CLINICAL ORAL IMPLANTS RESEARCH

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Evaluation of maxillary sinus width on cone-beam computed tomography for sinus augmentation and new sinus classification based on sinus width

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Abstract

Purpose: The degree of difficulty in performing lateral window sinus augmentation may depend on the morphology of the maxillary sinus. The aim of this was to measure the distances between the medial and lateral sinus wall (sinus width [SW]) at different levels and apply those SW values to formulate a new sinus classification.

Materials and methods: Edentulous sites adjacent to maxillary sinuses with inadequate ridge height (RH; <10 mm) were included from cone-beam computed tomography database in the University of Michigan. SW was measured at the heights of 5, 7, 10, 13, and 15 mm from alveolar crest at the edentulous sites. Mean SW was stratified by residual RH into three different groups (group 1: <4 mm, group 2: $\geq$4 and <7, and group 3: $\geq$7 and <10), study sites (first and second premolars and molars), and measurement levels.

Results: Three hundred and twenty subjects (mean 50.1 years old) with 422 edentulous sites were included. Mean SW was wider at molar sites, higher measurement levels, and sites with shorter residual RH. Mean SW at the lower (average 2.3 mm from sinus floor) and higher boundary (15 mm from the alveolar crest) of lateral window osteotomy was 9.0 (2.8) and 16.0 (4.4) mm, respectively. Narrow, average, or wide sinuses were classified when the SW was <8, 8–10 and >10 mm at the lower boundary or <14, 14–17 and >17 mm at the upper boundary, respectively.

Conclusion: SW at levels that were relevant to lateral window sinus augmentation was measured. The proposed sinus classification could facilitate communication between health providers and determine the degree of easiness of sinus augmentation. It might be particularly useful for the selection of grafting materials and surgical approaches. Further studies are required to test its clinical implications.

Implant therapy for rehabilitation of posterior maxillary regions often presents a challenge due to reduced RH and lower bone density. The RH decreases as a consequence of sinus pneumatization and crestal bone resorption after tooth loss (van den Bergh et al. 2000). Inadequate RH precludes placement of standard implants ($\geq$10 mm). Therefore, procedures to increase vertical RH by means of sinus lifting have been developed during the past two decades (Boyne & James 1980; Tatum 1986; Summers 1994a,b). Currently, two main procedures are used, namely the transcrestal (Tatum 1986; Summers 1994a,b) and lateral window (Boyne & James 1980; Tatum 1986) sinus augmentation. As the name indicated, for the transcrestal approach, the maxillary sinus is reached through the osteotomy site in the alveolar ridge and is considered less invasive (Summers 1994a,b). The average elevation from the transcrestal approach is 2–4 mm (Tan et al. 2008). Its counterpart, the lateral window approach provides a direct view of the sinus and better control on delivering bone grafts (Boyne & James 1980). Indications for the transcrestal approach include moderately resorbed ridges, relatively flat sinus floor, and single implants (Wang & Katranji 2008). On the other hand, the lateral window approach is commonly reserved for severely resorbed ridges and multiple implants (Wang & Katranji 2008). Apart from differences in indications, the two procedures are predictable, and implants placed in grafted sinuses have high survival rates (Pjetursson et al. 2008, 2009; Tan et al. 2008).

Based on original descriptions (Boyne & James 1980; Tatum 1986) of the surgical

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procedures for the lateral window approach, an osteotomy on the lateral wall of the maxillary sinus is performed, after which the Schneiderian membrane is elevated to create a space for bone grafts. It is advised that the membrane should be elevated to the medial wall of the maxillary sinus for the following reasons. First, the grafts can gain additional blood supplies from the medial wall. The sinus membrane is supplied on the lateral wall by branches of the posterior superior alveolar artery (PSAA) and infraorbital artery (Solar et al. 1999; Elian et al. 2005; Rosano et al. 2010; Chan et al. 2011; Guncu et al. 2011). The posterior lateral nasal artery that is located on the medial wall provides another source of blood supply to the grafts (Flanagan 2005; Rosano et al. 2009). Second, by lifting the membrane to the medial wall, the tension in the membrane can be sufficiently relieved. Reduced membrane tension is beneficial in decreasing the incidence of membrane perforations (Schwartz-Arad et al. 2004). Third, reaching the medial wall ensures that implants could be totally surrounded by regenerated bone once bone grafts are integrated. Without proper membrane elevation to the medial wall, a void can still be present between the medial wall and the grafted sinus, which could compromise implant survival (Katranji et al. 2008; Li & Wang 2008).

