Radiographic Evaluation of Maxillary Sinus Lateral Wall and Posterior Superior Alveolar Artery Anatomy: A Cone-Beam Computed Tomographic Study

Seyed Amir Danesh-Sani, DDS;* Ali Movahed, DDS;[†] Edgard S. ElChaar, DDS, MS;[‡]
King Chong Chan, DMD, MS, FRCD;[§] Niloufar Amintavakoli, DDS, MSc, FRCD[#]

ABSTRACT

Objective: The purpose of the current study is to assess the thickness of the maxillary sinus lateral wall in dentate and edentulous patients using cone beam computed tomography (CBCT). This study also provides information about the diameter, prevalence, and course of the posterior superior alveolar artery (PSAA), and its relation to the maxillary sinus floor.

Materials and Methods: Four hundred and thirty CBCT scans of the maxillofacial complex (860 maxillary sinuses) were reviewed. Measurements of the lateral wall of the maxillary sinus and PSAA were performed on the CBCT images.

Results: Statistical analysis showed that dental status (edentulous, non-edentulous) of the patients had no significant effect on the lateral wall thickness. The mean thickness of the lateral wall of the maxillary sinus was 1.21 ± 1.07 mm at the second molar (M2), 1.98 ± 1.87 mm at the first molar (M1), 2.02 ± 1.53 mm at the second premolar (P2) and 2.16 ± 1.25 mm at the first premolar (P1). There was statistically significant difference between the left and right sides of the maxillary sinus only at P2 (p =.043). Detection rate of the PSAA on CBCT was reported as 60.58%. The mean diameter of the artery was 1.17 mm (range 0.4–2.8 mm). There was no significant correlation between age and the size of the PSAA. The most frequent path of the PSAA was intraosseous (69.6%), followed by intrasinusal (24.3%) and superficial (6.1%). The overall mean distance of the PSAA from the floor of the maxillary sinus is 8.16 mm.

Conclusions: The results from this study suggest that using CBCT prior to the surgery provides valuable diagnostic information. However, undetected intraosseous canal in CBCT does not exclude its existence. Alteration in the lateral window design and the use of piezoelectric instruments are recommended if intraoperative complications are expected.

KEY WORDS: cone beam computed tomography, maxillary sinus lateral wall thickness, posterior superior alveolar artery, sinus augmentation

INTRODUCTION

Sufficient amount of bone surrounding implants is mandatory for having long-term satisfactory treatment outcome.[1] Compromised alveolar ridge and the maxillary sinus are the main limiting factors that make reconstruction of the posterior maxilla more challenging. [2] Maxillary sinus floor elevation has been regarded as a successful and predictable approach for augmentation of the posterior maxilla and provides clinicians with adequate bone volume for implant placement.[3–5]

Lateral wall and crestal approach are the main techniques for maxillary sinus augmentation. Lateral wall technique was first described by Tatum and subsequently, Boyne and James in 1980.[6,7] This approach

*Department of Periodontology and Implant Dent, New York University College of Dentistry, New York, NY, USA; [†]Avicenna Research Institute, Dental Research Center, Oral Surgery Division, Mashhad University of Medical Sciences, Mashhad, Iran; [‡]Program director of advanced program in periodontology and Implant Dent, Department of Periodontology and Implant Dent, New York University College of Dentistry, New York, NY, USA; [§]Program director, Department of Oral and Maxillofacial Radiology, New York University College of Dentistry, New York, NY, USA; [#]Clinical associate professor, Department of Oral and Maxillofacial Radiology, New York University College of Dentistry, New York, NY, USA

Corresponding Author: Dr. Seyed Amir Danesh-Sani, Department of Periodontology and Implant Dent, 345 E 24th St, 10010, New York University College of Dentistry, New York, USA; e-mail: sds521@nyu.edu

