

Association Between Bone Graft Volume and Maxillary Sinus Membrane Elevation Height

Tetsuya Sonoda, DDS, PhD¹/Takehiro Harada, DDS, PhD²/Nobuyuki Yamamichi, DDS, PhD³/
Alberto Monje, DDS⁴/Hom-Lay Wang, DDS, MS, PhD⁵

Purpose: Maxillary sinus augmentation via crestal approach has been advocated as an alternative approach for sinus membrane elevation. Presently, no study has examined the relationship between the amount of bone grafting material placed and the final sinus membrane elevation height. Therefore, the present study was aimed at investigating the extent of sinus membrane elevation height depending on the amount of bone grafting material inserted as well as three-dimensionally assessing the likelihood of membrane perforation during membrane elevation. **Materials and Methods:** A total of 34 subjects (16 females and 18 males) with 61 crestal sinus elevation sites were recruited. The following changes in elevated sinus membrane area were recorded: vertical elevation height (VEH), buccopalatal elevation (BPE), and mesiodistal elevation (MDE). Cone beam computed tomography (CBCT) was used to measure the elevated height of the maxillary sinus floor at the initial examination, during surgery, and immediately after surgery. In addition, the VEH:BPE and VEH:MDE ratios at each site were calculated using CBCT to determine the probability of sinus membrane perforation. **Results:** In average, 0.1 mL of bone graft material placed elevated VEH an average of 3.5 mm, while 0.2 mL and 0.3 mL of graft placed elevated VEH 5 mm and 6 mm, respectively. Furthermore, it was demonstrated that the VEH:BPE and VEH:MDE ratios play a determinant role on membrane integrity. As such, a ratio greater than 1.0 may jeopardize membrane integrity, while a ratio ≤ 0.8 might represent a lower risk of membrane perforation. **Conclusion:** An initial 0.1 mL of bone material filling can elevate sinus membrane vertically by 3.5 mm. To avoid sinus membrane perforation, a VEH:BPE or VEH:MDE ratio of ≤ 0.8 should be obtained. *Int J Oral Maxillofac Implants* 2016 (6 pages). doi: 10.11607/jomi.5290

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Maxillary sinus bone augmentation was first introduced as the Cardwell-Luc method by Boyne and James in 1980 to overcome vertical ridge deficiency due to sinus pneumatization.¹ Since then, it has been performed by placing autologous bone and/or bone substitutes via the maxillary sinus lateral window.² In

1994, Summers described the osteotome technique to elevate the maxillary floor membrane through the crest of the alveolar ridge.³ Since then, this approach has been widely used due to its lower invasiveness and postoperative morbidity, as well as its better vascularization. Regardless of approach, both sinus augmentation procedures are safe and predictable, even though some complications might occur.^{4,5} Most of the reported complications are often associated with sinus membrane perforation,⁵⁻⁷ the incidence of which has been reported to be around 19.8%.⁸ Membrane perforation could lead to acute and chronic sinus infection, swelling, bleeding, loss and infection of the graft material, or disruption of normal sinus function.⁹⁻¹¹ The incidence of membrane perforation is related not only to the clinician's ability, but also to sinus anatomy (ie, septa or acute palatonasal recess).¹²⁻¹⁴

For crestal sinus augmentation (ie, osteotome) approach, one major drawback is the inability to know what actually happens inside the sinus cavity. Therefore, this approach relies largely on a surgeon's experience.¹⁵ It has been reported that there are four time

¹Private Practice, Fukuoka, Japan.

²Private Practice, Fukuoka, Japan.

³Private Practice, Fukuoka, Japan.

⁴Graduate Student and Research Fellow, Graduate Periodontics, Department of Periodontics and Oral Medicine, University of Michigan School of Dentistry, Ann Arbor, Michigan, USA.

⁵Professor and Director of Graduate Periodontics, Department of Periodontics and Oral Medicine, University of Michigan School of Dentistry, Ann Arbor, Michigan, USA.

Correspondence to: Dr Hom-Lay Wang, Department of Periodontics and Oral Medicine, University of Michigan School of Dentistry, 1011 North University Avenue, Ann Arbor, MI 48109-1078, USA. Fax: (734) 936-0374. Email: homlay@umich.edu

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Fig 1 Three-dimensional radiographic measurement methodology for VEH:BPE and VEH:MDE ratio determination. VEH = vertical elevation height; BPE = buccopalatal elevation; MDE = mesiodistal elevation.

points that might trigger tearing of the sinus membrane during crestal sinus augmentation surgery: (1) at the time of site preparation; (2) during sinus floor bone greenstick fracture; (3) at the time of bone graft placement; and (4) during implant insertion. As such, when the membrane is perforated, the filled bone grafting material might migrate into the maxillary sinus and trigger postoperative complications such as infection.

