Imaging Science in Dentistry 2023; 53: 177-91
https://doi.org/10.5624/isd.20230009

Anatomic evaluation of the posterior superior alveolar artery using cone-beam computed tomography: A systematic review and meta-analysis

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ABSTRACT

Purpose: This systematic review examined the detection of the posterior superior alveolar artery, along with various anatomic characteristics, on cone-beam computed tomography images.

Materials and Methods: Studies were identified electronically through the Web of Science, MEDLINE, Scopus, and Embase databases. The quality of the included studies was evaluated using a 5-item binary scale. The detection rate, location, and classified diameter of the posterior superior alveolar artery were estimated as prevalence values. The diameter of this artery, as well as the distances from the artery to the alveolar crest and sinus floor, were estimated as means with associated 95% confidence intervals.

Results: Thirty-seven studies were enrolled, with 34 of these included in the meta-analysis. The mean detection rate was 79% (range: 72%-84%), and the mean diameter was 1.06±0.05 mm (range: 0.96-1.16 mm). The posterior superior alveolar artery was located intraosseously in 64% of cases. The mean distance of the artery from the alveolar crest was 16.71±0.49 mm (range: 15.75-17.68 mm), while the mean distance from the artery to the sinus floor was 8.85±0.4 mm (range: 8.05-9.64 mm).

Conclusion: According to the findings of this meta-analysis regarding various anatomic characteristics of the posterior superior alveolar artery, severe hemorrhage after damage to this artery during sinus augmentation procedures is not a substantial clinical problem. ***(Imaging Sci Dent 2023; 53: 177-91)***

KEY WORDS: Cone-Beam Computed Tomography; Maxillary Artery; Hemorrhage; Sinus Floor Augmentation

Introduction

Maxillary posterior bone deficiency presents a considerable challenge in dental implant surgery. The presence of atrophic bones and the pneumatization of the sinus necessitate reconstruction of the posterior maxilla for the placement of dental implants.[1] Sinus augmentation is a highly predictable and safe method for increasing bone height prior to dental implant placement.[2]

Surgeons should remain cognizant of the potential intraoperative and postoperative complications associated with sinus augmentation. The most common intraoperative complication during sinus floor elevation is perforation of the Schneiderian membrane.[3,4] Additionally, trauma to a blood vessel is a frequent complication that can result in severe hemorrhage.[5]

The vascularization of the maxillary sinus is derived from the infraorbital artery, the greater palatine artery, and the posterior superior alveolar artery (PSAA).[6,7] An osteotomy procedure on the sinus lateral wall could potentially compromise the integrity of the PSAA.[8] Therefore,

Received January 10, 2023; Revised March 25, 2023; Accepted March 31, 2023
Published online August 2, 2023
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Imaging Science in Dentistry · pISSN 2233-7822 eISSN 2233-7830

understanding the blood supply of the maxillary sinus is crucial to avoid complications during sinus floor elevation surgery. These include excessive bleeding, Schneiderian membrane perforation, and bone necrosis.[7]

Cone-beam computed tomography (CBCT) is a valuable diagnostic tool commonly utilized in the field of dentistry, particularly for dental implant placement and sinus elevation procedures. CBCT images provide useful information regarding bone morphology, bone diseases, and the positioning of key anatomical landmarks such as the PSAA.[9] Moreover, this tomographic technique is advantageous due to its cost-effectiveness, reduced scan time, higher resolution and lower radiation dose for patients compared to medical computed tomography (CT).[10]

A thorough, advanced diagnosis is crucial for anticipating and mitigating complications prior to treatment. To these authors' knowledge, no new systematic review has been conducted on the characteristics of the PSAA since 2015.[11] However, numerous original articles have been published during this period.[12-36] These studies have revealed a broad range of detection rates for this artery using CBCT.[12-36] For instance, in the Iranian population, the detection rate varies between 25%[27] and 93%.[25] The detection rate of this artery in the Turkish population ranges from 72.2%[34] to 90%.[1] In another study, the detection rate was found to be 24.5% in a Taiwanese population.[35] Additionally, other anatomical characteristics such as artery diameter and location have been overlooked in previous reviews.[11] Therefore, this systematic review was conducted to examine the detection rate of the PSAA, the diameter of this artery, and its various anatomical characteristics on CBCT images.

Materials and Methods

The study received approval from the ethics committee of Tabriz University of Medical Sciences under the Vice Chancellor for Research (Ethics Code: IR.TBZMED.VCR.REC.1400.182). This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[37]

Cross-sectional and prevalence studies with full texts written in English were considered. Among these, articles investigating at least 1 characteristic of the PSAA using CBCT were included. All animal studies, abstracts, unpublished articles, reviews, studies conducted on cadavers or patients with systemic diseases that could impact bone metabolism, and studies of patients with anatomic abnormalities or a history of maxillary trauma were excluded. Studies that utilized medical CT, for assessment of the artery were also excluded. The literature search, which had no restrictions on publication date, was conducted until May 16, 2022 across the Web of Science, Medline, Scopus, and Embase electronic databases. Google Scholar was additionally searched for gray literature.[38] Medical Subject Headings and related keywords used in the search included "posterior superior alveolar artery," "PSAA," "sinus lift," "maxillary sinus," "cone-beam computed tomography," "CBCT," and "dental implants," including all subheadings. In addition, the references of selected citations, previous reviews on the same topic, and 2 major textbooks[39,40] were hand-searched. When articles contained incomplete data, emails were sent to the corresponding authors.

Two authors (F.R. and M.B.) independently screened studies for inclusion based on the titles and abstracts. Studies that did not meet the eligibility criteria were excluded. Full-text reading was conducted only when the title and abstract were unclear, or when consensus could not be reached. During these full-text readings, the studies were thoroughly evaluated against the eligibility criteria. Any disagreements that arose after the full-text reading were resolved through consultation with a third author (M.F.). Data from the included studies were independently extracted by 2 authors (F.R. and M.B.) using a pilot data extraction form and consolidated into a Microsoft Word file (ver. 2010, Microsoft Corp., Redmond, WA, USA). The extracted information included the author (s), year, country, study type, sample size, study population, and outcomes regarding various characteristics of the PSAA. In the event of any discrepancy, a third author (M.F.) was consulted. The investigation focused on 5 characteristics of the PSAA: detection rate, diameter, location, and the mean distances of the PSAA from the alveolar crest and sinus floor. Artery detection was defined as identification of the PSAA along the lateral wall of the maxillary sinus using coronal-axial or sagittal CBCT views. The diameter of the PSAA was defined as the maximum distance between the inner sides of the cortical borders. The location of the artery was classified into 3 categories based on a study by Ilgüy et al.:[41] intraosseous (IO; inside the lateral wall), intrasinus (IS; below the membrane, between the sinus membrane and the osseous wall), and superficial (SF; extraosseous, on the outer cortex of the lateral sinus wall). The distances from the inferior border of the PSAA to the alveolar crest and sinus floor were measured by the authors of the studies.

The quality of the articles was assessed using a 5-item binary scale (yes or no) developed by Varela-Centelles et al.[11] This scale was based on the Strengthening the Reporting of Observational Studies in Epidemiology guidelines for reporting observational studies. The 5 items were: 1) Does the report provide details about the study participants? 2) Are the aim and outcome of the study clearly defined? 3) Is the sampling frame a true or close representation of the target population? 4) Is the measuring instrument adequately described? and 5) Does the report offer a cautious overall interpretation of the results? Two investigators (F.R. and M.B.) independently graded the quality score in consultation with a third author (M.F.). Based on the overall score, articles were categorized into 3 quality groups: low (0 to 2), moderate (3 or 4), and high (5).

The detection rate, location, and classified diameter of the PSAA were estimated as prevalence values with associated 95% confidence intervals (CIs). The diameter of the PSAA and its distance from the alveolar crest and sinus floor were determined as means, again with corresponding 95% CIs.

For each characteristic, studies were enrolled in the meta-analysis if they reported the mean amount for the sinus unit. Specifically, for diameter classification, only studies utilizing the classification system of Mardinger et al.[42] were enrolled. This system categorizes diameters into 3 groups: less than 1 mm, between 1 and 2 mm, and greater than 2 mm. Regarding location, studies using the classification scheme of Ilgüy et al. were included in the meta-analysis.[41] Finally, the data from the included studies were entered into a standardized MS Excel spreadsheet (version 2010; Microsoft Corp.).

