

EVALUATION OF THE PRESENCE AND GENERAL CHARACTERIZATION OF CANALIS SINUOSUS BASED ON CONE-BEAM COMPUTED TOMOGRAPHY IMAGES: A LITERATURE REVIEW

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ABSTRACT

Canalis sinuosus (CS) is a small branch of infra-orbital canal that contains anatomical structures of clinical significance in dentist's daily practice. Accurate identification of CS and its branches is crucial for reducing complications in dental treatments. Therefore, knowledge about CS is systematically expanding, and its importance is increasing. The aim of this study was to conduct a literature review on the prevalence, location, diameter, and trajectory variations of CS as well as the influence of age, gender, and surgical implications. A systematic review of the literature was performed. Two reviewers gathered and analyzed articles from electronic databases, including PubMed, Semantic Scholar, and Google Scholar. The frequency of CS presence was evaluated through a systematic review conducted using MedCalc, with a significance level of 5%. Due to significant heterogeneity among included papers, a random effects model was applied. Out of 276 initially identified articles, 12 studies were eventually included in the review. All were based on cone-beam computed tomography (CBCT) examinations and their results. The systematic review showed that overall prevalence of CS was 54.44%, CS presence among women was 56.76% and men 43.24%, unilateral CS was observed in 41.78%, whereas bilateral was found in 58.22% of CBCT images. CS may exhibit variability in trajectory, location, and diameter. The analyzed articles did not demonstrate statistically significant differences in age. Recent research indicates an increasing prevalence of CS, possibly due to greater observer awareness regarding its presence.

Key words: canalis sinuosus, CS, infra-orbital canal, canalis sinuosus, CBCT, ASAN.

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INTRODUCTION

Infra-orbital canal is a canal located at the base of orbital cavity. It opens to the maxilla and is a continuation of infra-orbital groove, with access to the maxilla in the infra-orbital foramen. It contains infra-orbital artery and nerve [1]. Canalis sinuosus (CS) is a neuro-vascular canal, known as a small embranchment of the infra-orbital canal. It in-holds the anterior superior alveolar nerve (ASAN) and vessels supplying the front part of the maxilla [2]. ASAN is an embranchment of the maxillary branch of trigeminal nerve. It runs along the front maxilla and innervates the medial and lateral incisors as well as canines [3]. CS may demonstrate variations in its course, location, and diameter [4]. Differences in its course are found in different age groups, gender,

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localizations (i.e., bilateral or unilateral), general presence, diameter, and final trajectory [5]. Although CS was first described in 1940, it is still not properly distinguished by many dental practitioners. Most of them are not aware of the existence of CS and are unable to diagnose it. The adequate knowledge on CS impacts positively on its recognition on cone-beam computed tomography (CBCT) scans [6].

Vast amount of surgical procedures are executed in the anterior segment of the maxilla and mandible. The more procedures of implant placements, bone transplant, and rehabilitation of the oral cavity, the more potential complications in the post-operative period [7].

Moreover, the significance of CS is underlined in rehabilitation of the front part of maxilla when the canine pillar is used as a final fulcrum placing. Interacting with neuro-vascular bundle of CS can compromise the process of osseo-integration, and may lead to temporary or permanent paraesthesia, accompanied by bleeding at the site [8].

Therefore, CS identification during surgical procedures is crucial as well as awareness of its anatomical variability [4]. Dental implantation failure in the frontal area of the maxilla can be caused by several factors. One of them is injury of neuro-vascular structures, such as CS [9]. Surgical interventions in this area can be planned more precisely when considering three-dimensional (3D) imaging; therefore, it is possible to protect vulnerable structures from viable damage [10]. Furthermore, the presence of neuro-vascular bundles in the operating field can have a negative influence on the result of surgical treatment. Many specialists are not aware of the existence of CS where ASAN is located [3].

In general, the anterior part of the maxilla is claimed to be an extremely safe area for surgical procedures. Hence, doctors often pay attention only to the nasopalatine canal or the floor of nasal fossa during treatment in that segment. Lately, an increasing awareness of the existence of much finer neuro-vascular structures located in the front part of the maxilla has been observed [11].

