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Comparative study on lateral maxillary sinus augmentation of without grafting, particle bone grafting and recombinant human bone morphogenetic protein-2+absorbable collagen sponge grafting with simultaneous dental implant placement: a retrospective study

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Abstract (J Korean Assoc Oral Maxillofac Surg 2025;51:217-227)

Objectives: To compare the clinical and radiographic results of three approaches—involving particulate bone graft, recombinant human bone morphogenetic protein-2 (rhBMP-2)+absorbable collagen sponge (ACS), and no graft material—for lateral maxillary sinus augmentation with simultaneous dental implant placement.

Materials and Methods: From January 2015 to June 2021, a retrospective analysis was performed on 63 patients (a total of 122 implants) who underwent lateral maxillary sinus augmentation with simultaneous implant placement at the Department of Oral and Maxillofacial Surgery, Dong-A University Hospital. The patients were classified into three groups: no bone graft (n=46), particulate bone graft (n=44), and rhBMP-2+ACS graft material (n=32) groups. Panoramic and cone-beam computed tomography images taken before and after surgery were used to evaluate the residual bone height (RBH), postoperative bone height (POBH), bone density, and type of bone formation at the apex of the implant (BT). Additionally, the implant survival rates and postoperative complications were analyzed.

Results: The 1-year implant survival rate was similar across all three groups, exceeding 95%. The particulate bone graft group demonstrated the best clinical outcomes in terms of POBH and bone density, as well as the most active bone formation at the BT. The incidence of complications did not differ significantly among the three groups.

Conclusion: Although particulate bone graft was effective for bone formation and space maintenance, no significant differences were observed in the implant survival rate or complications compared with the other methods. The sinus augmentation outcomes did not vary considerably regardless of the type of bone graft material used.

Key words: Sinus floor augmentation, Recombinant human bone morphogenetic protein-2, Dental implants, Allografts, Xenograft

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I. Introduction

The number of patients requiring rehabilitation following tooth loss is gradually increasing due to population aging and an increase in the average life expectancy. Implant placement for managing tooth loss is currently considered the best option in terms of both functionality and esthetics[1].

Vertical bone defects frequently occur due to alveolar bone loss, resorption of the extraction socket, and pneumatization of the maxillary sinus following tooth loss, especially in the posterior maxilla. To address these issues, sinus augmentation procedures with bone grafting and implant placement have been widely used, demonstrating satisfactory treatment outcomes[2-4].

Traditionally, various particulate bone graft materials—such as autogenous bone, allogeneic bone, xenogeneic bone, and synthetic bone—have been used in sinus augmentation procedures. Each of these bone graft materials has its own advantages and disadvantages[5-8]. In particular, the use of particulate bone graft materials results in significantly greater

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endo-sinus bone gain compared to cases without bone graft material[9]. However, a common complication of sinus augmentation procedures with bone grafting is perforation of the sinus membrane, which has a reported incidence of approximately 23.5%[10]. The bone graft material may leak into the sinus cavity in cases of perforation, resulting in sinusitis. Therefore, particulate bone graft materials are potential sources of infection[11,12].

As an alternative, sinus augmentation procedures can also be performed without bone grafting[13]. Implant rehabilitation using this approach enables bone formation through the so called "tent pole effect," and carries a lower risk of sinusitis[14,15]. However, possible disadvantages of this technique include limited bone formation owing to insufficient space maintenance—since the sinus membrane is supported only by the implant fixture—and the potential for postoperative pneumatization[16].

Bone morphogenetic proteins (BMPs), which are unique osteoinductive proteins found in bone, are involved in bone remodeling following growth after birth, and promote bone formation in conjunction with other growth factors in cases of bone damage or infection. Recombinant human BMP-2 (rhBMP-2), when administered locally, is particularly effective in new bone tissue formation[17]. Since the amount of BMP available in the body is limited and is absorbed and degraded rapidly, selection of an optimal carrier is critical to delay its absorption while maintaining its osteoinductive capacity and allowing sufficient contact with surrounding cells. Absorbable collagen sponge (ACS) can be used as a scaffold to serve this purpose[18,19].

This study aimed to compare and analyze the results of sinus augmentation using either particulate bone grafts or rhBMP-2+ACS with those of sinus augmentation procedures performed without any graft material. Vertical bone height, bone density (BD), and bone formation pattern at the apical aspect of the implant were each measured before and after surgery and compared among the three groups with simultaneous implant placement via the lateral approach.