The meta-analysis was conducted, and forest plots were generated using Comprehensive Meta-Analysis (CMA) version 2.2.064 (Biostat Inc., Englewood, NJ, USA). Meta-regression, facilitated by CMA, was employed to identify the factors contributing to any observed heterogeneity.

Heterogeneity was assessed using the Cochran Q test and the I^2 statistic. Heterogeneity was considered significant if the I^2 value was at least 40% and/or if the P-value was less than 0.1.

Pooled prevalence estimates of the detection rate, location, and classified diameter of the PSAA were calculated. Additionally, pooled mean estimates were calculated regarding the diameter of the PSAA and its distance from the alveolar crest and sinus floor. These values were presented with 95% CIs, and calculations were made using either fixed or random effects models, based on the level of heterogeneity. If significant heterogeneity was detected, a random-effects model was applied; otherwise, a fixed-effects model was used. Given the descriptive nature of this systematic review, publication bias was not a relevant factor.

Results

Study selection and characteristics

Fig. 1 provides an overview of the PRISMA flow diagram illustrating the process of study selection. The databases yielded 1,474 records, while an additional 219 records were sourced from other materials, such as reference textbooks and gray literature. After eliminating duplicates, a total of 1,508 studies were assessed for eligibility based on their titles and abstracts. Out of these, 58 studies fulfilled the eligibility requirements and were selected for full-text review. Ultimately, 37 of these 58 studies were included in the final selection, with 34 incorporated into the meta-analysis.

Some studies initially seemed to meet the inclusion criteria but were ultimately excluded. These included studies utilizing radiographs other than CBCT,[22,42-51] studies with internal inconsistencies related to their reported results[52,53], those that did not investigate the PSAA as a whole unit (for instance, only analyzing a branch of the PSAA),[36,54-58] and those that did not analyze at least 1 PSAA characteristic pertinent to the present inclusion criteria.[59,60]

All studies included in this systematic review were cross-sectional and were published between 2011 and 2022. In the review, 6 characteristics of the PSAA were investigated. A total of 34[1,9,10,12-18,20,21,23-35,41,61-68] studies examined the detection of the artery, 27 studies analyzed its diameter,[1,12-16,18-21,23,24,26,28,31-33,35,41,61-63,65-69] 25 studies investigated its location,[1,10,12-17,20,21,25-27,29,31-34,41,62,63,65,66,68,69] 17 studies examined the distance from the sinus floor to the artery,[1,10,15,18,23-25,28-30,61,63,64,67-70] and 28 studies analyzed the distance between the alveolar crest and the PSAA.[10,12-15,17-21,23-25,28,30-33,35,41,62-69] The number of sinuses examined in these studies ranged from 83 to 788 (Table 1). In terms of quality assessment score, 13 studies were classified as high-quality,[9,15,19,23,24,28,29,31,61,62,65,66,69] 22 as moderate-quality,[1,10,12,14,16-18,21,25-27,30,32-35,41,63,64,67,68,70] and 2 as low-quality.[13,20] The results of this quality assessment are presented in Table 2.

Of the 37 studies that were included, 34 underwent meta-analysis based on varying characteristics. Both Duruel et al.[14] and Takahashi et al.[30] conducted investigations into distinct characteristics of the PSAA for each tooth, but they did not provide the mean values for these characteristics. Similarly, Padovani et al.[23] measured characteristics of the PSAA in 3 areas without reporting mean values. Consequently, these 3 studies were not included in the meta-analysis.

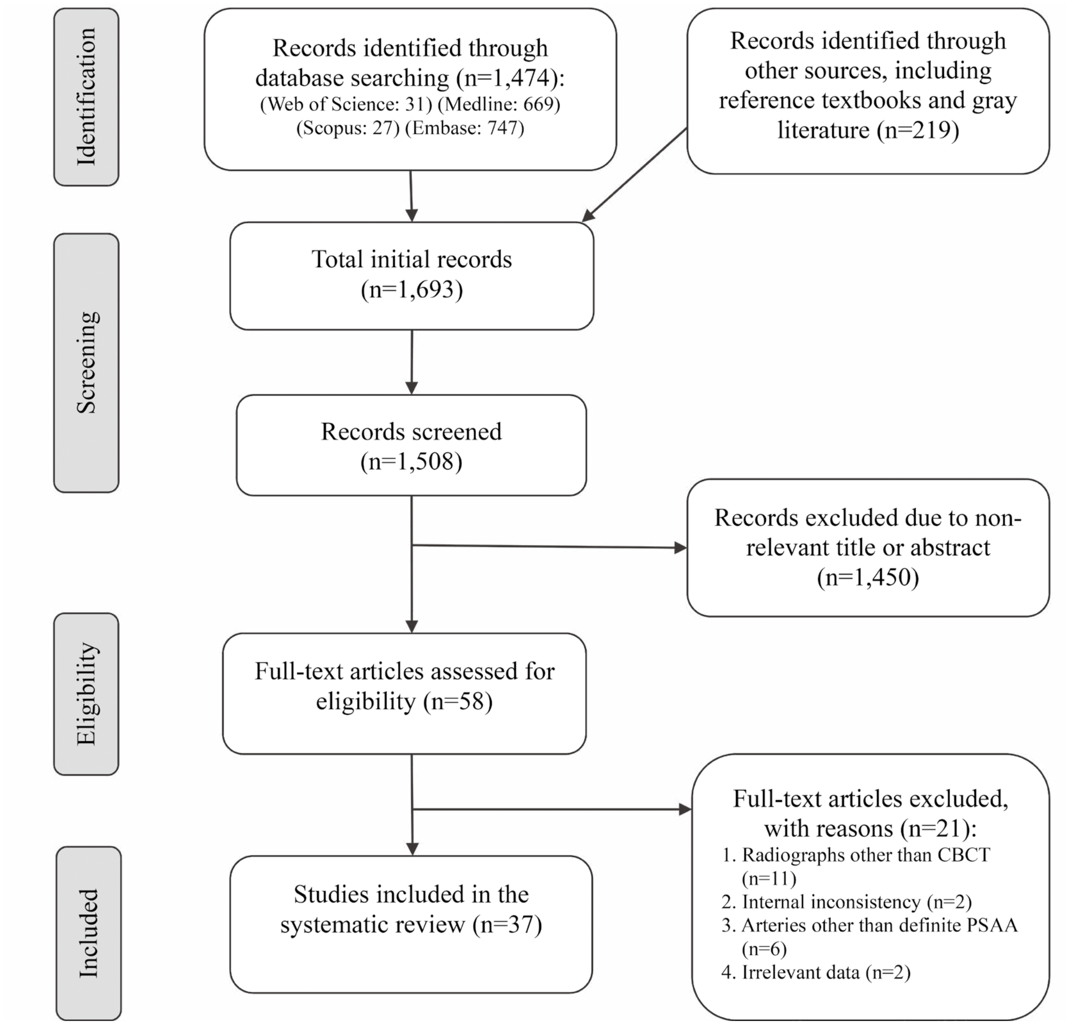


Fig. 1. Flow diagram of the inclusion process based on PRISMA protocols.

Among the studies included in the meta-analysis, 16 of them evaluated various characteristics based on sex.[10,12,13,16-18,20,21,24,31,33,34,41,63,68,69]

All characteristics assessed in this study demonstrated high heterogeneity.

Detection of the PSAA

The meta-analysis incorporated 31 articles. These studies collectively examined 11,402 sinuses from various populations. The meta-analysis revealed an overall detection rate of 79% for the PSAA (95% CI: 72%-84%) (Fig. 2A).

The meta-regression results indicated significant heterogeneity due to sex ($P<0.05$). Consequently, a subgroup analysis was conducted using the odds ratio, which was calculated from the detection rate in male participants divided by that in female patients. The odds ratio for the detection of PSAA in male participants was 1.34 (95% CI: 1.17-1.55; $P<0.05$), reflecting a significantly higher detection rate than in females. Figure 2B presents a forest plot of the meta-analyzed studies categorized by sex.

