]
	Median (min; max)	6.6 (3.7; 21)	6.2 (3.6; 21.5)	
CS-NPC (mm)	Mean (SD)	6.43 (0.24)	6.6 (0.23)	0.408[b]
	Median (min; max)	6.3 (1.4; 17.6)	6.65 (2;14.2)	

[a]Chi-square test, [b]Mann-Whitney U test. *Statistically significant at level $P < 0.05$.
SD = standard deviation; NCF = nasal cavity floor; BCB = buccal cortical bone; ARC = alveolar ridge crest; NPC = nasopalatine canal.

Table 2. Gender-based comparison of the *canalis sinuosus* (CS) distances (mm) and canal diameter on the right and left sides

Side	Measurements (mm)	Male		Female		P-value
		Mean (SD)	Median (min; max)	Mean (SD)	Median (min; max)	
Right	CS-NCF	15.82 (0.4)	16.5 (5.6; 24)	14.95 (0.34)	15.65 (4.5; 22.1)	0.049[b]*
	CS-ARC	7.77 (0.38)	6.75 (3.7; 18.6)	7.44 (0.34)	6.45 (3.7; 21)	0.297[b]
	CS-BCB	7.81 (0.13)	7.8 (5.4; 10.2)	7.21 (0.12)	7.2 (5.1; 12.5)	< 0.001[b]*
	CS-NPC	6.79 (0.37)	7 (2; 14.9)	6.15 (0.3)	5.75 (1.4; 17.6)	0.176[a]
	CS	0.82 (0.26)	0.8 (0.4; 1.4)	0.72 (0.02)	0.75 (0.35; 1.25)	0.006[b]*
Left	CS-NCF	16.46 (0.41)	17 (6.7; 28.8)	15.17 (0.3)	15.7 (5.5; 23)	0.005[b]*
	CS-ARC	7.25 (0.34)	6.45 (3.6; 21.5)	6.86 (0.29)	6.2 (3.7; 18.8)	0.167[b]
	CS-BCB	7.7 (0.14)	7.7 (5; 12.2)	6.91 (0.1)	6.8 (4.9; 9.2)	< 0.001[a]*
	CS-NPC	6.91 (0.37)	7 (2.3; 14.2)	6.39 (0.3)	6.5 (2; 13.3)	0.31[b]
	CS	0.77 (0.22)	0.75 (0.45; 1.65)	0.7 (0.21)	0.65 (0.22; 1.45)	0.005[b]*

[a]Student's t-test, [b]Mann-Whitney U test. *Statistically significant at level $P < 0.05$.
SD = standard deviation; NCF = nasal cavity floor; BCB = buccal cortical bone; ARC = alveolar ridge crest; NPC = nasopalatine canal.

Table 3. Comparison of canal location with gender

Side	Location	Male		Female		P-value[a]
		Number	%	Number	%	
Right	Intercentral	2	2.6	2	1.9	0.895
	Central incisors	29	37.2	34	32.1	
	Central-lateral incisors	8	10.3	16	15.1	
	Lateral incisors	27	34.6	40	37.7	
	Lateral incisors-canine	6	7.7	6	5.7	
	Canine	6	7.7	8	7.5	
Left	Intercentral	4	5.1	0	0	0.214
	Central incisors	24	30.8	42	40.8	
	Central-lateral incisors	10	12.8	10	9.7	
	Lateral incisors	29	37.2	35	34	
	Lateral incisors-canine	5	6.4	7	6.8	
	Canine	6	7.7	9	8.7	

[a]Statistically significant at level $P < 0.05$ (Chi-square test).

Similarly, no statistically significant differences were identified between genders with respect to unilateral or bilateral CS openings and CS count (P = 0.07 and P = 0.619, respectively).

The presence of statistically significant differences between age groups and distance measurements was evaluated. No significant differences were detected among age groups for the distances of CS-NCF, CS-ARC, CS-BCB, and CS-NPC on either the right or left side. In addition, no significant correlation was observed between age groups and canal diameter (Table 4). Likewise, no significant difference was found in CS count among the age groups (P = 0.348). By contrast, the distribution of unilateral and bilateral occurrences differed significantly among age groups (P = 0.002). Post-hoc comparisons indicated that individuals in the group 1 (18 to 30 years old) demonstrated a significantly higher proportion of unilateral occurrences compared with the older age groups.

