Maxillary Sinus Lateral Wall Thickness and Their Morphologic Patterns in the Atrophic Posterior Maxilla

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Purpose: The aim of the present study was to examine the sinus lateral wall thickness of atrophic posterior maxilla (< 10 mm) of complete and partial edentulous patients and determine the influence of the residual ridge height (RH), gender and age upon maxillary lateral wall thickness (LWT).

Material and methods: Four hundred fourteen measures were taken from 140 consecutive patients that met the inclusion criteria. On the selected sagittal section, a built-in digital caliper recorded in millimeters the following measurements: residual ridge and lateral wall thickness [a perpendicular line at 3, 5, 7, 10, 13 and 15 mm from the lowest point of the sinus floor]. The edentulous spans were further classified as complete edentulous atrophic maxilla (CEM) and partial edentulous atrophic maxilla (PEM). The mixed linear model was used to test the effects of “gender”, “type of edentulism”, “edentulous span”, and “residual height” on the measurement of the LWT of the sinus.

Results: Mean LWT for PEM was 1.71 ± 0.12 mm, while for CEM was 1.57 ± 0.07 mm (p=0.01). The mixed model yielded significant effect of “edentulous span” (p=0.048), and the interactions between “type of edentulism” and “edentulous span” (p<0.001), and “edentulous span” by RH (p<0.01). “Age” and RH were positively associated to LWT, however they do not interact with RH, “gender” or “type of edentulism”. RH has been shown to correlate with “edentulous span” (p<0.001) and “type of edentulism” (p=0.01). The longer the “edentulous span”, the thinner the LWT. Similarly, RH was larger for PEM (6.85, SE=0.34) than CEM (5.69, SE=0.26).

Conclusions: The maxillary sinus lateral wall tends to increase in thickness from the second premolar to the second molar; and from 5mm up to 15 mm. In addition, residual ridge height, presence of teeth adjacent to the edentulous atrophic ridge, and age have all been shown to influence maxillary sinus lateral wall thickness.

KEY WORDS (MESH 2013):
Maxillary sinus, maxillary sinus floor augmentation, Morphology, Maxillofacial procedures, Bone regeneration

Oral rehabilitation in the posterior maxilla often presents a challenge to the clinician due to ridge resorption after tooth extraction and subsequent sinus pneumatization. Several techniques have been used to overcome this challenge: bone augmentation, short implants or tilted implants; however, shorter and tilted implants may not have long-term stability due to strong occlusal forces exerted in this area. In addition, the atrophic posterior maxilla has lower bone density when compared to the non-atrophic posterior maxilla, and this may lead to other potential complications such as implant migration to the maxillary sinus. To avoid these potential complications, sinus
augmentation with variety of bone grafts has been regarded as one of the gold standards in reconstructing deficient posterior reabsorbed maxilla.\textsuperscript{10}

Two main approaches for sinus augmentation have been proposed: lateral window approach\textsuperscript{11} and crestal approach using primarily osteotomies.\textsuperscript{12} Both have shown acceptable results;\textsuperscript{10} however, the lateral window approach is still considered more predictable in terms of outcomes and safety, especially for cases with minimal bone height.\textsuperscript{13} Despite this predictability, complications do occur, most related to sinus anatomy.\textsuperscript{14} Extensive bleeding, implant migration and sinus infection should be considered when performing sinus augmentation. Hence, clinicians should learn how to prevent and manage these problems.\textsuperscript{15} Sinus membrane perforation (19.8\%)\textsuperscript{16} remains the most common complication during sinus augmentation. To avoid this, pre-operative assessment of anatomy variations by radiographic assessments are essential.\textsuperscript{14} The presence of septum, sinus shape/morphology, and a sharp angulation between the lateral and medial wall have all been shown to increase the chance of membrane perforation and indirectly leads to sinus complications\textsuperscript{14}. In addition, osteotomy of the lateral wall may tear the Schneiderian membrane.\textsuperscript{17} Hence, knowledge of the sinus anatomy, including lateral wall thickness, is key to minimize these potential complications.

Cone-beam computed tomography (CBCT) offers a 3-dimensional reliable diagnostic image for detecting anatomical variations of the maxillofacial region and enables us to report more precise data. Presently, only two studies have evaluated sinus lateral wall thickness by radiographic assessment,\textsuperscript{18, 19} however; this data cannot be extrapolated to Caucasian patients due to racial differences in studied populations. In addition, none of the current studies have examined the influence of residual height (RH) upon lateral wall thickness (LWT). Hence, the present study aimed to study: 1) the posterior atrophic maxilla (< 10 mm) sinus LWT in complete and partially edentulous patients; and 2) the influence of the RH, gender and age upon LWT.