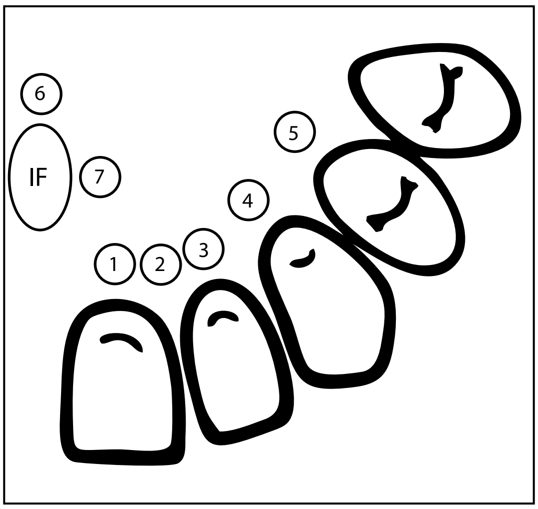

FIGURE 1. Schematic illustration of classification of palate location of canalis sinuosus and accessory canals accessory by Oliveira-Santos *et al.* (own elaboration)

Two dimensional (2D) radiographs, such as panoramic radiography and periapical X-ray, have limited value in the assessment of CS due to image overlapping. Moreover, many clinicians identify this structure as a pathology. CBCT is a method commonly used in dentistry for obtaining three-dimensional images of teeth and dento-maxillofacial skeleton. It is especially helpful in CS identification because it provides high quality images derived from detailed 3D scans [11].

Conventional methods of imaging are characterized by lower efficiency in detecting neuro-vascular structures. CBCT may uncover anatomical variants that are important in accurate diagnosis [12]. CBCT accessibility enable a profound analysis of periapical conditions and possible surgical interventions [13]. However, it is extremely easy to overlook CS. CBCT often presents CS as a wide canal located laterally to the nasal cavity and under the front part of the nasal floor, close to the nasopalatine canal (NPC). The use of CBCT has been validated as the best and most helpful technique in detecting additional canals in the region of interest [11].

Branches of CS are also important. Being aware of their presence while planning a surgical procedure and assessing radiographs is crucial in preventing complications and misdiagnosis. The location of bifurcation as well as its neuro-vascular component is important in terms of planning various dental implantations. The vicinity of upper teeth is also worth including in treatment plans [14, 15].

CS often imitates osteolysis in conventional radiographs. If the bone canals reach the roots of the front maxillary teeth, there is a risk of misinterpretation as root resorption or periapical lesion [16]. Therefore, the meaning of CS is highly emphasized in endodontic treatment [17].

Oliveira-Santos *et al.* [18] proposed a classification of palate location of CS and canal accessory (CA) (Figure 1). They distinguished eight locations according to area relative to the teeth/incisive foramen:

1) central incisor region,
2) region between the central and lateral incisors,
3) lateral incisor region,
4) canine region,
5) first premolar region,
6) lateral to incisive foramen,
7) posterior to incisive foramen,
8) any other location not listed above,

The aim of the work was to conduct the literature review on CS on the basis of CBCT imaging.

MATERIAL AND METHODS

A systematic review of the literature was conducted with the use of electronic databases, such as PubMed, Semantic Scholar, and Google Scholar. The search strategies within the databases included the following key words: "canalis sinuosus", "CBCT", "dental volumetric tomography", "dental volumetric imaging", "cone-beam CT", and "cone-beam computed tomography". Reference lists of the selected articles were examined, aiming at identification of additional references.

The selection process was two-phased. In the first phase, as a result of database research, a review of the titles and abstracts of all identified publications was performed. Research studies with main topic on the assessment of canalis sinuosus by means of CBCT were selected. Articles not related to the topic were not considered. In the second phase, an independent review of full text resources was made. Duplicates, review papers, and case reports were excluded.

From a total of 276 initially identified articles, 22 articles were selected. Following the second selection phase, there were 12 articles left, which were included in the literature review. PRISMA diagram showing the search strategy and selected studies is presented in the Figure 2.

DATA SYNTHESIS

Literature review of the prevalence was conducted using MedCalc (Microsoft). Significance level was 5%. Model of random effects was applied due to significant heterogeneity of the research included in meta-analysis. MedCalc version 19.8. is a statistical software package for biomedical research, compatible with Windows system. It was chosen in view of its fully functional meta-analysis module. It allows an easy input of the research, heterogeneity tests, such as Q Cochran test with statistics I to the power of 2, calculation of the stable and random effects models, and the visualization of data. This can be performed by means of many whacks and figures. Forest figure was chosen to demonstrate the results of our study.

