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Clinical Study on Applicability of Sinus Floor Augmentation Surgical Technique by Evaluating Postoperative Bone Absorption Around the Dental Implants

Jun SONOYAMA[1,2], Hiroyuki INOUE[1,3], Koji TSUNEMATSU[1,4], Aya YOSHINO[1], Takahiro KANNO[1], Yoshiki NARIAI[1,5] and Joji SEKINE[1]

[1]*Department of Oral and Maxillofacial Surgery, Shimane University Faculty of Medicine, 89-1 Enya-cho, Izumo, Shimane 693-8501, Japan*

[2]*Sono Prosthodontic Laboratory, 5-6-2 Koshibara, Matsue, Shimane 690-0012, Japan*

[3]*Inoue Dental Clinic, Implant Center Hokkaido, 12-2 Minami 2-chome Nishi 9-jyo, Obihiro, Hokkaido 080-0019, Japan*

[4]*Department of Oral and Maxillofacial Surgery, National Hospital Organization Hamada Medical Center, 777-12 Asai-cho, Hamada 697-8511, Japan*

[5]*Division of Oral and Maxillofacial Surgery, Matsue City Hospital, 32-1 Noshiro-cho, Matsue 690-8509, Japan*

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We assessed the applicability of the surgical procedure for maxillary sinus floor augmentation prior to dental implant（DE）placement. Our subjects comprised 40 patients receiving DEs: 28 without bone augmentation（WBA）and 25 with maxillary sinus floor augmentation. The crestal approach（CA）and lateral approach（LA）were used in 12 and 13 patients, respectively, based on the residual bone height（CA: ≥6 mm, LA: <4 mm）. DEs were placed following bone augmentation. Bone absorption was measured using radiographs of DEs' shoulder and tip taken immediately after DE placement and at 1 year and 3 years postoperatively. No significant differences between CA and LA were noted. Applicability of the surgical technique for sinus floor augmentation should be decided based on the residual bone volume of the posterior maxilla.

Key words: sinus floor augmentation, bone absorption, atrophy, maxilla, dental implant

Corresponding author: Joji Sekine, D.D.S., Ph.D., FIBCSOMS
Department of Oral and Maxillofacial Surgery, Shimane University Faculty of Medicine, 89-1 Enya-cho, Izumo, Shimane 693-8501, Japan
Tel: +81-853-20-2301
Fax: +81-853-20-2299
E-mail: georges@med.shimane-u.ac.jp

INTRODUCTION

Dental implants（DEs）are a reliable method for the replacement of missing teeth in edentulous patients with an adequate bone volume in terms of height and width. Inadequate alveolar bone volume is a common limitation for DEs in the posterior maxilla since advanced absorption following premature tooth loss is frequently accompanied by pneumatization of the maxillary sinus［1］. A number of sinus floor augmentation techniques have been proposed to overcome these problems［2-5］, such as the crestal approach（CA）and lateral approach（LA）, which are chosen depending on the existing residual bone height.

CA is an expansive osteotome technique through the alveolar ridge, which allows bone compression by gentle pushing and tapping of the osteotome, whereby the adjacent bone layer can be compressed and the sinus floor membrane elevated（Fig. 1）. The LA technique has been reported to result in a significantly larger increase in bone height than the CA technique［2-4, 6, 7］. In LA, a bone window is created in the lateral sinus wall with a small round bur, with the aim of leaving the sinus membrane intact. The sinus membrane is then carefully elevated, and the resected bone window is replaced（Fig. 2）. However, the precise indications for these two maxillary sinus floor augmentation procedures have remained controversial with respect to the recon-

struction of the posterior maxilla in conjunction with simultaneous or delayed placement of DEs [6, 7].