No statistically significant differences in CS location were observed among the age groups on either the right or left side (P = 0.114 and P = 0.34, respectively) (Table 5).

DISCUSSION

Anatomical variations, if not properly identified and accounted for, can be a decisive factor in surgical failure. In the maxilla, the primary concern involves the close relationship with the maxillary sinus, nasal cavity, and incisive foramen [38]. However, another critical structure - CS, a variation of the superior alveolar nerve - may also contribute to surgical complications. To the authors' knowledge, to date, no studies have investigated CS in the Lithuanian population or any Baltic country, which highlights the importance of studying this anatomical structure and its relationship with adjacent teeth in the anterior maxilla. This is the first Lithuanian study to explore the anatomical features of CS using CBCT, with results expected to expand scientific knowledge, help doctors plan treatment safely, and enhance their clinical practice.

Several studies have investigated the CS, examining its prevalence in Australian, Turkish, Cypriot, Chinese, South African, Brazilian, Russian, German, Iranian, Chennai, Yemeni populations [6,18,30,37,39-49].

Table 4. Comparison of right and left the *canalis sinuosus* (CS) distance (mm) measurements and diameters across the age groups

Measurement (mm)	Group (years)	Right				Left			
		N	Mean (SD)	Median (min; max)	P-value[a]	N	Mean (SD)	Median (min; max)	P-value[a]
CS - NCF	Group 1 (18 to 30)	26	15.49 (0.47)	15.7 (9.8; 20.7)	0.671	15	14.97 (0.93)	15.3 (6.1; 23)	0.212
	Group 2 (31 to 43)	75	15.37 (0.35)	15.4 (4.5; 21.8)		73	15.28 (0.39)	16 (5.5; 23)	
	Group 3 (44 to 56)	45	15.5 (0.62)	16.4 (4.8; 24)		50	16.36 (0.47)	16.45 (6.3; 22.9)	
	Group 4 (> 56)	38	14.88 (0.67)	15.85 (5.6; 22.1)		43	16 (0.57)	16 (7.7; 28.8)	
CS - ARC	Group 1 (18 to 30)	26	7.35 (0.55)	6.6 (4.8; 16.1)	0.407	15	7.54 (0.95)	6.3 (4; 15.8)	0.109
	Group 2 (31 to 43)	75	7.51 (0.33)	7 (3.9; 21)		73	7.46 (0.39)	6.6 (3.8; 21.5)	
	Group 3 (44 to 56)	45	7.24 (0.54)	5.9 (3.7; 18.6)		50	6.74 (0.31)	6.2 (3.6; 14.9)	
	Group 4 (> 56)	38	8.26 (0.73)	6.3 (3.7; 20.6)		43	6.45 (0.4)	5.8 (3.7; 16.4)	
CS - BCB	Group 1 (18 to 30)	26	7.21 (0.2)	7.45 (5.1; 10.2)	0.348	15	7.01 (0.3)	6.8 (5; 9.2)	0.092*
	Group 2 (31 to 43)	75	7.39 (0.13)	7.4 (5.1; 11)		73	7.53 (0.14)	7.5 (5.5; 12.2)	
	Group 3 (44 to 56)	45	7.49 (0.22)	7.3 (5.3; 12.5)		50	7.07 (0.16)	7 (4.9; 10)	
	Group 4 (> 56)	38	7.76 (0.2)	7.65 (6; 10.2)		43	7.08 (0.18)	6.9 (5; 9.6)	
CS - NPC	Group 1 (18 to 30)	26	5.27 (0.63)	4.35 (1.4; 12.8)	0.183	15	7.65 (0.97)	8.4 (2.3; 14.2)	0.422
	Group 2 (31 to 43)	75	6.49 (0.32)	7.2 (2; 14.9)		73	6.42 (0.35)	6.4 (2; 13.5)	
	Group 3 (44 to 56)	45	6.35 (0.45)	5.7 (2; 14.5)		50	6.42 (0.35)	7.15 (2.2; 13.3)	
	Group 4 (> 56)	38	7.14 (0.65)	6.5 (2; 17.6)		43	6.36 (0.51)	6.5 (2.5; 13.7)	
CS	Group 1 (18 to 30)	26	0.71 (0.03)	0.73 (0.4; 1.15)	0.06*	15	0.66 (0.06)	0.7 (0.22; 1.2)	0.731
	Group 2 (31 to 43)	75	0.74 (0.02)	0.7 (0.4; 1.4)		73	0.75 (0.03)	0.7 (0.35; 1.65)	
	Group 3 (44 to 56)	45	0.77 (0.03)	0.8 (0.4; 1.2)		50	0.73 (0.03)	0.7 (0.45; 1.2)	
	Group 4 (> 56)	38	0.84 (0.04)	0.83 (0.35; 1.2)		43	0.71 (0.03)	0.7 (0.4; 1.25)	