Many tools and techniques (eg, piezosurgery, balloon, hydrolic pressure, reamers, instruments) have been developed to overcome the concern of membrane perforation; however, the most common and widely accepted approach is still a combination of the osteotome instrument and bone graft to elevate the sinus membrane.⁸ In an attempt to minimize sinus membrane perforation, it is essential to know the required amount of bone graft material associated with the extent of vertical bone height elevation. Furthermore, with the development of cone beam computed tomography (CBCT), the clinicians can have a better idea of sinus anatomy prior to the surgery, which can significantly minimize procedure complication rates.¹⁶

Hence, the purpose of this study was to use CBCT to determine the amount of bone graft material needed to successfully elevate the sinus floor via crestal approach while maintaining the sinus membrane integrity.

MATERIALS AND METHODS

Subject Recruitment

Subjects who were in need of sinus augmentation to increase vertical bone height for implant-supported prostheses were recruited for this two-center study. The study was conducted according to the Declaration of Helsinki.¹⁷ Prior to patient enrollment, the treatment procedure, potential risks, and need for obtaining several CBCT scans were discussed and the consent forms obtained. Patients were informed about the risks of the study, especially the radiation dosage. The patient inclusion criteria were: patients ≥ 18 years old; nonsmokers; without presence of systemic infectious

diseases at the time of implant insertion; and no serious medical diseases or conditions known to alter bone formation. In addition, patients who presented ongoing periodontitis, sinus pathology, skeletal disorder, or taking medication that would influence sinus membrane integrity as well as bone metabolism were excluded. Sites included in the study had to possess the following conditions: ≥ 5 -mm and < 9 -mm bone height had to be present¹⁸; CBCT showed buccopalatal wall distance of 10–15 mm at 5 mm above the sinus floor; and no presence of local septa. This was to ensure the buccopalatal wall distance variation did not influence the outcome. In addition, if the membrane thickness was more than 3 mm, it was not included in the study to minimize the potential influence.

Image Acquisition and Measurements

All radiographic images were obtained with a CBCT machine (PreVistaR, Kyocera Medical). The parameters of exposure were set at 10 mA, 70 kV for 32.4 seconds. 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 μ m. A total of 61 sites were examined by CBCT with 0.1 mL of filling for 13 sites, 0.2 mL of filling for 22 sites, and 0.3 mL of filling for 26 sites. The graft particle size used in this study was 250–850 μ m. The following changes in elevated sinus membrane area were recorded: vertical elevation height (VEH), buccopalatal elevation (BPE), and mesiodistal elevation (MDE). CBCT was used to measure the elevated height of maxillary sinus floor at the initial examination, during surgery, and immediately after surgery. In addition, the VEH:BPE and VEH:MDE ratios at each site were calculated to determine the probability of sinus membrane perforation. Sagittal and cross-sectional images were combined and converted. Maximum MDE was measured on a sagittal image while maximum BPE and VEH were assessed on a cross-sectional image (Fig 1). All measurements were done by a single trained radiologist (T.H.) using the scale that comes with CBCT.

Table 1 Results of Elevated Measurements at 0.1 mL, 0.2 mL, and 0.3 mL of Bone Material Substitute

	0.1 mL					0.2 mL					0.3 mL				
	VEH	BPE	VEH/ BPE	MDE	VEH/ MDE	VEH	BPE	VEH/ BPE	MDE	VEH/ MDE	VEH	BPE	VEH/ BPE	MDE	VEH/ MDE
Mean (mm)	3.7	6.51	0.62	6.25	0.64	4.95	8.2	0.61	7.77	0.65	5.84	9.54	0.62	9.78	0.61
SD	1.08	1.45	0.37	1.53	0.36	0.88	1.07	0.13	1.18	0.15	0.81	1.09	0.12	1.41	0.13

VEH = vertical elevation height; BPE = buccopalatal elevation; MDE = mesiodistal elevation; SD = standard deviation.

