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Original Article

Multivariable analysis of use of absorbable collagen sponge graft for maxillary sinus floor elevation and augmentation

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Bone height

Abstract *Background/purpose:* Various studies have shown that use of absorbable collagen sponge (ACS) in maxillary sinus augmentation promotes new bone formation. This study aimed to assess changes in bone height of the maxillary sinus floor and to identify factors associated with these changes when performing sinus augmentation using ACS.
Materials and methods: This retrospective study included patients who underwent simultaneous implant placement and maxillary sinus augmentation using ACS through a crestal (CA) or lateral (LA) approach. Changes in bone height at 12 months (G2, primary outcomes) were evaluated by cone-beam computed tomography. Factors associated with these changes were evaluated, including age, sex, smoking, location, span, number of ACSs, sinus perforation, sinus membrane elevation height, and residual bone height. Variables significantly associated with G2 were evaluated by multivariable analyses based on the generalized estimating equation.
Results: Overall, 108 patients were evaluated, including at 182 implant sites (CA, 53; LA, 129). G2 was 2.16 ± 1.51 mm (residual bone height, 8.11 ± 1.58 mm) and 4.62 ± 2.04 mm (residual bone height, 5.54 ± 2.52 mm) in the CA and LA, respectively ($P < 0.001$). Factors significantly associated with G2 included sex ($P < 0.001$), perforation ($P < 0.001$), and residual bone height ($P < 0.001$) in the CA, and sinus membrane elevation height ($P = 0.013$) and residual bone height ($P < 0.001$) in the LA.
Conclusion: Clinicians need to make efforts to sufficiently elevate the sinus membrane and minimize perforations in order to achieve desired levels of new bone formation.

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Introduction

Maxillary sinus elevation is regarded as a predictable and effective technique for augmenting atrophic maxillary alveolar ridges. The choice of a crestal (CA) or lateral (LA) approach depends on a number of factors, such as sinus pneumatization, residual alveolar bone volume, and structural sinus anatomy.[1,2] Various types of bone substitutes (autogenous, xenogeneic, allogeneic, or alloplastic) are available for maxillary sinus elevation and they all provide satisfactory results because the Schneiderian membrane provides an encapsulated space and insulation to elicit osteogenic effects.[3,4]

Studies of alternative sinus augmentation techniques have evaluated the use of absorbable collagen sponge (ACS),[5—10] a gelatin sponge,[11] and oxidized regenerated cellulose,[12] rather than particulate bone substitutes, and even a graftless lateral sinus lift approach using only blood clots has been proposed.[4,7,13—18] These surgical techniques generally eliminate the possibility of allergic reactions and maxillary sinus infections caused by bone substitutes.[6,8,9,19—21] In addition, these graft materials are less expensive than bone substitutes and are technically easy to handle, thus reducing the operation time.[7] If these techniques have the same efficacy as sinus augmentation using bone substitutes, they may be satisfactory for both patients and clinicians.

Unlike typical bone substitutes, which experience very little change in volume and shape, ACS may be absorbed and its dimensions may change substantially during the postoperative healing phase.[20] Therefore, it is difficult to predict volumetric changes over time or to measure quantities of new bone after sinus floor elevation using ACS. There are no precise clinical data to determine the volume of ACS that is sufficient for new bone formation in the sinus cavity, and no studies have identified factors that affect sinus bone formation. Although ongoing studies are evaluating the ACS-based sinus floor elevation technique, most studies to date have been case reports or series with a small number of cases, and the length of the implant fixture used for sinus floor elevation has not been uniform. Moreover, no studies have compared the CA and LA for sinus floor elevation using ACS.

The purpose of the present study was to assess changes in bone height of the maxillary sinus floor and the degree of postoperative implant stability achieved when performing sinus floor elevation procedures using ACS grafts through the CA and LA. This study hypothesized that ACS can adequately replace bone substitutes and promote sufficient bone formation and subsequent implant stability after maxillary sinus floor elevation. In addition, factors that affect changes in bone height were evaluated in patients who underwent sinus floor elevation using ACS.

Materials and methods

Patient selection

This was a retrospective cohort study. All participants underwent posterior maxillary dental implant installation at the Department of Oral and Maxillofacial Surgery of Seoul Metropolitan Government - Seoul National University Boramae Medical Center (SMG-SNU BMC) (Seoul, Korea) between 2017 and 2021. The protocol was approved by the Institutional Review Board of SMG-SNU BMC (IRB No. 20-2017-25), adhering to the tenets of the 1964 Declaration of Helsinki and its later amendments. All surgeries were performed by a single experienced oral and maxillofacial surgeon (YSH).

Inclusion criteria were as follows: (1) adults who had completed jaw growth; (2) patients who required tooth rehabilitation by implant surgery in the maxillary premolar or molar areas; (3) patients who had intact maxillary sinuses without pathological findings such as tumors, cysts, or sinusitis; and (4) patients who underwent simultaneous sinus elevation and implant placement.

Surgical procedures

Bone level implants (TS III SA, Osstem Implant Co., Seoul, Korea) used for implant surgery in the premolar region were 4 mm in diameter and 11.5 mm in length, whereas implants in the molar region were 5 mm in diameter and 11.5 mm in length. The ACS used in this study was Ateloplug (Bio-land, Cheong-ju, South Korea), which has a sponge block configuration and a bullet-shaped matrix for easy placement at the surgical site. Medium-sized Ateloplug is 15 mm in diameter and 25 mm in length, and has a volume of 4.42 cm^3. Each ACS was divided into four pieces, each of which was used for surgery.