Schlegel *et al* [8] reported that a bone height of 5-6 mm is required for DE placement in the posterior maxilla. When the panoramic radiograph shows a bone height less than 4 mm during the initial diagnosis, two-phase DE placement through sinus floor augmentation by LA is recommended [9]. If the residual bone height is between 4 and 6 mm, one-phase sinus floor augmentation by CA is recommended. However, sinus floor augmentation using CA is also suggested if the residual bone height is greater than 6 mm [9]. Although different surgical techniques for sinus floor augmentation can be used depending on the residual bone height, the indications of these two techniques remain controversial.

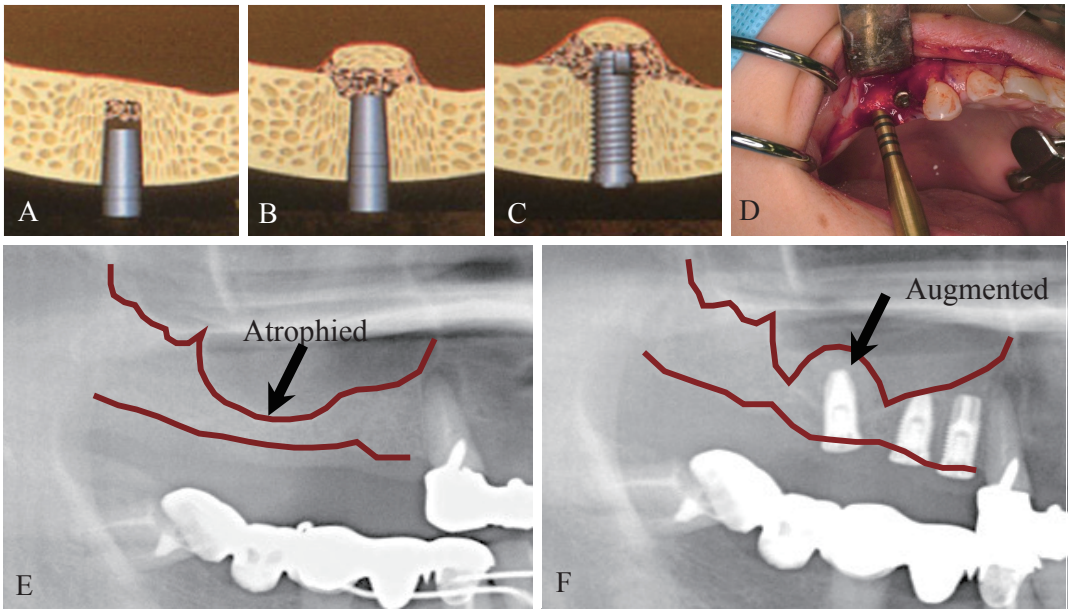

Fig. 1. Sinus floor augmentation by the crestal approach (CA)
A. First procedure of CA, creating the socket for dental implant placement using osteotome, B. Second procedure of CA: Elevating the sinus floor with grafting materials, C. Final step of CA, D. Intraoperative view of CA, E. Preoperative panoramic radiograph of the right posterior maxilla showing atrophy, F. Postoperative panoramic radiograph of CA and dental implant placement showing the augmented area.

