CLINICAL ORAL IMPLANTS RESEARCH

Shih-Cheng Wen
Yen-Hua Lin
Yeuh-Chao Yang
Hom-Lay Wang

The influence of sinus membrane thickness upon membrane perforation during transcrestal sinus lift procedure

Authors' affiliations:
Shih-Cheng Wen, Private Practice, Taipei County, Taiwan,
Yen-Hua Lin, Yeuh-Chao Yang, Department of Dentistry, Cathay General Hospital, Taipei City, Taiwan
Hom-Lay Wang, Department of Periodontics and Oral Medicine, School of Dentistry, University of Michigan, Ann Arbor, MI, USA

Corresponding author:
Hom-Lay Wang
1011 North University Avenue, Ann Arbor, MI 48109-1078, USA
Tel.: +734 763 3325
Fax: +734 936 0374
e-mail: homlay@umich.edu

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Abstract

Objectives: Schneiderian membrane perforation is one of the main complications during sinus augmentation. The reasons may be associated with surgical technique, septum, inadequate ridge height, and membrane thickness. However, reports that used cone-beam computed tomography (CBCT) to quantify the thickness of sinus membrane were limited. The aims of this retrospective study were: to study the correlation between membrane thickness and perforation rate during transcrestal sinus lift and to propose a classification system of sinus membrane thickness based upon CBCT data.

Material and methods: One hundred and twenty-two subjects who received dental implant restorations over posterior maxilla with a total of 185 transcrestal sinus lift procedures between years 2010 to 2013 were selected consequently. Each patient selected had to have taken CBCT in the initial examination and immediately after surgery. The membrane thickness, perforation rate, residual bone height, and elevated bone height were recorded and processed for statistical analysis.

Results: The mean thickness of the Schneiderian membrane was 1.78 ± 1.99 mm. There was a significant correlation between membrane thickness and perforation rate ($P < 0.05$), and the perforation rate was higher in thicker (≥3 mm) and thinner membrane (≤0.5 mm). Among the thickness group, Class B (between ≥1 and <2 mm) had the lowest perforation rate. No significant difference was between the perforation and the membrane morphology. A negative relationship between residual bone height and membrane thickness was found. Trend showed that in the thicker and the thinner residual bone height, the higher the perforation rate would be.

Conclusions: There was a significant correlation between membrane thickness and perforation rate. The perforation rate was lowest when the thickness was 1.5–2 mm.

Dental implant has become a popular treatment modality for replacing missing teeth. However, patients with edentulous ridge over posterior maxilla often suffered from insufficient bone height for dental implantation. Besides alveolar ridge resorption, maxillary sinus pneumatization exacerbated the situation. Sinus floor elevation technique had been proposed to overcome the insufficient bone height problem. It can be accomplished via either a lateral approach (Boyne & James 1980) or a crestal approach (Summers 1994), depending on the residual bone height and the possibility of achieving adequate primary implant stability (Wang & Katranji 2008).

High survival rate of dental implants placed into the grafted sinus had been reported (Wallace & Froum 2003; Pjetursson et al. 2008; Yamamichi et al. 2008; Del Fabbro et al. 2012) and compared favorably to those placed in the non-grafted posterior maxilla (Wallace & Froum 2003). Nonetheless, the complications do occur. The most common complication during sinus augmentation was membrane perforation (Vlassis & Fugazzotto 1999; Schwartz-Arad et al. 2004; Nkenke & Stelzle 2009). The incidence of perforation ranged from 20% to 44% in lateral approach and 0% to 25% in crestal approach (Katranji et al. 2008). A small tear in the membrane resulted in direct communication between the graft material and the contaminated sinus cavity. This can cause infection and chronic sinusitis, which could lead to loss of graft volume or implant failure (Katranji et al. 2008). The size of perforation was also suggested to be related to the prognosis of the implant (Hernandez-Alfaro et al.