LA technique

After injection of local anesthetic (2 % lidocaine HCl), a full thickness mucoperiosteal flap was raised through one midcrestal and two vertical incisions. A bony window in the lateral sinus wall was created using a low-speed surgical bur to allow access to the sinus membrane (Fig. 1A). The bony window was separated from the sinus membrane using sinus curettes, and the sinus membrane was carefully elevated from the surrounding wall to make space for the implant fixtures (Fig. 1B). After final drilling for implant installation, ASCs were inserted into the space created (Fig. 1C). Following installation of the implants (Fig. 1D), additional ACSs were inserted into the sinus space (Fig. 1E). The bony window was returned to its original configuration, covering the antrostomy (Fig. 1F), and the flap was repositioned and

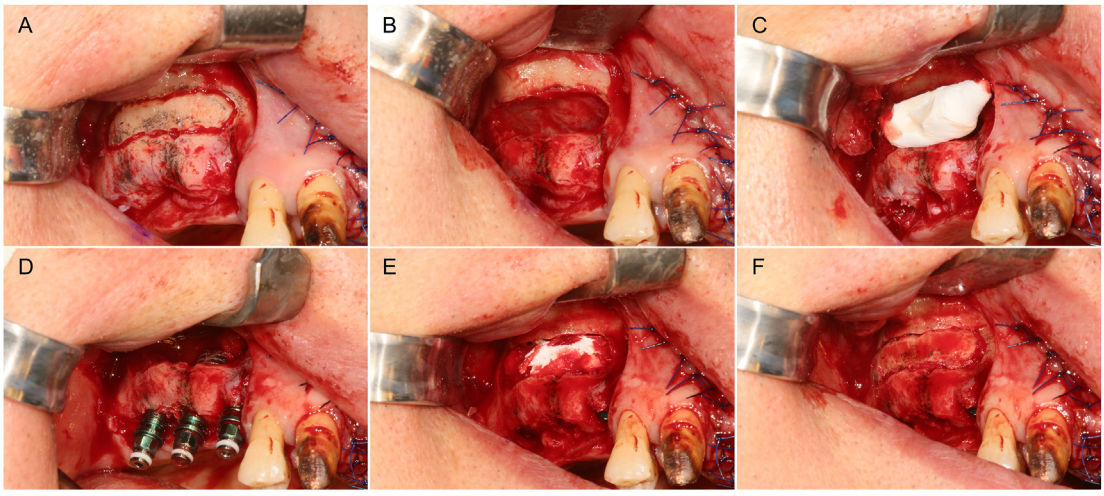

Figure 1 Lateral approach to sinus floor elevation using absorbable collagen sponge (ACS). (A) Opening of a window in the lateral sinus wall to access the sinus membrane. (B) Elevation of the sinus membrane upon completion of osteotomy. (C) Insertion of ACSs into the cavity after final drilling for implant installation. (D) Simultaneous placement of implants. (E) Insertion of additional ACSs into the sinus space. (F) Repositioning of the bony window, covering the antrostomy site.

sutured using 4-0 Dafilon sutures (B. Braun Medical, Johannesburg, South Africa). Six months after surgery, the implant stability test (IST) value was measured using an AnyCheck device (Neobiotech, Seoul, South Korea), and the prosthetic phase commenced.

CA technique

After injection of local anesthetic, a midcrestal incision was made, which enabled flap elevation. Drilling was performed to a depth of 1 mm from the sinus floor (pending final preparations). The sinus floor was elevated using a crestal osteotome technique while the cut bony segment was cautiously pushed at least 2 mm into the sinus cavity, thereby elevating the sinus lining (Fig. 2A). ACSs were inserted into the newly lifted space (Fig. 2B), followed by insertion of the implants and repositioning of the flap (Fig. 2C). Six months after surgery, the IST value was determined, and the prosthetic process was performed.

Variables and data collection methods

The predictor variables were age, sex, smoking, location, span, number of ACSs, sinus perforation, sinus membrane elevation height, and residual bone height. The outcome variable was change in sinus bone height.

The progress of bone regeneration at sinus elevation sites was assessed by cone-beam computed tomography (CBCT). CBCT images were obtained before and immediately after surgery, as well as 6 and 12 months after surgery, using a Dinnova 3 scanner (HDX Corp, Seoul, Korea) with a scan time of 7 s, a voltage of 95 kV, a tube current of 9 mA, a voxel size of 0.3 mm, and a field of view of 9 mm. All images were stored in Digital Imaging and Communication in Medicine (DICOM) format.

Changes in sinus floor bone height following implant insertion were evaluated by two-dimensional analysis of CBCT images. DICOM data were reconstructed at 0.5 mm thickness using the INFINITT Picture Archiving and Communication System (INFINITT PACS; INFINITT Healthcare, Seoul, Korea). Images were reconstructed in the multiplanar mode, relying on the buccopalatal plane for radiographic evaluations. An arc was drawn along the maxillary arch contour in the axial view, and a tangent was drawn to the arc where it met the implant center. A plane perpendicular to the tangent and parallel to the long axis of the implant was selected as the buccopalatal plane. The implant center was identified using a cover screw (Fig. 3A).