RESULTS

Research works included eight different countries: Brazil, Chile, China, Colombia, India, Japan, Russia, and Turkey (Table 1), and all of the papers were published in English. Sample size was ranging from 28 to 673 of CBCT examinations (Table 1, positions 3 and 12). The presence of canalis sinuosus based on CBCT examinations was assessed (Tables 1 and 2). The outcome of the literature review demonstrated that the presence of CS was 54.44% (Figure 3), the presence of CS among women was 56.76%, and men 43.24% (on the basis of 11 articles, in which the division on men and women was included) [3, 5, 8, 11, 19, 20-25]. In a total of 8 researches, the unilateral CS was observed in 41.78%, whereas bilateral CS was found in 58.22% CBCT images [3, 5, 8, 21-23, 25, 26].

DISCUSSION

This literature review contains data that were not incorporated in a study by Ferlin *et al.* [4]. In 2019, Ferlin *et al.* [4] conducted a meta-analysis concerning the presence of canalis sinuosus based on CBCT. However,

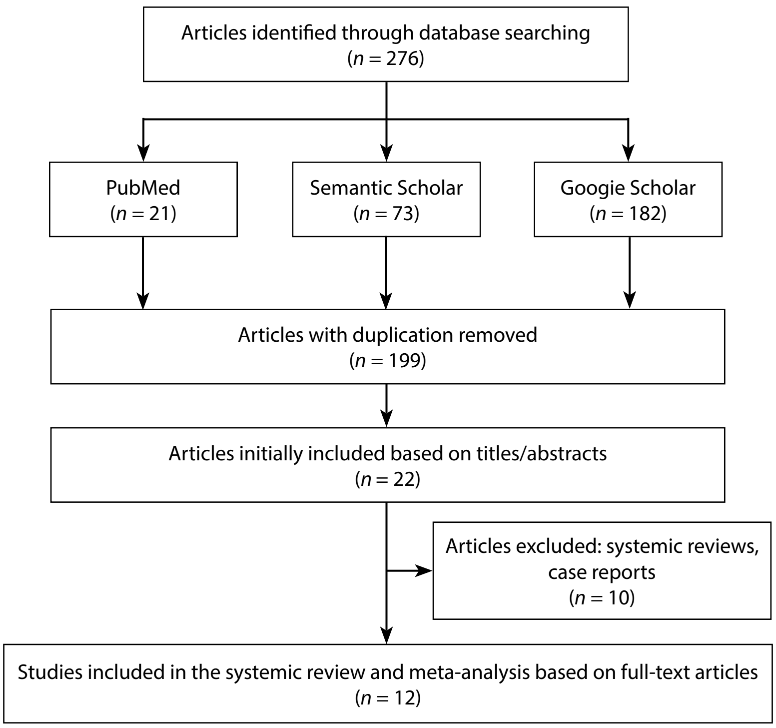

FIGURE 2. PRISMA diagram for the search strategy and selected studies

TABLE 1. Summary of studies included in meta-analysis

	Study (year) [Ref.]	Country	Sample size	Patients, *n*		Patients with CS present, *n*	Patients with CS present, *n*		Age of patients	Laterality		Preva-lence (%)	Diameter (mm)
				M	F		M	F		Unilateral	Bilateral		
1	Wanzeler *et al.* (2014) [23]	Brazil	100	31	69	88	26	62		1	87	88.0	
2	Manhães Júnior *et al.* (2016) [8]	Brazil	500	216	284	181	82	99		137	44	36.2	
3	Şalli *et al.* (2017) [11]	Turkey	673	351	322	55	36	19	14-82			8.17	
4	Gurler *et al.* (2017) [3]	Turkey	111	35	76	111	35	76	12-79	0	111	100.0	0.75-2.25
5	Velpula *et al.* (2018) [26]	India	63			25			20-80	19	6	39.7	
6	Aoki *et al.* (2019) [5]	Brazil	200	93	107	133	70	63	18-85	61	72	66.5	≤ 1 (96.6%), > 1 (3.4%)
7	Sedov *et al.* (2019) [25]	Russia	100	39	61	74			46-81	37	37	74.0	0.95 ± 0.23
8	Anatoly *et al.* (2019) [22]	Russia	150	61	89	101			24-80	55	47	67.0	
9	Baena-Caldas *et al.* (2019) [20]	Colombia	236	106	130	236	106	130	9-93			100.0	
10	Lello *et al.* (2020) [19]	Japan	100	38	62	100	38	62	21-82			100.0	
11	Brücker *et al.* (2021) [24]	Brazil	230	65	165	224			7-81			97.4	
12	Alves et *al.* (2021) [21]	Chile	28	6	22	28	6	22	> 15	0	28	100.0	

