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Preservation and augmentation of molar extraction sites affected by severe bone defect due to advanced periodontitis: A prospective clinical trial

Liping Zhao DDS[1] | Tao Xu DDS[2] | Wenjie Hu DDS, PhD[1] | Kwok-Hung Chung DDS, PhD[3]

[1]Department of Periodontology, Peking University School and Hospital of Stomatology, National Engineering Laboratory for Digital and Material Technology of Stomatology, Beijing Key Laboratory of Digital Stomatology, Beijing, People's Republic of China

[2]Department of Emergency, Peking University School and Hospital of Stomatology, National Engineering Laboratory for Digital and Material Technology of Stomatology, Beijing Key Laboratory of Digital Stomatology, Beijing, People's Republic of China

[3]Department of Restorative Dentistry, University of Washington, Seattle, Washington, USA

Correspondence
Wenjie Hu, DDS, PhD, Professor, Department of Periodontology, Peking University School and Hospital of Stomatology, National Engineering Laboratory for Digital and Material Technology of Stomatology, Beijing Key Laboratory of Digital Stomatology, 22 Zhongguancun Avenue South, Haidian District, Beijing 100081, PR China.
Email: huwenjie@pkuss.bjmu.edu.cn

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Abstract

Background: Studies of the extracted infected-molar ridge preservation are limited.

Purpose: To compare alterations of hard and soft tissue in infected-molar sockets receiving ridge preservation compared with natural healing.

Materials and Methods: Thirty-five infected-molar extraction sites either preserving with Bio-Gide membrane covered the Bio-Oss material or receiving natural healing procedure as controls. The soft tissue profile was evaluated before tooth extraction and after 6-month healing. Cone-beam computed tomography scans were taken immediately and 6 months after extraction. Vertical and horizontal bone changes were assessed radiographically. Data were analyzed with Mann-Whitney U test and $\alpha = 0.05$.

Results: No significant differences in soft tissue and vertical bone changes in the medium region of the sockets were found ($P > .05$). Buccal bone changes in the mesial and distal sites in the test group were significantly lower than the control group ($P < .05$). Ridge width increased from 0.21mm to 5.30mm at 1mm apical from the crest in the test and reduced from 0.12 mm to 1.00 mm in the control groups.

Conclusion: Ridge preservation at periodontally compromised molar extraction sites might compensate for ridge width and buccal bone resorption that occurs with natural healing alone.

KEYWORDS
bone grafting, clinical trial, cone beam computed tomography, tooth extraction, xenograft

1 | INTRODUCTION

Animal studies as well as human clinical studies have demonstrated that, following tooth extraction, undisturbed wound healing leads both to loss of ridge volume and to change in ridge shape.[1–3] A systematic review by Van der Weijden and colleagues demonstrated that for anterior and premolar teeth, the clinical alveolar bone width and mid-buccal height decreased by 3.87 and 1.67 mm, respectively.[4] Tan and colleagues reported that vertical dimension changed by 11%-22% at 6 months and horizontal dimensional changed by 32% at 3 months and 29%-63% at 6–7 months in the post-extraction alveolar ridge.[5] This bone resorption positions the post-extraction alveolar ridge margins at

a more apical level and to a more lingual/palatal position resulting in changes to the overlying soft tissue contours and reduces the quantity and architecture of bone available for a biologically acceptable and prosthetically driven location for a conventional prosthesis and implant-supported restoration.[2,5–7]

Lopez-Martinez and colleagues reported that the most frequent reason for tooth extraction was periodontal disease (69.20%), followed by endodontic failure (25.67%) and trauma (6.20%).[8] Additionally, loss of alveolar bone may occur prior to tooth extraction due to periodontal disease, periapical pathology, or trauma to teeth and bone.[4,9] Extraction sockets in such studies rarely present with four intact bony walls, and most are damaged by infection, irregular and severe bone loss.

The alveolar process is a tooth-dependent anatomic structure that atrophies when permanent teeth are lost.[10] Great variation has been observed among individual subjects and tooth position with respect to the resorption process that occurs following tooth extraction. Numerous factors may affect the resorption of sockets, such as the presence of infection, previous periodontal disease, the extent of traumatic injury and the number or the thickness and height of the remaining bony socket walls, soft tissue thickness, metabolic factors, and functional loading.[11,12] The irregular deficiency of bone plate that occurs before tooth extraction and the bone resorption that occurs after tooth extraction as a result of the natural remodeling process cause reduction in volume of ridge bone and deformation of ridge contour. Clinicians now reconstruct this lost volume by several augmentation techniques including onlay bone graft, block graft, sinus augmentation, ridge split/expansion, distraction osteogenesis and guided bone regeneration[13–17] to guarantee an ideal prosthetically-driven three-dimensional position and contour for optimal dental implant placement. However, none of these techniques fulfills a desired objective of the field, which is to create suitable ridge height and width for further implant or prosthetic treatment with minimum effort.[18]

Alveolar ridge preservation and augmentation commonly are performed immediately after tooth extraction to preserve or increase ridge volume within or beyond the skeletal envelope that exists at the time of extraction.[19] The purpose of this is to maintain the soft and hard tissue contour of the ridge to facilitate implant placement in a prosthetically driven position.[9] Systematic reviews of the literature have confirmed that socket preservation procedures are effective in mitigating the changes in bone when compared with extraction alone, however some loss in width and height probably still will occur.[9,20–22] Vignoletti and colleagues[23] demonstrated that ridge preservation reduces bone height loss by 1.47 mm and reduces bone width loss by 1.83 mm. Similarly, when compared with tooth extraction alone in non-molar teeth, Avila-Ortiz[24] showed that ridge preservation sites experienced 1.89 and 2.07 mm less reduction in bucco-lingual width and mid-buccal height, respectively. Ridge preservation/augmentation may reduce the need for further bone augmentation during implant placement, may reduce sinus pneumatization, and may increase the possibility of inserting implants without the need for a sinus augmentation procedure in the posterior maxilla.[25–28] Furthermore, the augmentation procedure for severely resorbed alveolar sockets provides better results in terms of bone regeneration when compared with traditional GBR procedures performed at the time of implant placement in untreated sites.[29] Also of note, however, is the fact that success rates of implants placed in grafted sockets are comparable to those for implants placed in untreated sockets.[26,30,31]

