Palatonasal Recess on Medial Wall of the Maxillary Sinus and Clinical Implications for Sinus Augmentation via Lateral Window Approach

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Background: Anatomic variations of the maxillary sinus determine the degree of difficulty in performing sinus augmentation. Whereas some variations, e.g., the septum and morphology of the sinus, have been extensively studied, the structure of the medial wall has never been investigated. The aims of this study are to measure the location and angulation of the palatonasal recess (PNR) on the medial wall and identify risk sites that are related to the shape of the PNR.

Methods: Cone-beam computed tomography (CBCT) scans were screened from the University of Michigan School of Dentistry database. Edentulous sites with <10 mm between the floor of the maxillary sinus and the alveolar crest were selected. The residual ridge height (RH), the distance between the PNR and the alveolar crest, and the angulation of the PNR were measured on the selected sagittal planes. The percentage of sites (risk sites) with recesses that were <90°and <15 mm from the alveolar crest was calculated. The PNR location and angulation were compared among premolar and molar edentulous sites.

Results: Two hundred seventy-four sites were studied. The mean ± SE PNR location was 14.2 ± 2.8 mm, 13.1 ± 2.2 mm, and 12.5 ± 2.5 mm for the second premolar, first molar, and second molar sites, respectively, with significant differences between the second premolar and second molar sites. The mean PNR angulation was 109.8° ± 25.3°, 121.6° ± 22.1°, and 144.9° ± 23.1° in the corresponding sites, with significant differences among the site groups. The respective percentages of risk sites were 15%, 8.2%, and 2.4% in the second premolar, first molar, and second molar sites.

Conclusions: Maxillary sinuses with acute-angled PNRs might present a challenge for performing sinus augmentation. Therefore, this anatomic structure should be carefully evaluated. *J Periodontol 2013;84:1087-1093.*

KEY WORDS

Alveolar ridge augmentation; dental implants; maxillary sinus/surgery; paranasal sinus diseases/complications; oral surgical procedures, preprosthetic.

Restoration of the posterior edentulous maxilla by dental implants often presents a challenge because of inadequate quality and quantity of alveolar bone. After the tooth is lost, both the alveolar bone and the floor of the maxillary sinus increase the remodeling process, resulting in alveolar bone resorption and sinus pneumatization. Several treatment strategies have been developed to overcome anatomic deficiencies; among them is the sinus augmentation via the lateral window (SALW) approach. Described by Boyne and James[1] and Tatum Jr.,[2] SALW aims to increase the vertical bone height by elevating the sinus floor. According to the original descriptions, an osteotomy was made on the maxillary lateral wall, followed by elevation of the Schneiderian membrane and implantation of bone grafts in the space that was created.[1,2] The original technique has been subsequently modified by using different instruments, such as the piezoelectric machine,[3] the balloon,[4] and the biologic agent.[5] SALW has been proven to be predictable in terms of amount of bone gain and survival of implants placed in grafted sinuses.[6,7]

One of the prerequisites for a successful SALW procedure is prudent management of the Schneiderian membrane. Perforation of the membrane

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requires extra time and effort to repair during the surgery, or it can result in the termination of the procedure. Membrane perforation has been linked to higher postoperative complications[8] and implant failures.[9] It is recommended that the membrane should be elevated to the medial wall of the maxillary sinus[1,2] for the following reasons: 1) lifting the membrane to the medial wall reduces membrane tension, which is related to the occurrence of perforations; 2) a space between the elevated membrane and the medial wall (which might compromise implant placement) can be avoided; and 3) additional blood supply can be obtained from the medial wall. The sinus membrane is vascularized by branches of the posterior superior alveolar artery (PSAA) and infra-orbital artery from the lateral wall of the sinus.[10] The posterior lateral nasal artery, which originates from the medial wall, adds more blood supply to the bone grafts.[11,12]