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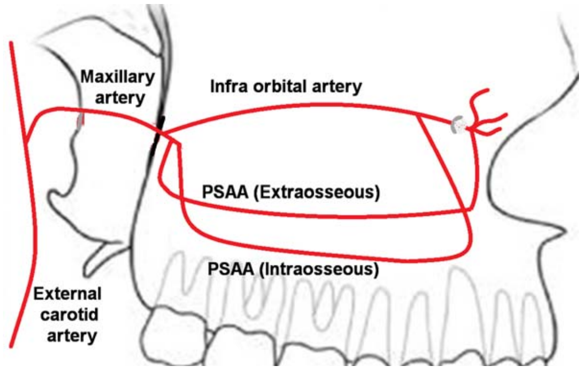

Figure 1 Schematic diagram demonstrating an anastomosis of the PSAA and infraorbital artery at the maxillary sinus lateral wall.

results in more predictable outcome in cases with minimum amount of alveolar ridge height.[8] Although the procedure has been proven to be predictable with high success rate, various complications have been reported during surgery or the postoperative period.[9] Therefore, clinicians should be aware of the complications and their management.

Perforation of the Schneiderian membrane is the most common intraoperative complication during sinus elevation procedure and occurs in 11% to 56% of surgeries.[9,10] Perforation of the membrane may occur while reflecting the membrane or preparing the window to access the sinus cavity. Technical and anatomical factors such as the presence of sinus septum, lateral wall thickness, and the angle between the lateral and medial walls have been implicated in membrane perforation.[11–13]

Understanding the vascular anatomy of the maxillary sinus is also critical to avoid hemorrhage and membrane perforation (Figure 1). Blood vessels with large diameters may impose more serious risk of bleeding during the surgery.[14]

Dental implant site evaluation, oral and maxillofacial trauma, and orthodontics are some of the most frequent indications for cone beam computed tomography (CBCT).[15] Utilizing CBCT prior to treatment planning for maxillary sinus elevation is recommended as a radiographic modality for multiplanar imaging since it provides useful diagnostic information at lower radiation risk compared to multislice computed tomography.[16–20]

Previous studies reported results that were based on small sample size and most of those studies didn't investigate several parameters including the course of the artery and the influence of age, sex, the side of maxillary sinus, and dental status on the position of the artery and the lateral wall thickness.

The purpose of the current study was to assess the thickness of the lateral wall in dentate and edentulous patients using CBCT scans and investigate the influence of the side of maxillary sinus, age and sex on thickness of the lateral wall. It also provides information about the anatomy of the PSAA including the diameter, prevalence, course of the artery and its relation to the maxillary sinus floor.

METHODS AND MATERIALS

In the current study, we reviewed 430 CBCT scans (860 sinuses, 239 men, and 191 women, mean age of 53.45 years ranging from 23 and 86 years), who were referred to the Department of Periodontology and Implant Dentistry for reconstruction of the posterior maxilla with dental implants. Patient's information including age, sex, reasons for tooth loss, smoking status, and medical history was obtained. This study was approved by the Ethics Committee of the Dental School. The principles of the Declaration of Helsinki were followed in this study.

Prior to CBCT, patient's position were adjusted using Frankfort-Horizontal plane and the office floor as reference points. The CBCT scans were obtained using a Promax 3D® CBCT (Planmeca, Helsinki, Finland) at voxel size of 160 μm. The imaging parameters were set at 90 kVp, 14.55 mAs for 15.5 seconds.

CBCT scans of the patients were saved in DICOM format. The axial, sagittal, and coronal images were reformatted using SimPlant software (SimPlant 3-D Pro; Materialize, Leuven, Belgium). Appropriate background lighting and a color LCD computer screen were used for the processing of the scans.

CBCT images were obtained with a slice thickness of 0.1 mm. The measurements were made to the nearest 0.01 mm with a caliper. All measurements were performed by two trained examiners.

Exclusion criteria were the presence of sinus pathology, jaw fracture, grafted sinuses, dental implants and non-diagnostic CBCT scans.

Image Analysis

On the selected coronal images, thickness of the lateral wall at a distance of 5 mm from the maxillary sinus floor was measured by the digital caliper.