Most studies relevant to this work have included only fresh extraction sockets without bone defect in the aesthetic area,[32,33] but other work has reported that the healing of compromised sockets is delayed compared with the healing process of fresh sockets.[34–36] An experimental study in dogs demonstrated that ridge preservation in diseased extraction sockets could compensate for buccal bone resorption, and a human study established that ridge preservation/augmentation in periodontally compromised extraction sockets including anterior and posterior teeth is safe with an overall safety rate of 99.4%.[36,37]

Given that the orifice and morphology of molar sockets are quite different from those of single-rooted teeth, their healing processes are not comparable. The effect of ridge preservation specific to molars has rarely been studied. Ridge preservation specific to molar sites with at least 10 mm of alveolar bone height on a radiograph, from which molars were extracted due to carious lesions, prosthetic failures, root fractures, or endodontic failures, significantly decreased buccal bone height reduction compared to sockets that healed naturally.[38]

To the best of our knowledge, studies of ridge preservation/augmentation limited to molars extracted due to periodontal pathosis in humans are rare and limited to case reports.[39] The objective of the present prospective human clinical study was to evaluate and compare the dimensional alterations of soft and hard tissue in periodontally compromised molar sites that received a ridge preservation/augmentation procedure to those left to heal spontaneously without any other intervention. Evaluation of soft tissue was by clinical measurement and of hard tissue was by cone beam computed tomography (CBCT) scans during a 6–month healing period following molar extraction, and ridge preservation/augmentation procedure used Bio-Oss and Bio-Gide (Geistlich, Pharma AG, Wolhusen, Switzerland).

2 | MATERIALS AND METHODS

2.1 | Patient selection

This prospective clinical trial was performed from December 2013 to December 2016 at the Peking University School and Hospital of Stomatology, department of periodontology, conducted in full accordance with the ethical principles established in the World Medical Association Declaration of Helsinki of 1975 as revised in 2000, and approved by the Institutional Review Boards of the Peking University School and Hospital of Stomatology (Approval Number: PKUSSIRB-201310068; Chinese Clinical Trial Registry Identifier: ChiCTR-ONN-16009433). Thirty-three patients who contributed 36 molar teeth were enrolled in the study. The first consecutive 18 teeth were assigned to the control group, and the following 18 teeth were assigned to the test group. All patients received thorough explanations about the study protocol and provided complete written consent to participate in the study.

Patients scheduled for molar extraction as a consequence of severe periodontal disease and for whom implant-retained prostheses were

TABLE 1 Inclusion and exclusion criteria

Inclusion	Exclusion
At least 25 years old Able to comply with study-related procedures and recall visits Systemically healthy Presence of a hopeless molar with severe bone destruction requiring extraction due to advanced periodontal disease At least two socket walls with alveolar bone beyond the apex of the extraction socket $\geq$ 3mm and one adjacent tooth at the proximal region	Poor oral hygiene Pregnancy and lactation Medications or disease that would complicate bone healing, for example, bisphosphonates and osteoporosis Absence of both adjacent teeth Teeth with ongoing acute pathology: abscess, suppuration, and severe swelling Smoking more than 10 cigarettes per day History of head and neck radiotherapy Teeth extracted due to caries, endodontic failures or fracture Teeth with extreme bone loss or gingival recession

planned for the resulting extraction sockets were eligible for this study. Inclusion and exclusion criteria are listed in Table 1.

2.2 | Preparation for treatment

Patients were assessed with periapical radiographs, clinical photographs, and clinical periodontal examination to confirm the unsalvageable nature of the tooth to be extracted. At least 7 days prior to the surgery procedure, all patients underwent scaling, root planning, oral hygiene instructions, and any necessary supportive periodontal treatment to provide a more favorable oral environment for wound healing.

2.3 | Surgical procedures

Figure 1A-I present surgical procedures and radiographic examination of a representative patient in the test group. All patients received prophylactic antibiotic therapy (Amoxicillin, 1 g or Erythromycin 300 mg if allergic to Penicillin) 1 hour prior to tooth extraction and an anti-inflammatory drug (Ibuprofen 300mg) if needed and for as long as required. Patients rinsed with a 0.2% chlorhexidine solution for 1 minute before the procedure. All procedures were performed by the same periodontist (WH) and all patients were managed with the same surgical technique, as follows. Following the administration of local anesthesia, an internal bevel incision to the bone crest was performed approximately 0.5-1 mm below the buccal and the lingual free gingival