Surgical Procedure

The surgeries were performed by a single experienced surgeon (T.S.) to ensure the consistency and quality of the surgeries performed. After proper anesthesia, the sites were fully reflected by crestal incision and periosteal elevation. Each site was then prepared using a 3.7-mm diameter drill up to 1 mm away from the maxillary sinus floor. Piezosurgery instrument was used to remove the remaining 1 mm of bone, and the sinus membrane was then carefully elevated with a 3.3-mm diameter osteotome instrument. After confirming that the sinus membrane was intact (using the Valsalva maneuver),¹⁹ bone substitute materials (mixture of 1:1 ratio of hydroxyapatite [HA, OsteoGen, Implants Ltd]) and demineralized freeze-dried bone (Salvin Dental) were used as graft materials. Precise amounts of 0.1 mL, 0.2 mL, or 0.3 mL were aspirated by syringe and filled in the implant bed. Then, the filling was pushed gently into the sinus cavity by the osteotome instrument. Subsequently, sites were closed following tension-free suture.

RESULTS

Study Data

Overall, 34 subjects were recruited (16 females and 18 males), and 61 sites fulfilled the inclusion criteria: 9 in first premolar site, 11 in second premolar site, 20 in first molar site, and 21 in second molar site. Mean \pm standard deviation (SD) bone height in the selected areas was 6.51 ± 1.2 mm.

Association Between Bone Graft Volume and Vertical Elevation Height

The amount of bone graft placed (0.1 mL, 0.2 mL, and 0.3 mL) resulted in an average of 3.7 mm, 4.95 mm, and 5.84 mm, respectively, of VEH (Table 1). Moreover, as the filling amount increased from 0.1 to 0.2 to 0.3 mL, the gained vertical height per additional 0.1-mL graft material decreased from 3.7 mm to 1.25 mm and to 0.89 mm, respectively. Therefore, roughly 0.1 mL of bone graft material can gain about 3.5 mm of

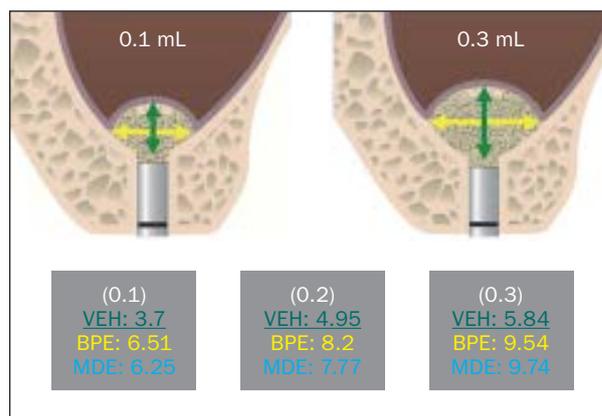


Fig 2 Membrane elevation height associated with bone grafting material inserted.

elevation, 0.2 mL can gain about 5 mm, and 0.3 mL can gain about 6 mm of elevation (Fig 2).

Incidence of Membrane Perforation

With 0.1 mL and 0.2 mL of graft material, all cases were dehiscence free and no infections were detected. Membrane perforation was noted in one subject (two sites) in the 0.3-mL group (4.9%).

Association Between Three-Dimensional Graft Elevation Height and Membrane Perforation

The average VEH:BPE and VEH:MDE ratios with 0.1 mL of graft material were 0.62 ± 0.37 and 0.64 ± 0.36 , respectively. These ratios did not change significantly when 0.2 mL or 0.3 mL of bone graft materials were filled. With 0.1 mL of bone graft material, only 8 out of 61 cases revealed a VEH:BPE or VEH:MDE ratio higher than 0.8 (Table 2, Fig 3).

The VEH:BPE and VEH:MDE ratios displayed no problems at 0.2 mL and 0.3 mL of bone graft material cases; however, these cases showed VEH:BPE and VEH:MDE ratios from 0.4 to 0.8. Hence, this value should be considered the key to surgical success. Similarly, at 0.1 mL of bone substitute material, when VEH:BPE or VEH:MDE ratio was from 0.4 to 0.8, no membrane perforation