TABLE 2. Summary of studies included in meta-analysis

	Study (year) [Ref.]	CBCT device	Voxel size (mm)	Field of view (cm)	Operating parameters/ tube voltage		Focal spot (mm)	Exposure time
1	Wanzeler *et al.* (2014) [23]	I-Cat						
2	Manhães Júnior *et al.* (2016) [8]	I-Cat™ Classic	0.25	8.0	120 kV	5-7 mA		40 s (acquisition time)
3	Şalli *et al.* (2017) [11]	Sirona Galileos Comfort Plus	0.25	15.0 × 15.0	98 kV	6.0 mA		
4	Gurler *et al.* (2017) [3]	I-Cat CBCT		16.0 × 8.0				
5	Velpula *et al.* (2018) [26]	9300 select 3D unit			90 kV	4.0 mA		11.0 s
6	Aoki *et al.* (2019) [5]	Prexion® Corporation	0.16	8.1 × 7.5	90 KVp	4.0 mA	0.15 (focal distance)	
7	Sedov *et al.* (2019) [25]		0.2/0.3	10.0 × 8.5	55-99 kB	4-16 mA	0.5	18 (scanning time)
8	Anatoly *et al.* (2019) [22]		0.2/0.3	10.0 × 8.5	55-99 kB	4-16 mA	0.5	18 (scanning time)
9	Baena-Caldas *et al.* (2019) [20]	Next Generation I-Cat						
10	Lello *et al.* (2020) [19]	3D Accuitomo 170	0.125, 0.160, 0.250	6.0 × 6.0, 8.0 × 8.0, 10.0 × 10.0	90 kV	5.0 mA		17.5 s
11	Brücker *et al.* (2021) [24]	I-Cat™	0.2 - 0.4		125 kVp	3-7 mA		
12	Alves *et al.* (2021) [21]	PAX Zenith 3D	0.12	8.0 × 6.0	120 kVp	10 mA		24.0 s

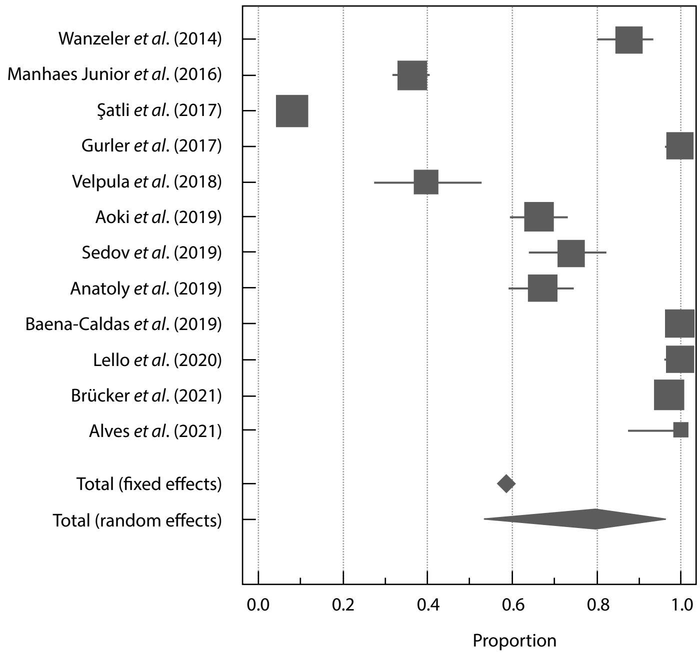

FIGURE 3. Forest plot of 12 prevalence studies and pooled prevalence using random effects model

since. Those who proposed a correlation between CS and age claimed that there is no or only a little difference between different age groups. Others observed a higher prevalence of CS in the older age groups comparing with young adults. The second examined parameter was gender, with men showing a higher incidence of CS, but without statistically significant differences. The results of this systematic review showed that CS may show differences in location, diameter, and course, but there were no statistically significant differences in age or sex [4].

Our results show that in the 12 analyzed research papers, the prevalence of CS among the examined patients fluctuated from 8.17% to 100%. The authors observed the occurrence of CS (Table 1). One hundred percent prevalence of CS was detected in 4 studies [3, 19-21].