**MATERIALS AND METHODS**

This research study used a retrospective clinical database that included patients who were previously treated as part of routine periodontal care using accepted therapy for each patient’s specific clinical needs. Since the current research involved a retrospective analysis of pre-existing data and current data do not include any identifiable private information, this research did not require approval by an institutional ethics board.

**Patient Selection**

Overall, 414 measures were taken from 140 consecutive Caucasians patients fulfilling the inclusion criteria, of which 270 were female and 144 were males (2:1 female: male ratio) with a mean age of 67.2 ± 18.8 years.

**Image Acquisition**

The scans used in the present study were selected from the CBCT database. All images were obtained with a CBCT machine\textsuperscript{‡‡‡} in the Center of Implantology, Oral and Maxillofacial Surgery (CICOM), Badajoz, Spain by an experience radiologist (VC) between 2010 and 2013. The imaging parameters were set at 120kVp, 18.66mAs, scan time 20 seconds, resolution 0.4 mm, and a field of view (FOV) which 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\textsuperscript{§§§}. Data were saved in the Digital Imaging and Communications in Medicine (DICOM) format.
**Inclusion and Exclusion Criteria**

One examiner (AM) conducted the image screening using the following inclusion/exclusion criteria.

- Images were included if:
  1. Maxillary sinuses located between premolars and molars as a result of missing single or multiple teeth
  2. The residual ridge height (RH) was < 10 mm.
  3. Presence of teeth adjacent to or opposing the edentulous area so the location of the edentulous ridges corresponding to the tooth site could be identified
  4. The maxillary sinus to be measured was visible from its floor to at least 15 mm 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 ridge height was more than 10 mm
  3. The location of the edentulous ridge cannot be determined
  4. Presence of sinus pathology that made the measurement impossible
  5. The outline of the edentulous ridge cannot be identified, e.g. extraction sockets
  6. The sinus had been grafted or in which implants had been placed

**Image Analysis**

On the selected sagittal section, a built-in digital caliper made the following measurements in millimeters: residual ridge height (RH) [the distance from the alveolar crest up to the lowest point of the sinus floor] and lateral wall thickness (LWT) [a perpendicular line at 3, 5, 7, 10, 13 and 15 mm from the lowest point of the sinus floor] (Figure 1). The 15-mm level was chosen to be the level where the lateral window augmentation ends. The edentulous areas were further classified as complete edentulous atrophic maxilla (CEM) and partial edentulous atrophic maxilla (PEM) in an attempt to determine the influence of the presence of teeth upon LWT.

**Statistic Analysis**

The mixed linear model as implemented in SPSS v17.0 was used to test the effects of “gender”, “type of edentulism”, “edentulous span” (within patients: 1M, 2M, 2PM), and RH of the measurement (within patients: 3, 5, 7, 10, 13 and 15 mm) on the LWT of the sinus. The RH and patient age served as covariates for the analysis. The mixed model was also used to test the effects of “gender”, “type of edentulism”, and “edentulous span” on RH, with patient age serving as a covariate. The type of covariance matrix was selected using the Schwarz Bayesian criterion. A p-level of 0.05 was setup for significance level. When needed, the Sidak correction for post-hoc comparison was used.

**RESULTS**

The average thickness in millimeters (mm) and the 95% confidence intervals for the LWT as a function of edentulous span and height of the measurement are presented in Table 1. Figure 2 displays the interaction between edentulous span and measured height.
for LWT. Additionally, Table 2 lists the percentiles according to edentulous span, type of edentulism and height of edentulism.

Using a compound symmetry covariance matrix, the mixed model yielded main effect of “edentulous span” (Table 3), $F(1,1520)=3.03$, $p=0.048$), and the interactions between “type of edentulous” and “edentulous span” (Figure 3), $F(2, 1013)=9.37$, $p<0.001$, and “edentulous span” by RH, $F(10,1394)=2.56$, $p<0.01$. “Age” and RH were positively associated to LWT (slope: 0.017 mm/year, $p=0.033$, slope=0.15 mm/year, $p=0.044$, respectively), but they do not interact with RH of the measure, “gender” or “type of edentulous” (all $p>0.30$). However, RH does interact with “edentulous span” ($p<0.001$), which indicated that slopes between RH and the LWT were different for each “edentulous span”.