Diameter of the PSAA

The diameter was subjected to meta-analysis in 2 steps. In the first step, the mean diameter of the PSAA was analyzed. In the second, the prevalence of various diameters was examined based on the classification system proposed by Mardinger et al.[42] In this system, diameters were categorized into 3 groups: less than 1 mm, between 1 and 2 mm, and greater than 2 mm.

In the first section, 16 studies were included in the analysis of mean diameter. These studies collectively included 3,757 sinuses from various populations. The meta-analysis revealed that the mean diameter of the PSAA was 1.06 ± 0.05 mm (95% CI: 0.96-1.16 mm) (Fig. 3A).

Table 1. Extracted data

Author (year)	Sample size (sinus)	Study population	Mean detection (%)	Mean diameter (mm)	Intraosseous location (%)	Intrasinus location (%)	Superficial location (%)	Mean distance from sinus floor (mm)	Mean distance from alveolar crest (mm)	Quality assessment
Anamali et al.[9] (2015)	508	North American	92.7	–	–	–	–	–	–	5
Apostolakis and Bissoon[61] (2014)	312	Not mentioned	82	1.1 ± 0.4	–	–	–	Not applicable	–	5
Bedeloğlu and Yalçın[1] (2020)	120	Turkish	90	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	–	4
Chitsazi et al.[12] (2017)	400	Iranian	71	1.37 ± 0.44	73.3	21.7	5	–	16.17 ± 1.63	3
Dursun et al.[13] (2019)	479	Multicenter (Turkey, Lithuania, Spain, USA)	37	Not applicable	63.8	31.6	4.6	–	14.35 ± 4.99	2
Duruel et al.[14] (2019)	354	Not mentioned	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	–	Not applicable	4
Fayek et al.[15] (2021)	600	Egyptian	92	1 ± 0.5	82.2	13.8	4	7.7 ± 2.2	Not applicable	5
Genç et al.[16] (2018)	174	Turkish	87.4	Not applicable	39.5	46	14.5	–	–	3
Godil et al.[17] (2021)	500	Indian	99.4	–	84.7	12.1	3.2	–	17.41 ± 3.96	4
Hafezi et al.[18] (2021)	299	Iranian	76.2	0.89 ± 0.2	Not applicable	Not applicable	Not applicable	9.12 ± 3.21	20.88 ± 3.79	4
Hayek et al.[62] (2015)	348	Lebanese	50	Not applicable	69.2	27.9	2.9	–	Not applicable	5
Ilgüy et al.[41] (2013)	270	Turkish	89.25	0.94 ± 0.26	79.7	14.5	5.8	–	16.87 ± 3.44	4
Jung et al.[10] (2011)	250	Korean	52.8	–	Not applicable	Not applicable	Not applicable	8.17 ± 3.25	14.64 ± 3.91	4
Kang et al.[63] (2013)	150	Korean	90	1.18 ± 0.45	64.3	29.1	6.6	8.25 ± 3.25	17.03 ± 3.53	4
Karslioglu et al.[69] (2021)	300	Turkish	–	Not applicable	59.7	18.7	21.7	10.37 ± 3.98	17.6 ± 4.46	5
Kawakami et al.[19] (2019)	88	Colombian	–	1.1 ± 0.4	–	–	–	–	14.4 ± 2.9	5
Keceli et al.[20] (2017)	570	Multicenter (Turkey, Lithuania, Spain, USA)	49.82	Not applicable	60.6	36.6	2.8	–	14.15 ± 5.91	2
Khojastehpour et al.[21] (2016)	211	Iranian	80.6	1.2 ± 0.72	35.9	61.8	2.3	–	16.43 ± 9.36	4
Kim et al.[70] (2021)	83	Korean	–	–	–	–	–	11.91 ± 4.79	–	4
Kurt et al.[64] (2014)	292	Turkish	78	–	–	–	–	Not applicable	Not applicable	4
Lozano-Carrascal et al.[65] (2017)	284	Caucasian	48.6	Not applicable	Not applicable	Not applicable	Not applicable	–	Not applicable	5
Nicolielo et al.[66] (2014)	200	Brazilian	73.5	0.83 ± 0.27	Not applicable	Not applicable	Not applicable	–	19.32 ± 3.86	5
Padovani et al.[23] (2020)	180	Brazilian	Not applicable	Not applicable	–	–	–	Not applicable	Not applicable	5
Pandharbale et al.[24] (2016)	100	Indian	72	0.63 ± 0.38	–	–	–	Not applicable	Not applicable	5
Panjnoush et al.[25] (2017)	600	Iranian	25	–	51.3	48.7	0	Not applicable	Not applicable	4
Rathod et al.[26] (2022)	300	Indian	87.3	1.24 ± 0.41	66.5	24	9.5	–	–	3
Shahidi et al.[27] (2016)	396	Iranian	93	–	65.7	20.6	13.5	–	–	4
Shams et al.[28] (2020)	400	Iranian	73.2	0.83 ± 0.33	–	–	–	6.29 ± 4.59	19.87 ± 5.72	5
Sun et al.[29] (2018)	484	Chinese	87.6	–	Not applicable	Not applicable	Not applicable	9.2 ± 3.5	–	5
Takahashi et al.[30] (2022)	90	Japanese	Not applicable	–	–	–	–	Not applicable	Not applicable	4
Tassoker[68] (2022)	400	Turkish	85.5	0.9 ± 0.39	59.3	38.9	1.8	9.04 ± 3.77	17.82 ± 3.6	4
Tehranchi et al.[31] (2017)	300	Iranian	87	1.29 ± 0.39	47	47	6	–	16.7 ± 3.96	5
Vasegh et al.[32] (2019)	514	Iranian	78	1.32 ± 0.32	Not applicable	Not applicable	Not applicable	–	Not applicable	4
Velasco-Torres et al.[67] (2016)	788	Spanish	84.64	Not applicable	–	–	–	Not applicable	13.4 ± 3.72	4
Waingade et al.[33] (2021)	402	Indian	90.04	Not applicable	65.7	34	0.3	–	Not applicable	4
Yalcin and Akyol[34] (2019)	650	Turkish	72.2	–	56.6	39.9	3.5	–	–	4
Yu et al.[35] (2019)	101	Taiwanese	24.5	1.22 ± 0.42	–	–	–	–	17.11 ± 4.88	4

Table 2. Quality assessment scores by study

Author (year)	Score (points)	Question(s) not earning a point
Anamali et al.[9] (2015)	5	–
Apostolakis and Bissoon[61] (2014)	5	–
Bedeloğlu and Yalçın[1] (2020)	4	4
Chitsazi et al.[12] (2017)	3	1, 4
Dursun et al.[13] (2019)	2	1, 3, 4
Duruel et al.[14] (2019)	4	4
Fayek et al.[15] (2021)	5	–
Genç et al.[16] (2018)	3	3, 4
Godil et al.[17] (2021)	4	1
Hafezi et al.[18] (2021)	4	4
Hayek et al.[62] (2015)	5	–
Ilgüy et al.[41] (2013)	4	1
Jung et al.[10] (2011)	4	1
Kang et al.[63] (2013)	4	1
Karslioglu et al.[69] (2021)	5	–
Kawakami et al.[19] (2019)	5	–
Keceli et al.[20] (2017)	2	1, 3, 4
Khojastehpour et al.[21] (2016)	4	4
Kim et al.[70] (2021)	4	1
Kurt et al.[64] (2014)	4	1
Lozano-Carrascal et al.[65] (2017)	5	–
Nicolielo et al.[66] (2014)	5	–
Padovani et al.[23] (2020)	5	–
Pandharbale et al.[24] (2016)	5	–
Panjnoush et al.[25] (2017)	4	1
Rathod et al.[26] (2022)	3	2, 4
Shahidi et al.[27] (2016)	4	4
Shams et al.[28] (2020)	5	–
Sun et al.[29] (2018)	5	–
Takahashi et al.[30] (2022)	4	1
Tassoker[68] (2022)	4	4
Tehranchi et al.[31] (2017)	5	–
Vasegh et al.[32] (2019)	4	1
Velasco-Torres et al.[67] (2016)	4	1
Waingade et al.[33] (2021)	4	1
Yalcin and Akyol[34] (2019)	4	1
Yu et al.[35] (2019)	4	4

The meta-regression revealed significant heterogeneity due to sex ($P<0.05$). Therefore, a subgroup analysis was conducted based on the mean difference (mean diameter in males - mean diameter in females). The mean difference in diameter was 0.14±0.05 mm (95% CI: 0.05-0.23; $P<0.05$), a statistically significant finding. Fig. 3B presents a forest plot of the meta-analyzed studies based on sex.