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2008; Yilmaz & Tozum 2012). Risk factors associated with the membrane perforation besides surgical technique, septum (Ardekian et al. 2006; Becker et al. 2008; Hernandez-Alfaro et al. 2008), inadequate residual bone height (Yilmaz & Tozum 2012) and gingival phenotype (Yilmaz & Tozum 2012), membrane thickness (van den Bergh et al. 2000; Ardekian et al. 2006; Yilmaz & Tozum 2012) may also play an important role.

Previous studies investigated that the thickness of sinus membrane mostly were from cadavers (Tos & Mogensen 1979; Pommer et al. 2009). Tos & Mogensen (1979) reported the thickness of Schneiderian membrane ranging from 0.3 to 0.8 mm in 10 unfixed, fresh cadavers without signs of sinusitis. Furthermore, Pommer et al. (2009) revealed that the average thickness of normal mucous membrane of maxillary sinus was 0.09 mm. Due to the improvement of techniques and instruments, more studies measured the variables from living subjects. Aimetti et al. (2008) obtained mucosal specimen from healthy subjects through endoscope and found a mean thickness of 0.97 mm. Studies from computed tomography (CT) reported that the average sinus membrane thickness ranged from 0.8 to 1.99 mm (Pommer et al. 2012; Yilmaz & Tozum 2012; Anduze-Acher et al. 2013). Nevertheless, the inter-individual variety, shape description, measurement methods, and location differed greatly. Use of CBCT for 3-dimensional(3D) treatment planning was the recently recommended approach for sinus augmentation (Benavides et al. 2012; Harris et al. 2012). However, reports that quantified the thickness of sinus membrane with CBCT were limited (Janner et al. 2011; Shanbhag et al. 2014). Therefore, the aims of the present retrospective study were: to study the correlation between membrane thickness and perforation rate during transcrestal sinus lift and to propose a classification system of sinus membrane thickness based upon CBCT data.

Material and methods

Patients' selection

Data from subjects who received dental implant restorations over posterior maxilla with sinus lifting procedure in a private practice setting (S.-H. W.) between years 2010 and 2013 were retrospectively analyzed. Only patients who had treated sinus via transcrestal technique were enrolled in this study. Each patient selected had to have taken CBCT in the initial examination and immediately after surgery. Patients who presented ongoing periodontitis, sinus pathology, skeletal disorder, or taking medication that would influence bone metabolism were excluded. All patients received one or more dental implants with length ≥11.5 mm (TSV; Zimmer Dental Inc., Carlsbad, CA, USA) through transalveolar sinus floor elevation via sequential reaming (SCA kit; Neobiotech Co. Ltd, Seoul, South Korea) and bone graft (PUROS; Zimmer Dental Inc.) insertion.

Imaging procedure

The images were obtained with a KODAK-9000 3D Unit CBCT (Carestream Health, Inc., Toronto, Canada). The parameters of exposure were set at 10 mA, 70 kV for 32.4 s. For all CBCT images, a limited field of view (FOV) of 5 × 3 cm was selected. The data were reconstructed with slices at an interval of 200 μm.

Measurements of the images

Images were analyzed by specialized software (Kodak Dental Imaging Software 3D module V2.4.10) for linear measurement to the nearest 0.1 mm on the monitor with a resolution of 1440 × 900 pixels (Chimei Corporation, Tainan City, Taiwan).

Initial membrane thickness, residual bone height, and elevated bone height were measured in the coronal section and along the center of the implant site. The residual bone height was measured from the top of the alveolar crest to the sinus floor (Fig. 1). The membrane thickness was measured from the top of the membrane to the underlying sinus floor (Fig. 2). Elevated bone height was counted by subtracting between the post-surgical and initial ridge height (Fig. 3). Each site of transcrestal sinus lifting was considered as independent because Schneiderian membrane thickness was varied upon regions even in the same sinus cavity (Janner et al. 2011). Membrane morphology was categorized into three shapes (Fig. 4): flat, polyp, and irregular (ruffle border). Presence of perforation was checked during operation by direct visualization or Valsalva maneuver. CBCT that took immediately after surgery was also examined whether the dome-shape elevation in grafted area was maintained or not (Fig. 5).