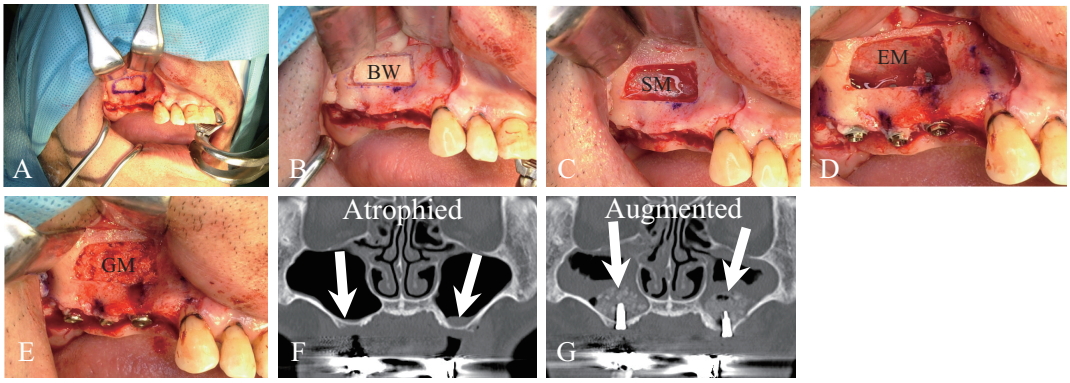

Fig. 2. Surgical procedure of lateral approach (LA)
A. Exposure of the right lateral wall of the maxillary sinus, B. Preparation of the bone window, C. Removal of the bone window and lateral surface of the maxillary sinus membrane, D. Elevated maxillary sinus membrane, E. Grafting materials, F. Preoperative CT image (frontal view, white arrows show atrophied maxillary sinus floor), G. Postoperative appearance of LA showing grafted materials and dental implants (white arrows).

In both techniques, some types of material, such as autogenous bone and/or biomaterials, are grafted into the surgically created spaces of the maxillary sinus floor. Recently, a technique for bone reformation with sinus floor elevation without using grafting materials has been established [1]; however, marginal bone resorption occurs up to 1 mm immediately after DE loading [10-12]. Given these gaps in knowledge and residual problems, a detailed analysis of bone remodeling following sinus floor elevation would help to improve the stability of DEs and patients' quality of life. Recently, three-dimensional finite element analysis has been applied to evaluate implant stability [13]. However, few reports have examined the effects of sinus floor augmentation on bone remodeling [14].

This retrospective study aimed to clarify the applicability of surgical bone augmentation in patients with an atrophied posterior maxilla by evaluating preoperative residual bone volume and postoperative bone absorption.

PATIENTS AND METHODS

Participants

We assessed 141 DEs in 40 patients (10 men and 30 women; mean age, 58 years) performed at the Inoue Dental Clinic, Implant Center Hokkaido, Obihiro, Japan, an affiliated organization of Department of Oral and Maxillofacial Surgery, Shimane University Hospital, between July 2002 and September 2008.

This clinical retrospective investigation was performed in accordance with the Declaration of Helsinki. In all patients, informed consent was taken according to written and verbal form prepared by the Inoue Dental Clinic, Implant Center Hokkaido. This study did not require approval of the authors' Institutional Review Board, because it was performed using unlinked, anonymous information from the clinic database of Inoue Dental Clinic, Implant Center Hokkaido. The unlinked anonymity of the patients was ensured by the president of Inoue Dental Clinic, Implant Center Hokkaido.

Surgery

In 28 patients (44 sides), DEs were placed without bone augmentation (WBA). Maxillary sinus floor augmentation was performed in 25 patients: CA was indicated in 12 patients (14 sides), while LA was performed in 13 patients (20 cases). WBA and CA in 6 patients and WBA and LA in 7 patients were included in the analysis (Table 1). DE placement was performed simultaneously following bone augmentation using a 70:30 mixture of autogenous bone and anorganic bovine hydroxyapatite (Bio-Oss, Geistlich Pharma, Wolhusen, Switzerland). All the cases were operated by the same maxillofacial surgeon.

DEs used this study were the Brånemark System™ MKIII TiUnite™ with the length of at least 10 mm (Nobel Biocare, Göteborg, Sweden). In all cases, abutment was connected at 6 months after DE placement, and the temporary prosthesis was applied within 1 week postoperatively.

Table 1. Characteristics of the subjects and surgeries
LA: lateral approach, CA: crestal approach, WBA: without bone augmentation, DEs: dental implants

Surgery	No. of procedures	No. of sites	No. of DEs
LA	13	20	45
CA	12	14	21
WBA	28	44	75
Total	53	78	141

Measurement of bone volume and absorption

The following 3 points were measured using panoramic radiographs: (1) vertical bone height between the top of the alveolar ridge and the maxillary sinus floor before DE placement; (2) vertical length between the tip of the placed DE and the top of the elevated sinus floor (preoperatively, immediately after DE placement, and at 1 year and 3 years after DE placement); and (3) vertical and horizontal bone absorption around the platform of the DE (preoperatively, immediately after DE placement, and at 1 year and 3 years after DE placement). Measurement #3 was divided into 2 components: above the alveolar ridge (AA) and beneath the alveolar ridge (BA), according to the relationship of the alveolar ridge and the top of the DE (Fig. 3).