II. Materials and Methods

1. Patient selection

A retrospective analysis was conducted on 122 implants (46 without bone graft, 44 with particulate bone graft, and 32 with rhBMP-2+ACS) placed in 63 patients (39 females, 24 males) who underwent implant placement and lateral sinus augmentation procedures at the Department of Oral and Maxillofacial Surgery, Dong-A University Hospital between January 2015 and June 2021. Of these 63 patients, 26 underwent a lateral sinus augmentation without bone graft, 20 underwent a sinus augmentation with particulate bone graft such as allograft (OraGraft; LifeNet Health) and xenograft (Cerabone; Straumann) used alone or in combination, and the remaining 17 underwent a sinus augmentation using rhBMP-2 (COWELL BMP; Cowellmedi) (as the graft material) and ACS (Atelo Plug; Hyundai Bioland) (as the carrier).(Fig. 1)

1) Inclusion criteria
(1) Adults aged 18 years or older
(2) Patients who underwent a simultaneous sinus augmentation with simultaneous implant placement, in which either particulate bone graft material or rhBMP-2+ACS was used as the graft material, or no graft material was used
(3) Patients who received implants with a diameter of 4-6 mm and a length of 10-12 mm
(4) Patients with relevant dental records, such as preoperative and postoperative panoramic radiographs and cone-beam computed tomography (CBCT) images
(5) Relatively healthy patients who met the American Society of Anesthesiologists (ASA) physical status (PS) classification I or II (ASA PS I, ASA PS II), i.e., healthy or with mild systemic disease
(6) Patients with good oral hygiene

2) Exclusion criteria
(1) Patients under 18 years of age with further growth potential
(2) Patients with current or history of infections or diseases that could affect bone or soft tissue healing
(3) Patients with a history of head and neck radiotherapy
(4) Patients with uncontrolled systemic diseases
(5) Patients with mental illnesses or those suspected of having mental illnesses
(6) Patients with poor oral hygiene
(7) Others who were deemed inappropriate for participation in the clinical study by the principal investigator for ethical reasons or due to potential influence on the clinical study results

2. Pre-operative evaluation

To assess the residual bone height (RBH) and sinus anato-

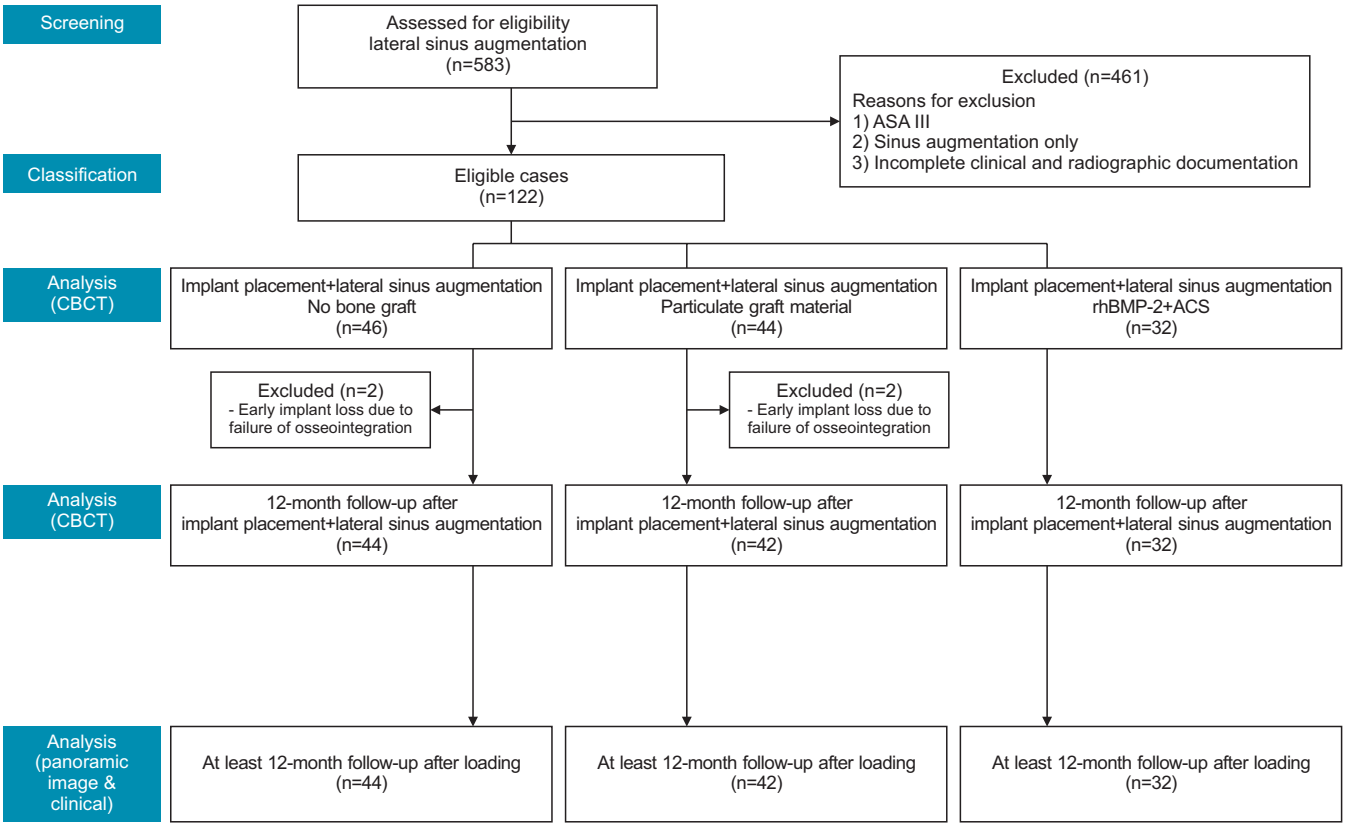

Fig. 1. Flow diagram of patient selection. (CBCT: cone-beam computed tomography, ASA: American Society of Anesthesiologists, rhBMP-2+ACS: recombinant human bone morphogenetic protein-2+absorbable collagen sponge)