Statistical analysis

Differences in the presence of perforation between membrane thickness groups and morphology groups were compared by Chi-square test. Linear regression was used to identify the correlation among membrane thickness, perforation rate, residual bone height, and elevated bone height. Statistical significance level was defined as $P \leq 0.05$. Analysis was performed by specialized software (Microsoft Excel 2010, Seattle, WA, USA).

Results

A total of 122 patients (43 males, 79 females) were included in this study. Mean age was 52.28 ± 12.40 years. Only four of them were smokers (3.28%). One hundred and

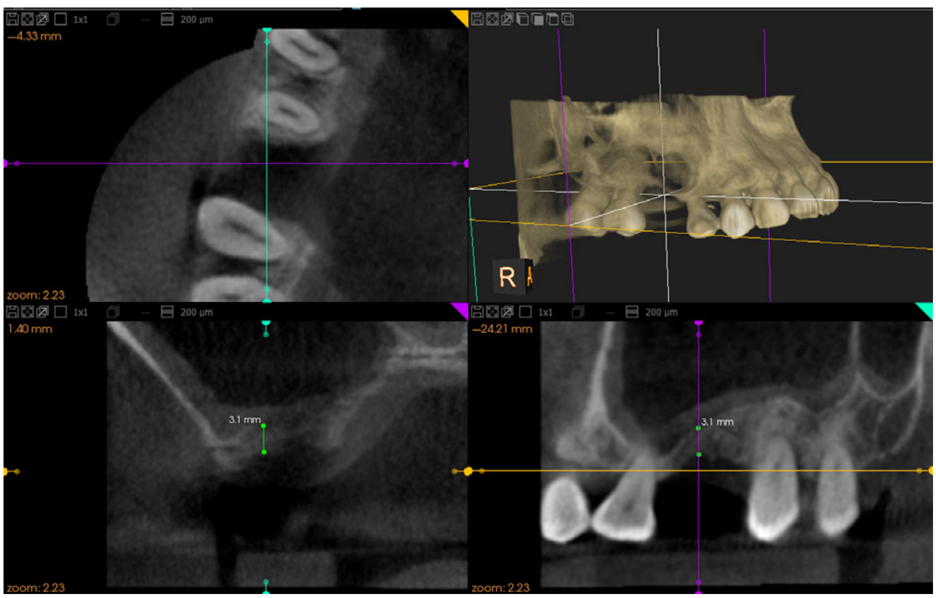

Fig. 1. Measurement of the residual bone height from the top of the alveolar crest to the sinus floor along the axis of the implant placement. The residual bone height is 3.1 mm as shown in green line.

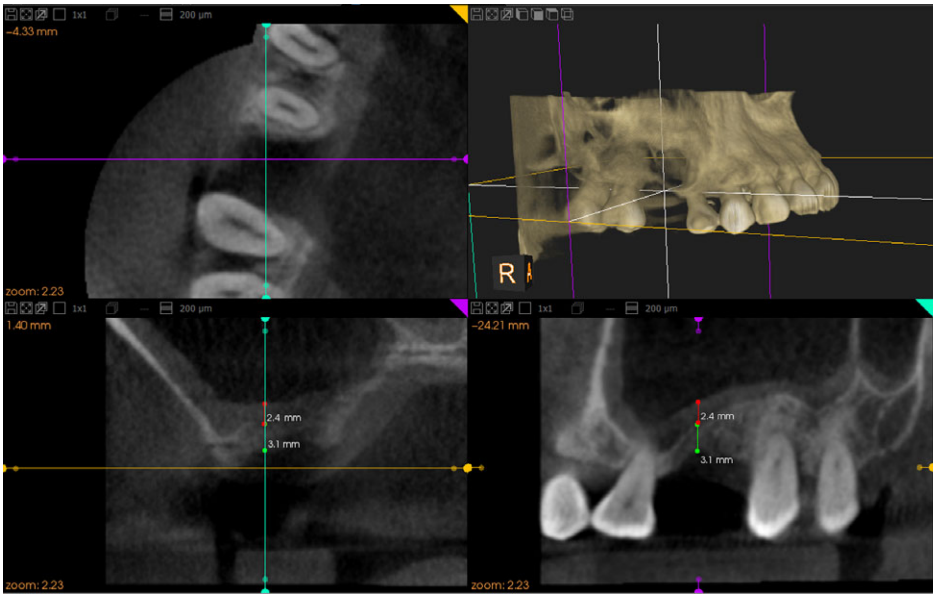

Fig. 2. The membrane thickness was measured from the top of the membrane to the underlying sinus floor along with the axis of implant placement. The thickness is 2.4 mm as shown in red line.