[a]Kruskal-Wallis H test. *Statistically significant at level P < 0.05.
SD = standard deviation; NCF = nasal cavity floor; BCB = buccal cortical bone; ARC = alveolar ridge crest; NPC = nasopalatine canal; N = number.

Table 5. Evaluation of the canal locations according to age groups

Side	Location	Age groups				P-value[a]
		Group 1 (18 to 30 years)	Group 2 (31 to 43 years)	Group 3 (44 to 56 years)	Group 4 (> 56 years)	
		N (%)	N (%)	N (%)	N (%)	
Right	Intercentral	1 (3.8)	1 (1.3)	1 (2.2)	1 (2.6)	0.114
	Central incisors	14 (53.8)	22 (29.3)	12 (26.7)	15 (39.5)	
	Central-lateral incisors	1 (3.8)	8 (10.7)	11 (24.4)	4 (10.5)	
	Lateral incisors	8 (30.8)	35 (46.7)	14 (31.1)	10 (26.3)	
	Lateral incisors-canine	1 (3.8)	2 (2.7)	5 (11.1)	4 (10.5)	
	Canine	1 (3.8)	7 (9.3)	2 (4.4)	4 (10.5)	
Left	Intercentral	0 (0)	2 (2.7)	0 (0)	2 (4.7)	0.34
	Central incisors	6 (40)	27 (37)	17 (34)	16 (37.2)	
	Central-lateral incisors	0 (0)	6 (8.2)	6 (12)	8 (18.6)	
	Lateral incisors	6 (40)	27 (37)	18 (36)	13 (30.2)	
	Lateral incisors-canine	0 (0)	7 (9.6)	5 (10)	0 (0)	
	Canine	3 (20)	2 (2.7)	4 (8)	4 (9.3)	

[a]Statistically significant at level P < 0.05 (Fisher-exact test).
N = number.

Identification of the CS in all these studies was done using CBCT, the method employed in the present research as well.

Prevalence of CS

In the current study, the overall prevalence of CS in the Lithuanian population was 73%. The reported prevalence of CS in the literature varies widely. For instance, Aoki et al. [8] reported CS in 66.5% of 200 patients, Shan et al. [18] 36.9% of 1007 patients, Anatoly et al. [40] 67% of 150 patients, Wanzeler et al. [41] 87.5% of 100 patients, Allaberdiyev et al. [42] 18.4% of 500 patients, Yılmaz et al. [43] 82.04% of 323 patients, Schnutenhaus et al. [44] 97% of 210 patients, Aktuna Belgin et al. [45] 8.9% of 1000 patients, Jabali et al. [46] 10.5% of 400 patients, Fernandes et al. [47] 18% of 100 patients, Salari et al. [48] 50% of 200 patients, Ahmed et al. [49] 100% of 226 patients, Rao et al. [37] 59.75% of 159 patients, Samunahmetoglu et al. [50] 94.66% of 300 patients, Yeap et al. [6] 98.5% of 201 patients, and Devathambi et al. [51] 54.46% of 650 patients. Such diversity could be explained by multiple factors. Among the possible explanations, population differences may account for the observed discrepancies in results. Variations may also result from differences in the CBCT equipment used. Spatial resolution depends mainly on detector pixel size, beam geometry, patient scatter, detector motion blur, fill factor, focal spot size, number of basis images, and reconstruction algorithm. Voxel size also varies between manufacturers [52]. In addition, studies have shown that accessory canals of the CS measuring less than 1 mm in diameter are less visible. The ability to detect CS canals smaller than 1 mm on CBCT scans is influenced by the voxel size [7]. The high incidence rate of CS in the present study could be explained by inclusion of CS of any diameter and usage of high-resolution CBCT scans with thin slice thickness (at least 200 µm) compared to other studies. Previous studies that included only canals with a diameter greater than 1 mm or used thicker slice thicknesses reported a lower prevalence of the CS [42,45,46,53]. Yeap et al. [6] acknowledged that the detection of the CS was lower in teeth scanned at a 0.25 mm resolution (P = 0.02).