In the second section, 8 studies were included in the diameter-based classification analysis. These studies included 2,076 sinuses from various populations. The meta-analysis revealed that the prevalence of a PSAA with a diameter of <1 mm was 55% (95% CI: 42%-68%). PSAAs with a diameter between 1 and 2 mm accounted for 41% (95% CI: 31%-53%), while those measuring more than 2 mm represented 2% of cases (95% CI: 1%-5%).

Location of the PSAA

The location analysis incorporated 18 studies, which collectively examined 3,339 sinuses from various populations. The findings of the PSAA location analysis in 3 distinct areas - IO, IS, and SF - are depicted in Figure 4. The meta-analysis revealed that the PSAA location was IO in 64% of cases (95% CI: 57%-69%), IS in 30% (95% CI: 24%-37%), and SF in 5% (95% CI: 3%-7%). The meta-regression indicated that sex did not contribute to heterogeneity in the location of the artery (P: IO=0.12, IS=0.12, SF=0.77).

Distance of the PSAA from the alveolar crest

The meta-analysis incorporated 17 studies regarding the mean distance of the PSAA from the alveolar crest. These studies collectively included 4,271 sinuses from various populations. The meta-analysis revealed that the mean distance of the PSAA from the alveolar crest was 16.71±0.50 mm (95% CI: 15.75-17.68 mm) (Fig. 5A).

The results of the meta-regression indicated that sex significantly contributed to heterogeneity ($P<0.05$). Consequently, a subgroup analysis was conducted based on the mean difference (mean distance in males - mean distance in females). The mean difference in distance from the alveolar crest was 0.59±0.11 mm (95% CI: 0.01-0.36 mm; $P<0.05$), a statistically significant finding. Figure 5B presents a forest plot of the examined studies based on sex.

Distance of the PSAA from the sinus floor

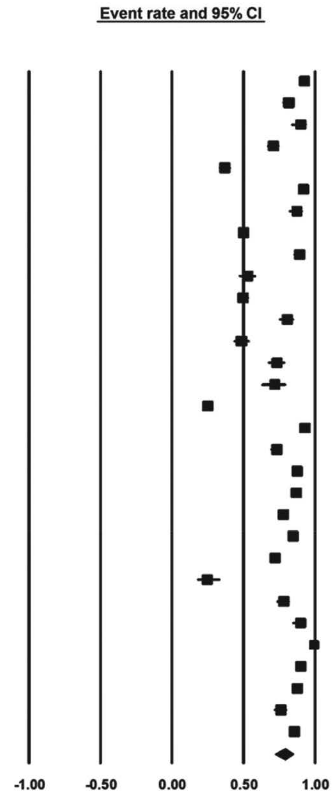
Nine studies were included in the analysis of the mean distance between the sinus floor and the inferior border of the PSAA. These studies collectively examined 2,489 sinuses from various populations. The meta-analysis revealed that the mean distance between the sinus floor and the inferior border of the PSAA was 8.85±0.40 mm (95% CI: 8.06-9.65 mm) (Fig. 6A).

The meta-regression revealed significant heterogeneity due to sex ($P<0.05$). Therefore, a subgroup analysis was conducted based on the mean difference (mean distance in males - mean distance in females). The mean difference in distance was 0.89±0.37 mm (95% CI: 0.16-1.61 mm; $P=0.017$), a statistically significant finding. Figure

A

Statistics for each study

Author (year)	Study population	Event rate	Lower limit	Upper limit	z-Value	p-Value	Relative weight
Anamali et al.[9](2015)	North American	0.93	0.90	0.95	14.90	0.00	3.24
Apostolakis[61](2014)	Greek	0.82	0.77	0.86	10.23	0.00	3.26
Bedeloglu[1](2020)	Turkish	0.90	0.83	0.94	7.22	0.00	3.07
Chitsazi et al.[12](2017)	Iranian	0.71	0.66	0.75	8.13	0.00	3.29
Dursun et al.[13](2019)	Multi-center	0.37	0.33	0.41	5.64-	0.00	3.30
Fayek[15](2021)	Egyptian	0.92	0.90	0.94	16.23	0.00	3.26
Genc et al.[16](2018)	Turkish	0.87	0.82	0.92	8.47	0.00	3.18
Hayek et al.[62](2015)	Lebanese	0.50	0.46	0.54	0.00	1.00	3.31
Ilguy et al.[41](2013)	Turkish	0.89	0.85	0.92	10.77	0.00	3.21
Jung[10](2011)	Korean	0.53	0.47	0.59	0.88	0.38	3.28
Keceli et al.[20](2017)	Multi-center	0.50	0.46	0.54	-0.08	0.93	3.31
Khojastehpour et al[21](2016)	Iranian	0.81	0.75	0.85	8.17	0.00	3.24
Lozanocarrascal et al.[65](2017)	Caucasian	0.49	0.43	0.54	0.47-	0.64	3.29
Nicolielo et al.[66](2014)	Multi-center	0.73	0.67	0.79	6.37	0.00	3.25
Pandharbale et al.[24](2016)	Indian	0.72	0.62	0.80	4.24	0.00	3.18
Panjnoush et al.[25](2017)	Iranian	0.25	0.22	0.29	11.65-	0.00	3.30
Shahidi et al.[27](2016)	Iranian	0.93	0.90	0.95	13.14	0.00	3.21
Shams et al.[28](2020)	Iranian	0.73	0.69	0.77	8.92	0.00	3.29
Sun et al.[29](2018)	Chinese	0.88	0.84	0.90	14.18	0.00	3.27
Tehranchi et al.[31](2017)	Iranian	0.87	0.83	0.90	11.07	0.00	3.24
Vasegh et al .[32](2019)	Iranian	0.78	0.74	0.81	11.89	0.00	3.29
Velasco-Torres et al.[67](2016)	Spanish	0.85	0.82	0.87	17.28	0.00	3.30
Yalcin[34](2019)	Turkish	0.72	0.69	0.75	10.88	0.00	3.31
Yu et al.[35](2019)	Taiwanese	0.25	0.17	0.34	4.82-	0.00	3.17
Kurt et al.[64](2014)	Turkish	0.78	0.73	0.82	8.98	0.00	3.27
Kang et al.[63](2013)	Korean	0.90	0.84	0.94	8.07	0.00	3.11
Godil et al.[17](2021)	Indian	0.99	0.98	1.00	8.82	0.00	2.54
Waingade[33](2021)	Indian	0.90	0.87	0.93	13.22	0.00	3.25
Rathod et al.[26](2022)	Indian	0.88	0.83	0.91	11.17	0.00	3.24
Hafezi et al.[18](2021)	Iranian	0.76	0.71	0.81	8.58	0.00	3.27
Tassoker[68](2022)	Turkish	0.86	0.82	0.89	12.50	0.00	3.27
		0.79	0.72	0.84	6.87	0.00	



B

Statistics for each study

Author (year)	Odds ratio	Lower limit	Upper limit	z-Value	p-Value	Relative weight
Dursun et al.[13](2019)	1.613	1.110	2.344	2.507	0.012	14.66
Genc et al.[16](2018)	3.100	1.001	9.603	1.961	0.050	1.60
Ilguy et al.[41](2013)	0.971	0.444	2.123	0.074-	0.941	3.34
Jung[10](2011)	0.936	0.559	1.569	0.251-	0.802	7.68
Keceli et al.[20](2017)	1.443	1.038	2.007	2.179	0.029	18.80
Khojastehpour et al[21](2016)	1.969	0.985	3.933	1.918	0.055	4.27
Pandharbale et al.[24](2016)	2.667	1.090	6.524	2.149	0.032	2.56
Tehranchi et al.[31](2017)	1.089	0.555	2.138	0.247	0.805	4.50
Yalcin[34](2019)	1.716	1.209	2.436	3.020	0.003	16.67
Kurt et al.[64](2014)	1.718	0.964	3.061	1.837	0.066	6.14
Kang et al.[63](2013)	1.824	0.624	5.329	1.099	0.272	1.78
Godil et al.[17](2021)	0.166	0.009	3.226	1.187-	0.235	0.23
Waingade[33](2021)	0.473	0.233	0.960	2.073-	0.038	4.10
Hafezi et al.[18](2021)	1.010	0.590	1.728	0.036	0.971	7.09
Tassoker[68](2022)	0.817	0.468	1.428	0.709-	0.479	6.58
	1.344	1.165	1.551	4.048	0.000	