Although sinus augmentation via the lateral approach is a predictable procedure, surgical complications do occur (Katranji et al. 2008; Li & Wang 2008). The most important method to avoid complications is to familiarize maxillary sinus anatomy and possible anatomical variations (Chan & Wang 2011). The maxillary sinus is a pyramid-shape cavity with its base facing the nasal wall. The average dimensions of the adult maxillary sinus are 25–35 mm in width, 36–45 mm in height, and 38–45 mm in length (van den Bergh et al. 2000). Its estimated average volume is 15 cm^3 (Ariji et al. 1994). The maxillary sinus is lined with pseudo-stratified ciliated columnar or cuboidal epithelium. Anatomical variations, such as septa, have been extensively studied regarding their locations, dimension, and orientations (Velasquez-Plata et al. 2002; Kim et al. 2006). The presence of a septum can increase the incidence of membrane perforation (Ardekian et al. 2006; Becker et al. 2008; Hernandez-Alfaro et al. 2008). Another variation is the location of the intra-osseous branch of the PSAA (Solar et al. 1999; Elian et al. 2005; Guncu et al. 2011). When it is in proximity to the osteotomy site on the lateral wall of the sinus, every care should be taken to prevent damaging it.

In addition to internal sinus structures and adjacent vessels, the morphology of the maxillary sinus itself was shown to link strongly to the surgical complications (Cho et al. 2001; Velloso et al. 2006). Angulations between the mesial and lateral wall were associated with the incidence of membrane perforations (Cho et al. 2001). Sharper angles that were often observed at second premolar sites are at a higher risk of membrane perforations (Velloso et al. 2006). In the same route, the width of the sinus mediolaterally might determine the easiness of performing a sinus lifting procedure, which might be associated with the incidence of intra-operative complications. Too small or too large, the mediolateral dimension of the maxillary sinus can present a difficult case for sinus lifting procedures. Little information is available regarding the average mediolateral distances of the maxillary sinus, especially those that are related to lateral window sinus augmentation. Therefore, the aim of this study was to measure the distance between the medial and the lateral wall at various distances from the ridge crest on cone-beam computed tomography (CBCT) scans. Based on the results, a sinus classification using mediolateral sinus width (SW) was proposed.

Material 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.

Image acquisition

All images were acquired with a CBCT machine (i-CAT Cone-Beam Computed Tomography machine; Imaging Sciences International, Hatfield, PA, USA) in the Department of Periodontics and Oral Medicine, University of Michigan School of Dentistry by board-certified Oral and Maxillofacial radiologists (EB and SB) between 2005 and 2012. The imaging parameters were set at 120 kVp, 18.66 mAs, scan time 20 s, resolution 0.4 mm, and a field of view, which varied based on the scanned region. The scans used in this study were selected from the CBCT database and were not specifically acquired for this project. The CBCT scans of each individual were transferred to a desktop computer equipped with an implant planning software program (InvivoDent, Anatomage, San Jose, CA, USA). Data were saved in the Digital Imaging and Communications in Medicine format.