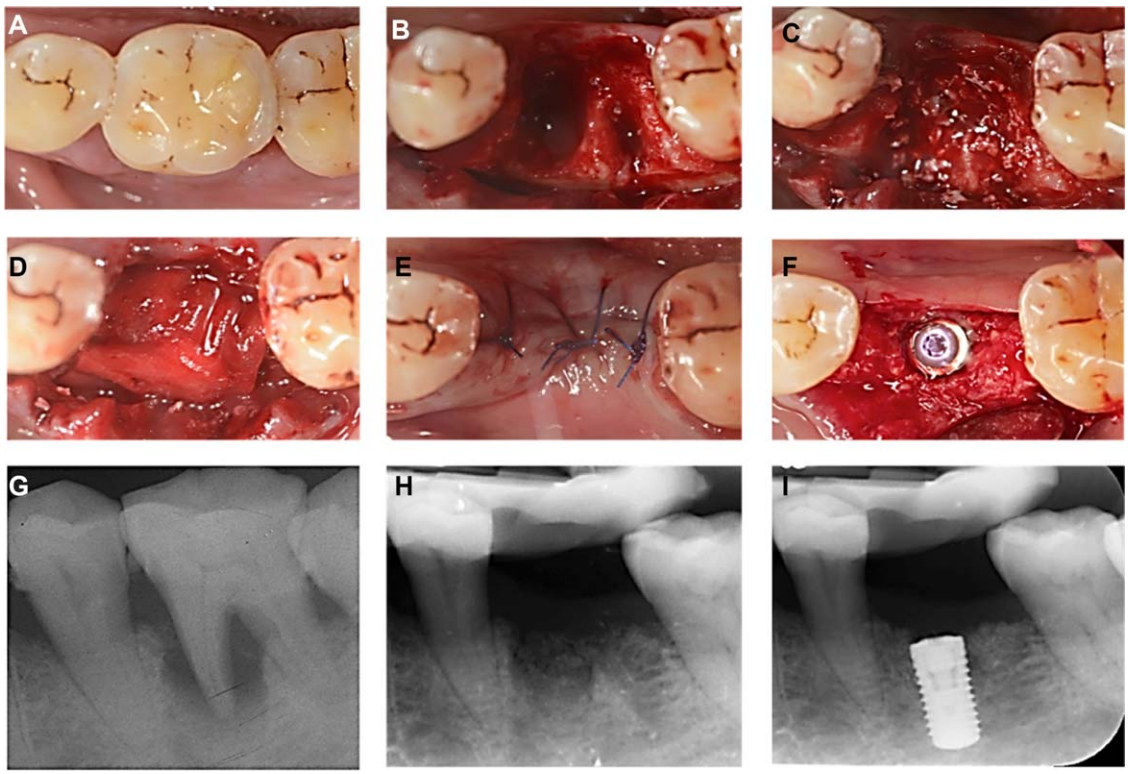

FIGURE 1 Clinical and radiological photographs of a representative case: left mandible 1st molar from the test group: A, pre-extraction clinical aspect, B, severe buccal bone defect after atraumatic extraction and vertical releasing incision in the buccal aspect, C, socket grafted with Bio-Oss, D, covered with Bio-Gide, E, cross-mattress and interrupted sutures for primary wound closure, F, flap elevation and implant placement following 6 months of healing; periapical radiographic images taken, G, before tooth extraction, H, immediately after ridge preservation/augmentation, and I, immediately after implant placement

margin of the tooth in question to remove the inner wall of the periodontal pocket without flap elevation. The ailing tooth was extracted atraumatically using periotomes and extraction forceps, sectioning the roots with diamond fissure burs and allowing root separation within the socket if required to avoid unnecessary trauma to the surrounding alveolar bone walls. Sockets were carefully examined and meticulously debrided with surgical curettes to remove all granulation tissue, then irrigated with sterile saline solution and curetted to stimulate fresh bleeding from the osseous base of the alveolus. Extraction sockets in the ridge preservation/augmentation test group received a full-thickness mucoperiosteal flap procedure with two vertical releasing incisions beyond the mucogingival junction in the mesial and distal aspects of the sockets and extending to the mucosal vestibular groove at the buccal side (Figure 1A,B,G). Sockets were filled with graft material (Bio-Oss; Geistlich Pharma AG, Wolhusen, Switzerland) placed loosely without condensation, which consists of small granules of particle size 0.25-1 mm and hydrated with sterilized saline up to the crest of the socket, making no attempt to go outside the confines of the ridge and excessive graft particles avoided (Figure 1C). An absorbable collagen membrane (Bio-Gide; Geistlich Pharma AG, Wolhusen, Switzerland) was trimmed and applied to completely cover the socket with 2–3 mm extending over the alveolar bone crest (Figure 1D). Subsequently, the buccal flap was advanced coronally to allow maximum primary soft tissue closure (Figure 1E). Immediately after surgery, digital intra-oral periapical radiographs were taken (70 KVp, 12–20 mA) (Figure 1H). Sutures in this test group were removed 3 weeks postoperatively, when the soft tissue had healed.

No alveolar ridge preservation procedure was performed on patients in the control group and silk sutures were used in this group only to stabilize blood clotting, without aiding primary closure of soft tissue. Sutures were removed after 1 week of healing.

All patients were instructed to continue to take the antibiotic postoperatively three times daily for 7 days and received ibuprofen (300 mg twice daily for 3–5 days) to manage post-surgical discomfort and inflammation. Regular tooth brushing in the rest of the mouth and rinsing twice daily with a 0.12% chlorhexidine solution was prescribed for the first 3–4 weeks post-surgery until the soft tissue healed adequately. Normal oral hygiene practices then were resumed. Removable prostheses were not worn over the extraction site. Recall appointments were scheduled weekly for the first month following extraction, then after three months and after 6 months. Oral hygiene instructions and any necessary treatment related to periodontal health were given throughout the study. All complications and adverse events were recorded. Six months after healing, dental implants were inserted according to the standard protocol (Figure 1F,I).

The periodontal conditions of the extraction site were assessed by measuring probing depth (PD), gingival recession (GR) and bleeding index (BI). Width of keratinized tissue (WKT) was measured midfacially from the mucogingival junction to the gingival margin of the ailing tooth before extraction (WKT_0) and from the most coronal part of the edentulous crest to the mucogingival junction of the edentulous area 6 months later (WKT_1), before implant surgery. Data were rounded down to the nearest 0.5 mm and collected by the same periodontist (WH), using an UNC-15 probe (Hu Friedy® Chicago, IL). Examiner reliability was assessed in a previous pilot study and intra-examiner differences were within 1 mm.