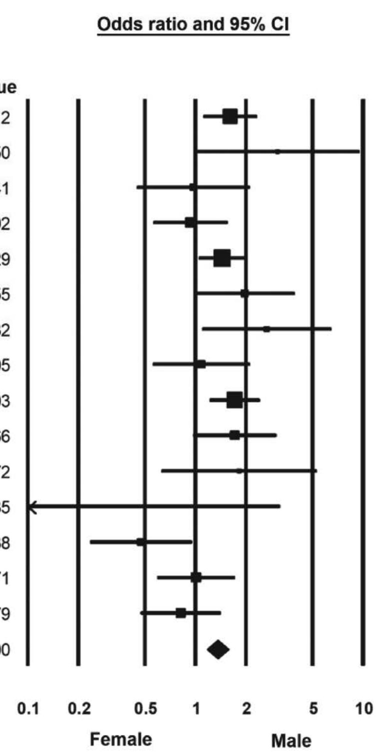


Fig. 2. A. Forest plot depicting the pooled prevalence of the detection rate of the posterior superior alveolar artery (PSAA) with associated 95% confidence intervals (CIs), based on the meta-analyzed studies. B. Forest plot depicting the ratio of PSAA detection rates of male to female participants, with associated 95% CIs, from the examined studies.

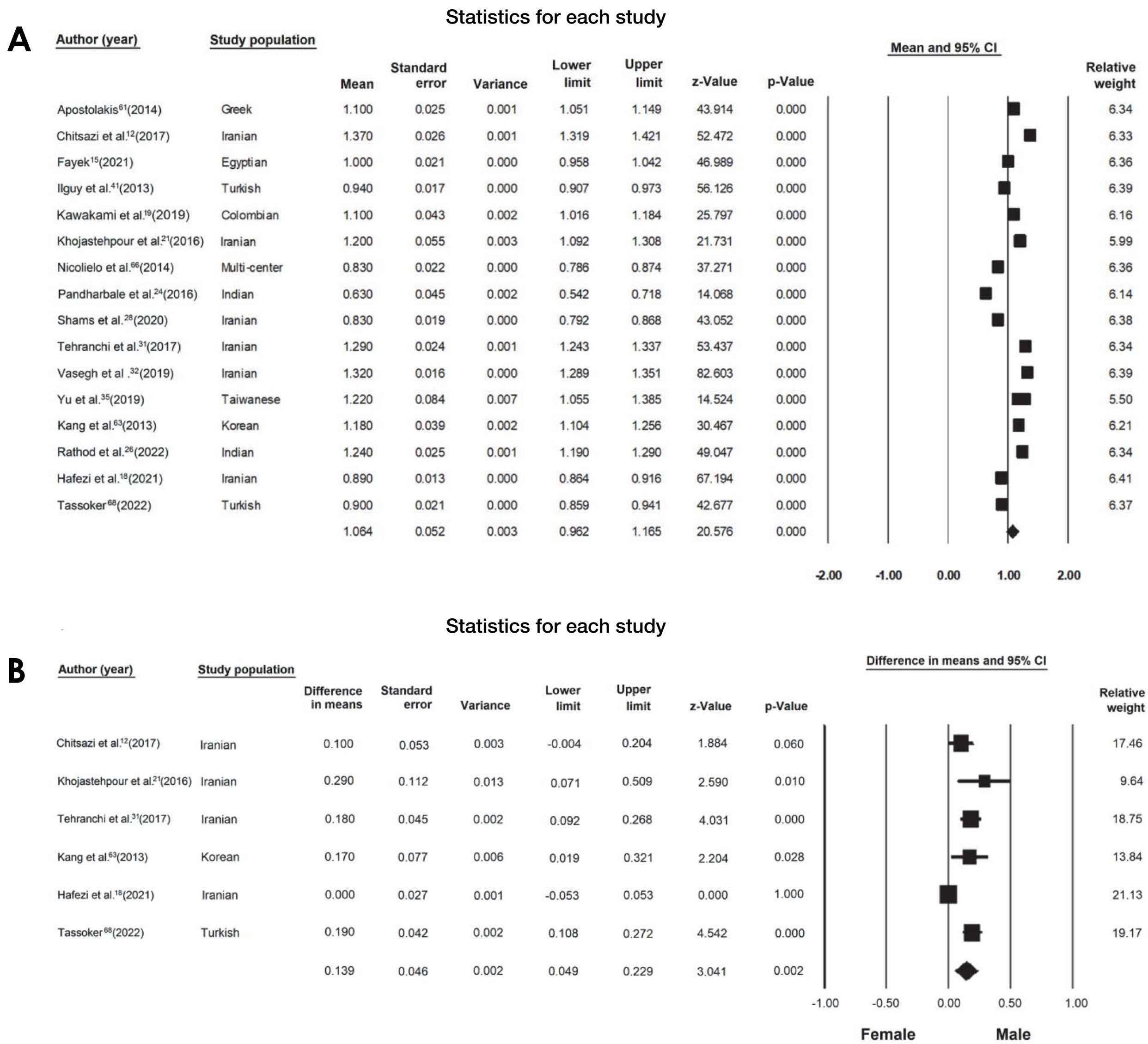


Fig. 3. A. Forest plot depicting the pooled mean diameter of the posterior superior alveolar artery (PSAA) with associated 95% confidence intervals (CIs), based on the meta-analyzed studies. B. Forest plot of the mean difference (mean diameter in males - mean diameter in females) of the diameter of the PSAA, with corresponding 95% CIs, from the examined studies.

6B presents a forest plot of the examined studies based on sex.

Discussion

This study was conducted to assess various anatomical characteristics of the PSAA as seen on CBCT images. A previous review indicated that preoperative evaluation using CBCT facilitates more frequent and effective identification of the PSAA compared to medical CT;[11] hence, studies utilizing CBCT were incorporated into this research. According to this meta-analysis, the detection rate of the PSAA via CBCT was 79%. In comparison, Varela-Centelles et al. reported a 78.12% detection rate of the PSAA via CBCT.[11] This discrepancy could be due to the publication of new studies since 2015.[12-36] Notably, however, this artery is present in all sinuses, as confirmed by multiple cadaveric studies.[7,71,72] The inability to detect the vessel can be attributed to several factors. First, some studies suggest that a PSAA with a diameter of less than 0.5 mm may not be detectable by CBCT.[10,12,15,42,45,51,71] Second, the path of the artery may not be consistent through the lateral wall of the maxillary sinus. The artery may be located in an extra-bony or completely intrasinus position in areas examined by the operator. The absence of arteries on radiographs could be due to the limited capacity of CBCT to discern soft tis-