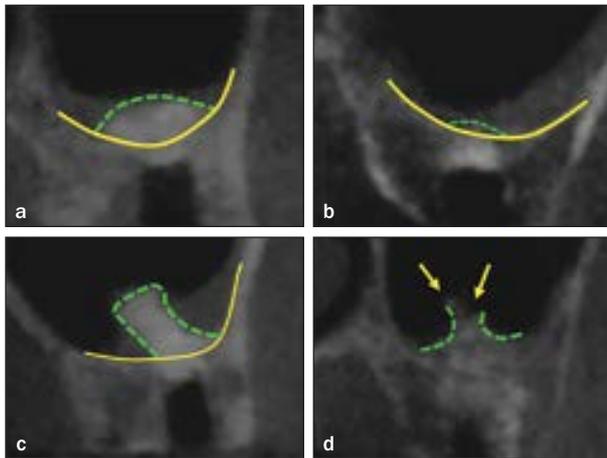


Fig 3 Clinical scenarios affect amount of sinus augmentation vertical bone gain and sinus membrane integrity. (a) Type I: The osteotome was inserted in greenstick fracture perpendicular to the sinus floor, and major vertical gain can be easily obtained forming a mushroom shape image. The membrane can be smoothly elevated without any problem, even with the largest amount (0.3 mL) of bone graft material. (b) Type II: The osteotome was inserted in greenstick fracture but not totally perpendicular to the sinus floor, and minor vertical gain can be obtained. The area of greenstick-fractured sinus floor is not wide enough to allow graft material to fill into a sinus antrum. Refilling graft material after another attempt of greenstick fracture is needed unless the implant bed may be obturated with graft material. (c) Type III: The osteotome was inserted in greenstick fracture perpendicular to the sinus floor, and major vertical gain can be obtained. However, the mucosal membrane cannot be completely detached, and a distorted shape is formed. The area of sinus floor around the implant bed in the extraction socket is not detached, but only a very limited area on the apex of the implant is vertically elevated. This is a high-risk approach, and it is suggested that implant insertion into the sinus should be limited to one thread or that the technique be switched to the lateral window approach. (d) Type IV: Due to a VEH:BDE or VEH:MDE ratio of ≥ 0.8 at the time of 0.1-mL bone-grafting material insertion, membrane integrity is damaged. The crestal approach should be discontinued and the lateral window approach used instead. Yellow lines = floor of sinus membrane; green lines = graft placed.

Table 2 VEH:BPE and VEH:MDE Ratios to Predict Potential Sinus Membrane Perforation

VEH/BPE or VEH/MDE ratio	≤ 0.8	> 0.8
Risk for sinus membrane perforation	Low	High
Safety	High	Low

VEH = vertical elevation height; BPE = buccopalatal elevation; MDE = mesiodistal elevation.

was noted. Based on the present authors' past clinical experience, membrane perforation only occurred when the VEH:BPE or VEH:MDE ratio was more than 0.8 (even with 0.1 mL of graft material insertion). Hence, the ratio of ≤ 0.8 should be adopted as the cutoff ratio to avoid any sinus membrane perforations.

DISCUSSION

Successful maxillary sinus membrane elevation can be predictably achieved as long as no surrounding anatomical barriers, such as septum, membrane adhesion, sinus pathology, or blood vessels, are present on the surgical field.^{7,20} A mushroom shape of sinus floor form has been regarded as an important clinical indicator of intact sinus membrane after crestal sinus augmentation. Nonetheless, the achievable elevation height via osteotome is often limited due to potential membrane perforation.^{21,22} If this happens, bone graft migration to the sinus antrum, acute or chronic sinus infection, bacterial invasion, or disruption of the normal sinus physiologic function might occur.^{23–25} To recognize the optimal amount of graft filling material to obtain the required vertical height for standard-length implant placement, it is essential to minimize membrane perforation as well as related future sinus complications. Furthermore, besides the technical factors, detachment of the sinus mucosal membrane is further influenced by mucosal adhesion, sinus cavity shape, presence of blood vessels, and other anatomical variations.²³ Hence, understanding the maxillary sinus anatomy through a three-dimensional examination (eg, CBCT) is essential to foresee this complexity and to curtail any risks associated with potential membrane perforation. These findings indicate that (1) 0.1 mL of bone substitute material can gain an average of 3.5 mm of VEH, 0.2 mL can gain about 5 mm, and 0.3 mL can gain about 6 mm; and (2) the VEH:BPE or VEH:MDE ratio plays an important role in predicting the integrity of the sinus membrane. Accordingly, a ratio of > 0.8 might possess a higher risk of sinus membrane perforation (Fig 4a), while a ratio of ≤ 0.8 could indicate a low risk of membrane perforation (Fig 4b).

During sinus augmentation, 2 mm of additional bone height above the implant apex is often recommended to prevent future bone resorption.²⁶ Results from the present study show the estimated amount of grafting material needed to obtain precise membrane elevation. Simplifying these findings, one implant thread (1-mm height) in the maxillary sinus requires an average amount of 0.1 mL of bone graft material (which will result in 3.5 mm of vertical elevation). The literature often recommends a minimum of 5 mm of vertical residual bone height for safely performing crestal sinus approach predictably.¹⁸ From the present data and considering at least 5 mm of remaining vertical bone height, 0.3 mL of bone graft material should be able to achieve a reliable vertical elevation of 6 mm, which can be applied to almost all standard-length implant cases (eg, implant length of ≥ 10 mm).¹⁸ As reported, when the bone graft was increased from 0.1 mL to 0.3 mL, there was no significant change in the ratios.