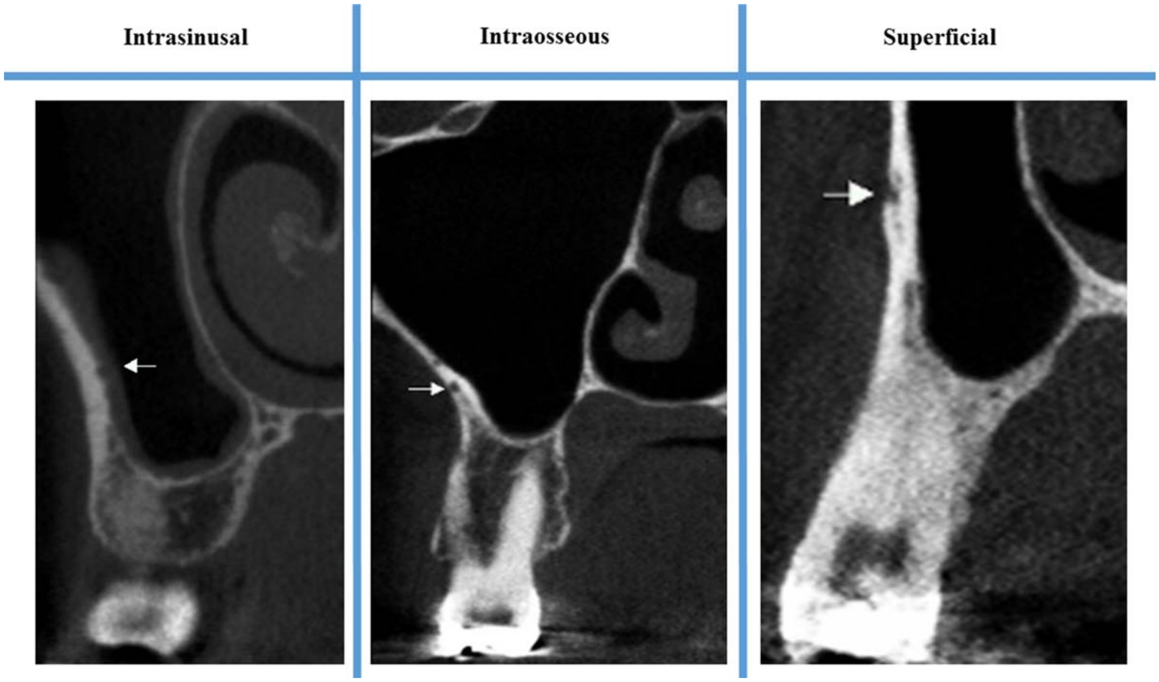

Figure 2 Transverse view of the CBCT scan of a sinus showing PSAA below the Schneiderian membrane (intrasinusal), inside the bone (intraosseous), and on the outer cortex of the lateral sinus wall (superficial).

Measurements of the lateral wall thickness were performed at four different sites including the first premolar (P1), second premolar (P2), first molar (M1) and second molar (M2).

The vessel diameter was measured on the coronal sections at locations corresponding to the crowns of M2, M1, P2, and P1. In edentulous patients, different locations identified by the help of radiographic template. Vessel diameter was categorized into three groups: (1) $<$ 1 mm, (2) 1-2 mm, and (3) $>$2 mm.[21]

The diameter and location of the vessel from the sinus floor was evaluated from the anterior to the posterior of the maxillary sinus in each of following locations: P1, P2, M1, and M2. The vessel position was classified as superficial (on the outer cortex of the lateral sinus wall), intraosseous (inside the lateral wall), and intrasinusal (below the membrane) (Figure 2).

In order to assess the reliability of our measurement method, diameter of the vessel and thickness of the lateral wall were measured on 10% of the total number of cases. Four weeks later, the measurements on these scans were repeated showing good intra-observer agreement.

Statistical Analysis

The mean and standard deviations were calculated. Intraclass correlation coefficient was used to calculate interobserver and intraobserver agreement. Differences in the means of the lateral wall thickness between the left and the right side, were tested by means of Paired *t*-test. Pearson's correlation test as implemented in statistics software (SPSS Inc., Chicago, IL, USA) was used to test differences in the variable measurement values according to the age. Unpaired t test was used to evaluate the differences between male and females.