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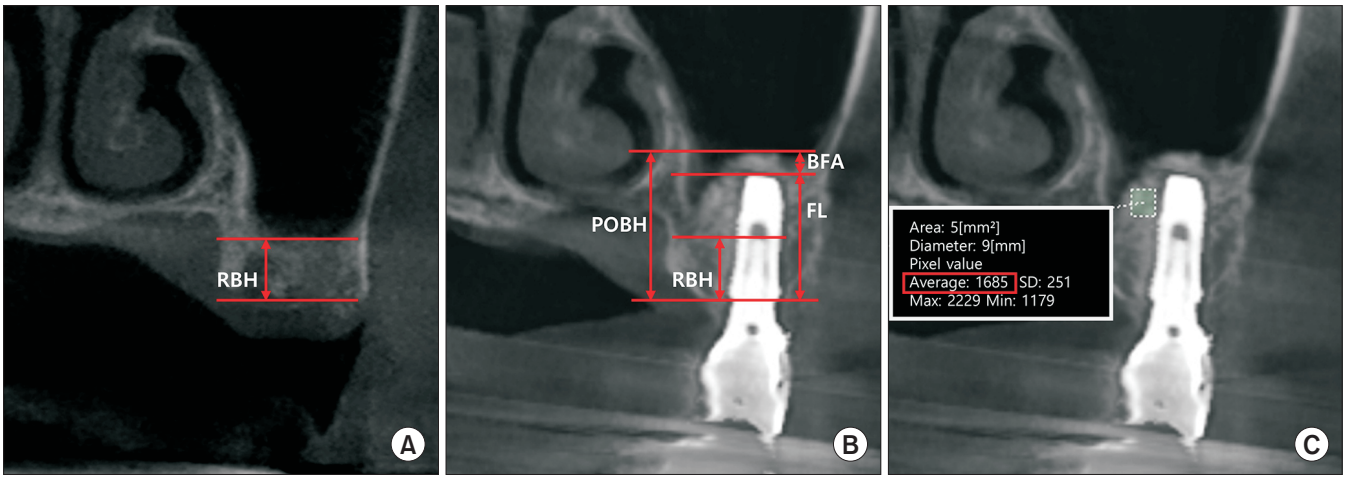

Fig. 2. Coronal images on cone-beam computed tomography scans. A. Preoperative height measurement. B. Postoperative height measurement. C. Postoperative bone density. (RBH: residual bone height, POBH: postoperative bone height, FL: fixture length, BFA: bone formation over implant apex)

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my prior to surgery, panoramic radiograph and CBCT imaging were obtained[20].(Fig. 2. A)

The average preoperative RBH at the edentulous sites where implants were to be placed was 4.59±1.85 mm (range: 0.6-10.1 mm).