Inclusion criteria

One examiner (HC) screened CBCT imagines that were projected by a 28-inch desktop monitor with 1024 × 768 pixels under room lightening. The distance between the examiner and the monitor was approximately 30 cm. Images selected for this study had to fulfill the following inclusion criteria:

1. Presence of edentulous ridges that were in vicinity to the maxillary sinus as a result of missing single or multiple teeth
2. The residual RH was <10 mm
3. Presence of adjacent or opposing teeth to the edentulous span so that the location of the edentulous ridges in correspondence to the tooth site could be identified
4. The maxillary sinus to be measured was visible from its floor to at least 15 mm in height, as measured from the alveolar crest of the edentulous ridge

Images were excluded if:

1. Images were unclear or incomplete due to scattering or other reasons
2. Edentulous RH was more than 10 mm
3. Absence of adjacent or opposing teeth to the edentulous span so that the location of the edentulous ridges in correspondence to the tooth site could not be identified
4. Presence of sinus pathology, for example, the pseudocyst that made the measurement impossible
5. The outline of the edentulous ridge could not be identified, for example, extraction sockets
6. The sinus had been grafted or in which implants had been placed

Qualified scans were reoriented, so the maxilla was bilaterally symmetrical and the hard palate was parallel to the ground. The reference arch (80 mm wide) was drawn at the level of crestal bone at the cross-sectional view, with its center corresponding to the center of the ridge. The sagittal section that included the middle part of each missing tooth was selected for SW measurements. When both sinuses were eligible for the study, only one sinus was randomly selected for the measurements. On the selected sagittal section, the following measurements were made by a built-in digital caliper in mm, including residual ridge height (RH) and SW at 5, 7, 10, 13, and 15 mm from the level of alveolar crest (Fig. 1). The SW was measured from the lateral to the medial wall of the sinus. The 15-mm level was chosen because that level is usually where the membrane elevation

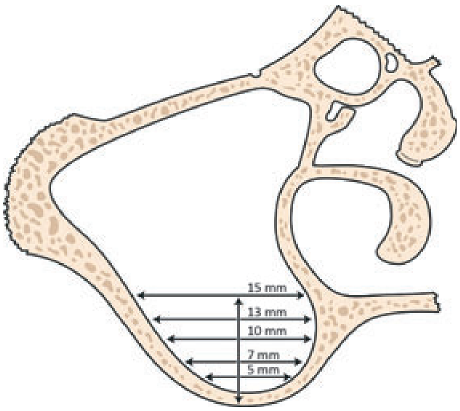

Fig. 1. Photograph demonstrating sinus width measurements at different levels.

procedure for lateral window sinus augmentation ends (Wang & Katranji 2008). The edentulous sites were further classified as severely deficient (SvD), moderately deficient (MdD), or slightly deficient (SlD) when the residual RH was <4 mm, between ≥4 mm and <7 mm, and between ≥7 mm and <10 mm, respectively. Hence, the first measurement level for sites with SvDRH, MdDRH, and SlDRH was 5, 7, and 10 mm, respectively. Two calibrated examiners (SF and MA) performed the measurements. Interexaminer and intra-examiner agreements were calculated to be 0.83 and 0.89 by the Kappa test.

Statistical analysis

SW was obtained at each level of each missing tooth site and expressed as mean (standard deviation, SD) in mm. Tooth sites were grouped into second molars (#2 and #15), first molars (#3 and #14), second premolars (#4 and #13), and first premolars (#5 and #12). The SW at the first-level measurements of each RH group (5, 7, and 10 mm level for SvD, MdD, and SlD RH groups, respectively) was pooled to represent the SW at the usual lower boundary of the lateral window osteotomy. Likewise, the SW at 15 mm level was collected from the three RH groups, representing the usual upper boundary of the lateral window osteotomy. The mean (SD), median, and thirty-third and sixty-seventh percentile values for the SW at the lower and upper boundary were calculated. Descriptive analyses were conducted with commercially available software (SPSS 19; SPSS Inc., Chicago, IL, USA).

Results

Of 2114 subjects screened, 320 subjects (135 men) with a mean age of 50.1 years (range from 38–74) were qualified, yielding an inclusion rate of 15.14%. The three most common reasons of exclusions were fully dentate status (45.4%), edentulous ridges with adequate height (17.9%), and fully edentulous ridges (9.6%) for which tooth sites could not be recognized. For the features of edentulous ridges of the included subjects, 1, 2, 3, and 4 missing teeth were presented in 231, 75, 11, and 3 subjects, respectively. As a result, 422 edentulous sites were evaluated, consisting of five-first premolars, 60 second premolars, 214 first molars, and 143 second molars.