The proportion of cases where the PSAA was identified was calculated as a total. The mean values, range, median values, and standard deviation of the PSAA measurements were calculated and categorized by tooth position. To compare the measured values for differences in gender and dental status, the multivariate ANOVA was used. Spearman's rho correlation coefficient was calculated to check for the correlation between the diameter of the artery and the age of the patients. Paired *t*-test was used to compare the means of the diameter of the canal between the left and the right side. A *p* value of.05 was set for significance level.

RESULTS

The area with the thickest bone was P1 followed by P2, M1 and M2. The mean thickness of the lateral

TABLE 1 The Lateral Bone Thickness of Maxillary Sinus in Different Tooth Site (mm)

Area	Sinuses (*n*)	Mean ± SD
P1	718	2.16 ± 1.25
P2	776	2.02 ± 1.53
M1	860	1.98 ± 1.87
M2	860	1.21 ± 1.07

wall of the maxillary sinus was 1.21± 1.07 mm at M2, 1.98 ± 1.87 mm at M1, 2.02 ± 1.53 mm at P2, and 2.16 ± 1.25 mm at P1 (Table 1). The only statistically significant difference between the left and right sides of the maxillary sinuses was at P2 (Table 2).

When comparing thickness of the lateral wall between men and women, women tended to have a thinner lateral wall than men at P1, P2 and M2 (Table 3). There was no statistically significant difference between men and women at M1.

Dental status (edentulous, non-edentulous) and age of the subjects had no statistically significant effect on the lateral wall thickness (Table 3).

Detection rate of the PSAA on CBCT was reported as 60.58%. The mean diameter of the artery was 1.17 mm (range 0.4–2.8 mm). The vessel diameter was significantly smaller in females in comparison to males in all the areas ($p = .034$).

Vessel diameters less than 1 mm, 1-2 mm and more than 2 mm were observed in 37.8%, 55.8%, and 6.4% of the cases, respectively.

Mean diameter of the artery was recorded as 1.19 ± 0.6 and 1.15 ± 0.6 for the right and the left sides, respectively ($p > .05$). There was no correlation between the size of the PSAA and subject age ($p = .068$).

When evaluating the course of the artery, the most frequent path of the artery was intraosseous (69.6%), followed by intrasinusal (24.3%) and superficial (6.1%).

The overall mean distance of the PSAA from the maxillary sinus floor was 8.16 mm, with the lowest distance being 0.43 mm from sinus floor. Distance of the PSAA to the sinus floor in different locations are presented in Table 4. When comparing men and women or right and left sinuses, no statistically significant differences for the distance of the artery to the floor of the sinus were noticed ($p = 0.44$ for the right side and $p = .21$ for the left side).

The statistical analysis revealed good interobserver and intraobserver reliability (0.64 and 0.57, respectively)

DISCUSSION

Maxillary sinus floor elevation via lateral window presents complexity, often due to fragile structures and anatomical variations related to the sinus. Perforation of the Schneiderian membrane is the most common intraoperative complication during sinus elevation procedure. The presence of a thin or thick lateral wall increases the risk of the membrane perforation.[9,22] Zijderveld et al. reported the prevalence of a thin lateral maxillary sinus wall in 78% of cases.[9] It is important to evaluate thickness of the lateral wall prior to surgical treatment since it may influence the integrity of the sinus membrane during the procedure.

The infracture and wall-off techniques are two approaches to prepare the lateral window osteotomy.[23,24] The infracture technique includes tapping of the lateral wall over the graft materials as a roof, while in wall-off technique the lateral wall should be removed to get an access to the sinus. In both techniques, it is recommended to place the inferior border of the window 3–5 mm from the sinus floor.[23,25] In the present study, the measurement point of the lateral wall, 5 mm from the sinus floor, was determined by the data from previous studies that discussed the distance of the inferior border of the window to the sinus floor.[23,25–27]

Based on cadaveric studies, the three branches of the maxillary artery that provide the blood supply of the Schneiderian membrane, the maxillary sinus

TABLE 2 Comparison of the Lateral Wall Thickness of Both Sides of Maxillary Sinus (mm)

Area	Side	Number	Mean ± SD	*p* value
P1	Right	359	2.21 ± 1.57	.098
	Left	359	1.11 ± 1.24	
P2	Right	388	2.32 ± 1.35	.043
	Left	388	1.91 ± 0.88	
M1	Right	430	2.03 ± 1.76	.265
	Left	430	1.95 ± 1.29	
M2	Right	430	1.26 ± 1.55	.132
	Left	430	1.19 ± 0.65	