In light of the importance of sinus membrane management for sinus augmentation, research on sinus anatomy has emerged and received profound attention from implant surgeons.[13] The distance between the branches of the PSAA and the alveolar ridge was measured from cadavers[10] and cone-beam computed tomography (CBCT) scans.[14,15] This artery may be encountered if it is proximate to the osteotomy site on the lateral wall, thus increasing the risk of massive hemorrhage. Sinus septa have been extensively studied with regard to their location, size, and orientation.[14,16,17] The presence of a septum is associated with a higher incidence of sinus perforation. The shape of the sinus in the cross-sectional view might also be related to the occurrence of membrane perforation.[18] A study[19] has shown that a sharp angulation between the medial and lateral wall is associated with more perforations.

The above knowledge greatly enhances our understanding of the sinus anatomy and its variations, which can help surgeons to reduce surgical complications. The anatomy of the medial wall has never been investigated. On CBCT scans, a recess (the palatonasal recess [PNR]) between the roof of the hard palate and the lateral wall of the nasal cavity is a common finding (Fig. 1). The location and angulation of such a recess will determine the degree of difficulty in elevating the membrane on the medial wall. Therefore, the aim of this study is: 1) to evaluate the location and angulation of the PNR on CBCT scans; and 2) to identify challenging cases for performing sinus elevation according to the features of the PNR.

MATERIALS AND METHODS

This study was approved by the Institutional Review Boards of the University of Michigan (HUM00049915) and was conducted from February 1 to April 30, 2012.

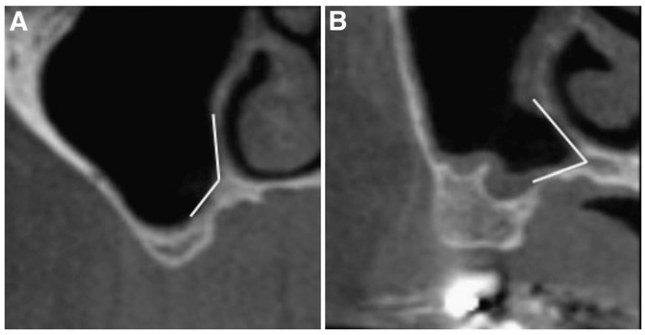

Figure 1.
Demonstration of PNRs with an obtuse angle ***(A)*** *and an acute angle* ***(B)*** *on the medial wall of the maxillary sinus on CBCT scans.*

Image Acquisition

The scans used in the present study were selected from the CBCT database and were not specifically acquired for this project. All images were obtained with a CBCT machine‡ in the Department of Periodontics and Oral Medicine, University of Michigan School of Dentistry, by board-certified oral and maxillofacial radiologists (EB and Sharon Brook) between 2005 and 2012. The imaging parameters were set at 120 kVp, 18.66 mAs, scan time 20 seconds, resolution 0.4 mm, and a field of view that varied based on the scanned region. The CBCT scans of each individual were transferred to a desktop computer equipped with an implant-planning software program.§ Data were saved in the Digital Imaging and Communications in Medicine format.

Inclusion Criteria

Image screening was performed by one examiner (H-LC) using the following inclusion criteria: 1) presence of an edentulous ridge in vicinity of the maxillary sinus as a result of a missing single tooth or multiple teeth; 2) residual ridge height (RH) <10 mm; 3) presence of adjacent or opposing teeth to the edentulous span so that the location of the edentulous ridges corresponding to the tooth site could be identified; and 4) visibility of the maxillary sinus to be measured from its floor to ≥15 mm from the alveolar crest of the edentulous ridge.

Images were excluded if: 1) they were unclear or incomplete because of scattering or other reasons; 2) edentulous ridge height was >10 mm; 3) location of the edentulous ridge could not be determined; 4) sinus pathology was present that made the measurement impossible; 5) the outline of the

‡ i-CAT, Imaging Sciences International, Hatfield, PA.
§ InvivoDent, Anatomage, San Jose, CA.

edentulous ridge could not be identified, e.g., extraction sockets; or 6) the sinus had received grafts or implants.