In a research by Aoki *et al.* [5], 133 (66.5%) patients had CS, including 61 (45.86%) unilateral and 72 (54.14%) bilateral. According to Gurler *et al.* [3], CS was noted bilaterally in all of 111 CBCT scans. Anatoly *et al.* [22] noticed an outweigh of unilateral occurrence of CS among patients. In 22 of 101 patients with CS present (21.7%), the canal was seen only unilaterally in 55 patients (55.3%) and in 47 (45.7%) bilaterally. No factors determining clearly the unilateral or bilateral occurrence of CS were stated in the cited literature.

Among the chosen research, the occurrence of CS was higher in men in 2 research papers [5, 11]. In Aoki *et al.* [5], CS was found in 133 patients (66.5%), more often among men ($p < 0.05$). Similar results were observed by Şalli *et al.* [11], where the scans proved the predominance of CS in men ($n = 36$, 10.3%) than in women ($n = 19$, 5.9%). However, Anatoly *et al.* [22] determined a statistically higher occurrence of CS in women ($p < 0.01$). The predominance of CS in women was also documented by Manhães Júnior *et al.* [8], where the presence of CS was observed in 99 women (34.9%) and 82 men (38%). In four studies, in which the overall occurrence of CS was 100%, it was also more frequently observed in women [3, 19-21]. The relationship between the occurrence of CS and age of the examined patients was analyzed in 4 out of 12 studies [5, 22-24]. Aoki *et al.* [5] tested patients aged 18 to 85 years, with a median age of 53 years. They did not observe a relationship between the occurrence of CS and age ($p > 0.05\%$). In a research by Anatoly *et al.* [22], 150 CBCT scans of patients aged 24-80 years were analyzed retrospectively. The authors observed no statistically significant difference between the age groups ($p = 0.8$). Also, Wanzeler *et al.* [23] did not find any crucial discrepancies in the occurrence of CS in relation with age. According to a study by Brücker *et al.* [24], the age of individuals with identified CS varied from 7 to 81 years, with the median age of 48 years, and standard deviation of 15 years. There was a strong and significant kappa value of 0.74 ($p < 0.05$) in the intra-examiner error test.

Aoki *et al.* [5] focused on the diameter of CS. The researchers stated that most of the canals had a diameter of less than 1 mm ($n = 198/205$, 96.6%). They did not observe a statistically significant correlation between the diameter of the canal, the end of the CS trajectory, and the location (i.e., unilateral and bilateral). Sex and age were not related to the diameter, spatial location, and the end of the CS trajectory ($p > 0.05\%$). According to Sedov *et al.* [25], the CS diameter ranged from 0.3 to 2.1 mm; however, the analysis of age and sex did not show any statistically significant differences, both in total and separately on the right and left side.

According to a study by Wanzeler *et al.* [23], no significant variations in the diameter of CS concerning sex or between the left and right sides were observed. However, they did find a difference between the initial and final segments, suggesting that the caliber of CS remains relatively constant along its entire length. Gokhan Gurler *et al.* [3] reported an average diameter of the canal as 1.37 mm (ranging from 0.75 to 2.25 mm). The mean diameter in males was significantly larger than in females ($p = 0.001$). There were no meaningful differences between gender, sides, and age groups when analyzing the diameter in each segment ($p > 0.05$). However, it was observed that the CS diameter in S2 was significantly larger than in S3, except for individuals aged 30-44 years. Additionally, the diameter of CS in S1 was significantly greater than in S3, particularly among women on the right side and within the age range of 15-29 years. Moreover, the CS diameter in S2 was larger than that of S1 in women on the left side, and patients aged 45 and above. Furthermore, segments 1 and 3 had a higher proportion of CS, with a diameter between 1.0 and 1.4 mm (Table 3).

Aoki *et al.* [5] found that the end of the CS trajectory was more frequent in the area of the central incisor ($n = 91$, 44.39%), followed by the lateral incisor ($n = 45$, 21.95%), and the canine ($n = 29$, 14.15%). No statistically significant correlation was observed between the end of the CS trajectory and its location (i.e., unilateral or bilateral).

In a study by Anatoly *et al.* [22], the most commonly CS was located in the lateral and palatine incisor regions. CS most often occurred in the area of the lateral incisor (33.5%), central incisor (24.2%), canine (21.5%), and near the palate, which makes its location in various directions similar to other populations.

Wanzeler *et al.* [23] found that the end of CS was variable, and its terminal part was most often located in the floor of the nasal cavity, and only in one case, this structure ended in the area of the maxillary sinus. This canal therefore tends to be located in the front part of the jaw and may be located near the apex of the incisor, as was the case in the three samples assessed in the study, which leads to a false diagnosis of a periapical lesion on these teeth.