TABLE 3 Analysis for Differences in Means of Variable Measurement Values by Gender and Dental Status

Area	Sex	Mean ± SD	*p*	Dental status	Mean ± SD	*P*
P1	Female	2.05 ± 1.09	.037	Edentulous space	2.13 ± 1.11	.129
	Male	2.27 ± 1.21		Dentate	2.19 ± 1.53	
P2	Female	1.91 ± 098	.041	Edentulous space	1.99 ± 1.11	.143
	Male	2.15 ± 0.87		Dentate	2.04 ± 1.53	
M1	Female	1.88 ± 1.45	.163	Edentulous space	1.96 ± 1.42	.252
	Male	2.11 ± 1.23		Dentate	1.99 ± 1.55	
M2	Female	1.16 ± 1.78	.027	Edentulous space	1.25 ± 0.78	.319
	Male	1.39 ± 1.21		Dentate	1.29 ± 0.49	

lateral wall and the overlying periosteum are PSAA, the infraorbital artery, and the greater palatine artery.[28–30]

The PSAA divides to give an endosseous branch, which travels through the lateral wall, and an extraosseous branch, which supplies the periosteum and the buccal vestibule.[31] The infraorbital artery gives off one or two branches at the anterior part of the maxillary sinus; one of these branches make an anastomosis with the intraosseous branch of PSAA (Figure. 1).[28] All the cadaveric studies have shown this anastomosis between the PSAA and infraorbital artery.[28–30]

Accidental severing of this anastomosis is considered the second most common intraoperative complication that may complicate the procedure by causing hemorrhage that obscure the surgical field.[9,32] Consequently, perforation or incomplete reflection of the membrane may result.[33]

In addition to the maxillary sinus floor elevation procedure, evaluation of the lateral wall thickness and PSAA is critical in presurgical treatment planning for many other surgical interventions such as fixation of the facial and jaw bone, Lefort I osteotomy, miniscrew placement in orthodontics, and Caldwell-Luc surgery.[34,35] However, in spite of this significant fact, few studies have assessed the maxillary sinus lateral wall thickness and the PSAA, and their potential correlations with various parameters, such as patient age, sex and dentition status. The current study evaluates the thickness of the lateral wall in dentate and edentulous patients using CBCT. It also investigates the prevalence, diameter, and position of the PSAA and its relation to the maxillary sinus floor. To the best of our knowledge, the present study has the largest study sample to date.

TABLE 4 Distance of the Posterior Superior Alveolar Artery to the Sinus Floor (mm)

Location	Range Min–Max	Mean
First Premolar	0.69–33.09	8.57
Second Premolar	0.87–32.86	8.45
First Molar	0.43–30.90	8.09
Second Molar	0.59–31.24	9.27

Based on our findings, the bone above the P1 area has the thickest wall and the least thickness of the lateral wall was documented in the M2 area. Therefore, caution should be taken when preparing the lateral window or harvesting the bone in the maxillary molar region. Similar results were also obtained by Kang et al. in CBCT scans of patients of Korean ethnicity.[36] They reported that the more anterior the region, the thicker lateral wall. However, Yang et al. showed that lateral wall thickness decreases from the M2 to the P1 region.[2] The difference in the thickness of the lateral wall in different areas may be related to the position of the adjacent structures such as the buttress of the zygoma, maxillary tuberosity, and the canine eminence.[14,37] Therefore, clinicians should consider these anatomic landmarks during the surgery.