When both sinuses were eligible for the study, one sinus was randomly selected by flipping a coin. Qualified scans were reoriented so that the maxilla was bilaterally symmetric and the hard palate was parallel to the ground. The reference arch (80 mm wide) was drawn at the level of the alveolar crest at the cross-sectional view, with its center set at the center of the ridge. The sagittal section that included the middle part of each missing tooth was selected. On the selected sagittal section, measurements were made by a built-in digital caliper in millimeters, including RH and location and angulation of the PNR. The PNR was defined as the intersection point of the two imaginary lines following the lower part of the lateral nasal wall and the palatal wall in the maxillary sinus (Fig. 1). The location of the PNR was measured from the alveolar crest in millimeters, and the angulation was measured in degrees. Two calibrated examiners (FS and AM) performed the measurements. Interexaminer and intra-examiner agreements were calculated to be 0.87 and 0.83, respectively, with the κ test by comparing the measurements in three randomly selected cases at two time points 3 days apart.

Statistical Analyses

The data, including the location and angulation of the PNR, were stratified by site and RH. Sites were grouped into first premolars (#5 and #12), second premolars (#4 and #13), first molars (#3 and #14), and second molars (#2 and #15). RHs were classified as severely deficient (SvD), moderately deficient (MdD), or slightly deficient (SlD) at <4 mm, ≥4 mm to <7 mm, and ≥7 mm to <10 mm, respectively. The location and angulation of the PNR were compared among sites in the same RH group and among RH groups of the same sites with the one-way analysis of variance test. Post hoc examination was performed using the Dunnett test. The significance level was set at 0.05. To identify the risk group that might have a higher perforation rate due to the features of the PNR, a two-by-two table was made for each site, using the PNR location at 15 mm and angulation of 90° as cutoff points. The 15-mm level was chosen because that level is usually considered the upper limit for the membrane elevation;[20] the 90° level was chosen arbitrarily. The risk group is defined when the PNR location is <15 mm and the angulation is <90°. The prevalence of risk groups for each site was calculated as a percentage. Statistical analyses were conducted with commercially available software.‖

RESULTS

A total of 225 individuals (99 males and 126 females; average age: 49.2 years; range: 38 to 74 years) fulfilled the inclusion criteria. Of those included, 181, 39, four, and one had one, two, three, and four missing teeth in the posterior maxilla, respectively. A total of 274 sites were evaluated, consisting of three first premolars, 40 second premolars, 147 first molars, and 84 second molars. Because of the small sample size in the first premolar sites, those data were excluded from further analyses.

The location of the PNR in relation to the alveolar crest is presented in Table 1. In the pooled data (regardless of the RH), there was a trend that the mean PNR location was gradually lower from the premolar to the molar sites. The mean PNR locations were 14.2 ± 2.8 mm, 13.1 ± 2.2 mm, and 12.5 ± 2.5 mm for the second premolar, first molar, and second molar sites (Fig. 2). Significant differences in the PNR location were found between the second premolar and second molar sites in the SlD group (15.2 ± 1.8 mm and 13.2 ± 2.0 mm) and the pooled group (14.2 ± 2.8 mm and 12.5 ± 2.5 mm). The PNR location was statistically higher in the first molar sites of the SlD group (14.1 ± 2.1 mm) than those of the MdD (12.6 ± 1.8 mm) and SvD (12.2 ± 2.4 mm) groups (Table 1).

The mean PNR angulations from the pooled data were 109.8° ± 25.3°, 121.6° ± 22.1°, and 144.9° ± 23.1°, respectively, for the second premolar, first molar, and second molar sites (Fig. 3). The mean PNR angulation was significantly different among the three sites. When the data were stratified by RH, the PNR angulation was significantly wider in the second molar sites than in the second premolar and first molar sites (Table 2).

The two-by-two table (Table 3) showed that in the second premolar sites, the proportion of risk cases was higher (15%) than in the first molar sites (8.2%). The second molar sites had the smallest proportion of risk cases (2.4%).