The mean SW was presented in Table 1, stratified by the RH, study sites, and measurement levels. A total number of 85, 167, and 170 study sites were available for SvD, MdD, and SlD RH groups. Overall, the SW was wider for molar sites than premolars in all three RH groups, especially at higher measurement levels. In addition, the SW was wider at higher measurement levels and at sites with more severely resorbed ridges, given the same measurement level. For the first measurement level of each RH group, the mean SW was 8.9 (2.4), 8.7 (2.6), and 9.3 (3.0) mm, respectively for SvD, MdD, and SlD RH groups. For the 15-mm measurement level, the mean SW was 17.6 (4.3), 16.5 (4.3), and 14.6 (4.1) mm, respectively.

The average first measurement level was 2.3 mm coronal to the floor of maxillary sinus. The mean SW at this level (lower boundary of the lateral window osteotomy) was 9.0 (2.8) mm from a total number of 422 sites (Table 2). The thirty-third percentile and sixty-seventh percentile were 7.6 and 9.9 mm, respectively. The mean value at the upper boundary of the lateral window osteotomy was 16.0 (4.4), with the thirty-third and sixty-seventh percentile being 14.0 and 17.3 mm, respectively. The distributions of SW at the lower and upper boundary of the lateral window osteotomy were plotted in Fig. 2a,b, respectively.

A sinus classification was proposed based on the thirty-third and sixty-seventh percentile SW values. For narrow, average, and wide sinuses, the SW at the lower boundary of lateral windows was <8, 8–10, and >10 mm, whereas at the upper boundary, the SW was <14, 14–17, and >17 mm, respectively (Table 3). Representative sinuses that belong to narrow, average, and wide sinus groups were presented in Fig. 3.

Discussion

Schneiderian membrane perforation is the most common surgical complication for

***Table 1.* Sinus width presented as mean (SD) at edentulous sites (first premolars to second molars) with different ridge height (SvD, MdD, and SlD RH) and measurement levels (5–15 mm from the ridge crest)**

Ridge height (RH)				Measurement level (mm)				
Classification	Range (mm)	Study sites	*N*	5	7	10	13	15
SvD	<4	First premolar	0	NA	NA	NA	NA	NA
		Second premolar	13	8.5 (2.2)	10.5 (2.9)	12.9 (4.2)	14.4 (5.2)	14.8 (5.8)
		First molar	49	8.7 (2.5)	11 (2.9)	13.9 (3.3)	16.2 (3.5)	17.3 (3.7)
		Second molar	23	9.5 (2.5)	12.1 (2.7)	14.8 (3.7)	17.8 (4)	19.5 (4.3)
		Total	85	8.9 (2.4)	11.2 (2.9)	14 (3.5)	16.3 (4)	17.6 (4.3)
MdD	≥4 and <7	First premolar	2	NA	*	*	*	*
		Second premolar	21	NA	8.9 (3.3)	12 (4)	14.2 (4.5)	14.8 (5.8)
		First molar	95	NA	8.5 (2.3)	12.2 (2.4)	15.1 (2.8)	16.4 (3.2)
		Second molar	49	NA	9.4 (3.9)	12.2 (4.1)	15.4 (4.7)	17.6 (5.1)
		Total	167	NA	8.7 (2.6)	12.2 (3.2)	15.1 (3.7)	16.5 (4.3)
SlD	≥7 and <10	First premolar	3	NA	NA	*	*	*
		Second premolar	26	NA	NA	6.6 (2.4)	10.3 (3.5)	11.3 (3.7)
		First molar	70	NA	NA	9.8 (3.3)	12.9 (3.3)	14.4 (3.7)
		Second molar	71	NA	NA	9.7 (2.4)	13.6 (3.2)	16.1 (3.8)
		Total	170	NA	NA	9.3 (3)	12.8 (3.5)	14.6 (4.1)

NA, not applicable.
*Mean (SD) was not calculated due to small sample size.