The following radiographic measurements were performed: (1) residual bone height (T0), which was the distance between the implant platform and the sinus floor at

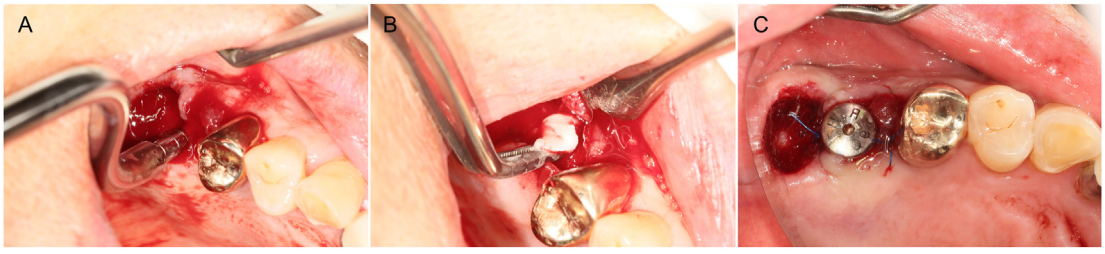

Figure 2 Crestal approach to sinus floor elevation using absorbable collagen sponge (ACS). (A) Elevation of the sinus floor through the ridge crest using an osteotome. (B) Insertion of ACSs into the cavity under the elevated sinus membrane. (C) Simultaneous placement of implants.

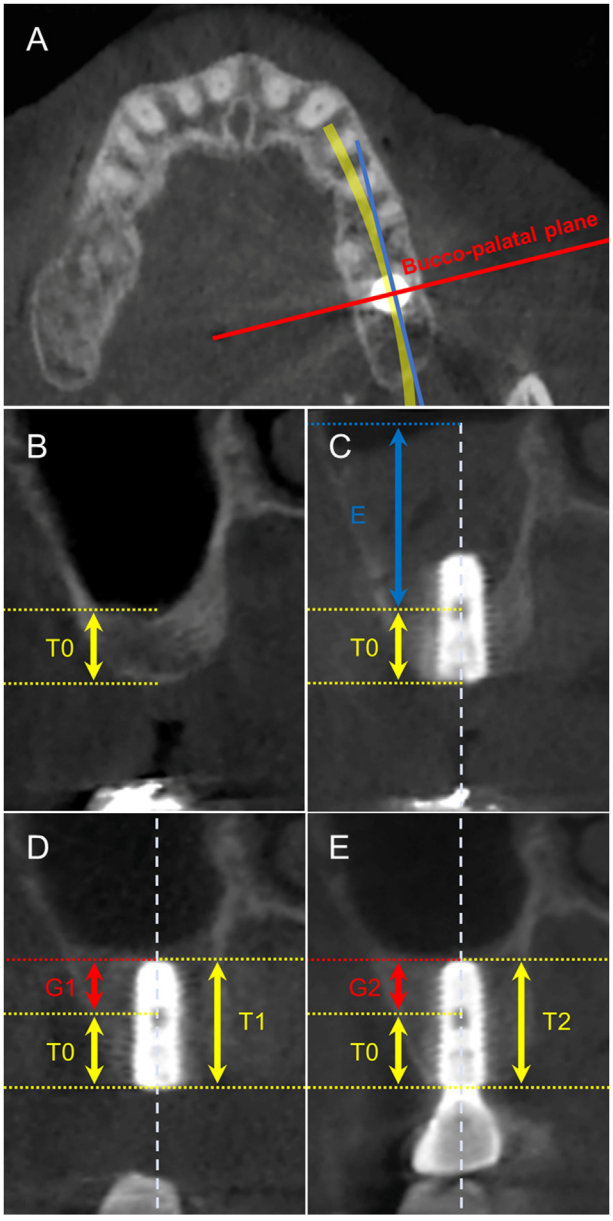

Figure 3 Two-dimensional bone height analysis of sinus floor elevation using absorbable collagen sponge. (A) Selection of the buccopalatal plane for radiographic evaluation. An arc is drawn along the contours of the maxillary arch in the axial view, and a tangent is drawn to the arc where it meets the center of the implant. The buccopalatal plane is established perpendicular to the tangent line and parallel to the long axis of the implant. (B) Preoperative cone-beam computed tomography view. (C) Residual bone height and sinus membrane elevation height measured after implant installation. (D) New bone formation at 6 months postoperatively. (E) New bone formation at 12 months postoperatively. E, sinus membrane elevation height; T0, residual bone height; T1, new bone height at 6 months postoperatively; T2, new bone height at 12 months postoperatively; G1, bone height change at 6 months postoperatively; G2, bone height change at 12 months postoperatively.

the midportion of the implant immediately after surgery (Fig. 3B and C); (2) sinus membrane elevation height (E), which was the distance between the upper border of the elevated sinus membrane and the sinus floor at the midportion of the implant immediately after surgery (Fig. 3C); (3) bone height at 6 months (T1) and 12 months (T2) postoperatively, which was the distance between the implant platform and the top of the regenerated sinus bone at the midportion of the implant (Fig. 3D and E); (4) bone height change at 6 months postoperatively (G1), which was T1 minus T0 (Fig. 3D); (5) bone height change at 12 months postoperatively (G2), which was T2 minus T0 (Fig. 3E); and (6) bone height change from 6 to 12 months postoperatively (G3), which was T2 minus T1.