2.4 | Cone beam computed tomography (CBCT) measurements

CBCT scans were performed immediately after surgery and repeated 6 months later using the same three-dimensional x-ray unit (NewTom VG; Aperio Services, Italy) at a resolution of 0.125 mm with field of view size 8 × 8 cm for 360 degrees rotation. For standardized radiographic measurements, two sets of DICOM (Digital Imaging and Communications in Medicine) data were generated and transferred to a volumetric imaging software (Mimics 17.0, Materialise, Leuven, Belgium) in which three-dimensional reconstruction and image analyses were conducted. Grafted bone material was easily distinguished from residual bone by density and structure on the scans immediately after grafting in the test group. Superimposition of virtual models completed for selected areas of the data used identified landmarks such as the inferior border of the mandible and the palatal vault of the maxillae. After superimposition, the two data sets were aligned and manually checked for perfect matching (Figure 2A-F).

Once superimposition was complete, vertical, and horizontal reference lines were drawn.[40] To establish a reproducible and precise protocol to measure the changes of horizontal and vertical bone loss immediately after extraction and after a 6-month healing period, measurements were taken at different levels and sites on the alveolar crest (Figure 3). Measurements were made at the following three coronal sections: (1) in the center, (2) in the mesial one-sixth, and (3) in the distal one-sixth of the mesio-distal distance of the alveolar socket. Residual buccal and lingual (or palatal) plate thicknesses in the center of the socket at three levels below the bone crest (–1 mm, −3 mm, and −5 mm) were measured in the coronal section on the baseline scan. Residual height measurements were made at 8 points on the baseline scans: mesial, central, and distal points over both the buccal and lingual/palatal crests in the coronal planes in the mesio-distal direction, and at points in the center of both the mesial and distal margin of the socket in a sagittal plane in the bucco-lingual/palatal direction.

Horizontal width changes were calculated as the difference between baseline and post-6 month' healing time at 1 mm, 3 mm, and 5 mm below the bone crest in coronal slices. In the center of the socket, horizontal ridge width was measured relative to the crest of the buccal and lingual (or palatal) bone plate, whereas in the mesial and distal one-sixth of the socket, horizontal ridge width was measured only below the buccal crest. If the buccal or lingual/palatal plate was missing at any level immediately after extraction, ridge width at this level corresponds to the thickness of the residual alveolar wall on the corresponding lingual/palatal or buccal side.

Measurements of vertical height of the alveolar crest 6 months after extraction were repeated as described above for baseline measurements. In addition, ridge height in the center of the socket was measured for 6-month healing CBCT scans because it was assigned to

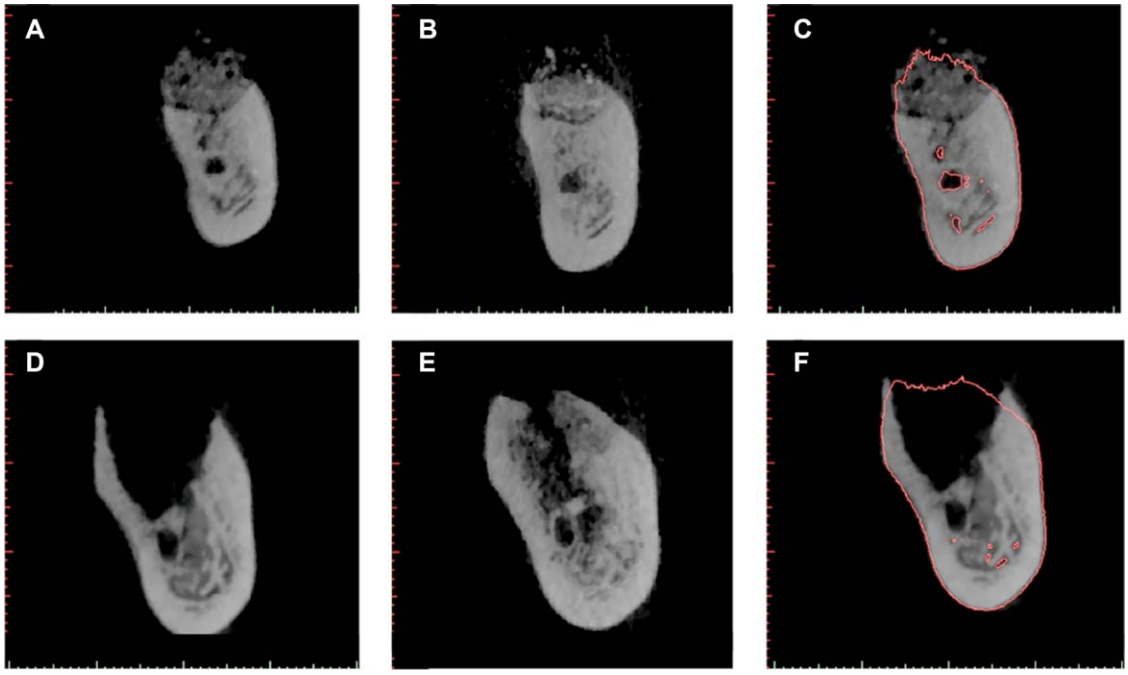

FIGURE 2 Coronal views and superimposition of CBCT images of alveolar process after immediate and a 6-month period healing of a representative case of the test group (A-C) and the control group (D-F)

zero for the center of the socket in immediate scans. Thus, vertical ridge changes were calculated at a total of 9 points.

2.5 | Statistical analysis

According to the previous study[41] reported a mean and SD values for horizontal ridge changes, a power analysis using two-tailed Mann-Whitney U test to show an effect size difference of 2 mm in ridge width between groups at $\alpha = 0.05$ indicated that 18 subjects per group would be adequate to achieve 80% power in this study.