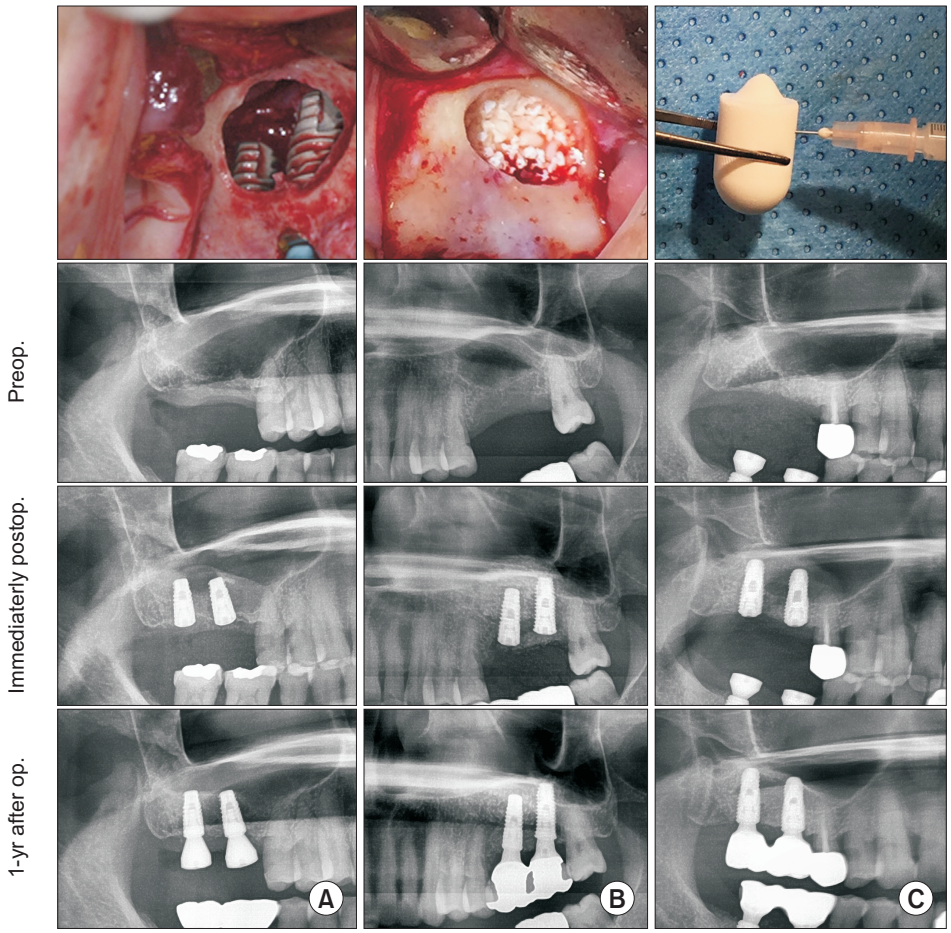

Fig. 3. Clinical and radiographic comparison of sinus augmentation. A. No bone graft. B. Particulate bone. C. Recombinant human bone morphogenetic protein-2+absorbable collagen sponge. *Min Seong Kang et al: Comparative study on lateral maxillary sinus augmentation of without grafting, particle bone grafting and recombinant human bone morphogenetic protein-2+absorbable collagen sponge grafting with simultaneous dental implant placement: a retrospective study. J Korean Assoc Oral Maxillofac Surg 2025*

3. Operative methods

The operations were performed using conventional techniques. All surgeries were conducted under local anesthesia. A full-thickness flap was elevated using a crestal incision, vertical incision, and buccal releasing incisions if necessary. After creating a lateral window in the buccal bone, the maxillary sinus membrane was elevated, and the procedure was performed with or without the use of bone graft material. Internal connection bone level implants were placed simultaneously.(Fig. 3) Except for the use and type of bone graft material, the surgical procedures were identical among the three groups. When bone graft materials were used, particulate bone (allograft, or xenograft used alone or in combination) or rhBMP-2+ACS (rhBMP-2 loaded on to ACS carrier) was utilized as the graft material. When bone graft materials were not used, the sinus membrane was merely elevated before placing the implant. Postoperative management was performed identically in all three groups.

4. Post-operative evaluation

Regular follow-ups were conducted for a minimum of 1 year and up to a maximum of 8 years after surgery. The primary point of comparison and evaluation was at 1 year postoperatively. Postoperative bone height (POBH), density, and morphology at the implant site were assessed using CBCT based on the coronal section.

The height of postoperative bone formation was calculated by subtracting the preoperative RBH from the POBH.(Fig. 2. B) Postoperative BD (PBD) was measured based on the CBCT grayscale values, specifically in a 5 mm^2 area adjacent to the palatal bone graft region located 2 mm below the apex of the implant.(Fig. 2. C)[21,22]

Regarding postoperative bone morphology around the apex of the implant, the type of bone formation at the apex of the implant (BT) was evaluated based on the distance between the residual bone and the apex of the implant at 1 year after surgery. These types were classified into the following three categories (Fig. 4):

0: Dehiscence (presence of bone defect)

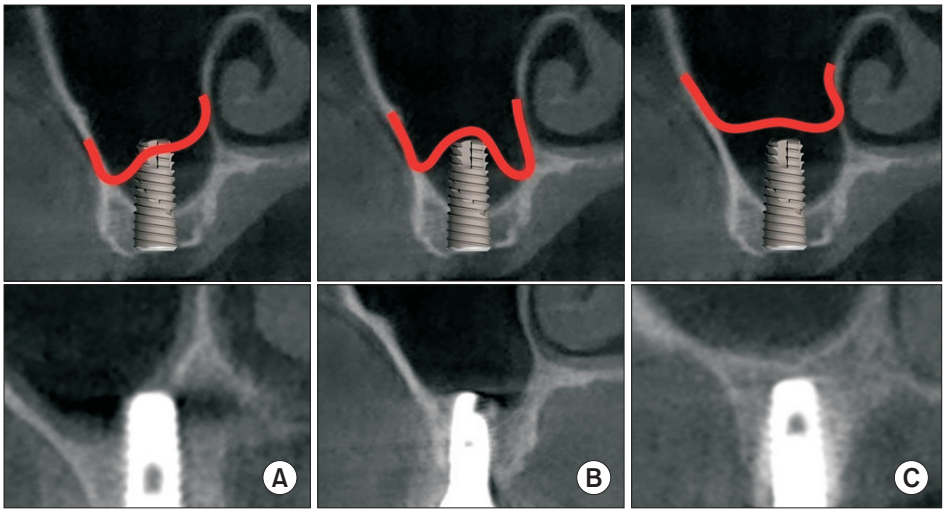

Fig. 4. Morphology of bone formation relative to implant apex. A. Dehiscence type, presence of bone defect. B. Apex only type, bone formation only at the implant apex. C. Apex over type, bone formation 1 ≥1 mm beyond the implant apex.
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1: Apex only (bone formation only at the implant apex)
2: Apex over (bone formation ≥1 mm beyond the implant apex)

Postoperative complications were assessed either based on patient-reported symptoms at the time of suture removal and follow-up or using postoperative CBCT. Patients reported symptoms such as epistaxis, sneezing, nasal congestion, and sinusitis.