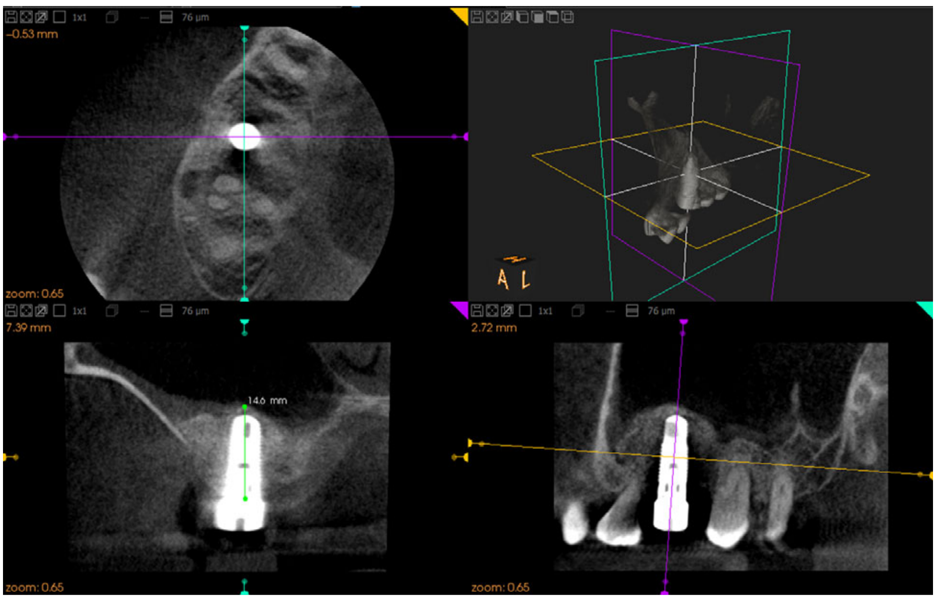

Fig. 3. Measurement of the bone height after transcrestal sinus lift and simultaneous implant placement. The post-surgical bone height is 14.6 mm as shown in green line. The elevated bone height was counted by subtracting between the post-surgical and initial bone height.

eighty-five transcrestal sinus lifting surgeries were performed with a mean residual bone height of 6.88 ± 2.98 mm. Through osteotomy by sequential reaming and bone graft insertion, the mean elevated bone height was 6.75 ± 3.59 mm.

The mean thickness of the Schneiderian membrane was 1.78 ± 1.99 mm with a median of 1.2 mm and range from 0.2 to 11.8 mm based on site-specific data. To the authors' best knowledge, there was no study that reported the classification system of Schneiderian membrane based on the thickness. Therefore, a classification system was proposed with three categories (Table 1): thickness <1 mm (A), between ≥1 and <2 mm (B), and ≥2 mm (C). Most of the thickness was ≤2 mm (75.14%). Besides, over than half of the membrane shapes were flat morphology (58.92%; Table 2).

Mean perforation rate was 17.30%. There was a significant correlation between membrane thickness and perforation rate (R^2 adjusted = 0.8416, $P = 0.011$). The perforation rate was lowest when the thickness was 1.5–2 mm and in category B (Table 1). However, the perforation rate increased abruptly when the membrane became thinner than 0.5 mm or thicker than 3 mm (Fig. 6). Although there was no significant difference between the perforation and the membrane morphology ($P = 0.099$), the perforation rate was highest in irregular shape (28.95%) and lowest in flat shape (13.76%; Table 2).

There was a negative relationship between residual bone height and membrane thickness although not significant ($P = 0.113$; Fig. 7). In most groups, the relationship was mild. However, it appeared that there was another trend (red dot imaginary line) with strong correlation.