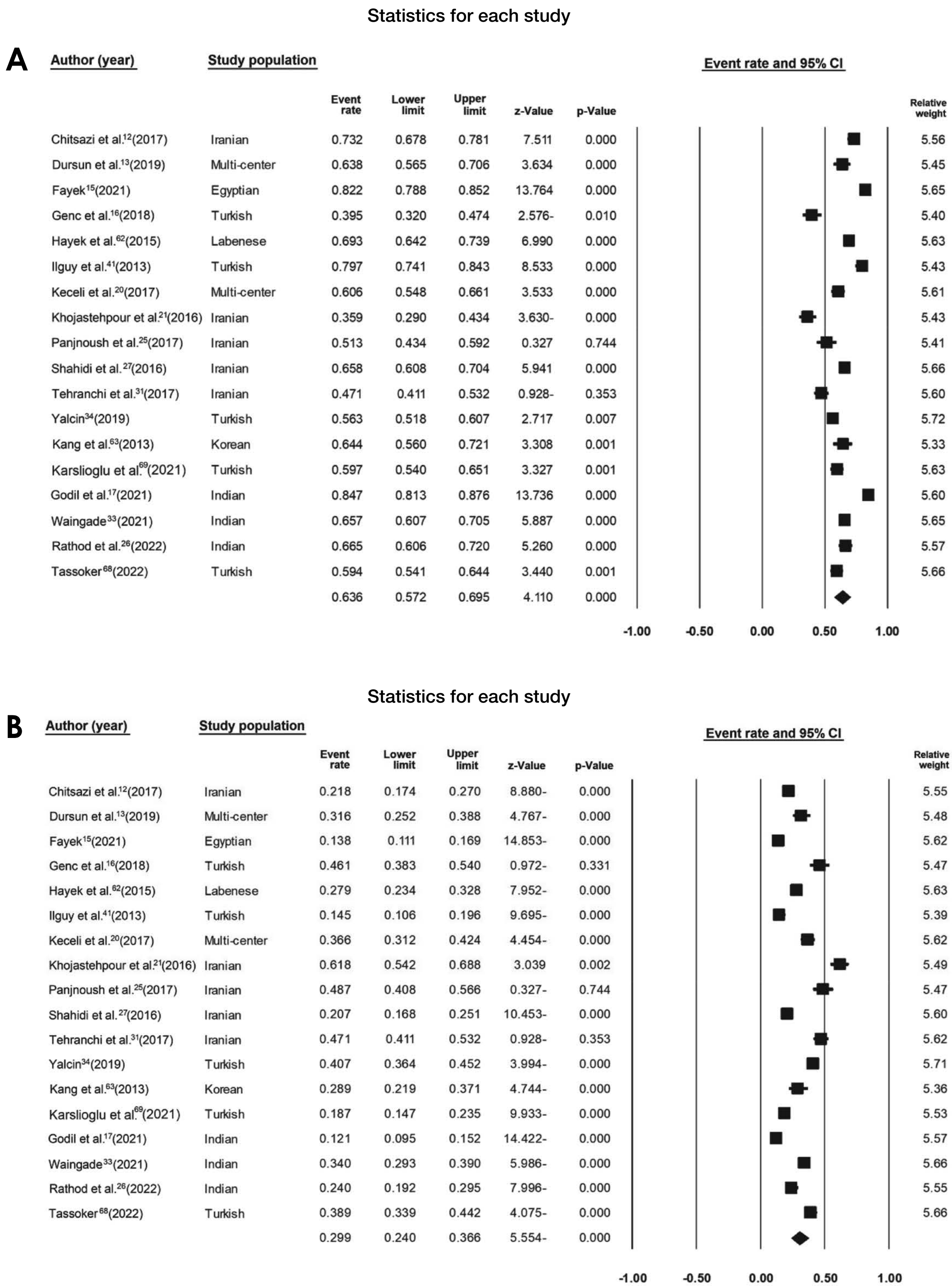


Fig. 4. Forest plots of the pooled prevalence of the location of the posterior superior alveolar artery (PSAA) in intraosseous (A), intrasinus (B), and superficial (C) groups, with associated 95% confidence intervals, from the meta-analyzed studies.

sues.[44,54] Third, variations in methodologies and operator experience could lead to a lower detection rate relative to cadaveric studies.[27,32] Differences in image resolution, voxel size, and the use of more advanced software for analysis have been cited in previous studies as reasons for the lower detection rate of the PSAA.[15,61]

C

Statistics for each study

Author (year)	Study population	Event rate	Lower limit	Upper limit	z-Value	p-Value	Relative weight
Chitsazi et al.[12](2017)	Iranian	0.049	0.029	0.082	10.797-	0.000	6.04
Dursun et al.[13](2019)	Multi-center	0.045	0.023	0.088	8.431-	0.000	5.66
Fayek[15](2021)	Egyptian	0.040	0.026	0.060	14.624-	0.000	6.25
Genc et al.[16](2018)	Turkish	0.145	0.097	0.210	7.706-	0.000	6.21
Hayek et al.[62](2015)	Labenese	0.029	0.016	0.053	10.972-	0.000	5.85
Ilguy et al.[41](2013)	Turkish	0.058	0.035	0.096	10.117-	0.000	6.04
Keceli et al.[20](2017)	Multi-center	0.028	0.014	0.055	9.873-	0.000	5.68
Khojastehpour et al.[21](2016)	Iranian	0.024	0.009	0.061	7.363-	0.000	4.96
Panjnoush et al.[25](2017)	Iranian	0.003	0.000	0.051	4.029-	0.000	1.82
Shahidi et al.[27](2016)	Iranian	0.136	0.104	0.175	12.161-	0.000	6.45
Tehranchi et al.[31](2017)	Iranian	0.057	0.035	0.093	10.518-	0.000	6.08
Yalcin[34](2019)	Turkish	0.030	0.018	0.050	12.830-	0.000	6.06
Kang et al.[63](2013)	Korean	0.067	0.035	0.123	7.649-	0.000	5.74
Karslioglu et al.[69](2021)	Turkish	0.217	0.174	0.267	9.171-	0.000	6.48
Godil et al.[17](2021)	Indian	0.032	0.020	0.052	13.392-	0.000	6.12
Waingade[33](2021)	Indian	0.003	0.000	0.019	5.881-	0.000	2.85
Rathod et al.[26](2022)	Indian	0.095	0.065	0.137	10.718-	0.000	6.28
Tassoker[68](2022)	Turkish	0.018	0.008	0.038	9.773-	0.000	5.43
		0.048	0.031	0.072	13.376-	0.000	

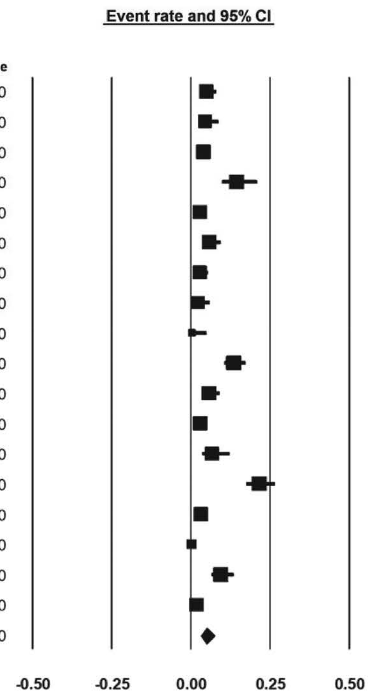
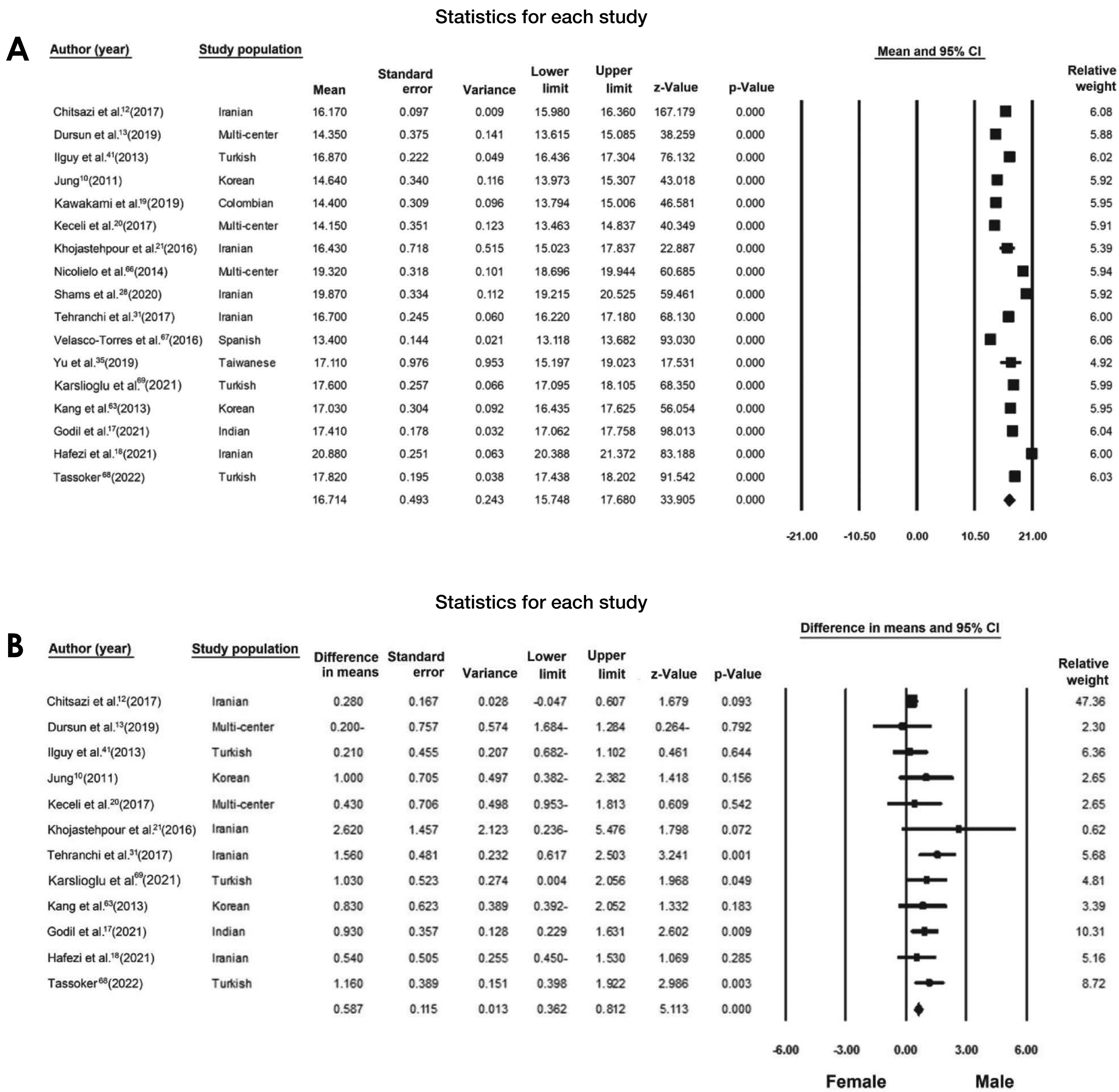