5. Statistical analysis

Categorical variables were presented as frequencies and percentages, and compared using the chi-square and Fisher's exact test. Continuous variables were expressed as means±standard deviations and medians (min-max), and were compared using the analysis of variance with Scheffe's post-hoc test or the Kruskal–Wallis test with Dunn's post-hoc test.

The correlations between POBH-RBH (bone height formed at 1-year follow-up), type (pattern of bone formation at the upper margin of the implant), PBD, and fixture length (FL)-RBH (implant length minus RBH; height of sinus membrane elevated by the implant) were assessed using Spearman's correlation coefficient.

All statistical analyses were carried out using IBM SPSS Statistics for Windows ver. 29.0.2.0 (IBM). *P*-values <0.05 were considered statistically significant.

III. Results

A total of 122 implants were placed in the posterior maxilla of 63 patients (39 females, 24 males) with a mean age of 56.31 years (range: 24.0-79.0 years). Of the 63 patients, 26 (9 males, 17 females) underwent a sinus augmentation procedure without bone grafting, and a total of 46 implants were placed; 20 patients (10 males, 10 females) underwent a sinus augmentation procedure using particulate bone grafts, with a total of 44 implants placed; and the remaining 17 patients (5 males, 12 females) underwent a sinus augmentation procedure using rhBMP-2+ACS as the graft material, with a total of 32 implants placed.(Table 1)

1. Survival rate

Among the 122 implants, two were removed in the group without bone graft and two were removed in the group using particulate bone grafts, while the remaining 118 implants were followed up 1 year after surgery. The follow-up period ranged from 1 to 8 years, and the 1-year implant survival rate in this study was 96.7%.(Table 2)

2. Implant diameter and length

The mean implant diameter was 4.63±0.35 mm, 4.78±0.31 mm, and 4.69±0.32 mm in the no bone graft, particulate bone graft, and rhBMP-2+ACS groups, respectively. The mean implant length was 11.47±0.78 mm, 11.89±0.44 mm, and 11.39±0.90 mm in the no bone graft, particulate bone graft, and rhBMP-2+ACS groups, respectively.(Table 1)

3. Complications

Postoperative complications were reported in 2, 2, and 1 patient(s) in the no bone graft, particulate bone graft, and

Table 1. Baseline characteristics of implants according to groups

Variable	Overall (n=118)	Group			*P*-value	Post-hoc
		No bone graft[a] (n=44)	Particulate bone[b] (n=42)	rhBMP-2+ACS[c] (n=32)		
Age (yr)						
Mean±SD	56.31±12.84	56.73±14.26	53.71±11.79	59.13±11.76	0.154[2]	
Median (range)	58.0 (24.0-79.0)	59.0 (24.0-79.0)	51.5 (31.0-70.0)	59.0 (42.0-78.0)		
Sex						
Male	47 (39.8)	18 (40.9)	21 (50.0)	8 (25.0)	0.092[3]	
Female	71 (60.2)	26 (59.1)	21 (50.0)	24 (75.0)		
Diameter of implant						
Mean±SD	4.70±0.33	4.63±0.35	4.78±0.31	4.69±0.32	0.014[2]	a<b
Median (range)	4.8 (4.0-6.0)	4.7 (4.1-6.0)	4.8 (4.3-5.2)	4.8 (4.0-5.0)		
Length of implant						
Mean±SD	11.60±0.74	11.47±0.78	11.89±0.44	11.39±0.90	<0.01[2]	a,c<b
Median (range)	12.0 (10.0-12.0)	12.0 (10.0-12.0)	12.0 (10.0-12.0)	12.0 (10.0-12.0)		
RBH						
Mean±SD	4.59±1.85	4.74±1.89	4.36±1.98	4.67±0.90	0.614[1]	
Median (range)	4.6 (0.6-10.1)	4.7 (1.3-10.1)	4.1 (0.6-9.1)	4.8 (1.7-6.9)		
POBH						
Mean±SD	13.07±2.42	12.30±2.11	14.10±2.50	12.78±2.29	<0.001[2]	a<b
Median (range)	12.6 (7.8-21.2)	12.1 (7.9-18.7)	13.8 (10.-21.2)	12.7 (7.8-19.6)		
POBH-RBH						
Mean±SD	8.84±2.87	7.56±2.64	9.74±3.20	8.11±2.07	0.001[1]	a,c<b
Median (range)	8.3 (1.9-17.7)	7.4 (1.9-16.3)	9.9 (2.3-17.7)	8.1 (3.8-13.2)		
FL-RBH						
Mean±SD	7.01±1.88	6.73±1.94	7.53±2.06	6.73±1.37	0.081[1]	
Median (range)	7.0 (1.9-11.4)	6.8 (1.9-10.3)	7.9 (2.9-11.4)	6.6 (4.1-9.7)		
Bone density						
Mean±SD	1,228.73±830.37	842.41±570.52	1,996.12±617.65	752.72±634.65	<0.001[2]	a,c <b
Median	1,136.00	708.00	1,959.00	770.00		
Type						
0	7 (5.9)	4 (9.1)	0 (0.0)	3 (9.4)	0.001[4]	
1	58 (49.2)	29 (65.9)	14 (33.3)	15 (46.9)		
2	53 (44.9)	11 (25.0)	28 (66.7)	14 (43.8)		