In the current study, the presence of the CS did not differ significantly according to gender (P = 0.619), in line with Aktuna Belgin et al. [45] (P > 0.05), Jabali et al. [46] (P > 0.05), Rao et al. [37] (P = 0.424), Shan et al. [18] (P = 0.154). However, previous studies have reported a higher prevalence of CS in males. Aoki et al. [8], Fernandes et al. [47], and Salari et al. [48] observed higher frequency of CS in males (P < 0.05, P = 0.029, and P = 0.021, respectively). In contrast, Anatoly et al. [40] found CS prevalence to be significantly higher in women (P < 0.01).

Consistently, no significant differences in CS count were observed across age groups (P = 0.348), as reported by Aoki et al. [8] (P > 0.05), Shan et al. [18] (P = 0.734), Anatoly et al. [40] (P = 0.8), Aktuna Belgin et al. [45] (P > 0.05), Rao et al. [37] (P = 0.96). In contrast, Salari et al. [48] reported that CS prevalence was significantly higher in patients aged over 40 years (P = 0.026).

CS diameter

Our analysis demonstrated that in the anterior maxilla, 324 canals (88.7%) had a diameter < 1 mm, whereas 41 canals (11.3%) measured ≥ 1 mm, which is comparable to the results of Aoki et al. [8], who reported that 96.6% of CS measured ≤ 1 mm and only 3.4% exceeded 1 mm. Median CS diameters were 0.78 mm (0.35 to 1.4) on the right and 0.7 mm (0.22 to 1.65) on the left, with the right side being significantly greater in diameter (P = 0.034) (Table 1). A similar pattern has been observed in several studies, although the difference was not statistically significant: Yılmaz et al. [43] reported mean CS diameters of 0.79 (SD 0.26) mm on the right and 0.83 (SD 0.28) mm on the left (P > 0.05), while Samunahmetoglu et al. [50] determined that CS ≥ 1 mm measured 1.31 (SD 0.19) mm on the right and 1.29 (SD 0.17) mm on the left (P = 0.212).

Additionally, significant sex-related differences were observed in CS diameter, with males exhibiting a larger diameter than females on the right (P = 0.006) and left (P = 0.005) sides (Table 2). Similar results have been consistently observed in previous studies. Shan et al. [18] reported the axial CS diameter was larger in men (1.2 [SD 0.1] mm) than in women (1.1 [SD 0.1] mm, P = 0.025). According to Schnutenhaus et al. [44], the mean axial CS diameter was 0.9 mm overall, with women showing slightly smaller diameters (0.8 mm) compared to men (0.9 mm). Similarly, Salari et al. [48] found a mean canal diameter of 0.99 (SD 0.26) mm, with a significant association between canal diameter and gender (P < 0.001), males showing larger diameters than females.

Furthermore, no significant correlation was observed between age groups and CS diameter. Such findings also align with earlier studies: Aktuna Belgin et al. [45] found a mean terminal CS diameter of 1.34 (SD 0.53) mm (0.58 to 3.39 mm) with no variation by gender, age, or canal direction; Jabali et al. [46] reported a mean canal diameter of 1.06 (SD 0.29) mm with no differences by age, side, or gender; Rao et al. [37] noted an average CS opening diameter of 0.887 (SD 0.274) mm with no differences by gender (P = 0.534) or age (P = 0.869); and Yeap et al. [6] observed no significant differences in narrowest or widest CS diameters by quadrant or age, with the widest measuring 1.08 (SD 0.39) mm (0.42 to 2.6 mm) and the narrowest 0.71 (SD 0.26) mm (0.25 to 1.59 mm).

Results of the present study indicate that the CS in the anterior maxilla predominantly has a diameter of less than 1 mm, with a slightly larger median diameter on the right side. Sex-related differences were evident, with males exhibiting larger canal diameters than females, whereas no significant correlation with age was observed. These findings are in line with previous studies, confirming the consistency of CS morphometric characteristics across different populations. Due to its smaller diameter compared to the incisive foramen, proper knowledge and calibration are essential for visualizing the CS in dental imaging. This helps prevent potential injuries and inappropriate treatment [41].