Data analyses

Changes in bone height and volume from before to after sinus floor elevation using ACSs were analyzed using the generalized estimating equation (GEE) method. This method does not necessarily depend on a strict covariance structure. The primary outcome measure was change in bone height (G2). GEE-based univariable and multivariable analyses were performed to identify variables significantly associated with changes in bone height (G2). All statistical analyses were performed using SAS v9.4 statistical software (SAS Institute Inc, Cary, NC, USA), with $P < 0.05$ defined as statistically significant.

Intra-rater reliability was evaluated by calculating intraclass correlation coefficients (ICCs). Twenty of the 182 implant sites were randomly selected and measured twice.[22]

Results

Patient-related factors

The present study included 108 patients: 59 (54.6 %) male and 49 (45.4 %) female. The mean age of patients in the CA and LA groups was 66.55 ± 12.48 years and 62.43 ± 12.44 years, respectively. In the CA group, 0 (0 %) patients were smokers and 38 (100 %) patients were nonsmokers, whereas in the LA group, seven (9.72 %) patients were smokers and 65 (90.28 %) patients were nonsmokers (Table 1).

Table 1 Patient-related factors in the CA and LA groups.

Patient-related factor	CA (n = 38)	LA (n = 72)
Age, years	66.55 ± 12.48	62.43 ± 12.44
Sex		
Male	16 (42.11)	45 (62.50)
Female	22 (57.89)	27 (37.50)
Smoking		
Smoker	0 (0)	7 (9.72)
Nonsmoker	38 (100)	65 (90.28)

Data are expressed as n (%) or mean ± standard deviation.
CA, crestal approach; LA, lateral approach.

Implant-related factors

Overall, 182 implant sites, including 53 (29.1 %) and 129 (70.9 %) in the CA and LA groups, respectively, were included in present study. The implant survival rate over 12 months was 100 % in both groups. None of the patients experienced sinus infection, even when the sinus membrane was perforated, had any signs or symptoms of sinusitis after surgery, or had radiographic evidence of sinusitis. IST values were acceptable in the CA (82.66 ± 6.61) and LA (81.16 ± 5.41) groups. Implants were more frequently inserted into molar areas than into premolar areas in both the CA (84.9 % [45/53] vs. 15.1 % [8/53]) and LA (84.5 % [109/129] vs. 15.5 % [20/129]) groups. Of the 53 implants in the CA group, 37 (69.8 %) were single implants and 16 (30.2 %) were double implants. Of the 129 implants in the LA group, 56 (43.4 %) were single implants, 58 (45.0 %) were double implants, and 15 (11.6 %) were triple implants. The number of ACSs used at the surgical site was 0.56 ± 0.16 and 1.00 ± 0.30 in the CA and LA groups, respectively. The sinus membrane perforation rate was higher in the CA group (24.5 % [13/53]) than in the LA group (10.9 % [14/129]) (Table 2).

In the CA and LA groups, E was 7.88 ± 3.92 mm and 13.21 ± 3.96 mm, respectively, T0 was 8.11 ± 1.58 mm and 5.54 ± 2.52 mm, respectively, T1 was 10.10 ± 1.51 mm and 9.88 ± 1.92 mm, respectively, and T2 was 10.27 ± 1.47 mm and 10.16 ± 1.86 mm, respectively. Bone height was significantly increased at all time points (G1, G2, and G3) ($P < 0.01$), but G2 was significantly lower in the CA group (2.16 ± 1.51 mm) than in the LA group (4.62 ± 2.04 mm) ($P < 0.001$) (Table 2). In 33 cases (18.1 %), new bone extended beyond the apical ends of implants (T2 > 11.5 mm), including two (3.8 %) in the CA group and 31 (24.0 %) in the LA group (Fig. 4).

Table 2 Implant-related factors in the CA and LA groups.

Implant-related factor	CA (n = 53)	LA (n = 129)
Implant survival		
Yes	53 (100)	129 (100)
No	0 (0)	0 (0)
Sinus infection		
Yes	0 (0)	0 (0)
No	53 (100)	129 (100)
Location		
Premolar	8 (15.09)	20 (15.50)
Molar	45 (84.91)	109 (84.50)
Span		
1	37 (69.81)	56 (43.41)
2	16 (30.19)	58 (44.96)
3	0 (0.00)	15 (11.63)
IST	82.66 ± 6.61	81.16 ± 5.41
Number of ACSs	0.56 ± 0.16	1.00 ± 0.30
Perforation		
Yes	13 (24.53)	14 (10.85)
No	40 (75.47)	115 (89.15)
Radiographic measures, mm		
E	7.88 ± 3.92	13.21 ± 3.96
Bone height		
T0	8.11 ± 1.58	5.54 ± 2.52
T1	10.10 ± 1.51	9.88 ± 1.92
T2	10.27 ± 1.47	10.16 ± 1.86
Bone height change		
G1	1.99 ± 1.54**	4.35 ± 2.06**
G2	2.16 ± 1.51**	4.62 ± 2.04**
G3	0.17 ± 0.45*	0.28 ± 0.56**

Data are expressed as n (%) or mean ± standard deviation. *$P < 0.01$, **$P < 0.001$ (based on the generalized estimating equation).
CA, crestal approach; LA, lateral approach; IST, implant stability test; ACS, absorbable collagen sponge; E, sinus membrane elevation height; T0, residual bone height; T1, bone height at 6 months postoperatively; T2, bone height at 12 months postoperatively; G1, bone height change at 6 months postoperatively; G2, bone height change at 12 months postoperatively; G3, bone height change from 6 to 12 months postoperatively.