DISCUSSION

Leonardo da Vinci (1452-1519) illustrated the presence of the sinuses in the maxillary bones. He said of the sinuses, "I wish to elevate that part of the bone, the support of the cheek,... to demonstrate through the exposed opening the size and depth of the two cavities which are hidden behind it. The eye, the instrument of vision, is hidden in the cavity above, and in that below is the humor which nourishes the roots of the teeth."[21] This pyramid-shaped hollow structure is located in the

‖ SPSS v.19, IBM, Chicago, IL.

Table 1.

Location of PNR by RH and Site

RH and Site	n	Mean ± SD
SvD		
Second premolar	9	14.2 ± 3.2
First molar	30	12.2 ± 2.4*
Second molar	12	12.2 ± 1.9
Subtotal	51	12.5 ± 2.5
MdD		
Second premolar	11	13 ± 3.6
First molar	67	12.6 ± 1.8†
Second molar	36	12.2 ± 3
Subtotal	115	12.5 ± 2.4
SlD		
Second premolar	20	15.2 ± 1.8‡
First molar	50	14.1 ± 2.1*†
Second molar	36	13.2 ± 2‡
Subtotal	108	14.1 ± 2.2
Total		
Second premolar	40	14.2 ± 2.8§
First molar	147	13.1 ± 2.2
Second molar	84	12.5 ± 2.5§

Matching symbols denote significant difference (P <0.05) between groups.

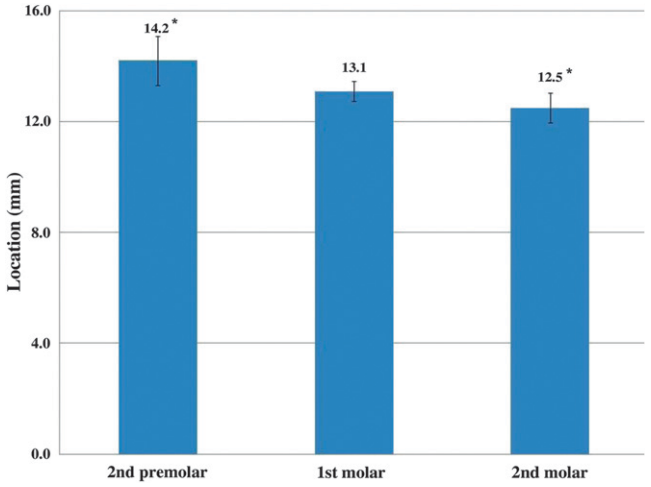

Figure 2.
Bar chart showing the location of the PNRs for the second premolar, first molar, and second molar sites. The mean location in the second molar sites was significantly closer to the alveolar crest (12.5 mm) than in the second premolar sites (14.2 mm). * P <0.05.

body of the maxilla, with its base at the lateral wall of the nose and apex at the zygomatic process. Although in most instances confined to the maxillary bone, it may expand into the palatine and zygomatic bones in older age.[21] With the popularity of implant therapy and sinus augmentation, knowledge on the anatomy of the maxillary sinus has