It is also noteworthy to mention that the thickness of the lateral wall may be affected by chronic inflammatory conditions of the maxillary sinus such as chronic rhinosinusitis.[38] Further studies should be done to investigate the relation between the bony changes in the maxillary sinus and inflammation. In addition, anatomic landmarks used to measure lateral wall thickness, instruments utilized to record the data, and study population might be reasons of disparity among different studies.[14,36,37]

Results from this study showed that the mean thickness of the lateral wall was higher in patients with teeth in all the measured areas; however the difference between the dentate and edentulous cases was not statistically significant. These findings are in agreement with Khajehahmadi et al. study, which showed no significant difference between dentate and edentulous cases, but a trend of thicker lateral wall for dentate patients.[39] Monje et al. examined the effect of the edentulous span on the thickness of the wall and found that the longer the edentulous span, the thinner the lateral wall.[37]

According to the literature, only few studies have assessed the effect of age and sex on the lateral wall thickness.[2,37] The current study demonstrated a significant difference in the mean lateral wall thickness between males and females at the P1, P2, and M2 locations. We noticed thicker lateral wall in men in comparison to women. Previous works showed significant gender differences only in the premolar region.[2,37] Regarding the lateral wall thickness, Kang et al. showed a significant difference between males and females at a site that was 3 mm from the sinus floor.[36]

With respect to aging, it is speculated that continued pneumatization of the maxilla with age can lead to a thin layer of cortical bone.[40] Consequently, older patients would have thinner lateral sinus walls. However, in the current study, the thickness did not vary with age ($p > .05$). Our findings are in agreement with data reported from previous studies, which showed that pneumatization of the sinus lateral wall does not increase with age.[2,36,37,41]

In the present study, detection rate of the artery on CBCT was reported as 60.58% which is in agreement with previous works.[36,42,43] It is noteworthy to mention that the detection rate of the PSAA is 100% in cadaveric studies, but highly variable in radiographic evaluations (10.5% to 93.9%).[28,34,44] Therefore, undetected intraosseous branch of the PSAA on CBCT does not exclude its existence.

In the current study, the detection rate of the PSAA exceeds the rate reported by Ella et al. (10.5%), Yang and Kye (32.5%), Rosano et al. (47%), Rysz et al. (50%), Jung et al. (52.8%), and Elian et al. (52.9%).[34,45–49] In comparison to our study, significantly higher detection rates of the PSAA were reported by Anamali et al. (93.9%), Ilgüy et al. (89.3%), and Apostolakis and Bissoon et al. (82%).[14,44,50] Of the published studies to date, Watanabe et al. (58.6%), Kang et al. (64.3%), and Güncü et al. (64.5%) have the closest detection rate to our study.[36,42,43] Explanations for this discrepancy among the various studies relate to several factors. First, it is related to the experience of the clinicians in reviewing CBCT data.[37] Second, previous studies with low detection rates all evaluated printed, film-based images. CBCT prints may compromise identification of the PSAA since the prints do not allow the use of software tools such as magnification and windowing.[14,21] Third, technical factors of image acquisition such as resolution/voxel size of the radiographic system, noise, contrast, resolution, and artifacts significantly affect image quality, which affects the identification of the PSAA.[14,36,43] Low resolution CBCT units are unable to display small blood vessels, which may contribute to the decreased detection rate in previous studies.[14] Finally, CBCT scans with small field of view will affect the identification of the PSAA artery, as only a limited part of the maxillary sinus is captured.[14,30,36]

Mean diameter of the PSAA was recorded as 1.17 mm, with 93.6% of the vessels with a diameter of equal or less than 2 mm and only 6.4% of the vessels with a diameter of more than 2 mm. These findings are in agreement with the studies of Apostolakis and Bissoon, Rosano et al., and Mardinger et al. where 4%, 6.7%, and 4.3% of the arteries have a diameter of more than 2 mm, respectively.[14,21,46]

Comparing our results to the cadaveric studies of Ella et al., Solar et al., and Hur et al., they reported mean diameter of the artery as 1.2 mm, 1.59 mm, and 0.8 mm, respectively.[28,34,44] It has stated that most of serious bleeding complications occur when the diameter of the artery is more than 2 mm.[14] Based on our results, presence of an artery with large diameter (>2 mm) is not common since it was noticed only in 55 out of 860 sinuses (6.4%).

When evaluating the course of the artery in relation to the lateral wall, we found an intraosseous course in 64.3%, intrasinusal in 29.1%, and superficial in 6.6% of the patients. Our findings on the course of the PSAA are similar to those obtained by previous studies listed in Table 5.