Statistical results

Univariable GEE analysis indicated that factors significantly associated with G2 included sex ($P = 0.005$), perforation ($P < 0.001$), and T0 ($P < 0.001$) in the CA group, and E ($P < 0.001$) and T0 ($P < 0.001$) in the LA group (Table 3). The number of ACSs did not significantly influence G2.

Multivariable GEE analysis indicated that factors significantly associated with G2 included sex ($P < 0.001$), perforation ($P < 0.001$), and T0 ($P < 0.001$) in the CA group, and E ($P = 0.013$) and T0 ($P < 0.001$) in the LA group (Table 4).

The shorter the residual bone height, the more new bone formed. For residual bone heights ≥5 mm, the increase in sinus bone height was significantly greater in the LA group than in the CA group ($P < 0.05$) (Table 5 and Fig. 5).

ICCs ranged from 0.976 to 0.997, with no significant differences between the two sets of measurements at the 95 % confidence level ($P < 0.001$). The ICCs were 0.997, 0.996, 0.977, and 0.976 for E, T0, T1, and T2, respectively.

Discussion

Alveolar bone resorption and sinus pneumatization hinder posterior maxillary implant placement. The role of blood clots in sinus augmentation to increase the alveolar bone height is important for new bone formation. The osteoinductive properties of blood clots in guided bone regeneration and bone grafting have been well established through various studies and involve many growth factors that initiate and promote bone formation.[23,24] A blood clot that fills the space formed by Schneiderian membrane elevation also acts as a space maintainer. Given the multiple phases, including angiogenesis, migration of osteogenic progenitor cells from adjacent medullary bone to the operative site, and actual bone formation, some authors believe that blood clots alone cannot maintain sufficient space for new bone formation.[16,24–26]

The purpose of the present study was to assess bone height changes of the maxillary sinus floor and to evaluate factors that affect these changes after maxillary sinus elevation using ACS. In the present study, ACS placed within the sinus cavity under the elevated Schneiderian membrane

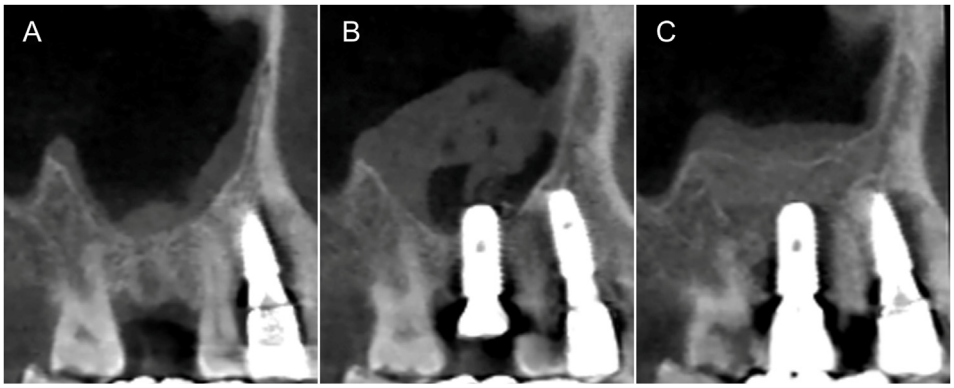

Figure 4 Extension of new bone beyond the apical ends of implants at 12 months after sinus floor elevation using absorbable collagen sponge by the crestal approach. (A) Before surgery. (B) Immediately after surgery. (C) Twelve months after surgery.

Table 3 Univariable analysis of factors associated with bone height change at 12 months postoperatively (G2) in the CA and LA groups, based on the generalized estimating equation.

Predictor variable	CA		LA	
	Estimate (SE)	*P*-value	Estimate (SE)	*P*-value
Age	0.005 (0.018)	0.781	−0.012 (0.016)	0.447
Sex −1.082 (0.387) 0.005 −0.731 (0.402) 0.069				
Male (reference)				
Female				
Smoking 0.753 (0.949) 0.428				
Nonsmoker (reference)				
smoker				
Location 0.675 (0.365) 0.065 0.624 (0.552) 0.259				
Premolar (reference)				
Molar				
Span	0.191 (0.550)	0.728	−0.372 (0.277)	0.180
Number of ACSs	1.443 (1.199)	0.229	0.890 (0.734)	0.225
Perforation −1.395 (0.402) <0.001 0.131 (0.647) 0.840				
No (reference)				
Yes				
E	0.131 (0.075)	0.080	0.271 (0.038)	<0.001
T0	−0.522 (0.095)	<0.001	−0.553 (0.055)	<0.001

CA, crestal approach; LA, lateral approach; SE, standard error; ACS, absorbable collagen sponge; E, sinus membrane elevation height; T0, residual bone height; G2, bone height change at 12 months postoperatively.

Table 4 Multivariable analysis of factors associated with bone height change at 12 months postoperatively (G2) in the CA and LA groups, based on the generalized estimating equation.

Predictor variable	CA		LA	
	Estimate (SE)	*P*-value	Estimate (SE)	*P*-value
Sex	−0.940 (0.256)	<0.001		
Male (reference)				
Female				
Perforation	−1.298 (0.282)	<0.001		
No (reference)				
Yes				
E			0.108 (0.044)	0.013
T0	−0.489 (0.082)	<0.001	−0.458 (0.075)	<0.001

CA, crestal approach; LA, lateral approach; SE, standard error; E, sinus membrane elevation height; T0, residual bone height; G2, bone height change at 12 months postoperatively.