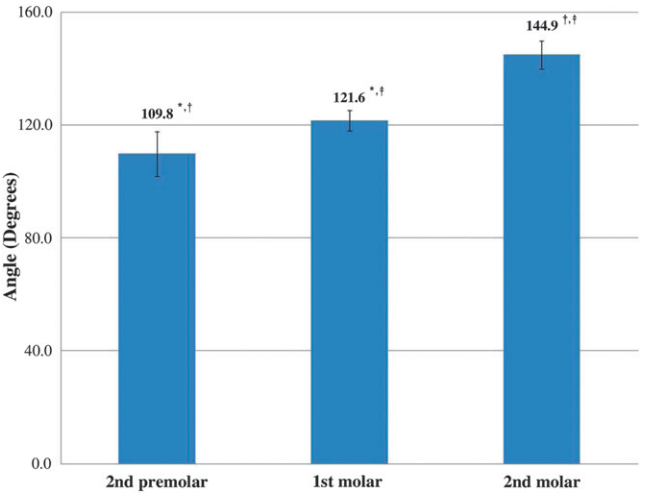

Figure 3.
Bar chart showing the angulation of the PNRs (mean ± 2SE, degrees). The mean angulations were 109.8° ± 25.3°, 121.6° ± 22.1°, and 144.9° ± 23.1°, respectively, for the second premolar, first molar, and second molar sites. *†‡ *Significant differences (P <0.05) among the three sites.*

expanded tremendously. However, this study is the first to systematically evaluate the PNR in the maxillary sinus.

The PNR was studied in 274 edentulous sites via CBCT scans. CBCT scans provide accurate three-dimensional reconstructed images for diagnosing and treatment planning of implant surgeries.[22] The results of this study showed that the location of the PNR is closer to the crestal ridge at the molar sites than at the premolar sites. Therefore, it will be more commonly encountered at the molar sites during the SALW approach. On the other hand, its angulation is more obtuse in the molar sites, rendering an easier bypass in these regions. Taking both the location and angulation into consideration, an acute-angled PNR, which makes membrane elevation more difficult, might be present in 15% of premolar sites that are scheduled for sinus augmentation. On the contrary, only ≈2% of molar sites might have such an acute-angled PNR within the working field of an SALW procedure. Because the membrane is more difficult to elevate at acute-angled recesses, the amount of sinus augmentation might be limited. Additionally, the tension in the membrane might increase the incidence of perforation. The perforation may not necessarily occur at the recess but at the weakest point in the membrane. Based on the results of this study, performing sinus membrane elevation on the medial wall would be more prudent in premolar sites.

Sinus membrane perforation is the most common complication of SALW.[6] The presence of a sinus septum is the most probable cause for this

Table 2.

Angulation of the Palatonasal Recess by RH and Site

RH and Site	n	Mean ± SD
SvD		
Second premolar	9	108.5 ± 26.1*
First molar	30	115.2 ± 19.7†
Second molar	12	149.1 ± 19.6*†
Subtotal	51	122.1 ± 25.7
MdD		
Second premolar	11	115.7 ± 21.4‡
First molar	67	122.5 ± 24.6§
Second molar	36	144.1 ± 26.7‡§
Subtotal	115	128.6 ± 27.8
SlD		
Second premolar	20	107.2 ± 27.5‖
First molar	50	124.1 ± 19.8¶
Second molar	36	144.2 ± 16.3‖¶
Subtotal	108	127.4 ± 22.8
Total		
Second premolar	40	109.8 ± 25.3#**
First molar	147	121.6 ± 22.1#††
Second molar	84	144.9 ± 23.1**††

Matching symbols denote significant difference (P <0.05) between groups.

Table 3.

Percentage of Risk Sites in Second Premolar, First Molar, and Second Molar

PNR Location*	Angle		Total
	<90°	≥90°	
Second premolar			
<15 mm	**6 (15.0%)**	18	24
≥15 mm	5	11	16
Total	11	29	40
First molar			
<15 mm	**12 (8.2%)**	110	122
≥15 mm	2	23	25
Total	14	133	147
Second molar			
<15 mm	**2 (2.4%)**	66	68
≥15 mm	0	16	16
Total	2	82	84

Bold type indicates risk sites.
* Distance from alveolar crest.

complication.[14,16,17] Other predisposing factors include inadequate surgical experience, narrow sinuses,[23] thick lateral wall,[18] and thin sinus membrane.[24] This study has identified another anatomic variation, the PNR, that might be associated with the occurrence of membrane perforation. Therefore, during the treatment planning phase, the location and angulation of the PNR should be carefully analyzed.