Statistical analysis was performed using the SPSS 20.0 software package (SPSS Inc., Chicago, IL). Descriptive data for all parameters were reported as mean ± standard deviations. A Shapiro-Wilk test was applied to test for normal distribution of the sample for each variable. Independent samples *t* tests were performed to compare parameter means between control and test groups. A non-parametric Mann-Whitney *U* test was used to compare parameter ranks for control versus test groups if parameters were not normally distributed. Paired *t* tests or Wilcoxon signed-rank tests were applied to compare changes in height and width from baseline to 6 months post-extraction in each group. The level of significance was set at $\alpha = 0.05$.

3 | RESULTS

Thirty-two patients (8 females and 24 males; mean age: 50 ± 7.9 years) fulfilled the inclusion criteria and completed the clinical trial. One assigned to the control group was withdrawn after tooth extraction due to dropout. A total of the remaining 35 molar extraction sockets were included: 18 in the test group and 17 in the control group. No patients reported systematic disease or a history of smoking. All surgical wounds healed uneventfully and no signs of complications were reported throughout.

Patient and extraction site demographics and clinical indices are presented in Table 2. The distributions of ages of participants in the test group (49.7 ± 7.0; range 34–59 years) and the control group

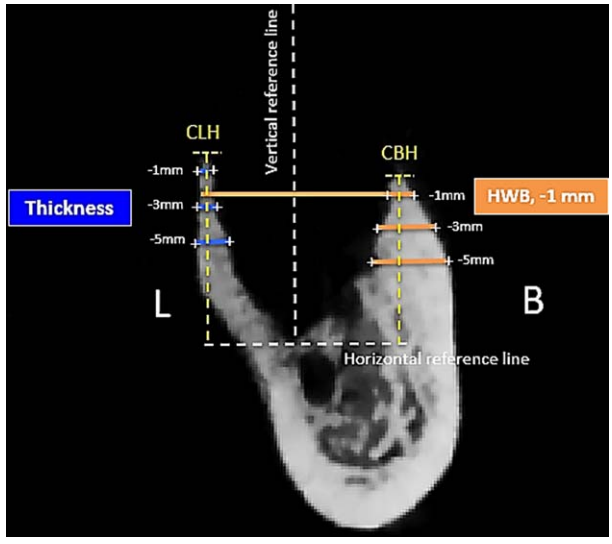

FIGURE 3 A coronal section of cone beam computer tomographic image at the center of a representative lower first molar extraction site immediately after extraction. The distance between two points (+) 1 mm, 3 mm, and 5 mm below buccal and lingual crest represents the thickness of buccal and lingual plate measured at three levels. The label (HWB, −1 mm) represents horizontal ridge width measured at 1 mm apically to the central-buccal height (CBH). B: buccal; H: height; W: width; C: central and L: lingual

TABLE 2 Demographic characteristics and clinical indices for test and control groups

	Control	Test	*P* value
Age (years)			
Median (range)	51.0 (34–65)	51.0 (34–59)	
Mean ± SD	50.4 ± 8.9	49.7 ± 7.0	.801
Gender (M:F)	10:6	15:3	
Total number of teeth	17	18	
Tooth position			
Maxillary 1st molar	7	1	
Maxillary 2st molar	1	1	
Mandible 1st molar	5	9	
Mandible 2st molar	4	7	
Probing depth (mm)	6.1 ± 1.3	6.0 ± 1.3	.884
Gingival recession (mm)	1.1 ± 1.3	1.3 ± 1.1	.786
Bleeding index	3.1 ± 0.7	3.2 ± 0.8	.601
Healing Time (months)			
Mean ± SD	6.5 ± 1.7	6.5 ± 0.8	.997

No significant differences were observed ($P > .05$).

(50.4 ± 8.9; range 34–65 years) were neither significantly different ($P = .801$) nor were baseline clinical parameters and healing time between test and control groups ($P > .05$).

TABLE 3 Baseline measurements for hard tissue in test and control groups (mm)

Parameters#	Control ($n = 17$) Mean ± SD	Test ($n = 18$) Mean ± SD	*P* value
B, −1 mm T	1.97 ± 1.09	2.27 ± 1.24	.462
B, −3 mm T	3.17 ± 1.78	4.32 ± 1.68	.086
B, −5 mm T	3.88 ± 3.10	6.23 ± 2.71	.076
P or L, −1 mm T	1.92 ± 1.64	1.89 ± 1.60	.948
P or L, −3 mm T	2.44 ± 1.60	2.61 ± 1.16	.732
P or L, −5 mm T	3.03 ± 1.87	2.88 ± 0.89	.811
CBH	6.54 ± 3.09	5.59 ± 3.15	.434
CP or LH	6.85 ± 3.06	6.18 ± 3.14	.526
MBH	5.14 ± 3.04	4.74 ± 2.92	.698
MCH	8.29 ± 3.20	8.03 ± 3.74	.829
MP or LH	5.91 ± 3.58	6.08 ± 3.03	.879
DBH	6.49 ± 2.82	5.33 ± 2.68	.230
DCH	5.78 ± 3.50	6.70 ± 3.35	.434
DP or LH	6.70 ± 3.31	6.88 ± 2.56	.230

B, buccal; P, palatal; T, bone plate thickness; L, lingual; H, height; M, mesial; D, distal.
C, center; *n*, sample size; SD, standard deviation.
–1 mm: 1 mm apically to the crest.
–3 mm: 3 mm apically to the crest.
–5 mm: 5 mm apically to the crest.
No significant differences were observed ($P > .05$).

TABLE 4 Width of keratinized tissue over time and mean changes from extraction to 6 months (mm; Mean ± SD)

	Control	Test	*P*-value#
Pre-extraction	4.7 ± 1.7	4.5 ± 1.7	.829
6 months	4.0 ± 0.9	3.4 ± 1.8	.368
Mean changes	−0.7 ± 1.4	−1.1 ± 1.7	.535
P-value§	0.101	0.020*	

P-value§ in the last row are intragroup *P* values comparing changes from baseline to 6 months by paired *t* test.
P-value# in the last column are intergroup *P* values from independent sample *t* tests.
*Statistically significant difference ($P < .05$).