Alveolar ridge level is expected to change after tooth extraction and these changes mainly depends on the anatomy of the socket and quality of the bone.[14,51] Maxillary sinus floor is also repositioned

TABLE 5 Course of the Artery in Relation to the Maxillary Sinus Lateral Wall

Study	*n* Sinuses	Intraosseous (%)	Intrasinusal (%)	Superficial (%)
Güncü et al.	242	68.2	26	5.7
Ella et al.	132	71.4	14.3	Not reported
Ilgüy et al.	135	71.1	13	5.2
Kang et al.	150	64.3	29.1	6.6

after tooth extraction which may be attributed to remodeling of the remaining bone between the root apex and the sinus floor.[14,40,51] It is noteworthy to mention that the maxillary sinus reaches its final position, 5 mm inferior to the nasal floor, by the age of 20.[14,52] We believe protruded roots of teeth result in thin cortical plate at the apex and eventually more resorption of the apical part of the extraction socket. Therefore, increasing volume of the sinus may represent a response to the trauma from the extraction, not additional pneumatization of the maxilla. However, we expected that alteration of the alveolar ridge to be far greater than changes in the maxillary sinus floor. Therefore, the measurements will be more reliable when the sinus floor is used as a reference point. From the clinical point of view, clinicians use the sinus floor as reference point to design borders of the lateral window osteotomy.[23] All the studies, except one,[14] used the alveolar ridge and floor of the sinus as reference points.

The mean distance of the PSAA from the sinus floor was 8.57 mm, 8.45 mm, 8.09 mm and 9.27 mm for the P1, P2, M1, and M2 regions, respectively. The distance of the artery decreased as it advances towards the first molar area and increased at the premolar area. This can be explained by (a) the anatomy of the sinus where the sinus floor gets higher at the anterior part and (b) the course of artery as it moves up toward the infraorbital artery.

Regarding the distance of the artery to the floor of the sinus, our study can be compared to the studies listed in Table 6, where the authors examined the distance of the PSAA to the maxillary sinus floor in different locations. The discrepancy between our results and previous studies may be due to the large variation in the measurements of the artery in different cases, subject ethnicity (Caucasian, Korean, etc.) and the greater number of cases evaluated in our study.[14,43]

From our results, the distance of the PSAA to the maxillary sinus floor varied significantly among individuals around the mean values in different positions (Table 4). This suggests that with such a high variation on the location of the PSAA, the mean value has no practical clinical significance. Apostolakis and Bissoon have also reported a large variation on the location of the PSAA, which is in support of our study.[14] Therefore, comprehensive assessment of each case is required prior to surgery.

Concerning the diameter of the artery, we did not find a significant relationship between the diameter of the PSAA and patient age. However, Mardinger et al. showed larger vessels in older patients in comparison to younger ones.[21] We observed significantly larger vessels in males compared to females, which is in agreement with the studies of Mardinger et al., Kang et al., and Guncu et al.[21,36,43] This was not the case in Apostolakis and Bissoon study, where no

TABLE 6 List of the Previous Studies that Measure the Distance of the Artery from the Sinus Floor (mm)

Author	Year	First Premolar	Second Premolar	First Molar	Second Molar	Mean
Yange and Kye	2014	6.67	8.19	7.59	7.80	7.75
Watanabe et al.	2014	10.40	10.40	9	8.50	9.57
Apostolakis and Bissoon	2014	5.90	5.80	5.90	8	6.47
Jung et al.	2011	9.20	8.07	7.58	9.02	8.17
Hur et al.	2009	9.40	9.70	10.30	9.60	9.70

statistically significant difference between men and women was observed.[14]

In conclusion, the results from our study suggest some factors to consider in order to minimize potential complications related to maxillary sinus floor augmentation:

1. Due to high variation on the location of the PSAA, it is not recommended to rely on the mean values and case by case evaluation is required prior to the surgery.
2. When preparing the bony window with rotary instruments, it is highly recommended to use piezoelectric instruments, rather than rotary burs, that can selectively cut bone without further injury to soft tissue.
3. CBCT provides valuable diagnostic information for better evaluation of the sinus and related anatomic landmarks. It is recommended to use CBCT prior to surgery, in order to minimize the risk of membrane perforation and bleeding complications.

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