Table 5 Bone height change at 12 months postoperatively (G2) relative to residual bone height (T0) in the CA and LA groups, based on the generalized estimating equation.

T0, mm	CA		LA		*P*-value
	n	Mean ± SD	n	Mean ± SD	
1–3			18	6.60 ± 1.90	
3–5			38	5.68 ± 1.54	
5–7	18	3.29 ± 1.57	36	4.31 ± 1.52	0.027
7–9	17	1.82 ± 1.18	19	3.74 ± 1.24	<0.001
9–11	18	1.35 ± 1.00	18	1.96 ± 0.92	0.043
Total	53	2.16 ± 1.51	129	4.62 ± 2.04	

CA, crestal approach; LA, lateral approach; SD, standard deviation; T0, residual bone height; G2, bone height change at 12 months postoperatively.

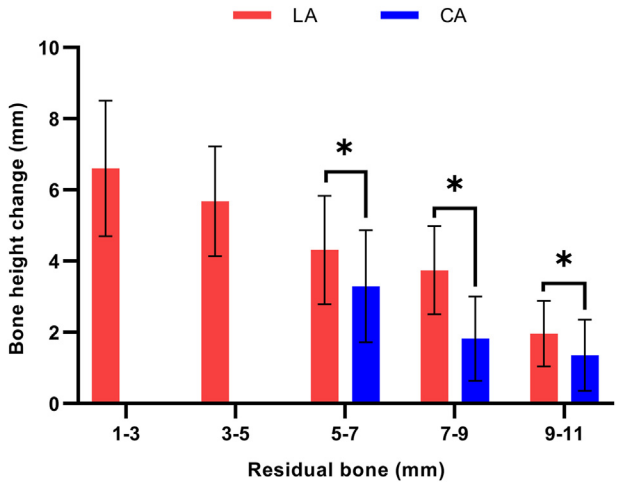

Figure 5 Sinus bone height change at 12 months after sinus floor elevation using an absorbable collagen sponge in the crestal (CA) and lateral (LA) approach groups (mean ± standard deviation). The shorter the residual bone height, the more new bone formed. For residual bone heights ≥5 mm, the increase in sinus bone height was significantly greater in the LA group than in the CA group (*$P < 0.05$).

served as an alternative to bone substitutes for maintaining space. T2 was 10.27 ± 1.47 mm and 10.16 ± 1.86 mm in the CA and LA groups, respectively, providing sufficient new bone to accommodate the 11.5 mm implants. Bone height changes were significantly affected by sex, perforation, and T0 in the CA group, and by E and T0 in the LA group.

Absorbable collagen is one of the most common scaffolding materials in bone tissue engineering, providing physical support for cell attachment and growth and influencing cell behavior through receptor-mediated interactions.[1,27] Ateloplug is made of atelocollagen, which is crosslinked through heat treatment for optimal biocompatibility and minimal antigenicity. It is composed of type I (85–95 %) and type III (5–15 %) collagens derived from porcine skin.[2,28] The rationale behind its incorporation into ACS is not only to preserve blood clots, but also to prevent collapse of the sinus membrane prior to degradation.[28] According to the manufacturer, Ateloplug is completely absorbed within 2–4 weeks. Despite its rapid resorption, Ateloplug begins to form new mineralized bone under elevated Schneiderian membranes within 2 weeks after sinus floor elevation using ACS and serves as a scaffold for space maintenance.[20] In this study, new bone appeared beyond apical ends of inserted implants in 18.1 % (n = 33) of cases overall and in 3.77 % (n = 2) and 24.03 % (n = 31) of cases in the CA and LA groups, respectively.

Five prior clinical studies and one animal model have evaluated sinus floor elevation using ACS for new bone formation.[6–10,20] However, only two of these studies performed simultaneous implant placement.[6,7] Volpe et al.[6] performed sinus floor elevation using ACS (36 patients and 36 implants) via the CA and confirmed new bone formation through periapical radiographs. The mean change in postoperative bone height at 4–6 months was 3.8 ± 1.1 mm (residual bone height, 5.9 ± 1.4 mm), resulting in relatively good stability, as shown by the mean implant stability quotient of 75.8 ± 3.9. Only one patient experienced sinus perforation, and none experienced sinus infection. Menassa et al.[7] used the LA for augmentation, achieving an increase of sinus bone height at 12 months of 4.4 ± 1.9 mm (residual bone height, 3.5 mm) on periapical radiographs. There were no complications, such as sinus perforation or infection. Cosola et al.[9] and Berberi et al.[8] also examined sinus floor elevation using ACS via the CA and LA, respectively, with both confirming new bone formation through CBCT imaging and histological analysis of tissue samples. The sinus bone height increase was 6 mm (residual bone height not determined) and 7.98 ± 1.04 mm (residual bone height, <4 mm) via the CA and LA, respectively, and all procedures were free of postoperative complications. Berberi et al. recorded an implant survival rate of 100 %. By comparison, in the present study, the sinus bone height change was 3.14 ± 1.60 mm (residual bone height range, 5–7 mm) via the CA at 6 months postoperatively and 5.68 ± 1.54 mm (residual bone height range, 3–5 mm) via the LA at 12 months postoperatively. Bone substitutes (autogenous, xenogeneic, allogeneic, or alloplastic) clearly surpass ACSs in terms of augmentation volume,[20] but the abundance of bone for implantation does not correlate with implant stability or survival.[6,7,15,17,18,29] Although the mean bone height increase in this cohort was inadequate to fully cover the apical ends of fixtures, IST scores were acceptable in both groups (CA, 82.66 ± 6.61; LA, 81.16 ± 5.41), and no implant loss was observed during the 12-month follow-up period.