Table 2. **Sinus width presented as mean (SD), median, and thirty-third and sixty-seventh percentile at lower (measured at 5, 7, 10 mm level for SvD, MdD, and SlD RH groups, respectively) and upper boundary (15 mm level) of lateral window osteotomy**

			Sinus width			
Ridge height (RH)	*N*	Measurement level (mm)	Mean (SD)	Median	Thirty-third percentile	Sixty-seventh percentile
SvD	85	5	8.9 (2.4)	8.7	7.5	9.9
MdD	167	7	8.7 (2.6)	8.5	7.3	9.6
SlD	170	10	9.3 (3)	9.1	7.6	10.2
Total	422	–	9 (2.8)	8.8	7.6	9.9
SvD	85	15	17.6 (4.3)	17.7	15.4	19
MdD	167	15	16.5 (4.3)	16	14.8	18
SlD	170	15	14.6 (4.1)	14	12.7	15.7
Total	422	15	16 (4.4)	15.4	14	17.3

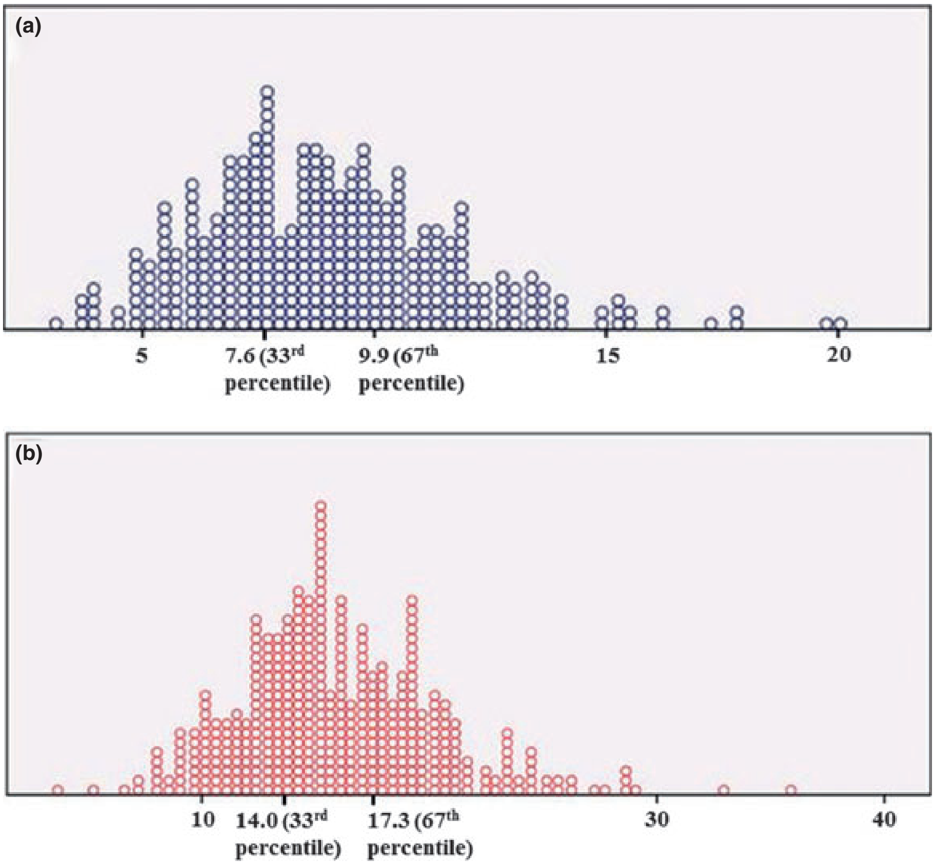

Fig. 2. Distributions of sinus width measurements from 422 sites with thirty-third and sixty-seventh percentile values at the (a) lower boundary and (b) upper boundary of lateral window osteotomy.