Although there was no significant difference between perforation and residual bone height ($P = 0.996$), there was a tendency that in the higher (≥11 mm) and the lesser (<2 mm) residual bone height, the higher the perforation rate would be (Fig. 8).

Comparing the elevated bone height and the perforation, a significant higher elevated bone height was obtained in non-perforation group ($P = 0.002$). It showed 1.28 mm higher in average elevated bone height than perforated group (Table 3).

Discussion

As previous investigations, membrane thickness was an influencing factor for sinus perforation (Janner et al. 2011; Shanbhag et al. 2014). Shanbhag and coworkers examined the membrane thickness in patients being evaluated for dental implant in posterior maxilla. In their studies, CBCT scans of 128 patients and 199 sinuses were recruited. Because they considered that thickness >2 mm was pathological, membrane was categorized by degree of thickening (2–5, 5–10 mm, >10 mm). Besides, mucosal appearance was classified as normal, flat thickening, and polypoid thickening. They found that thickened sinus membranes (>2 mm) were highly prevalent (53.6%) in patients with missing posterior maxillary teeth (Shanbhag et al. 2014). In another CBCT study (Janner et al. 2011) with 143 patients and 168 images included, dimensions of the Schneiderian membrane were analyzed. Thickness of Schneiderian membrane exhibited a wide range (0.16–34.61 mm) with a mean value of 1.68 mm. Most frequent mucosal findings were flat thickenings (37%) based on the following classification (Soikkonen & Ainamo 1995):

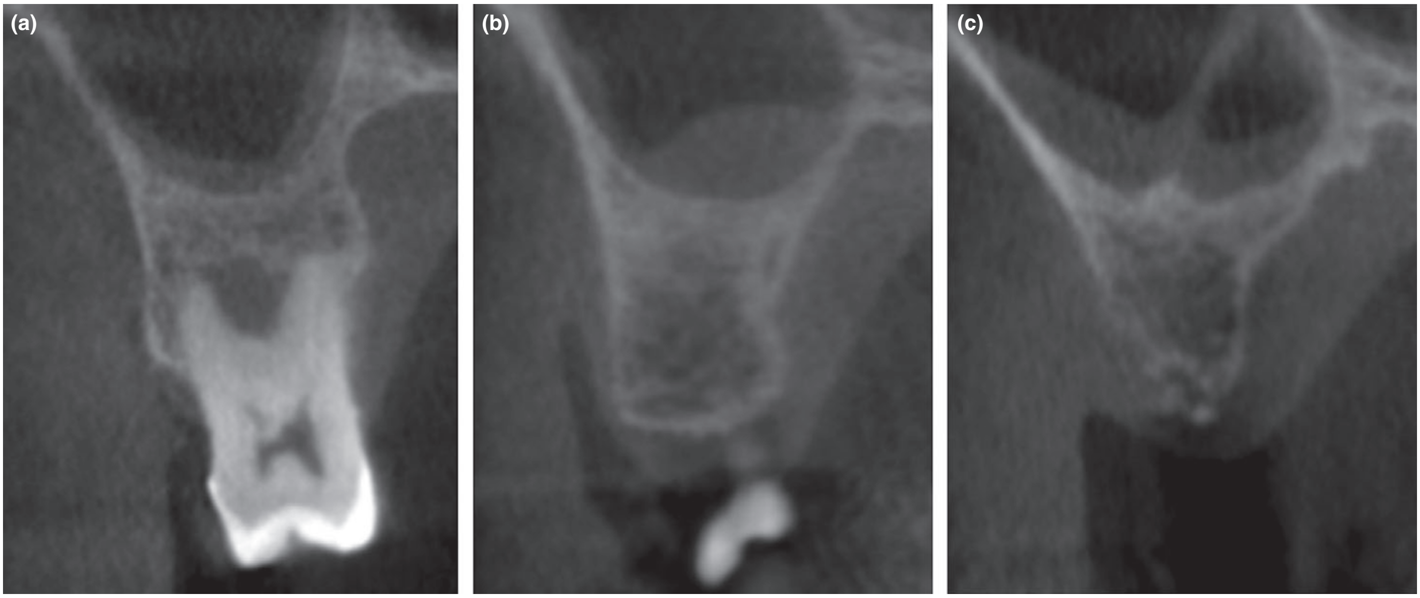

Fig. 4. Schneiderian membrane morphology in coronal section. (a) Flat type. (b) Polyp type. (c) Irregular type.