Regarding the influence of RH upon LWT, the mixed model yielded only main effect of “type of edentulous”, $F(1,141)=6.82$, $p=0.01$, and “edentulous span”, $F(2,213)=9.56$, $p<0.001$. RH was larger for PEM (6.85, SE=0.34) than CEM (5.69, SE=0.26). In addition, RH was found to be smaller for 1M and 2M (5.96, SE=0.23, 5.89, SE=0.30) than for 2PM (6.96, SE=0.27) edentulous spans.

DISCUSSION

Maxillary sinus augmentation via lateral approach presents complexity for dissection and elevation of sinus membrane, often due to the irregular anatomy associated with the sinus. This irregular anatomy may result in a tear of the Schneiderian membrane during surgery. To successfully perform this procedure, a thorough understanding of the anatomy of the maxillary sinus is imperative. Although the influence of membrane perforation upon implant success remains to be determined, the factors that influence membrane perforation must be thoroughly assessed in order to avoid surgical and postsurgical complications. The presence of septum, sinus shape/morphology, and a sharp angulation between the lateral and medial wall have all been shown to increase the incidence of membrane perforation. These findings are in agreement with the data reported from this study, which showed that RH, aging and the type of edentulism (partial or complete maxillary posterior edentulism) impact LWT. On the contrary, gender did not seem to affect LWT. Due to these factors, in order to reduce the number of membrane perforations and consequent complications, each case must be evaluated independently. The findings from the present study might help the clinician to overcome the pitfalls found during maxillary sinus augmentation by illustrating the anatomical patterns of the lateral wall.

The management of the lateral wall during sinus augmentation via lateral approach has been emphasized due to the fact that its thickness may influence the integrity of the Schneiderian membrane. Results from this study demonstrated that mean LWT for PEM was $1.71 \pm 0.12$ mm, while for CEM was $1.57 \pm 0.07$ mm ($p=0.01$). Yang et al. found thicker mean LWT in complete edentulous patients ($1.75 \pm 0.80$ mm) than PEM. This difference might be attributed to either the measuring reference used to determine LWT (i.e. anatomic landmarks or inclination of the line following the lateral wall anatomy) or the race of the patients screened. On the other hand, Neiva et al. showed, in Caucasian skulls, that mean LWT was thinner than the one found in the present study ($0.91 \pm 0.43$ mm). Again, instruments used to record the data might be the cause of this disparity. Furthermore, it is noteworthy that our findings demonstrated that the presence of teeth adjacent to the edentulous span is related to mean LWT.
In this study, we found that the maxillary sinus lateral wall tends to increase in thickness from the second premolar to the second molar area, and from 5mm up to 15 mm. In addition, residual ridge height, presence of teeth adjacent to the edentulous atrophic ridge, and age have all been shown to influence maxillary sinus lateral wall thickness. This is in agreement with a recent study, which reported that LWT tended to increase from the second premolar to the second molar. Our data are also in agreement with Neiva et al. who conducted a study on Caucasian skulls and reported that LWT varies depending on each individual and on the region measured; however, these differences were not significant. Similar results were also obtained by Yang et al. in nonembalmed Korean hemifaces. They reported that LWT was thinner in the second molar region than in the first molar region. In addition, it was pointed out that structures such as the zygomatic buttress or the maxillary tuberosity may influence LWT. Contrarily, Kang et al. in a CBCT study on Korean subjects found that the more anterior the region, the thicker the LWT. The differences noted in these studies might be due to ethnicity or the methods used to determine LWT. Additionally, it is important not to forget that researches conducted using CBCT have the intrinsic risk of bias due to the distortion, even light of this device; and that differences might be attributable to this fact as well.

Regarding the vertical height where LWT were measured, significant differences were found at 10 mm from the sinus floor of the edentulous region between the first molar and second premolar and between the second molar and second premolar, as well as at 15 mm between the first and second molar. Our results showed similarities to previous studies but cannot be compared due to the disparity in methodology, ethnicity and the inclusion criteria carried out in other research. We found that in the second premolar area, at all the measured points LTW was thinner than the rest of the plotted regions. Furthermore, we observed that there was a tendency to increase LWT when it increases from 5 mm and that at 3 mm in all measurements LWT were thicker than at 5 mm measurements. Furthermore, one striking finding was the fact that in PEM group, the first and second premolar regions were similar but both differed at second premolar. On the other hand, for CEM group, first molar region differed from the second molar region but again, both differed from the second premolar region.