The midface forms during the fourth and seventh developmental weeks in utero, when the medial and lateral nasal prominences, the lowest part of the intermaxillary segment and the maxillary process, fuse together.[25] The maxillary sinus begins its development at the 10th developmental week. It first presents as a sac with lining mucosa that is located at the deeper and anterior end of the ethmoid infundibulum, lateral to the primary uncinate process.[26] By the 15th to 16th week, the sinus is surrounded by a sleeve of cartilage. Shortly after, there is the first evidence of ossification on the lateral wall of the sinus, then the anterior wall between the maxillary sinus and nasolacrimal duct at the 20th week, and the posterior wall by the 21st week. However, at the 37th week, ossification of the medial wall is still not evident.[25] Two periods of peak growth are observed for the maxillary sinus, from the 17th to the 20th week and from the 25th to the 28th week.[27] The growth of the sinus follows that of the cranium, and as a result, its antero-posterior dimension increases at a greater speed than the mediolateral or supero-inferior dimensions at this stage.[26] There are two other spurts of growth: from birth to the third year and between the seventh and 12th years, after which the maxillary sinus gradually reaches adult size at the age of 18 years.[28]

It is not known when the PNR develops. The recess is bounded by the lateral wall of the nasal cavity and the palatal wall of the maxilla; thus the angulation of the recess might be determined when the development of these bone walls are completed. However, whether the maxillary sinus might continuously extend toward these bone walls by bone remodeling after the bone walls are fully developed is not clear.[29] Regarding its location, the reference point used in this study was the alveolar crest. After the tooth is fully erupted, the distance from the recess to the alveolar crest should be stable. After the tooth is lost, depending on the amount of vertical bone loss, the distance becomes shorter.[30] Shorter distances were observed in the SvD and MdD ridges than in the SlD ridges in the present study, although significant differences were found only at the first molar sites (Table 1). The development of this recess should be further studied

to understand factors that determine its position and angulation.

A number of alternatives are available with various success rates in lieu of a sinus augmentation procedure for restoration of the posterior edentulous maxilla. Short implants (<10 mm) might require less surgical skill and less treatment time and costs. However, the medium- and long-term prognosis is still unknown.[31] Furthermore, the posterior maxilla, because of its soft bone quality, might not represent a predictable treatment modality.[32] In addition, the use of tilted implants has been proposed to support fixed prostheses for rehabilitation of limited-height edentulous ridges. Results have shown that combining tilted and straight implants for supporting fixed prostheses can be considered a viable treatment modality because of the high survival rate and low rate of prosthetic complications.[33] Zygomatic implants might be another option, although they are not as popular as regular implants.[34] Cantilever prostheses could also function well, if provided with thorough biomechanical considerations. Nonetheless, cantilever prostheses might incur higher rates of prosthetic complications, such as abutment loosening and denture fracture, if they are >12 mm in the maxilla.[35] When planning a sinus augmentation surgery, other alternatives should be considered and discussed with the patient, especially when the risk of performing the surgery might outweigh its benefits.

Future studies should focus on studying anatomic landmarks that are correlated with the location and angulation of the PNR. Considering the close relationships among the maxillary sinus, palate, alveolar process, and nasal cavity from a spatial and embryologic point of view, possible correlations might exist among the following measurements: 1) the palatal vault depth and the distance between the PNR and the alveolar crest; 2) the shape of the palatal vault and the angulation of the PNR; and 3) the width of the nasal cavity and the angulation of the PNR. Understanding these possible correlations can help surgeons to predict potentially difficult cases that are related to the PNR during diagnosis and treatment planning of SALW surgery.

CONCLUSIONS

This CBCT study evaluates the location and angulation of the PNR in the maxillary sinus from 274 edentulous sites. At the second premolar sites, 15% of the recesses are <90° and ≤15 mm from the alveolar crest, compared to 8.2% and 2.4% at the first and second molar sites, respectively. Sharp-angled recesses might complicate sinus membrane elevation on the medial wall and increase the occurrence of membrane perforation. Therefore, this anatomic structure should be considered when planning the SALW approach.

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