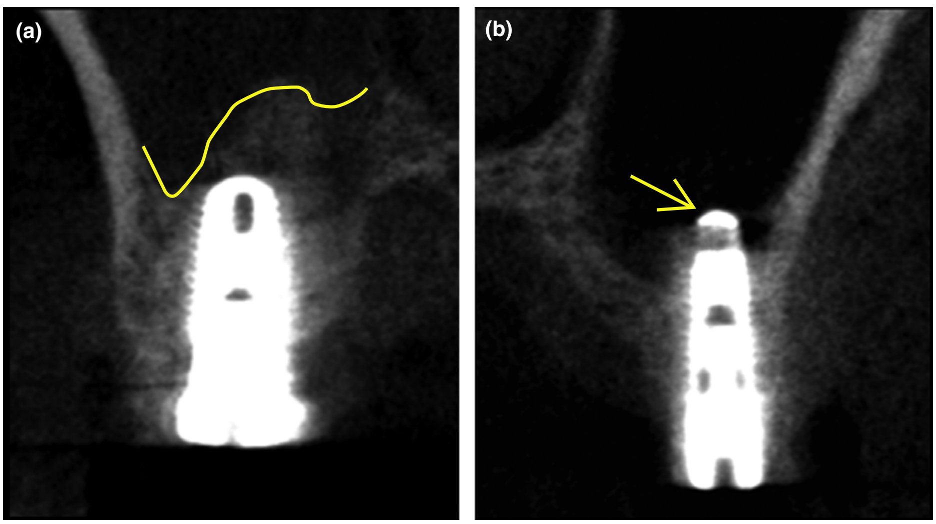

Fig. 5. CBCT scans of surgical site immediately after the procedure. (a) Presence of an intact Schneiderian membrane as indicated by the dome shaped appearance of the graft (yellow line). (b) Perforated Schneiderian membrane as indicated by the absence of graft apical to implant (arrow). Perforation was found after taking CBCT immediately after operation. We differentiated the perforation by the loss of dome shape in grafted area.

***Table 1.* Membrane thickness classification and perforation rate (*P* value by chi-square test: 0.610)**

Group	Membrane thickness	Mean ± SD (mm)	Max (mm)	Min (mm)	Percentage	Perforation rate (%)
A	<1 mm	0.64 ± 0.19	0.9	0.2	38.92	18.06
B	1 to <2 mm	1.36 ± 0.27	1.9	1.0	35.14	13.85
C	≥2 mm	4.07 ± 2.77	11.8	2.0	25.95	20.83

SD, standard deviation.

flat, semi-aspherical, mucocele like, mixed flat and semi-aspherical, and others. The mean thickness of the Schneiderian membrane in our study was 1.78 ± 1.99 mm, and also with a wide range (0.2–11.8 mm). Flat shape in membrane morphology was the most popular. The above findings resembled the results with Janner et al. However, 75.14% of our membrane thickness was ≤2 mm. This is different to the findings from Shanbhag et al., who noted that thickened membrane (>2 mm) was more prevalent. The reason for this difference is probably because the different populations were used for the study (India vs Chinese). It is generally believe that CBCT images are not accurate enough at the mm-scale. But CBCT has been widely used as a research tool to measure sinus membrane thickness (Janner et al. 2011; Shanbhag et al. 2014; Quirynen et al. 2014). To minimize this potential shortfall and to increase measurement accuracy, our CBCT data were reconstructed with slices at an interval of 200 μm, and all measurements were performed with a specialized software tool to the nearest 0.1 mm as well as to use 2.23× magnification to measure the membrane thickness.