Table 3. **New sinus classification based on sinus width at the lower and upper boundary of lateral window osteotomy**

Sinus width (mm)	Narrow	Average	Wide
Lower boundary	<8	8–10	>10
Upper boundary	<14	14–17	>17

lateral window sinus augmentation, which occurred on average 18.2% of cases, with a range of 10–30% (Pikos 1999; Cho et al. 2001; Pjetursson et al. 2009). Membrane perforations can increase the incidence of postoperative infection (Schwartz-Arad et al. 2004) and implant failure (Hernandez-Alfaro et al. 2008). Factors such as the presence of a septum have been reported to be associated with the occurrence of membrane perforation (Velasquez-Plata et al. 2002; Kim et al. 2006). In addition, the angle of the buccolingual maxillary sinus wall has been proposed as a factor to determine the likelihood of sinus perforation (Cho et al. 2001). It was reported the narrower the angle between the medial and lateral wall was, the higher the membrane perforation rate was. Sinuses with <30° interwall angles had a perforation rate of 37.5%, compared with 0% for those with more than 60° angles. Another study (Velloso et al. 2006) found that sharp angles were most commonly found in second premolar sites, with an average 36.3°, while in first and second molars, the mean angles were 58.2° and 47.7°, respectively. It was concluded that sinus membrane elevation might be more challenging in second premolar area.

Although the sinus morphology can be analyzed by measuring the interwall angles, mediolateral wall distances are more clinically relevant because they directly dictate the required membrane elevation before the medial wall can be reached. Literature (Avila et al. 2010; Jang et al. 2010) regarding the mediolateral SW is limited. One clinical study (Jang et al. 2010) evaluated the selection of grafting material in relation to maxillary SW for transcrestal sinus augmentation. Their results showed that the mean buccolingual distances were 12.7 ± 4.0, 15.2 ± 3.7, and 14.4 ± 4.0 at second premolar, first molar, and second molar, respectively, when measured from the apex of the implants. Another study (Avila et al. 2010) aimed at assessing the influence of SW on sinus augmentation outcomes. They reported mean buccolingual distances of 10.2 ± 3.4, 12.7 ± 3.2, and 14.6 ± 3.2, at 8, 10, and 12 mm from the alveolar crest. Although a direct comparison could not be made due to the fact that different measurement levels and tooth sites were used, our results seemed to be in accordance with their findings. When pooling the data from sites with different RH in our study, the average SW at the 13-mm level (corresponding to the average implant length in Jang's study) was 12.6, 14.6, and 14.9 mm for second premolar, first molar, and second molar sites, respectively. In addition, the SW at the 10-mm level was 11.4 mm in our study, compared with 12.7 mm in Avila's study in the same measurement level.

When evaluating mediolateral width of maxillary sinuses, the use of three-dimensional imagines are necessary, such as medical (conventional) or cone-beam computer tomography (CBCT). CBCT scans have been shown to be reliable and accurate and become a popular diagnostic and treatment planning tool for implant therapy (Chan et al. 2010). However, there is still no consensus on the indications of CBCT scans. Decisions on ordering CBCT scans largely rely on surgeon's confident level and preferences. Although some CBCT machines can deliver extremely low radiation dose, the associated

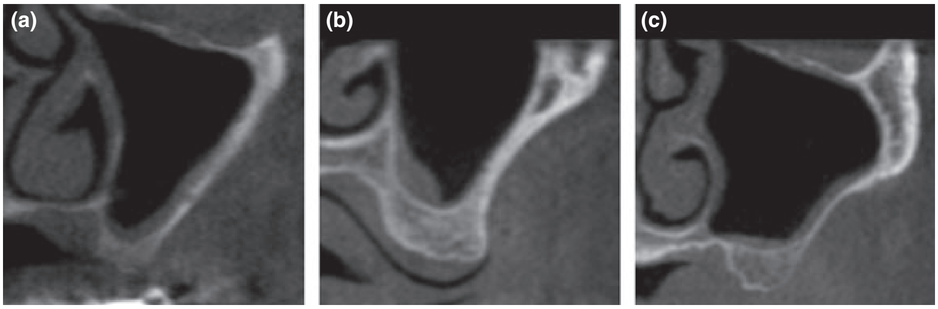

Fig. 3. Cone-beam computed tomography (CBCT) scans representing three types of maxillary sinuses with (a) narrow, (b) average, and (c) wide sinus widths.