Statistical analysis

Statistical comparisons between two groups were performed using unpaired *t*-test, while those between three groups were performed using the Kruskal-Wallis test (JMP ver. 9.0.0, SAS Institute, Cary, NC).

RESULTS

Bone volume and absorption

1. Vertical bone height between the top of the alveolar ridge and the maxillary sinus floor before dental implant placement

The vertical length between the top of the alveolar ridge and the floor of the maxillary sinus before DE placement was 12.8 mm (mean) in WBA, 5.92 mm in CA, and 4.11 mm in LA cases (Fig. 4).

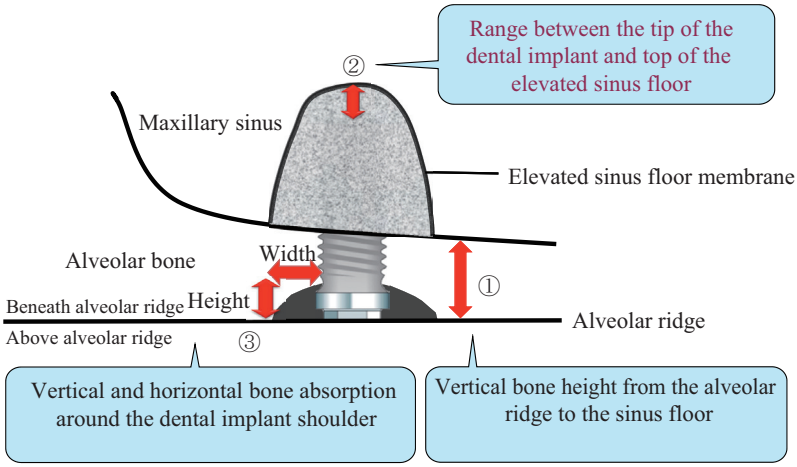

Fig. 3. Measurement of bone volume and reduction
Bone volume was evaluated using preoperative and postoperative panoramic radiographs.

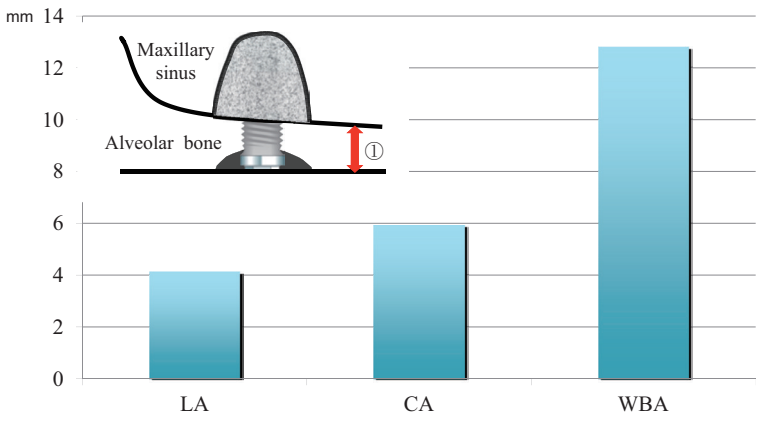

Fig. 4. Preoperative vertical residual bone height in each procedure
LA: lateral approach, CA: crestal approach, WBA: without bone augmentation

2. Vertical bone height between the tip of the placed dental implant and the top of the elevated sinus floor

The vertical length between the tip of the placed dental implant and the top of the elevated sinus floor was 2.27 ± 1.11 mm (mean ± SD) in CA and 2.30 ± 1.22 mm in LA cases. In CA, the bone volume reduced by 0.68 ± 0.59 mm (reduction rate (RR): 30.0%) at 1 year postoperatively and 1.10 ± 0.47 mm in total (total RR: 48.5%) at 3 years postoperatively. In LA, the bone volume reduced by 0.43 ± 0.50 mm (RR: 18.7%) at 1 year and 0.89 ± 0.40 mm in total (total RR: 38.7%) at 3 years postoperatively. No statistically significant differences were noted between the CA and LA cases (Fig. 5).