(SD: standard deviation, RBH: residual bone height, POBH: postoperative bone height, FL: fixture length)
Values are presented as number (%), mean±standard deviation, or median (range).
[1]*P*-values were derived from analysis of variance with Scheffe's post-hoc test.
[2]*P*-values were derived from Kruskal–Wallis test with Dunn's post-hoc test.
[3]*P*-values were derived from chi-square test.
[4]*P*-values were derived from Fisher's exact test.
Scheffe's post-hoc test or Dunn's post-hoc test was used for multiple comparisons between each the three groups. Shapiro–Wilk's test was employed for test of normality assumption.
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Table 2. Survival rate of implants at 1 year

Variable	Overall (n=122)	Group			*P*-value
		Without grafting (n=46)	Particle bone (n=44)	rhBMP-2+ACS (n=32)	
Success	118 (96.7)	44 (95.7)	42 (95.5)	32 (100.0)	
Fail	4 (3.3)	2 (4.3)	2 (4.5)	0 (0.0)	0.561

(rhBMP-2+ACS: recombinant human bone morphogenetic protein-2+absorbable collagen sponge)
Values are presented as number (%).
P-values were derived from Fisher's exact test.
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Table 3. Number of patients with postoperative complications after sinus augmentation

Variable	Overall (n=63)	Group		
		No bone graft (n=26)	Particulate bone (n=20)	rhBMP-2+ACS (n=17)
Complication				
No	58 (92)	24 (92)	18 (90)	16 (94)
Yes	5 (8)	2 (8)	2 (10)	1 (6)
Epistaxis	2	1	1	0
Sinusitis	1	0	0	1
Nasal obstruction	1	1	0	0
Sneeze	1	0	1	0

Values are presented as number only or number (%).
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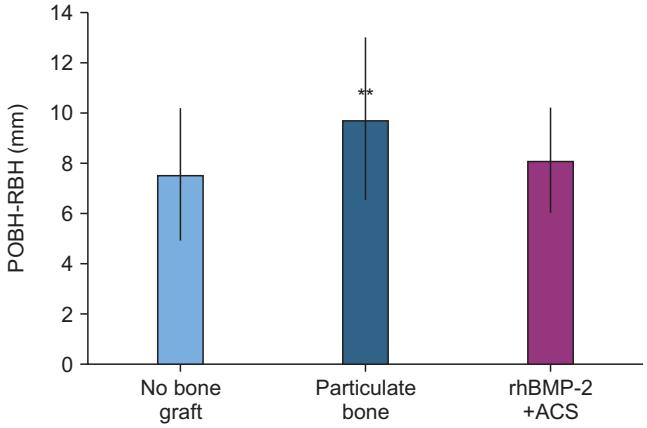

Fig. 5. The height of postoperative bone formation (POBH-RBH). (POBH-RBH: postoperative bone height-residual bone height, rhBMP-2+ACS: recombinant human bone morphogenetic protein+absorbable collagen sponge) ***P*=0.001.
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rhBMP-2+ACS groups, respectively.(Table 3)

4. Bone height

The RBH of the sinus floor before surgery was 4.74±1.89 mm, 4.36±1.98 mm, and 4.67±0.90 mm in the no bone graft, particulate bone graft, and rhBMP-2+ACS groups, respectively. The height of the sinus membrane elevated by the implant (FL-RBH) was 6.73±1.94 mm, 7.53±2.06 mm, and 6.73±1.37 mm in the without bone graft, particulate bone graft, and rhBMP-2+ACS groups, respectively. The height of postoperative bone formation at 1 year (POBH-RBH was 7.56±2.64 mm, 9.74±3.20 mm, and 8.11±2.07 mm in the without bone graft, particulate bone graft, and rhBMP-2+ACS groups, respectively.(Table 1, Fig. 5)

5. Type of bone formation

Regarding the BT, in the without graft group, 4, 29, and 11 cases of dehiscence, apex-only, and apex-over types, respectively were observed. In the group using particulate bone grafts, 0, 14, and 28 cases of dehiscence, apex-only, and apex-over types, respectively were observed. In the rhBMP-2+ACS group, 3, 15, and 14 cases of dehiscence, apex-only, and apex-over types, respectively were observed.(Table 1)

6. Bone density

The PBD was 842.41±570.52, 1,996.12±617.65, and 752.72±634.65 in the no bone graft, particulate bone graft, and rhBMP-2+ACS groups, respectively.(Table 1)

IV. Discussion

Vertical bone defects attributed to atrophy following tooth loss in the maxillary posterior alveolar bone can be managed through a sinus augmentation procedure[23,24]. In such procedures, implants can be placed either with no bone graft or a particulate bone graft. A sinus augmentation is recommended due to its space-maintaining effect attributed to blood clot formation and sinus membrane support[13,14]. However, sinus augmentation procedures have their own limitations regardless of whether bone grafting is performed or not[25-27]. To minimize the occurrence of side effects while maximizing bone formation efficiency, sinus lift procedures using osteoinductive agents (such as BMP) as graft materials have been studied, with many articles having discussed their outcomes[28].