cost may still be a concern to the patients and clinicians as well. Therefore, indiscriminate use should be avoided. The benefits of providing detailed anatomic structures and potential harms should be carefully weighed. The results of this study provided average SW at different levels that might be useful to identify patients for whom CBCT scans are indicated. Patients with sinuses that are wider or narrower than the normal might be candidates for CBCT scans because they are more challenging in performing sinus augmentation. Future research should focus on discovering clinically measurable anatomic landmarks that can predict SW so that the use of CBCT scans can be more efficient.

Limitations of this study include considerably smaller sample size for premolar sites, uneven numbers between genders (male/female = 2 : 3), and unknown time when subjects became edentulous. In our study, the proportions of molars and premolars are 84.6% and 15.4%. Fewer samples for premolar sites are inevitable because molars are the most commonly lost teeth (Hirschfeld & Wasserman 1978; McFall 1982). In addition, residual RH in premolar sites is usually adequate without the need of sinus augmentation. A recent publication (Kopecka et al. 2012) evaluating residual RH in relation to the sinus cavity reported that the anterior border of the maxillary sinus is above the first premolar in 96.9% of the cases. About 70% of first premolar sites presented with more than 9 mm of residual RH. Considering the small numbers for premolar sites, the results of this study are more representative for molar sites.

Multiples studies (Misch & Judy 1987; Cawood & Howell 1988; Simion et al. 2004; Wang & Katranji 2008) have attempted to classify maxillary sinuses. Misch & Judy (1987) were among pioneers proposing a 4-level classification, depending on available RH and width. Cawood & Howell (1988) classified maxilla into six categories from dentate jaw (class I) to depressed ridge (class VI), based on the severity of ridge resorption. Simion et al. (2004) used cementoenamel junctions (CEJs) as fixed points for measuring alveolar ridge dimensions. Wang & Katranji (2008) presented the ABC classification by summarizing the aforementioned systems and provided treatment recommendations for each conditions. This article added another horizon to classify maxillary sinuses. While previously mentioned classifications focus on adjacent structures of maxillary sinuses, for example, residual RH and CEJs, this study concentrates on mediolateral dimension of maxillary sinuses. Based on the sinus anatomy of 320 partially edentulous subjects, maxillary sinuses are divided into three categories: narrow, average, and wide. This new classification will assist communications between healthcare providers in describing the size of maxillary sinuses. Future studies should be designed to test the validity of the present sinus classification and explore its clinical implications. Possible implications might include determination of easiness of sinus elevation procedures, calculation of the amount of bone grafts, and selection of grafting material and sinus augmentation approaches. For example, sinuses with average widths are optimal candidates for a lateral window approach because of their easy access for membrane elevation. For narrow-width sinuses, the wall-off technique might be preferred to avoid difficulties in membrane elevation from limited space. For wide-diameter sinuses, a crestal approach might be indicated so that the medial wall could be reached more easily.

Conclusions

The SW was determined at various distances from the ridge crest in 422 edentulous sites on CBCT scans. The mean SW at the usual lower boundary of lateral window osteotomy (average 2.3 mm from the floor of sinus) was 9.0 (2.8) mm, with the thirty-third and sixty-seventh percentile SW values being 7.6 and 9.9 mm, respectively. The mean SW at the usual upper boundary of lateral window osteotomy (15 mm from crest) was 16.0 (4.4) mm, with the thirty-third and sixty-seventh percentile SW values being 14.0 and 17.3 mm, respectively. A maxillary sinus classification with three categories (narrow, average, and wide) was proposed, based on the thirty-third and sixty-seventh percentile SW values in the aforementioned two measurement levels. This new sinus classification could add diagnostic and treatment planning values to sinus augmentation procedures.

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