Fig. 4. Continued

Understanding the diameter of this artery is imperative for evaluating the risk of excessive bleeding. Managing complications becomes more complex and potentially alarming with arteries of larger diameters.[61] In this study, the mean diameter of the PSAA was 1.06±0.05 mm, with a range of 0.54-1.42 mm. To provide clinicians better insight into the diameter of the artery, a classification analysis was performed. This revealed that 55% of the arteries were <1 mm in diameter, while only 2% were >2 mm in diameter. Comparing the mean artery diameter obtained through CBCT with the limited evidence from cadaver studies,[7,72] it may be challenging to conclude that CBCT imaging overlooks arteries with a diameter less than 0.5 mm. For this to be the case, the mean artery diameter in cadavers should be lower than the mean diameter found in the meta-analysis. Interestingly, the mean sample diameter reported by Solar et al.[7] was even higher than the mean diameter in the present study. However, Hur et al.[72] reported a mean diameter of the PSAA of 0.8±0.3. This suggests that further studies are required to obtain more accurate results. Reportedly, the risk of severe hemorrhage decreases in canals smaller than 1 mm. In this context, this carries little clinical significance, as any resulting hemorrhage can be readily managed.[61,62] However, a PSAA with a diameter greater than 2 mm can lead to excessive bleeding and non-life-threatening bleeding complications.[52,61] Considering the results of this study and the risks associated with artery diameter, only 2% of the arteries could potentially lead to serious complications. A review of the literature revealed inconsistencies in detection rates and diameters based on sex.[10,12,13,16-18,20,21,24,31,33,34,41,63,68,69] In the present study, both the detection rate and the artery diameter were significantly higher in male participants. Given the latter, extra caution is warranted when the patient is male.

In this review, most PSAAs were found in the IO location (64%); 30% of the arteries had IS placement, and the least common location of the PSAA was SF (5%). The arterial branch within the canal is often obscured by the thickness of the osseous wall during lateral window preparation, which heightens the risk of inadvertent injury to the arterial branch.[10] The IS location of the PSAA should also be considered to avoid vascular injuries during membrane detachment.[73]

To prevent further complications in sinus lift surgery, practitioners must factor in the distances from the PSAA to the sinus floor and alveolar crest. Park et al.[46] found that the distance between the PSAA and sinus floor ranged from 7.71-8.01 mm. They suggested that the window height should be at least 8 mm to ensure adequate visualization, straightforward instrumentation, and proper osseous graft



Author (year)	Study population	Mean	Standard error	Variance	Lower limit	Upper limit	z-Value	p-Value	Relative weight
Chitsazi et al.[12](2017)	Iranian	16.170	0.097	0.009	15.980	16.360	167.179	0.000	6.08
Dursun et al.[13](2019)	Multi-center	14.350	0.375	0.141	13.615	15.085	38.259	0.000	5.88
Ilguy et al.[41](2013)	Turkish	16.870	0.222	0.049	16.436	17.304	76.132	0.000	6.02
Jung[10](2011)	Korean	14.640	0.340	0.116	13.973	15.307	43.018	0.000	5.92
Kawakami et al.[19](2019)	Colombian	14.400	0.309	0.096	13.794	15.006	46.581	0.000	5.95
Keceli et al.[20](2017)	Multi-center	14.150	0.351	0.123	13.463	14.837	40.349	0.000	5.91
Khojastehpour et al.[21](2016)	Iranian	16.430	0.718	0.515	15.023	17.837	22.887	0.000	5.39
Nicolielo et al.[66](2014)	Multi-center	19.320	0.318	0.101	18.696	19.944	60.685	0.000	5.94
Shams et al.[28](2020)	Iranian	19.870	0.334	0.112	19.215	20.525	59.461	0.000	5.92
Tehranchi et al.[31](2017)	Iranian	16.700	0.245	0.060	16.220	17.180	68.130	0.000	6.00
Velasco-Torres et al.[67](2016)	Spanish	13.400	0.144	0.021	13.118	13.682	93.030	0.000	6.06
Yu et al.[35](2019)	Taiwanese	17.110	0.976	0.953	15.197	19.023	17.531	0.000	4.92
Karslioglu et al.[69](2021)	Turkish	17.600	0.257	0.066	17.095	18.105	68.350	0.000	5.99
Kang et al.[63](2013)	Korean	17.030	0.304	0.092	16.435	17.625	56.054	0.000	5.95
Godil et al.[17](2021)	Indian	17.410	0.178	0.032	17.062	17.758	98.013	0.000	6.04
Hafezi et al.[18](2021)	Iranian	20.880	0.251	0.063	20.388	21.372	83.188	0.000	6.00
Tassoker[68](2022)	Turkish	17.820	0.195	0.038	17.438	18.202	91.542	0.000	6.03
		16.714	0.493	0.243	15.748	17.680	33.905	0.000	

Author (year)	Study population	Difference in means	Standard error	Variance	Lower limit	Upper limit	z-Value	p-Value	Relative weight
Chitsazi et al.[12](2017)	Iranian	0.280	0.167	0.028	-0.047	0.607	1.679	0.093	47.36
Dursun et al.[13](2019)	Multi-center	0.200-	0.757	0.574	1.684-	1.284	0.264-	0.792	2.30
Ilguy et al.[41](2013)	Turkish	0.210	0.455	0.207	0.682-	1.102	0.461	0.644	6.36
Jung[10](2011)	Korean	1.000	0.705	0.497	0.382-	2.382	1.418	0.156	2.65
Keceli et al.[20](2017)	Multi-center	0.430	0.706	0.498	0.953-	1.813	0.609	0.542	2.65
Khojastehpour et al.[21](2016)	Iranian	2.620	1.457	2.123	0.236-	5.476	1.798	0.072	0.62
Tehranchi et al.[31](2017)	Iranian	1.560	0.481	0.232	0.617	2.503	3.241	0.001	5.68
Karslioglu et al.[69](2021)	Turkish	1.030	0.523	0.274	0.004	2.056	1.968	0.049	4.81
Kang et al.[63](2013)	Korean	0.830	0.623	0.389	0.392-	2.052	1.332	0.183	3.39
Godil et al.[17](2021)	Indian	0.930	0.357	0.128	0.229	1.631	2.602	0.009	10.31
Hafezi et al.[18](2021)	Iranian	0.540	0.505	0.255	0.450-	1.530	1.069	0.285	5.16
Tassoker[68](2022)	Turkish	1.160	0.389	0.151	0.398	1.922	2.986	0.003	8.72
		0.587	0.115	0.013	0.362	0.812	5.113	0.000	