The limitations of these previous clinical studies[6–10,20] are the inconsistent or vaguely referenced lengths of installed implants and failure to quantitatively analyze residual bone heights.[7–9,20] By contrast, the present study analyzed factors that are likely related to changes in sinus bone height and quantitatively analyzed a number of variables (i.e., residual bone height, number of ACSs, sinus elevation height, implant length, change in sinus bone height, IST, survival rate, and postoperative complications). Moreover, to our knowledge, no previous studies have compared changes in sinus bone height achieved by the CA and LA for sinus floor elevation.

Sinus perforation, which occurred in 24.5 % and 10.9 % of implants in the CA and LA groups, respectively, was linked to changes in bone height. Unlike the LA, which allows

direct monitoring of elevation progress, the CA is performed blindly, making it challenging to recognize and manage perforations through ACS placement intraoperatively.[30] In our study, postoperative CBCT images indicated ACS migration across a perforated membrane, providing evidence of perforation in the CA group. The mean incidence of postoperative sinus infection due to the graft material is reported to be 2.9 %,[21] but no patients experienced sinus infection or implant loss due to perforation in our study. In conclusion, sinus floor elevation using ACS appears to be safe and is not associated with sinus infection.

In the CA group, the bone height increase was significantly lower in females than in males (Estimate, −0.940 mm; SE, 0.256 mm; $P < 0.001$). This difference tended to be similar in the LA group. The patients included in the present study were relatively old, with males and females aged 67.04 ± 13.32 years and 66.30 ± 12.64 years, respectively; therefore, impaired bone formation in these women may have been due to hormonal imbalances in postmenopausal women. A major change in postmenopausal women is reduced ovarian production of estrogens,[31] which are crucial regulators of osteoblast differentiation and function, and promote osteogenic differentiation of mesenchymal stem cells. Moreover, estrogens enhance differentiation of preosteoblasts into osteoblasts, and prolong the lifespan of osteoblasts and osteocytes by suppressing apoptosis.[32] In addition, estrogens stimulate procollagen synthesis as well as IGF1 and TGFβ production by osteoblasts.[33]

The results of the present study indicated that new bone formation was observed after maxillary sinus floor elevation using ACS and that sinus membrane elevation height affected the height of new bone formation when sinus membrane perforation was controlled. These findings emphasize the need to insert a sufficient number of ACSs in order to elevate the sinus membrane as much as possible when performing sinus floor elevation using ACSs.

A limitation of this study is that although newly formed bones were quantitatively analyzed by CBCT, histological qualitative analysis was not performed. In a previous histological analysis,[8—10] specimens were collected while inserting the implant 6 months after sinus augmentation. However, as in this study, patients undergoing simultaneous sinus floor elevation and implant surgery[6,7] are reluctant to provide consent for additional surgery for bone biopsy.

Declaration of competing interest

The authors have no conflict of interest relevant to this article.

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References

1. Boyne PJ, James RA. Grafting of the maxillary sinus floor with autogenous marrow and bone. *J Oral Surg* 1980;38:613—6.
2. Summers RB. A new concept in maxillary implant surgery: the osteotome technique. *Compendium* 1994;15. 152, 54-6, 58 passim; quiz 62.
3. Rong Q, Li X, Chen SL, Zhu SX, Huang DY. Effect of the Schneiderian membrane on the formation of bone after lifting the floor of the maxillary sinus: an experimental study in dogs. *Br J Oral Maxillofac Surg* 2015;53:607—12.
4. Lundgren S, Andersson S, Gualini F, Sennerby L. Bone reformation with sinus membrane elevation: a new surgical technique for maxillary sinus floor augmentation. *Clin Implant Dent Relat Res* 2004;6:165—73.
5. Sohn DS, Moon JW, Moon KN, Cho SC, Kang PS. New bone formation in the maxillary sinus using only absorbable gelatin sponge. *J Oral Maxillofac Surg* 2010;68:1327—33.
6. Volpe S, Di Girolamo M, Pagliani P, Zicari S, Sennerby L. Osteotome-induced blood clot and subsequent bone formation with the use of collagen sponge for integration of single dental implants into the atrophied posterior maxilla: a retrospective follow-up of 36 implants after 5 to 13 years. *Int J Dent* 2022; 2022:6594279.
7. Menassa G, Kassir AR, Landi L, Naaman NBA, Chakar C. Implant placement with sinus floor elevation via the lateral approach using only absorbable collagen sponge: 12-month post-loading radiographical outcomes and implant survival rate. *Oral Maxillofac Surg* 2021;25:231—6.
8. Berberi A, Nader N, Bou Assaf R, Fayyad-Kazan H, Khairalah S, Moukarzel N. Sinus floor augmentation with ambient blood and an absorbable collagen sponge: a prospective pilot clinical study. *Implant Dent* 2017;26:674—81.
9. Cosola S, Di Dino B, Traini T, et al. Radiographic and histomorphologic evaluation of the maxillary bone after crestal mini sinus lift using absorbable collagen-retrospective evaluation. *Dent J (Basel)* 2022;10:58.
10. Ahn JJ, Cho SA, Byrne G, Kim JH, Shin HI. New bone formation following sinus membrane elevation without bone grafting: histologic findings in humans. *Int J Oral Maxillofac Implants* 2011;26:83—90.
11. Samieirad S, Eshghpour M, Tohidi E, Jouya A, Soufizadeh R, Kermani H. Using absorbable gelatin sponge to facilitate sinus membrane elevation during open sinus lift: technical notes and case series. *J Dent Mater Tech* 2019;8:1—7.
12. Hussein LA, Hassan TAL. The effectiveness of oxidized regenerated cellulose as a graft material in transalveolar osteotome sinus lift procedure. *J Craniofac Surg* 2017;28:1766—71.
13. Falah M, Sohn DS, Srouji S. Graftless sinus augmentation with simultaneous dental implant placement: clinical results and biological perspectives. *Int J Oral Maxillofac Surg* 2016;45: 1147—53.
14. Scala A, Botticelli D, Faeda RS, Garcia Rangel Jr I, Américo de Oliveira J, Lang NP. Lack of influence of the Schneiderian membrane in forming new bone apical to implants simultaneously installed with sinus floor elevation: an experimental study in monkeys. *Clin Oral Implants Res* 2012;23:175—81.
15. Lie SAN, Claessen R, Leung CAW, Merten HA, Kessler P. Non-grafted versus grafted sinus lift procedures for implantation in the atrophic maxilla: a systematic review and meta-analysis of randomized controlled trials. *Int J Oral Maxillofac Surg* 2022; 51:122—32.
16. de Oliveira GR, Olate S, Cavalieri-Pereira L, et al. Maxillary sinus floor augmentation using blood without graft material. Preliminary results in 10 patients. *J Oral Maxillofac Surg* 2013; 71:1670—5.