In a study by Gurler *et al.* [3], the mean distance between the CS and the ridge of alveolar process was 16.81 mm(range, 0-23.5 mm). The shortest distance between the canine and CS was 0.75 mm, and the mean was 5.27 mm. In nearly all patients, the CS ended near the incisive canal at the nasal floor. Only in one case, the final segment of CS was superior to the naso-lacrimal canal. Anatomical variations of CS were found in a few images. The additional bone canals were a direct extension of CS that progressed downwards to the alveolar process.

Manhães Júnior *et al.* [8] reported that the most common location on both sides in a studied group was next to the incisal opening, with 27 cases on the right (14.92%) and 24 on the left (13.26%). It should be emphasized that on the left side, location behind the upper lateral incisor occurred with the same frequency as in the vicinity of incisal opening.

Lello *et al.* [19] conclusions about CS are demonstrated in Table 4. In a study conducted by Brücker *et al.* [24], the location of the most common CS was consistent

TABLE 3. Diameter in selected segments of canal sinuosus (CS)

Region	Minimum diameter (mm)	Maximum diameter (mm)	Percentage of CS with diameter
S1	0.70	1.60	82.1% (1.0-1.4 mm), 8.9% (> 1.5 mm)
S2	1.00	2.20	66.7% (1.0-1.4 mm), 33.3% (> 1.5 mm)
S3	0.70	1.90	75.0% (1.0-1.4 mm), 5.4% (> 1.5 mm)

TABLE 4. Conclusions of Lello *et al.*

Measurement	Value (mm)
Distance from CS beginning to innermost orbital edge	3.7 ± 2.51
Distance from CS beginning to anterior descending loop of CS	6.3 ± 3.00
Distance from CS beginning to floor of nasal cavity	16.6 ± 3.14
Distance form CS beginning to infra-orbital foramen	0.9 ± 3.52
Distance from CS to upper edge of orbital foramen	4.8 ± 2.43
Distance from CS beginning to point of anterior descending loop of CS	18.1 ± 4.18
Distance from CS beginning to nostril	2.1 ± 1.04
Distance from lowest point of orbital edge to anterior descending loop of CS	10.0 ± 3.16
Distance from anterior descending loop of CS to bottom of nasal cavity	10.5 ± 3.04
Lateral distance from anterior descending loop of CS to bottom of nasal cavity	10.0 ± 1.93

with the classification 3 – near the area of the upper lateral incisor on both sides, according to Oliveira-Santos's *et al.* [18] classification (Figure 1).

Alves *et al.* [21] observed that the nasal cavity was the region where CS ended with the highest frequency (57.1%), followed by the area of the alveolar crest (16.1%), and the area adjacent to the upper apex of the central incisor (12.5%). In 5.4% of the studies, the final segment of CS was observed in the lateral and anterior regions of the incisor, and the terminal segment of CS adjacent to the apex of the upper central incisor.

In a Velpula *et al.* [26] study, the most common place of occurrence of CS was in the area of the lateral incisor, with 12.7% and 20.6% on the right and left sides, respectively.

The current study have several limitations. Firstly, various articles addressed different aspects related to CS, making direct comparisons challenging. Additionally, some articles lack sufficient data, and the quality of the source studies may have influenced the outcomes of our analysis. There is a risk that not all relevant studies were included in our research, as some studies might not be readily accessible or published in full scope. Time frames of writing our article should also be mentioned as an influential element.

Moreover, considering all the above-mentioned CS aspects, there are features that the articles lack, and could be worth including in further studies. Future research should use standardized measurements and diverse samples to study the correlation of canalis sinuosus with human size, race, genetics, and bone density. Collaboration with geneticists and longitudinal studies can provide valuable insights into the genetic and dynamic aspects of this anatomical feature. Advanced statistical analyses should be employed to account for confounding factors and strengthen research credibility.

CONCLUSIONS

Throughout the research, we observed an increase of CS prevalence in papers published in recent years. This might be due to higher precision and use of CBCT scanners as well as growing awareness of CS presence. CS may exhibit variability in the trajectory, location, and diameter. It involves ASAN and extension up to the front part of the palate. No statistically significant differences were observed in terms of gender and age. The importance of the proper identification of CS and its branches is crucial during surgical procedures in the infra-orbital canal area.

CONFLICT OF INTEREST

The authors declare no potential conflicts of interest concerning the research, authorship, and/or publication of this article.

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