Lateral distribution of CS

The current study demonstrated a higher prevalence of bilateral presentation, observed in 63% of cases, compared with 37% of unilateral cases. In addition, group 1 (18 to 30 years old) demonstrated a significantly higher proportion of unilateral occurrences compared with the older age groups (P = 0.002). Similar distribution tendencies have been reported in earlier studies. Aoki et al. [8] observed 54.14% bilateral and 45.86% unilateral cases, while Wanzeler et al. [41] reported a very strong bilateral occurrence, with 87 cases bilateral and only one unilateral. On the contrary, in a study by Anatoly et al. [40], 45.7% of patients showed bilateral CS, while 54.3% had unilateral CS (right 21.7%, left 32.6%). In the study by Aktuna Belgin et al. [45] study, all 89 detected CS were unilateral. Rao et al. [37] reported that 67.37% of patients presented with unilateral CS, while 32.63% exhibited bilateral CS. In a study by Yılmaz et al. [43], among all patients examined, 31.3% presented with unilateral CS, while 25.4% had bilateral CS. According to Ahmed et al. [49], CS occurred bilaterally in 48.2% of participants and unilaterally in 51.8%. The findings of the current study, showing a higher prevalence of bilateral CS, are generally consistent with several previous reports, although some studies have observed a predominance of unilateral cases or exclusively unilateral occurrence. When comparing our findings with those of previous studies, no consistent pattern emerges. This variability may be attributed to differences in sample size, population, or imaging methodology.

Tooth-specific CS distribution

Surgical procedures in the anterior teeth region, particularly the incisors, have become increasingly common, as reflected by the growing number of recent studies [54]. CS was primarily observed in the anterior maxilla in our study. The canal was most frequently located in the left central incisor region (18.8%), followed by the right lateral (18.1%) and left lateral (17.8%) incisor regions.

The intercentral region, however, was the least common. Overall, it was predominantly observed in the central and lateral incisor regions across genders, with no significant side-related differences. In the literature, the central incisor region was most commonly reported as the predominant site [6,8,40,42,45,49,50], followed by the lateral incisor [8,37] and canine regions [8,45]. The first premolar was least frequent [47]. Gender-related differences were reported in some studies, with men more often exhibiting foramina near the left lateral incisor and women near the right lateral incisor (Schnutenhaus et al. [44], Ahmed et al. [49] [P = 0.007]).

CS and related anatomical distances measurements

For effective surgical and clinical decision-making, it is important to understand not only the CS anatomy but also its spatial relationships with adjacent structures.

Our findings demonstrate significant sex-related differences for CS-NCF and CS-BCB on both sides. On the right side, males showed larger CS-NCF and CS-BCB distances compared with females (P = 0.049 and P < 0.001, respectively). Likewise, on the left side, these measurements were significantly greater in males (P = 0.005 and P < 0.001, respectively). According to Ahmed et al. [49], the distance between the CS and the nasal cavity floor was larger in males (mean = 8.433 mm) than in females (mean = 7.924 mm). Salari et al. [48] also reported greater CS-NCF and CS-BCB distances in males (P < 0.001). Rao et al. [37] reported that CS and its distance from the buccal cortical plate was larger in males (P = 0.022). However, Aktuna Belgin et al. [45] observed no statistically significant differences between genders, age groups, or sides for CS-NCF, CS-BCB, and CS-ARC lengths (P > 0.05).

No significant sex-related differences were observed for CS-ARC, or CS-NPC on either side (P > 0.05). These findings are consistent with Salari et al. [48], who observed no significant sex-related difference in the CS-ARC distance (P = 0.088). Conversely, Rao et al. [37] and Wanzeler et al. [41] reported statistically significant sex-related differences in CS-ARC, with males exhibiting greater values (P = 0.014 and P = 0.0303, respectively).

Moreover, age-related differences in distance measurements were also assessed, with no significant variations found for CS-NCF, CS-ARC, CS-BCB, or CS-NPC on either side. These findings differ from those of Rao et al. [37], who reported that distances between the CS-BCB (P = 0.013) and CS-ARC (P = 0.014) decreased with increasing age.