Our results revealed a clear correlation between membrane thickness and perforation rate. As membrane became thinner or thicker, the perforation rate increased. From a cadaver study, the mechanical properties of Schneiderian membrane were explored. Thicker membranes demonstrated significantly higher load limits (Pommer et al. 2009). Hence, we can speculate that the thin membrane may not have sufficient mechanical property to resist elevated force or bone graft insertion. However, our results also showed that membrane with thickness that exceeded the twofolds of average values (>3 mm) had a high perforation rate. This may be because thick sinus membrane does not have structures, including pseudostratified columnar ciliated epithelium, lamina propria and periosteum-like connective tissue, with the same strength as in healthy status. It is also interesting to mention that based on our clinical experience, the perfora-

Table 2. **Membrane morphology classification and perforation rate (*P* value by chi-square test: 0.099)**

Group	Percentage	Mean membrane thickness mean ± SD (mm)	Perforation rate (%)
Flat	58.92	1.62 ± 1.71	13.76
Polyp	20.54	1.81 ± 1.99	15.79
Irregular	20.54	2.21 ± 2.60	28.95

SD, standard deviation.

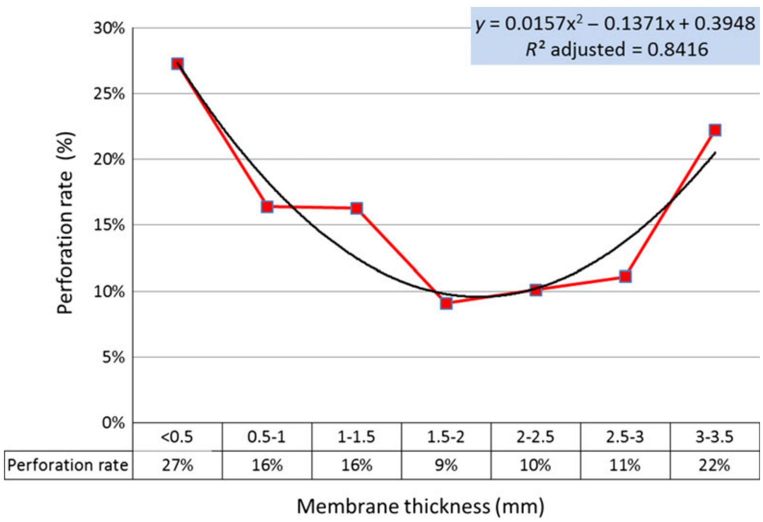

Fig. 6. Correlation between membrane thickness and perforation rate (R^2 adjusted:0.8416, $P = 0.011$).

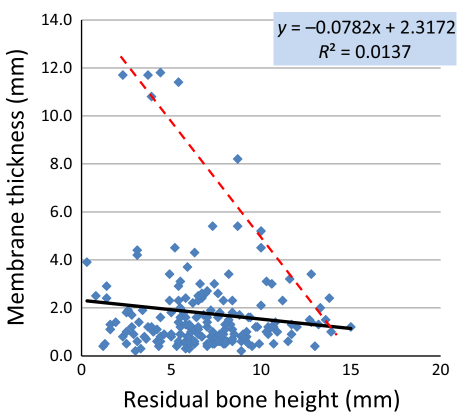

Fig. 7. The relationship between residual bone height and membrane thickness ($P = 0.113$). Red dot line is an imaginary line.

tion in thick type membrane usually happened during bone graft placement instead of osteotomy or membrane elevation.

Although an animal study documented the lack of influence of Schneiderian membrane in bone formation apical to implant simultaneously installed with sinus floor elevation (Scala et al. 2012), most believed that the sinus membrane had osteogenic potential (Srouji et al. 2009). New bone formation in the transalveolar technique does not only depend on pre-existing native bone surface of sinus floor (Tadjoedin et al. 2003; Avila-Ortiz et al. 2012), but also on the Schneiderian membrane (Lundgren et al. 2004). The perforation of the membrane prevented the primary coverage of the graft materials, hence the integrity of the membrane should be preserved as much as possible during surgical procedure.