Of the 122 implants evaluated in this study, two implants were removed from each of the no bone graft and particulate bone graft groups. These cases were classified as early failures due to a lack of primary stability, resulting in failed osseointegration[29]. There were no late failures in either group, and the 1-year implant survival rate was 95.7%, 95.5%, and 100.0% in the no bone graft, rhBMP-2+ACS, particulate bone graft, and rhBMP-2+ACS groups, respectively (*P*=0.561).(Table 2) Regardless of the various bone grafting methods, it can be observed that the initial stability of the implant and residual bone quality affect its success rate. Once osseointegration occurs, the long-term stability of the implant can be maintained regardless of the type of graft material used.

Postoperative complications were reported in two patients in the no bone graft (epistaxis and nasal obstruction). In the particulate bone group, two patients reported complications (epistaxis and sneezing), and in the rhBMP-2+ACS group, one patient reported postoperative maxillary sinusitis. Overall, the incidence of complications was low, and most were mild symptoms that could be managed clinically. Since maxillary sinusitis occurred in only one of several cases, there is insufficient evidence to conclude that the rhBMP-2 material itself caused the infection. Therefore, it emphasizes that each grafting method can be performed relatively safely

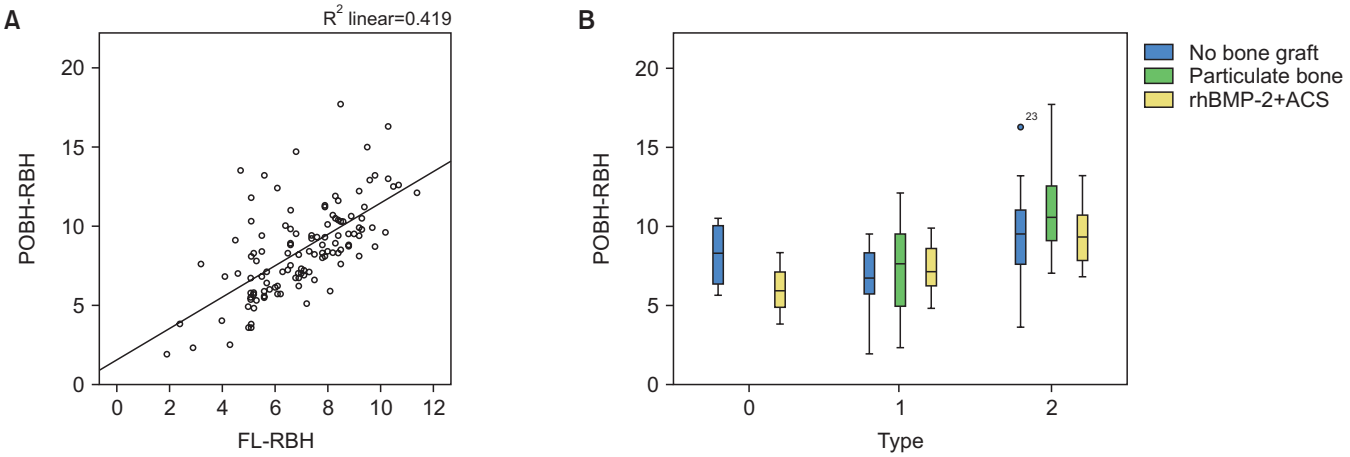

Fig. 6. The correlation among the groups. A. FL-RBH and POBH-RBH. B. Type and POBH-RBH. (FL-RBH: fixture length-residual bone height, POBH-RBH: postoperative bone height-residual bone height, rhBMP-2+ACS: recombinant human bone morphogenetic protein+absorbable collagen sponge)

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Table 4. The correlation among the measured values according to groups

Variable	FL-RBH	POBH-RBH	PBD	Type
FL-RBH	1			
POBH-RBH	0.650 (<0.001)	1		
PBD	0.193 (0.036)	0.384 (<0.001)	1	
Type	–0.016 (0.865)	0.534 (<0.001)	0.411 (<0.001)	1

(FL: fixture length, POBH: postoperative bone height, RBH: residual bone height, PBD: postoperative bone density)
Values are Spearman's rank correlation rho (*P*-value).

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in a clinical setting, and careful patient management is important to minimize the possibility of postoperative complications.