In addition, previous studies have assessed the influence of gender and age on the maxillary sinus anatomy; however, only one has focused on LWT. It was found a significant difference in mean LWT between sexes only in the premolar region. However, we did not find any correlation among gender and LWT in this study. Therefore, the present study is in agreement with previous studies in which significantly differences the maxillary sinus anatomy were not observed between sexes.

With respect to aging, it is hypothesized that aging causes the pneumatization of the maxillary sinus and consequently, younger subjects would have thicker LWT. Our findings showed that LWT are positively correlated to RH and age. In other words, the higher the RH is, the greater the LWT is expected with a slope of 0.15 mm/year. Furthermore, the older the patient is, the thicker LWT should be observed with a presumed slope of 0.017 mm/year. Hence, this study corresponds with findings from previous studies that lateral pneumatization is not increased with age. This might be explained by the different populations that were included in all these studies (Caucasian versus Korean).

Results from our study implies that the less RH, the thinner the lateral maxillary sinus wall. As reported by Monje et al. who showed that bone density in maxillary sinus region is influenced by the remaining bone height, a thinner LWT suggests a lower bone
density. This may hint that when performing a maxillary sinus augmentation via lateral approach in severely reabsorbed maxilla, increased care is required because LWT might be more soft and friable.

CONCLUSION
The maxillary sinus lateral wall tends to increase in thickness from the second premolar to the second molar and from 5mm up to 15 mm. In addition, residual ridge height, presence of teeth to adjacent the edentulous atrophic ridge, and age all have been shown to influence maxillary sinus lateral wall thickness. Nonetheless, each case must be individualized in order to foresee possible complications due to the anatomic variations.

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DISCLAIMER:
The authors do not have any financial interests, either directly or indirectly, in the products or information listed in the paper.

REFERENCES


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Figure 1.
Depiction demonstrating residual ridge height (RH) and lateral wall thickness at all the measured levels.

Figure 2.
Interaction between “edentulous span” and “measured height” for lateral wall thickness

Figure 3.
Interaction between “type of edentulous” and “edentulous span” for lateral wall thickness

Table 1.
Average thickness (in mm) and standard errors (in parenthesis) for the lateral wall thickness as function of edentulous span and measured height.

<table>
<thead>
<tr>
<th>Edentulous span</th>
<th>3mm</th>
<th>5mm</th>
<th>7mm</th>
<th>10mm</th>
<th>13mm</th>
<th>15mm</th>
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<tbody>
<tr>
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<td>1.37 (1.20, 1.54)</td>
<td>1.18 (1.01, 1.35)</td>
<td>1.22 (1.05, 1.39)</td>
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<td>1.67 (1.49, 1.84)</td>
<td>1.86 (1.69, 2.03)</td>
<td>2.07 (1.90, 2.25)</td>
<td>2.21 (2.04, 2.39)</td>
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Table 2.
Percentiles according to “edentulous span”, “type of edentulous” and “residual ridge height” (RH).

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<th>7mm</th>
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<td>2.5</td>
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</table>
PEM: partial edentulous atrophic maxilla; CEM: complete edentulous atrophic maxilla; RH: residual ridge height

Table 3.

Average thickness (in mm) and standard errors (in parenthesis) for the lateral wall thickness as function of type of edentulous and edentulous span.

<table>
<thead>
<tr>
<th>Edentulous span</th>
<th>PEM</th>
<th>CEM</th>
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<tr>
<td>1M</td>
<td>1.94 (0.09)</td>
<td>1.61 (0.07)</td>
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<td>1.93 (0.12)</td>
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<td>1.27 (0.11)</td>
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PEM: partial edentulous atrophic maxilla;
CEM: complete edentulous atrophic maxilla

‡‡‡ i-CAT (Imaging Sciences International, Hatfield, PA, USA)
§§§ InvivoDent (Anatomage, San Jose, CA, USA).
**Figure 1.** Depiction demonstrating residual ridge height (RH) and lateral wall thickness at all the measured levels.
Figure 2. Interaction between “edentulous span” and “measured height” for lateral wall thickness.
**Figure 3.** Interaction between “type of edentulism” and “edentulous span” for lateral wall thickness

![Graph showing interaction between type of edentulism and edentulous span for lateral wall thickness.](image-url)