3. Vertical and horizontal bone absorption around the shoulder of the dental implant

In WBA, for AA, the vertical bone loss was 0.76 ± 0.67 mm at 1 year and 1.14 ± 0.54 mm in total at 3 years postoperatively. Horizontally, the bone loss was 0.63 ± 0.54 mm at 1 year and 0.92 ± 0.42 mm in total at 3 years postoperatively. For BA, the vertical bone loss was 0.46 ± 0.34 mm at 1 year and 0.60 ± 0.40 mm in total at 3 years postoperatively, while horizontally, it was 0.46 ± 0.4 mm at 1 year and 0.60 ± 0.40 mm in total at 3 years postoperatively. No statistically significant difference was noted between these two groups (Fig. 6).

In CA, for AA, the vertical bone loss was 0.47

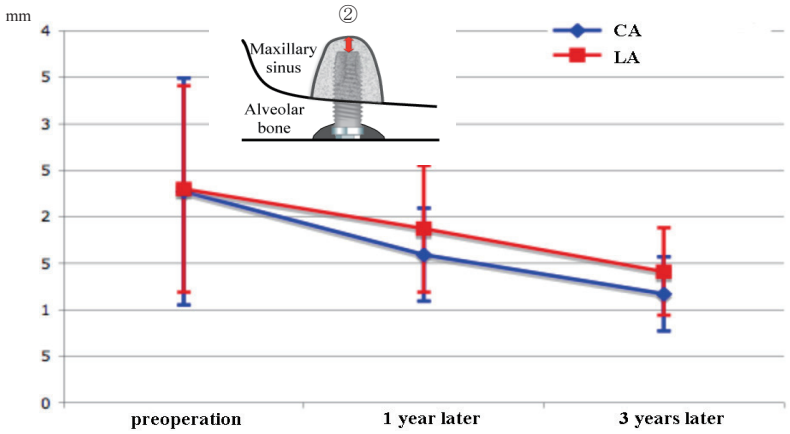

Fig. 5. Bone absorption between the tip of the dental implant and the top of the elevated sinus floor
LA: lateral approach, CA: crestal approach

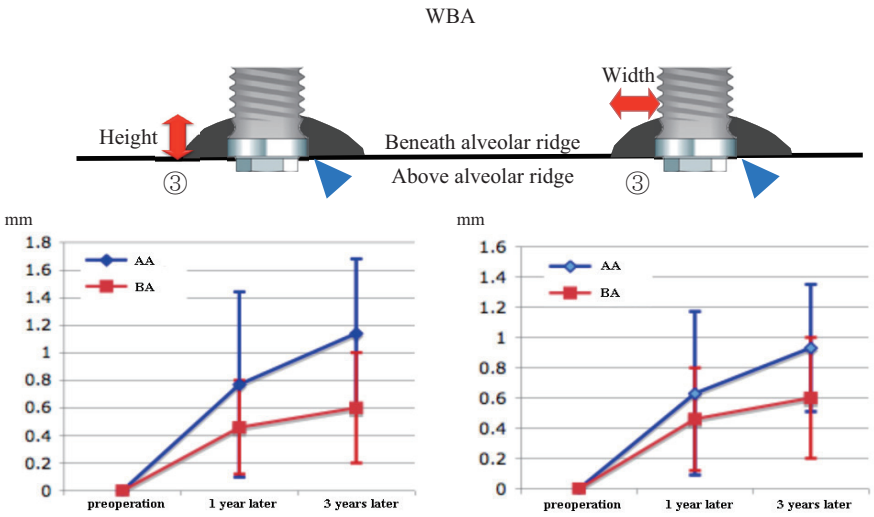

Fig. 6. Bone absorption around the shoulder of the dental implant in the WBA group
AA: above the alveolar ridge, BA: beneath the alveolar ridge, WBA: without bone augmentation