At 1 year postoperatively, the mean value of new bone height formed (POBH-RBH) was greatest in the particulate bone group (mean 9.74±3.20 mm), compared to 7.56±2.64 mm in the no bone graft group and 8.11±2.07 mm in the rhBMP-2+ACS group; a significant difference was observed among the groups (*P*=0.001).(Table 1, Fig. 5) The height of the elevated sinus membrane (FL-RBH) induced by the implant was highest in the particulate bone group (mean 7.53±2.06 mm), which was greater than that of the no bone graft (6.73±1.94 mm) and rhBMP-2+ACS (6.73±1.37 mm) groups; however, the differences were not statistically significant (*P*=0.081).(Table 1) This can be attributed to the space-maintaining ability and osteoconductive property of particulate bone, such as allograft and xenograft, whereas ACS does not maintain space and merely acts as a carrier for rhBMP-2, which may contribute somewhat to early bone formation; however, its effect is minimal[30]. Moreover, regardless of the group, a significant positive correlation was observed between FL-RBH and POBH-RBH (*P*<0.001) (Table 4, Fig. 6. A), indicating that a greater space created by the implant fixture results in greater bone formation postoperatively, which can be interpreted as a tenting effect[14].

As for the BT, the no bone graft group demonstrated 4, 29, and 11 cases of dehiscence, apex-only, and apex-over types, respectively. The particulate bone group demonstrated 0, 14, and 28 cases of dehiscence, apex-only, and apex-over types, respectively; while the rhBMP-2+ACS group demonstrated 3, 15, and 14 dehiscence, apex-only, and apex-over type cases, respectively. This demonstrates that the space-maintaining ability and osteoconductive property of particulate bone, such as allograft and xenograft, leads to enhanced bone formation over the implant[30]. Furthermore, the higher proportion of type 2 observed in the rhBMP-2+ACS group compared to the no bone graft group can be attributed to the initial bone formation capacity and osteoinductive properties of rhBMP-2 even within spatial constraints. Additionally, the blood clot-maintaining property of ACS may have contriuted to the above result[31]. A significant correlation was observed between the POBH-RBH coefficient and the bone formation type (*P*<0.001) (Table 4, Fig. 6. B), indicating that as bone formation occurs above the implant, the space-maintaining ability also increases.

PBD was significantly higher in the particulate bone graft

group than the no and rhBMP-2+ACS bone graft groups (P<0.001). This can be attributed to the space-maintaining ability and osteoconductive property of particulate bone, such as allograft and xenograft. However, when the BD is measured using gray scale, accurate bone quality or bone-to-implant contact (BIC) determination is challenging; thus, the low resorption rate of xenograft material should also be considered. Additionally, factors such as inflammation, presence of soft tissue, and limitations in image resolution should also be taken into consideration[32,33].

The group that used the particulate bone graft materials showed higher POBH-RBH, BD and a higher proportion of type 2 bone formation than the other groups, indicating that greater bone was formed around and above the implant. Moreover, regardless of the group, the longer the implant FL, the more bone formation was achieved. However, in terms of the implant survival rate and complications, no significant difference was observed among the three groups, indicating that the outcomes of sinus augmentation are not greatly affected by the type of bone graft material used. In caess where the use of particulate bone graft materials is not feasible due to sinus membrane perforation during surgery or cost-related issues, without using any graft materials or the use of rhBMP-2+ACS as the graft materials may also represent an effective treatment option.

The limitation of this study is that it lacks early bone formation rate and pattern evaluation before the 1-year follow-up, as well as long-term bone maintenance capacity assessment. Therefore, further in-depth retrospective studies are warranted.

V. Conclusion

In this study, we compared the outcomes of immediate implant placement with sinus augmentation using the lateral window approach in the maxilla, utilizing particulate bone graft and rhBMP-2+ACS as graft materials versus sinus augmentation without any graft material. We analyzed postoperative vertical bone height, BD, bone formation patterns at the superior aspect of the implant, implant survival rates, and postoperative complications. The use of a particulate bone graft as a graft material is recommended if the goal is to achieve greater bone formation around and above the implant. However, in terms of the implant survival rate and complications, no significant difference was observed among the three groups, indicating that the outcomes of sinus augmentation are not greatly affected by the type of bone graft material used. Therefore, clinicians should carefully consider the advantages and disadvantages of using bone graft materials according to the clinical situation, and determine the most appropriate surgical approach based on the clinical context.

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Authors' Contributions

M.S.K., J.H.K., and C.H.K. conceived and designed the study. M.S.K., S.H.K., K.M.I., and G.H.Y. acquired the data. J.H.K. and C.H.K. analyzed and interpreted the data collected. M.S.K., S.H.K., and J.H.L. wrote the manuscript. B.J.K. revised original manuscript. K.M.I. and G.H.Y. edited figures. J.H.K. did critical review and gave final approval. All authors read and approved the final manuscript.

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Ethics Approval and Consent to Participate

This study was approved by the Institutional Review Board (IRB) of Dong-A University Hospital (IRB No. DAUHIRB-25-044). The written informed consent was waived by the IRB due to the retrospective nature of the study.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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