Fig. 5. A. Forest plot depicting the pooled mean distance of the posterior superior alveolar artery (PSAA) from the alveolar crest, with associated 95% confidence intervals (CIs), based on the meta-analyzed studies. B. Forest plot of the mean difference (mean distance in males - mean distance in females) of the distance of the PSAA from the alveolar crest, with corresponding 95% CIs, from the examined studies.

placement. This implies that the risk of artery injury can be minimized if the surgeon positions the osteotomy site as low as possible on the sinus floor. The present review indicated that the mean distance between the sinus floor and the inferior border of the PSAA was 8.85±0.4 mm, indicating that the risk of vessel injury would be low if the window width did not exceed 8 mm. Based on the results of other studies, the bony window should be no more than 15 mm above the alveolar crest.[10,11,42,43,48,63] As a result, depending on the implant length, preparation of the lateral window closer to the alveolar crest should be considered.[62] According to the meta-analysis, the mean distance of the PSAA from the alveolar crest was 16.71±0.49 mm. This suggests that the risk of cutting the artery during the procedure is decreased in most cases, given that a distance of 15 mm is considered safe. Overall, the distance between the alveolar crest and the PSAA significantly decreases when teeth are missing, primarily in fully edentulous patients, although this reduction is not statistically significant in partially edentulous patients.[74] It is widely recognized that follow-

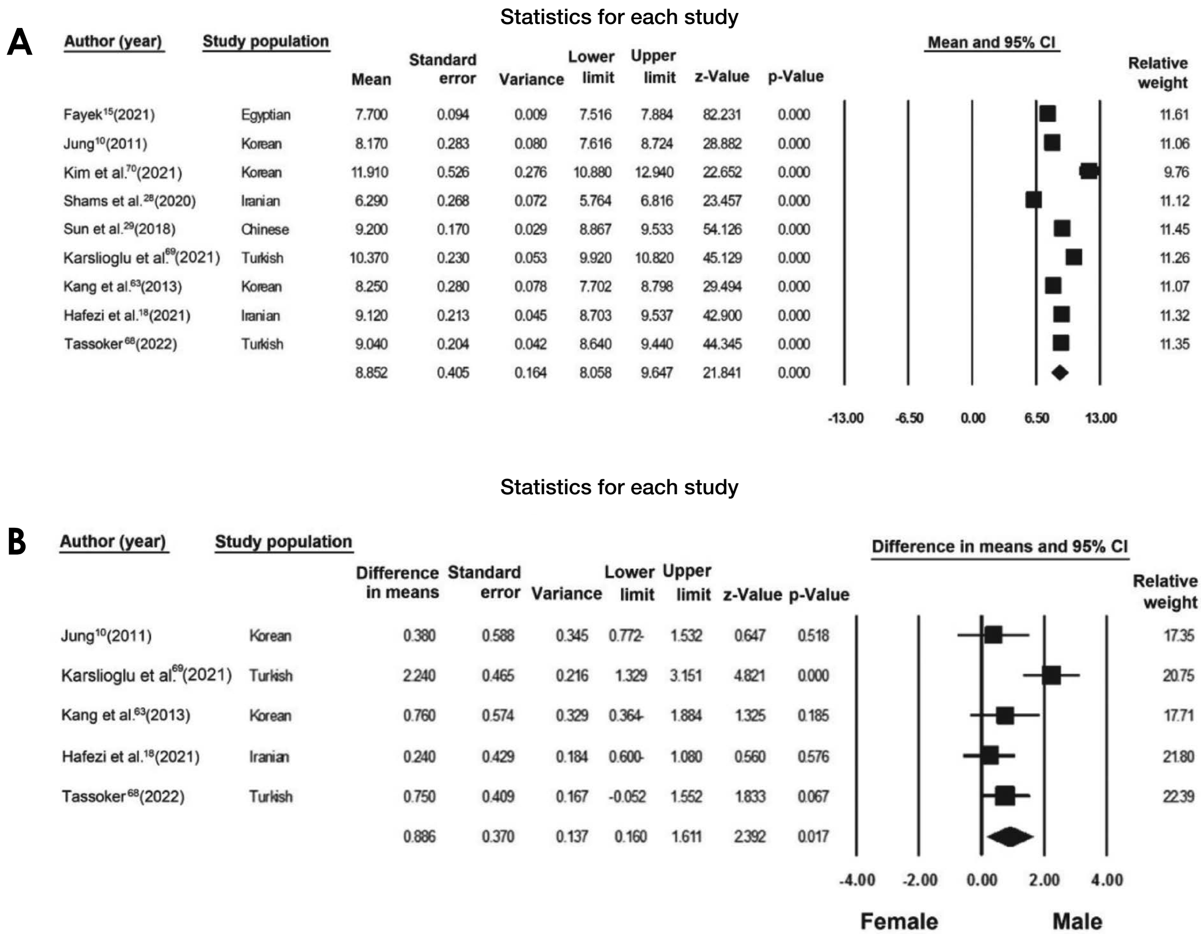


Fig. 6. A. Forest plot depicting the pooled mean distance of the posterior superior alveolar artery (PSAA) from the sinus floor, with associated 95% confidence intervals (CIs), based on the meta-analyzed studies. B. Forest plot of the mean difference (mean distance in males - mean distance in females) of the distance of the PSAA from the sinus floor, with corresponding 95% CIs, from the examined studies.

ing tooth loss, alveolar bone resorption and maxillary sinus pneumatization occur concurrently, leading to maxillary sinus expansion.[74,75] The distance between the sinus floor and the PSAA is expected to increase after tooth extraction, regardless of the time elapsed between the extraction and the measurement. However, this shift in the location of the sinus floor is far smaller than the dimensional change in the alveolar crest. The maxillary sinus volume increases from birth until around 20 years of age, at which point the pneumatization stops, and the maxillary sinus reaches its final position.[76] In studies[10,12-15,17-21,23-25,28,30-33,35,41,62-69] examining the distance from the artery to the alveolar crest, researchers may neglect to distinguish between edentulous and dentulous areas, resulting in imprecise interpretation due to the atrophic alveolar crest. Therefore, measurements are more reliable when evaluating the PSAA location using the sinus floor as a reference point. Furthermore, assessing the PSAA location in relation to the maxillary sinus floor is crucial when preparing the lateral window for a sinus lift, as it can help minimize bleeding complications.

The distance from the PSAA to both the sinus floor and the alveolar crest was found to be greater in male than in female patients. This difference was significant due to the larger craniofacial size in males.[21]

Excessive bleeding from the PSAA during sinus lift surgery can disrupt the clinician's view[61] and prolong the operation time.[66] However, according to the results of this meta-analysis, life-threatening hemorrhage resulting from injury to the superior alveolar arteries is not a genuine clinical concern in surgical procedures involving the maxilla, such as sinus augmentation. Furthermore, preoperative CBCT is essential for preventing complications during surgery. The limited diameter of the injured arteries and reactive vasoconstriction will ultimately minimize blood loss. Moreover, experienced clinicians can easily manage bleeding in patients with normal blood hemostasis. Conversely, severe bleeding may compromise visibility for less experienced surgeons.[6] Given the variability in the anatomical characteristics of the PSAA, relying solely on mean values is insufficient for making clinical decisions. That said, these mean measurements can provide clinicians with a better understanding of the PSAA. Variations in the study populations, CBCT machines, operators, and conditions of edentulism make it challenging to draw a definitive conclusion. The strength of the present study lies in its thorough investigation of PSAA characteristics and assessment of these characteristics based on sex. To reach a precise conclusion, it would be even better to analyze the anatomical characteristics based on the location of each tooth. Some studies[14,23] have examined PSAA characteristics based on tooth location, and further research is needed in this area. Future studies should also clearly state the populations investigated and the methods of measurement used, in accordance with quality assessment practices.

In conclusion, the mean distances of the PSAA from the alveolar crest and sinus floor, coupled with the small diameter of the artery, suggest a low risk of severe hemorrhage during the sinus floor lift procedure. Furthermore, preoperative CBCT is essential to prevent complications during surgery.

Conflicts of Interest: None

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