± 0.49 mm at 1 year and 1.03 ± 0.39 mm in total at 3 years postoperatively. The horizontal bone loss was 0.45 ± 0.50 mm at 1 year and 1.00 ± 0.40 mm in total at 3 years postoperatively. For BA, the vertical bone loss was 0.46 ± 0.34 mm at 1 year and 0.60 ± 0.40 mm in total at 3 years postoperatively; horizontally, the bone loss was 0.46 ± 0.4 mm at 1 year and 0.88 ± 0.00 mm in total at 3 years postoperatively. No significant difference was observed between these two groups (Fig. 7).

In LA, for AA, the vertical bone loss was 0.52 ± 0.66 mm at 1 year and 1.06 ± 0.76 mm in total at 3 years postoperatively. Horizontally, the bone loss was 0.48 ± 0.67 mm at 1 year and 0.88 ± 0.79 mm in total at 3 years postoperatively. For BA, the vertical bone loss was 0.73 ± 0.10 mm at 1 year and 0.80 ± 0.00 mm in total at 3 years postoperatively, while horizontally, it was 0.60 ± 0.22 mm at 1 year and 0.80 ± 0.00 mm in total at 3 years postoperatively. No statistically significant difference was demonstrated between these two groups (Fig. 8).

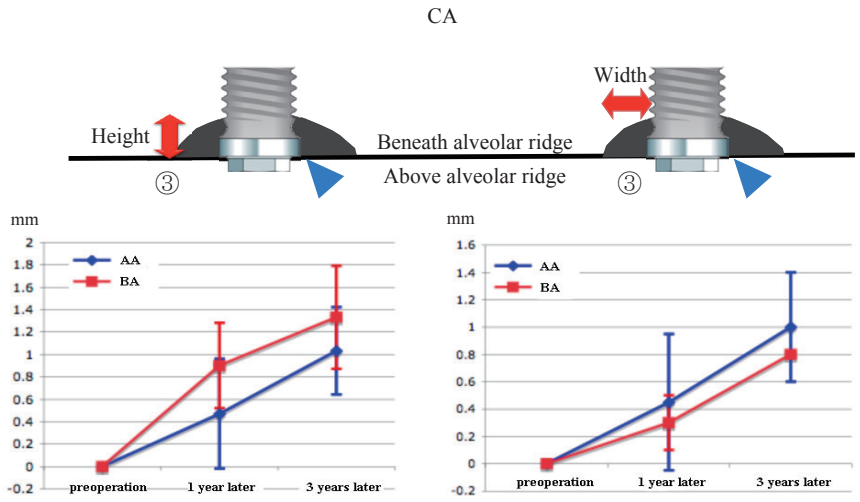

Fig. 7. Bone absorption around the shoulder of the dental implant in the CA group
AA: above the alveolar ridge, BA: beneath the alveolar ridge, CA: crestal approach