Differences in CS measurements are likely due to population and ethnic variations, age-related changes such as bone loss or remodelling, as well as sex-related differences, since sexual dimorphism in craniofacial growth typically becomes apparent by age 14, with males generally exhibiting larger distances [55-57]. Other factors including imaging methods, measurement techniques, and individual differences in bone density or dental status may also contribute. Therefore, results should be interpreted in the context of population, age, sex, study methodology, and sample size.

Surgical considerations for the CS

Since 2010, a growing number of reports have documented postoperative neurological complications associated with implant placement affecting the CS or its branches [58]. It was reported that if the CS is invaded during dental implant placement, patients experience severe pain immediately or within a few hours after the surgery. Symptoms gradually disappear once the implant is explanted [7,20,25,26]. A case report by Tan et al. [59] describes severe neuropathic pain and a marked decline in quality-of-life following injury to an accessory canal of the CS in the after endodontic treatment. Since accessory canals typically have a smaller diameter, they may be regarded as "minor" bony channels in the anterior maxilla and are therefore often considered unlikely to cause postoperative complications. However, in the referenced case report, the canal measured less than 1.0 mm, yet its damage still resulted in adverse outcomes, challenging the assumption that only canals ≥ 1.0 mm lead to serious complications [3,5,7,18,21,59]. The association between the diameter of the CS or accessory canals and the severity and frequency of related complications remains uncertain. This is further complicated by the fact that these structures vary in diameter, with both wider and narrower segments along their course [6]. Therefore, from a clinical safety perspective, it is advisable to assume that all bony channels - CS and accessory canals - regardless of size, may contain neural structures that could lead to clinically significant consequences if damaged [59]. This presumption is important, as reflected in our study of the Lithuanian population, where the majority of identified canals (88.7%) had a diameter of less than 1 mm. In addition, some authors have suggested that damage to the CS and its accessory canals in the anterior maxilla can cause excessive bleeding and implant osseointegration failure [9,13,20,25].

The measurements from the present study provide a reference for clinical planning in anterior maxillary surgery. The mean distances between the CS and key anatomical landmarks were as follows: 15.33 mm on the right and 15.71 mm on the left in CS-NCF; 7.47 mm on the right and 7.24 mm on the left in CS-BCB; 7.59 mm on the right and 7.02 mm on the left in CS-ARC; 6.43 mm on the right and 6.6 mm on the left in CS-NPC (Table 1). The findings could provide guidance to clinicians when planning procedures in the anterior maxilla, particularly in the context of immediate implant placement.

Recommendations

Due to the considerable anatomical variability of the CS in its course, opening location, and dimensions, conventional two-dimensional imaging may be insufficient for accurate assessment. Based on the findings of the present study, CBCT radiological examination is advised for the identification and evaluation of the CS.

Limitations

This study presents some limitations that should be taken into account. Due to the retrospective design, the study relied on pre-existing data, which limited control over imaging parameters. Furthermore, variations in CBCT image resolution may have affected the accuracy of assessment. Minor measurement errors cannot be excluded. The investigation focused on the anterior teeth segment, as the prevalence of the CS is higher in this region. Measuring a larger group of teeth would increase the number of excluded CBCT scans due to factors such as missing teeth, the presence of dental implants, and dental restorations containing radiopaque materials, which can obscure visualization and evaluation of the anterior maxilla. Additionally, scans with radiographic artefacts, indistinct images, or insufficiently thick CBCT slices were excluded, which may affect the representativeness of the sample. Also, this study is limited by a small sample size, therefore, future studies with larger sample sizes are recommended. Lastly, the limited detectability of CBCT due to small canal diameter or low corticalization, as well as anatomical variations such as accessory branches or plexiform morphology, may have affected the accuracy of identification.

CONCLUSIONS

This study demonstrated that the *canalis sinuosus* is a frequent anatomical structure in the anterior maxilla of the Lithuanian population, most commonly presenting bilaterally with openings directed toward the palate. The canal exhibited slightly larger diameters on the right side than on the left. Sex-related anatomical differences were identified, with males showing greater distances to the nasal cavity floor and buccal cortical bone and larger canal diameters bilaterally. Age did not appear to influence canal dimensions or location. However, unilateral occurrences were more prevalent in younger individuals. These findings highlight considerable anatomical variability of the *canalis sinuosus* and underline the importance of careful presurgical assessment in the anterior maxillary region.

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