Table 3 presents radiographic measurements at baseline for hard tissue. No statistically significant differences were observed between control and test groups for the thickness and height of residual alveolar plates at baseline. The buccal plate in the center of the socket was thicker than its palatal counterpart at all reference points, but this difference was not statistically significant ($P > .05$).

Table 4 gives changes in width of keratinized tissue following 6 months healing. Mean WKT decreases were of 0.7 ± 1.4 mm in the control group (no significant difference between pre-extraction and 6-months post extraction measurements; $P = .101$) and of 1.1 ± 1.7 mm in the test group (significant difference between pre-extraction and 6-month post extraction measurements; $P = .020$). However, decreases in WKT were not significantly different between test and control groups ($P = .535$).

Horizontal bone changes following tooth extraction and ridge preservation/augmentation procedure are presented in Table 5. At 1 mm apical from the crest, measured in mesial, central, and distal aspects, bone width decreased by 0.12-1.00 mm in the control group but increased by 0.21-5.30 mm in the test group. Horizontal changes at 1 mm apical the crest in the mesial and central aspects of the socket were significantly different between control and test groups ($P < .05$).

Vertical bone changes following tooth extraction and ridge preservation/augmentation procedure are presented in Table 6. An average resorption (ie, decrease) of 0.89 ± 1.34 mm, 0.85 ± 2.52 mm and 0.66 ± 1.22 mm occurred in the buccal bone plate at the mesial, medium, and distal aspects, respectively, in the control group. However, buccal bone height increased in the test group by 1.00 ± 2.30 mm, 0.46 ± 1.92 mm, and 1.04 ± 1.58 mm at the mesial, medium, and distal regions of the socket, respectively. Observed vertical changes in buccal bone plate after 6 months healing were significantly different between test and control groups in the mesial and distal regions of the socket ($P < .05$). No significant differences were detected between test and control groups with respect to diminution of the lingual bone, even though more crestal bone resorption occurred in the control than in the test group.

Given that all selected molars in the present study were extracted owing to advanced periodontitis and that extent and rate of resorption varies with irregular residual ridge dimensions, alveolar processes in this study presented with uneven heights. This unevenness included

TABLE 5 Ridge width changes in test (ridge preservation) and control (natural healing) groups from baseline to 6 months recall obtained at 1 mm, 3 mm, and 5 mm apically from the top of the alveolar crest (mm; Mean ± SD)

Ridge Width		Mesial			Central						Distal		
					Buccal			Lingual					
Location		1 mm	3 mm	5 mm	1 mm	3 mm	5 mm	1 mm	3 mm	5 mm	1 mm	3 mm	5 mm
Width Changes	Control	−1.00 ± 0.62	−0.66 ± 0.71	−0.35 ± 0.59	−0.70 ± 2.28	−0.58 ± 1.56	−0.11 ± 1.08	−0.14 ± 3.47	+0.37 ± 2.53	+0.41 ± 3.68	−0.12 ± 2.01	−0.04 ± 1.82	+0.26 ± 1.52
	Test	+0.21 ± 2.35	+0.09 ± 1.80	−0.06 ± 0.24	+1.46 ± 3.54	+0.36 ± 2.16	−0.04 ± 0.53	+5.30 ± 5.69	+0.53 ± 3.17	−0.10 ± 0.31	+0.43 ± 2.35	+0.21 ± 1.38	−0.04 ± 0.25
	P value	.016*	.072	.123	.015*	.064	.338	.002*	.637	.118	.528	.211	.439

*Statistically significant differences at $P < .05$.

TABLE 6 Mean changes and standard deviation in ridge height dimensions between extraction and 6 months measured in the mesial, medium, and distal aspects in control and test groups (mm; Mean ± SD)

		Mesial			Medium			Distal		
		Buccal	Central	Lingual	Buccal	Central	Lingual	Buccal	Central	Lingual
Height Changes	**Control**	−0.89 ± 1.34	+0.01 ± 0.93	−0.90 ± 1.64	−0.85 ± 2.52	+7.02 ± 3.18	−1.31 ± 1.53	−0.66 ± 1.22	+1.09 ± 2.84	−0.82 ± 0.99
	Test	+1.00 ± 2.30	+1.17 ± 2.65	−0.24 ± 1.21	+0.46 ± 1.92	+8.55 ± 2.53	−0.51 ± 1.35	+1.04 ± 1.58	+1.51± 2.96	−0.47 ± 1.11
	P value	.006*	.093	.187	.092	.124	.109	.001*	.672	.341

*Statistically significant differences at $P < .05$.

TABLE 7 Vertical dimensional changes and horizontal width changes 1 mm apical from the top of the alveolar crest for test (ridge preservation) and control (natural healing) groups after 6 months healing where buccal ridge height > lingual ridge height in the center of the socket (mm; Mean ± SD)

	Groups (Sample size)	Ridge height			Ridge width	
		Buccal	Central	Lingual	Buccal	Lingual
Baseline	Control (9)	7.55 ± 2.38	0.00 ± 0.00	5.20 ± 2.34	5.96 ± 4.72	12.99 ± 3.35
	Test (5)	7.98 ± 3.87	0.00 ± 0.00	4.26 ± 3.49	2.60 ± 2.12	14.80 ± 3.98
	P value	.798	1.000	.556	.162	0.381
6-month	Control (9)	6.36 ± 2.57	6.13 ± 3.31	4.65 ± 2.11	6.12 ± 4.44	12.61 ± 2.40
	Test (5)	7.11 ± 3.64	9.06 ± 2.37	4.55 ± 2.61	8.44 ± 2.79	12.84 ± 2.67
	P value	.660	.108	.939	.315	0.883
Difference	Control (9)	−1.18 ± 1.48	+6.13 ± 3.31)	−0.55 ± 1.00	+0.16 ± 2.53	−0.38 ± 2.07
	Test (5)	−0.87 ± 0.60	+9.06 ± 2.37	+0.29 ± 2.11	+5.84 ± 4.36	−0.52 ± 0.70
	P value	.898	.108	.797	.009*	0.898