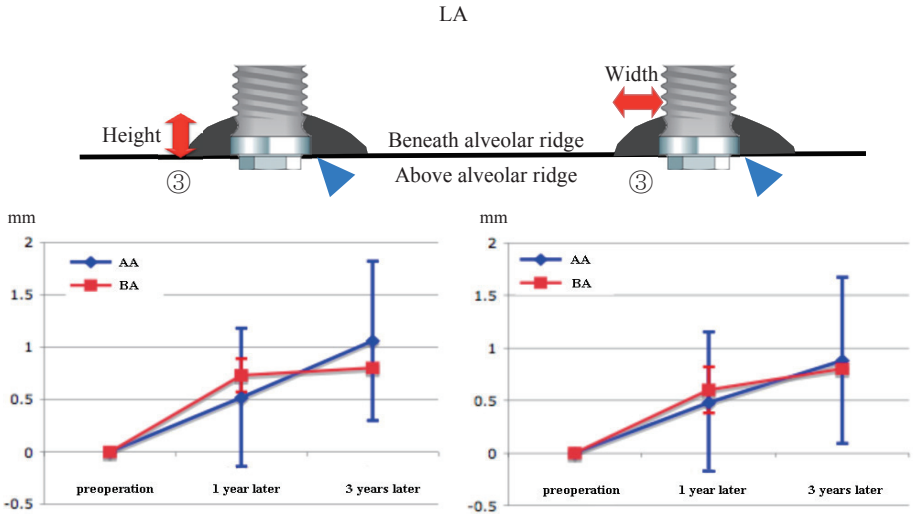

Fig. 8. Bone absorption around the shoulder of the dental implant in the LA group
AA: above the alveolar ridge, BA: beneath the alveolar ridge, LA: lateral approach.

DISCUSSION

For the application of DEs to the atrophied posterior maxilla, two treatment options have been proposed: the placement of DEs subsequent to sinus floor augmentation using graft materials and the use of short DEs [15, 16]. While the definition of short DEs remains controversial, they are considered to be DEs with a length less than 8 mm [17]. Recent systematic reviews of short DEs in the posterior atrophied mandible have provided evidence of high survival and success rates [18-20]. However, the indications for the use of short DEs in the atrophied posterior maxilla remain controversial, as the bone quality of the maxilla in such cases is relatively poor [1, 17]. In cases with relatively poor maxillary bone quality, we have used implants with a minimum length of 10 mm instead of short DEs (<8 mm) [21].

In the present study, sinus floor augmentation was indicated in 25 of 40 cases prior to DE placement in the posterior maxilla. CA (12 cases) was indicated in cases where the residual bone height between the top of the alveolar ridge and the floor of maxillary sinus was 5.92 mm (mean), while LA (13 cases) was performed in cases with a residual height of 4.11 mm (mean). Toffler [22] reported that sinus floor augmentation procedures are required when the residual bone height beneath the sinus floor is less than 8-10 mm, with CA being indicated in cases with a residual bone height of 6.9 mm, and LA for a bone height of 3.8 mm. Generally, CA is chosen for patients with a residual bone height of 6 mm between the alveolar ridge and sinus floor [23]. Thus, the indications used for CA and LA in this study were nearly identical to those in previous reports.

A variety of graft materials, either alone or in combination, have been validated for effective use in sinus floor augmentation, such as autogenous bone (e.g., iliac crest, chin and ramus of the mandible), allogeneic bone (e.g., deproteinized bovine bone mineral), and alloplastic materials (e.g., hydroxyapatite beta tricalcium phosphate) [24-26]. However, the induction of a foreign body reaction with the use of certain biomaterials remains a major concern, and the ideal material for sinus floor augmentation is still under debate [27]. Autogenous grafts are considered to be the golden standard in terms of osteogenic potential; however, the limited availability of materials from an intraoral donor site and morbidity at the bone graft donor site are important problems in using autogenous grafts [1, 8, 14, 31, 34].

Concerning the resorption patterns of autogenous bone, resorption rates of 5-20% during the initial 6 months after augmentation have been reported [8]. If the bone transplant is taken from the chin, a region representing desmal bone with a thick cortical layer and scarce spongious bone, higher mineralization remained prominent after 6 months compared with iliac bone transplants [8]. However, this rate is reduced by approximately one-third compared with mineralization of the original bone graft. This may be a iliac phenomenon, indicating the slow remodeling process of cortical bone granules in comparison with the highly osteoconductive proportions of spongious bone derived from the iliac area.