17. Parra M, Atala-Acevedo C, Fariña R, Haidar ZS, Zaror C, Olate S. Graftless maxillary sinus lift using lateral window approach: a systematic review. *Implant Dent* 2018;27:111—8.
18. Menassa G, Kassir AR, Landi L, Naaman NBA, Chakar C. Implant placement with graftless sinus floor elevation via the lateral approach: a case series with 4 years post-loading radiographical outcomes and implant survival rate. *J Craniofac Surg* 2022;33:e461—5.
19. Robinson D, Alk D, Sandbank J, Farber R, Halperin N. Inflammatory reactions associated with a calcium sulfate bone substitute. *Ann Transplant* 1999;4:91—7.
20. Caneva M, Lang NP, Garcia Rangel IJ, et al. Sinus mucosa elevation using Bio-Oss(®) or Gingistat(®) collagen sponge: an experimental study in rabbits. *Clin Oral Implants Res* 2017;28:e21—30.
21. Pjetursson BE, Tan WC, Zwahlen M, Lang NP. A systematic review of the success of sinus floor elevation and survival of implants inserted in combination with sinus floor elevation. *J Clin Periodontol* 2008;35:216—40.
22. Koo TK, Li MY. A guideline of selecting and reporting intraclass correlation coefficients for reliability Research. *J Chiropr Med* 2016;15:155—63.
23. Shiu HT, Goss B, Lutton C, Crawford R, Xiao Y. Formation of blood clot on biomaterial implants influences bone healing. *Tissue Eng Part B* 2014;20:697—712.
24. Lambert F, Léonard A, Drion P, Sourice S, Layrolle P, Rompen E. Influence of space-filling materials in subantral bone augmentation: blood clot vs. autogenous bone chips vs. bovine hydroxyapatite. *Clin Oral Implants Res* 2011;22:538—45.
25. Balleri P, Veltri M, Nuti N, Ferrari M. Implant placement in combination with sinus membrane elevation without biomaterials: a 1-year study on 15 patients. *Clin Implant Dent Relat Res* 2012;14:682—9.
26. Xu H, Shimizu Y, Ooya K. Histomorphometric study of the stability of newly formed bone after elevation of the floor of the maxillary sinus. *Br J Oral Maxillofac Surg* 2005;43:493—9.
27. Shimoji S, Miyaji H, Sugaya T, et al. Bone perforation and placement of collagen sponge facilitate bone augmentation. *J Periodontol* 2009;80:505—11.
28. Kim JW, Seong TW, Cho S, Kim SJ. Randomized controlled trial on the effectiveness of absorbable collagen sponge after extraction of impacted mandibular third molar: split-mouth design. *BMC Oral Health* 2020;20:77.
29. Stefanski S, Svensson B, Thor A. Implant survival following sinus membrane elevation without grafting and immediate implant installation with a one-stage technique: an up-to-40-month evaluation. *Clin Oral Implants Res* 2017;28:1354—9.
30. Lee BA, Lee SB, Kim YT. Crestal approach for the repair of the Schneiderian membrane perforated during transalveolar sinus elevation. *J Osseointegration* 2021;13:150—5.
31. Eastell R, O'Neill TW, Hofbauer LC, et al. Postmenopausal osteoporosis. *Nat Rev Dis Prim* 2016;2:16069.
32. Chow J, Tobias JH, Colston KW, Chambers TJ. Estrogen maintains trabecular bone volume in rats not only by suppression of bone resorption but also by stimulation of bone formation. *J Clin Invest* 1992;89:74—8.
33. Oursler MJ. Estrogen regulation of gene expression in osteoblasts and osteoclasts. *Crit Rev Eukaryot Gene Expr* 1998;8:125—40.