Report showed that severe periodontal bone loss was significantly associated with mucosal thickening of the maxillary sinus, and the odds were threefolds (Phothikhun et al. 2012). This finding corresponded to our results that the lesser the residual bone height was, the thicker the sinus membrane would occur. Our study also demonstrated that perforation rate increased in thicker membrane situations. It has been shown that the absence of alveolar bone was the risk factor to membrane perforation during maxillary sinus augmentation (van den Bergh et al. 2000). Furthermore, Ardekian et al. 2006 found that in residual ridge of 3 mm, perforation of the sinus membrane occurred in 85% of cases, while in residual ridge of 6 mm, perforation of the sinus membrane was only noted in 25% of cases. A significant statistical correlation was found between the residual ridge height and the membrane perforation ($P < 0.01$). This may due to technical difficulties. Large area of the membrane needed to be freed from the lateral wall in lesser residual bone height (Ardekian et al. 2006). This result is in agreement with our study.

Most clinical studies reported that mean sinus elevation via crestal approach was 2–4 mm (Ferrigno et al. 2006; Nedir et al. 2006; Pjetursson et al. 2009). However, an endoscopic study revealed that the sinus floor could be successfully elevated up to 5 mm without perforating the membrane (Engelke & Deckwer 1997). In the cadaver study, the incidence of the perforation was increased when the level of the maxillary sinus membrane elevation was over 6 mm (Reiser et al. 2001). Following the improved techniques, osteotome is gradually replaced by other surgical methods that provoked less tapping-induced complications. Reaming approach is one of the techniques that do not torn the membrane during osteotomy. Besides, it can be used in the presence of antral septae, a main cause of perforation. In a cadaver study, a mean elevated bone height of 8.1 mm was obtained via reaming technique (Chan et al. 2013). A study using reamer-mediated transalveolar sinus floor elevation showed that

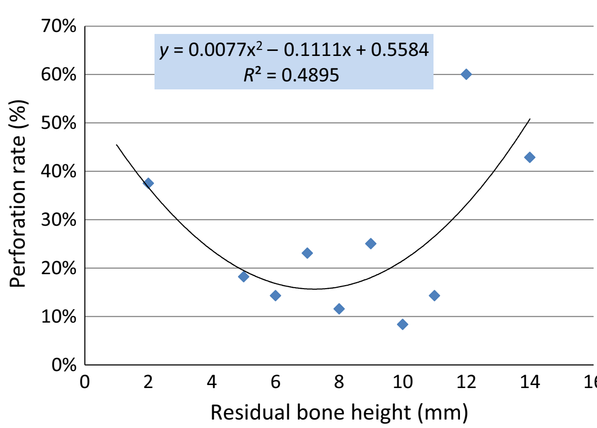

Fig. 8. The relationship between residual bone height and perforation rate.

Table 3. **Perforation vs. elevated bone height**

	n	Mean ± SD (mm)	*P* value (2-sample *T* test)
Perforation	32	5.69 ± 4.08	0.002
Non-perforation	153	6.97 ± 3.44	

SD, Standard deviation.

the mean elevation of the sinus floor was 6.2 mm (range 4–10 mm) (Ahn et al. 2012). Our data are in support of these findings.

In a systematic review, membrane perforation rate varied between 0% and 21.4%, with a mean of 3.8% in transalveolar sinus floor elevation (Tan et al. 2008). However, most study was only based on clinical observations, such as direct visualization and blow test, during operation. We took CBCT after surgery to confirm the dome shape over grafted area. Even that the membrane was intact during osteotomy, the perforation could occur during too much elevation and mask by the graft material. Therefore, we decreased the chance of underestimation by post-surgical CBCT examination. This may explain why we have membrane perforation rate higher than the other study that used sequential reaming during osteotomy (17.30% vs. 4.6%) (Ahn et al. 2012).

Conclusions

Membrane perforation is a common complication during sinus lifting procedure. Through our study, membrane thickness can be a causative indicator. A significant correlation between membrane thickness and perforation rate was identified. The perforation rate was lowest when the thickness was 1.5–2 mm. When the thickness was out of this range, perforation rate would increase two to threefolds. Future researches should collect more data to validate the proposed classification, so we can minimize sinus membrane perforation during surgery.

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