Although we strongly agree with the use of autogenous bone grafts, the availability of materials from an intraoral donor site is generally limited. In this study, following sinus floor elevation, a 70:30 mixture of autogenous bone and anorganic bovine hydroxyapatite was used for bone augmentation. Bone density has been shown to increase after maxillary sinus augmentation for autogenous bone when used alone or in combination with substitute materials that are based on hydroxyapatite and/or β-TCP particles [29]. Furthermore, the merits of using a mixture of autogenous and alloplastic materials have been reported from the viewpoints of osteoconduction, DE stability, postoperative absorption, and donor sites' morbidity [28, 30, 32].

Following sinus floor augmentation, volume changes can occur during graft consolidation (i.e., a discrepancy between the rate of graft resorption and host bone regeneration) and sinus pneumatization [30]. Knowledge of these changes can assist in clinical decision-making as follows: (1) preoperative estimation of the required graft volume and appropriate selection of graft materials and/or autologous donor sites, (2) intraoperative use of an adequate quantity of graft material that accounts for any anticipated remodeling/resorption, and (3) ensuring postoperative maintenance of bone around single-stage DE, or formation of adequate bone for stage-

two DE placement [31].

In this study, the bone volume reduction was evaluated two-dimensionally using panoramic radiographs. The results showed that the percentage of bone volume reduction around the tip of the DEs was 30.0% at 1 year postoperatively and 48.5% at 3 years postoperatively in CA, and 18.7% at 1 year and 38.7% at 3 years postoperatively in LA, respectively. Geurs *et al* reported a quantitative analysis of postoperative bone loss in 145 cases of sinus floor augmentation, showing that the amount of the bone loss was lower with autogenous bone grafts than with artificial bone substitutes over 3 years of postoperative follow-up. Bone volume reduction over time has been reported for all graft materials. In a previous long-term (>4 years) study, Shanbhag *et al* [30] suggested that the dimensional (height) reduction of autogenous or composite sinus grafts (approximately 20%) occur primarily during the initial postoperative phase (up to 2 years), with little or no changes in the subsequent years. In the present literature review, we noted that few studies have assessed long-term (>1 year) volume changes. Only one study reported significant volume reductions up to 1 year after sinus floor augmentation when using a block autogenous bone graft, followed by comparatively stable volumes up to 6 years [32]. Therefore, the current evidence does not indicate whether such volume changes are limited only to the initial postoperative period. Nevertheless, "over-augmentation" of the sinus floor, regardless of the choice of graft material, may be beneficial for compensating the expected volume reductions [30].

Generally, DEs may either be placed simultaneously via single-stage surgery (immediate or early loading) or after a healing period (two-stage protocol, conventional loading), depending on the quality and quantity of the residual bone [33]. According to the implant loading protocols for using fixed prostheses, immediate loading with fixed prostheses results in similar DE and prosthesis survival and failure rates as conventional loading via the two-stage protocol [33, 34]. The most important point of the DE placement procedure is to obtain good primary stabilization with a torque of at least 30 N·cm to achieve success in the one-stage procedure [34].

In cases of sinus floor augmentation, primary stability is gained within the residual bone, which means that it is completely impossible to achieve good stability if the volume of the residual bone is too low. Once DE placement is performed following sinus floor augmentation, it is very difficult to obtain good primary stabilization within the atrophied residual bone. Recently, however, improvement of the implant surface and shape has contributed to obtain good primary stabilization [1, 34].

In our procedure, all the DEs were placed at the same time as sinus floor augmentation, and good implant stability was gained by using residual bone with a minimum volume of 4 mm. The abutment was then connected and prostheses were loaded at 6 months after DE placement, accompanied by sinus floor augmentation. In this study, all the DEs survived over a long-term follow-up period of 7 years.

In conclusion, the applicability of the sinus floor augmentation can be decided simply based on the height and volume of the residual bone of the posterior maxilla. Sinus floor augmentation indicated when the residual bone height based on the residual bone height (CA: 4 - 10mm, LA: <4 mm).

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Conflicts of Interest: None

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