*Statistically significant differences at $P < .05$.

buccal ridges higher than corresponding lingual (or palatal) ridges as well as lingual (or palatal) ridges higher than corresponding buccal ridges, as measured in the center of the socket. Data on changes (from baseline to 6 months recall) in vertical height and in ridge width 1 mm apically from the crest for cases with buccal bone crest higher than lingual (or palatal) bone plate at the center of the socket are given in Table 7 ($n = 9$ cases in the control group and 5 cases in the test group). After a 6-month healing, the height of the buccal and lingual bone walls remained 6.36 ± 2.57 mm and 4.65 ± 2.11 mm, respectively in the control group and 7.11 ± 3.64 mm and 4.55 ± 2.61 mm, respectively in the test group. No statistically significant differences were observed between test and control groups with respect to either height of socket walls immediately after tooth extraction or to ridge height changes after a 6-month healing in the center of the sockets. After 6-month healing, mean ridge heights in the center of the sockets were 6.13 ± 3.31 mm and 9.06 ± 2.37 mm for the control and test groups, respectively.

For cases with buccal bone crest higher than lingual (or palatal) bone crest in the center of the socket (Table 7), ridge width at 1 mm apical from the buccal and lingual crests in the center of the sockets were 6.12 ± 4.44 mm and 12.61 ± 2.40 mm, respectively for the control group and 8.44 ± 2.79 mm and 12.84 ± 2.67 mm, respectively for the test group, after a 6-month healing. Ridge width changes were significantly different between control and test groups ($P = .009$) 1 mm apical from the buccal crest, increasing by 0.16 ± 2.53 mm and 5.84 ± 4.36 mm, respectively, after a 6-month healing.

For cases in which the buccal bone crest was lower than the lingual (or palatal) bone plate in the center of the sockets ($n = 8$ in the control group and $n = 13$ in the test group), changes in vertical ridge height and in width 1 mm apically from the crestal bone from baseline to 6 months recall are given in Table 8. After 6 months healing, height of the buccal and lingual bone walls was 4.91 ± 3.34 mm and 6.55 ± 3.43 mm, respectively in the control group and 5.64 ± 2.05 mm and 6.10 ± 2.77 mm, respectively, in the test group. No statistically significant differences were observed between test and control groups with respect to height of socket walls immediately after tooth extraction and with respect to ridge height changes after 6-month healing in the center of the socket.

After 6 months healing, ridge width 1 mm apically from the buccal and lingual crests in the center of the sockets were 12.77 ± 2.10 mm

TABLE 8 Vertical dimensional changes and horizontal width changes 1 mm apical from the top of the alveolar crest and in the center of the sockets in test (ridge preservation) and control (natural healing) groups after 6 months healing when buccal ridge height < lingual ridge height in the center of the socket (mm; Mean ± SD)

	Groups (Sample size)	Ridge height			Ridge width	
		Buccal	Central	Lingual	Buccal	Lingual
Baseline	Control (8)	5.39 ± 3.55	0.00 ± 0.00	8.71 ± 2.78	14.58 ± 1.13	6.35 ± 5.72
	Test (13)	4.67 ± 2.41	0.00 ± 0.00	6.92 ± 2.80	14.02 ± 2.14	4.98 ± 6.03
	P value	.542	1.000	.169	.526	.750
6-month	Control (8)	4.91 ± 3.34	8.02 ± 2.90	6.55 ± 3.43	12.77 ± 2.10	6.49 ± 4.53
	Test (13)	5.64 ± 2.05	8.35 ± 2.65	6.10 ± 2.77	13.79 ± 1.97	12.08 ± 1.50
	P value	.542	.793	.804	.294	.010*
Difference	Control (8)	−0.48 ± 3.42	+8.02 ± 2.90	−2.16 ± 1.62	−1.81 ± 1.39	+0.14 ± 4.73
	Test (13)	+0.97 ± 2.02	+8.35 ± 2.65	−0.81 ± 0.85	−0.22 ± 0.58	+7.10 ± 5.32
	P value	.140	.793	.057	.001*	.006*

*Statistically significant differences at $P < .05$.

and 6.49 ± 4.53 mm, respectively, in the control group and 13.79 ± 1.97 mm and 12.08 ± 1.50 mm, respectively, in the test group. After 6 months healing, ridge width changes were significantly different between control and test groups. Width of the lingual crest increased by 0.14 ± 4.73 mm in the control group and by 7.10 ± 5.32 mm in the test group ($P = .006$). Ridge width 1 mm apically from the buccal crest decreased by 1.81 ± 1.39 mm in the control group and by 0.22 ± 0.58 mm in the test group ($P = .001$).

4 | DISCUSSION

The present investigation compared changes in bone plate dimensions subsequent to ridge preservation/augmentation performed with Bio-Oss in combination with Bio-Gide coverage to those subsequent to unassisted socket healing in the specific case of severe bone deficiency related to periodontally infected molar teeth. Results demonstrated that preservation/augmentation in diseased molar extraction sockets is safe and more effective than unassisted socket healing in preventing physiologic ridge dimension loss after tooth extraction.