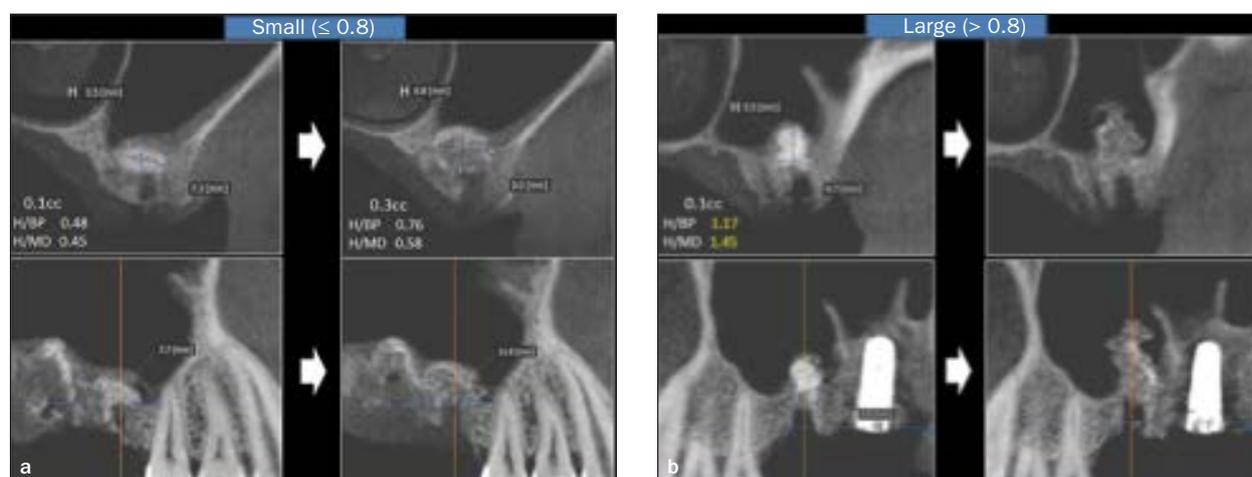


Fig 4 VEH:MDE ratio plays a determinant role on membrane integrity; (a) a ratio ≤ 0.8 represents a lower risk of sinus membrane perforation during crestal sinus augmentation and (b) a ratio > 0.8 may jeopardize sinus membrane stability during crestal sinus augmentation.

Therefore, maxillary sinus mucosal membrane was elevated not only vertically but also buccopalatally and mesiodistally. In this sense, it must be highlighted that certain anatomical features may impact the bone graft volume; for instance, while in the presence of a narrow mesiodistal distance, less graft volume may achieve greater VEH, and in the presence of a wider mesiodistal distance, greater volume may be required to reach the desired VEH. Furthermore, membrane thickness and adherence also play a role in membrane perforation, and to minimize this influence, only patients with sinus membrane ≤ 3 mm were selected. However, there is no actual way to examine the impact of membrane adherence on membrane perforation since there is currently no actual mechanism to assess this clinical condition.

In this study, for sinus floor access, piezosurgery was the preferred choice since the piezo instrument is less likely to damage soft tissues and hence can significantly reduce the odds of sinus membrane perforation.^{4,9,27,28} With this device, a very thin bone can be left as a trapdoor within the osteotomy, and so it is much easier to place the bone grafting materials (as a cushion and a protective layer) to successfully elevate the sinus floor vertically.

One of the major limitations of this study is the risk of radiation overexposure due to the need for taking various CBCT scans to measure the dimensional changes during the procedure. As has been demonstrated, one CBCT exposure will lead to approximately 0.037–0.09-mSv vs 0.0163–0.0391-mSv radiation in

one periapical film.¹⁶ Curiously, this radiation is minimal, being roughly similar with what is absorbed of daylight over the course of one day.¹ Thus, the benefits of getting one extra CBCT scan may outweigh the aforementioned risk, since CBCT can adequately prevent postsurgical infection, avoid damage to vital structures, prevent membrane perforation, and safeguard patient's safety.

CONCLUSIONS

Within the limits of this study, it can be concluded that for every 0.1 mL of bone material filling, sinus membrane vertical height can be elevated by 3.5 mm. This is particularly important in predicting the prognosis of sinus augmentation procedures, since complications derived from perforation might be potentially avoided. In moderate reabsorbed posterior ridges, 0.3 mL of bone graft material can consistently achieve 6 mm of vertical height, which allows placement of standard-length dental implants (≥ 10 mm). To avoid sinus membrane perforation, VEH:BPE and VEH:MDE ratios of ≤ 0.8 should be obtained.

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