Various grafting materials have been utilized individually or in combination with different barriers to reduce the post-extraction remodeling effect.[42–44] The issue of which biomaterial or type of surgical protocol used for ridge preservation is superior than others in terms of implant outcomes is still debated.[9,26] Bio-Oss is deproteinized bovine bone mineral and the most widely used biomaterial in alveolar ridge preservation procedures.[27,32,37] The osteoconductive grafts acted as a scaffold for new bone formation in combination with slow resorption and replacement rate to preserve most of the dimension of ridge,[45,46] but the graft in the extraction sockets may in fact delay healing.[46] Raising a flap and placement of biomaterials, then primary flap closure were recommended.[9] A systematic review reported that ridge preservation using a flapless approach after a minimum healing period of 12 weeks, xenografts and allografts resulted in the least loss of socket dimensions compared to alloplasts or sockets with no grafting.[21] Findings from meta-analysis revealed that the use of bone graft covered by a resorbable membrane to protect the graft material from epithelial infiltration during healing of the socket could reduce resorption by 2.19 mm in width and 1.72 mm in height of the alveolar ridge.[47] Absence of a bone plate may permit soft-tissue in growth into grafted sites, therefore other recent clinical studies have recommended the use of a barrier membrane with socket grafting in damaged extraction sockets.[20,48] Avila-Ortiz and colleagues[24] revealed that flap elevation and the application of a xenograft or an allograft with a membrane favor midbuccal and midlingual height preservation.

Whether or not primary closure at the time of extraction is necessary for healing of the socket is controversial. Darby and colleagues[20] observed bone resorption associated with flap coverage to guarantee primary soft tissue closure, whereas Engler-Hamm and colleagues[49] observed no significant differences in ridge width changes between primary flap closure and intentional exposure to collagen membranes. Furthermore, a meta-analysis reported that full flap closure tended to result in lesser horizontal resorption, and that surgical protocol with flap and flapless closure was the most important factor influencing ridge preservation results.[23] In fact, no firm conclusions could be drawn on the effect of flap versus flapless procedure on the healing process after tooth extraction. That flap elevation with interruption of vascular supply to underlying bone has a detrimental impact on horizontal bone remodeling and width of keratinized tissue when performing ridge preservation is generally acknowledged,[48,50] but some studies indicate that flap elevation does not promote alveolar bone loss.[51,52] For example, no histological or histomorphometrical differences were observed when comparing flap and flapless techniques for socket grafting procedures in premolar and molar teeth,[52] and Vignoletti and colleagues[23] even observed a significant positive effect of flapped surgery in regards to the ridge horizontal dimensional changes. For the sockets with irregular and severe bone defects in the present study, elevating the flap enabled placement of graft materials to the crest of the higher remaining bone plate and achieved full closure and first intension healing.

The surgical protocol applied in the present study used resorbable collagen membrane (Bio-Gide) and coronally advanced flap for primary closure to maintain the graft material (Bio-Oss) in situ and to prevent particle leakage. This procedure was clinically effective in controlling certain ridge changes when compared to the results of unassisted healing.

Horizontal width changes of the residual alveolar ridge were observed in both test and control groups. The alveolar ridge experienced horizontal resorption in the mesial, central and distal aspects of the sockets in the control group. By contrast, ridge width demonstrated horizontal gain in the test group. Final horizontal widths 1mm apically from buccal and lingual crests in the center of the socket were 12.31 ± 3.26 mm and 12.26 ± 1.77 mm, respectively, in the test group versus 9.03 ± 4.89 mm and 9.73 ± 4.67 mm, respectively, in the control group.

Ridge width changes reported in this study are consistent with findings by other studies.[29,53] Ridge dimensions obtained 6 months post-operatively in the present study compare favorably to ridge dimensions achieved by Fiorellini who reported a ridge width gain of 3.27 ± 2.53 mm when measuring from the palatal plate to the new extent of buccal plate after 4 months of healing compared to the initial palatal plate thickness following extraction of maxillary bicuspid forward teeth with ≥ 50% buccal wall defects.[53] The present study reports a comparable and improved ridge width gain of 5.3 ± 5.69 mm measured 1mm apically at the lingual crest in molar areas where the sockets were wider than the premolars (Table 5).

In consideration of the variable height of the residual alveolar ridge, we further evaluated dimensional alterations in the medium aspect of molar sockets affected by severe periodontitis according to height of the buccal and lingual bones (buccal ridge higher or lower than lingual ridge, Tables 7 and 8, respectively). No statistically significant difference in ridge height change was observed between ridge preservation/augmentation (test) and unassisted healing (control) groups, which is consistent with findings by Scheyer.[41] However, a gain of bone width 1 mm apical from the higher bone plate (buccal or lingual plate, whichever was highest) was observed. This finding is in overall agreement with the horizontal gain previously reported by Sisti and Scheyer who demonstrated horizontal regeneration in anterior and molar teeth with buccal bone defect, respectively.[29,41]

Mean resorption of vertical ridge height in the control group was by 0.85 mm and 1.31 mm at buccal and lingual sites in the medium of the sockets, respectively, compared to a gain of 0.46 mm at the buccal and resorption of 0.51 mm at the lingual sites, respectively, in the test group (Table 6). That the lingual bone plate experienced vertical bone resorption is notable, especially that it was even more pronounced than that for the buccal plate. Although no significant difference in height change was observed on the lingual aspect between groups, the test group did experience less vertical bone loss at the lingual aspect than did the control group. Vertical bone resorption observed for the present subject sample is consistent with findings by Jung and Sisti,[29,40] but in contrast with other previous studies[4,33] in which vertical bone height reabsorption was more pronounced at the buccal bone wall than at the lingual bone wall of the extraction socket. Vertical bone resorption in the present study was more pronounced at the lingual than at the buccal bone wall in the mesial, medium, and distal in both control and test groups, and in fact a gain rather than a loss was observed for buccal plates in the test group. The cause of this discrepancy between studies with respect to crestal resorption is mostly likely the result of differences in the degree of bone loss prior to tooth extraction. In the samples presented in other studies,[29,40] the buccal bone wall resorbed severely, in the present study both the buccal and the lingual bone were reduced markedly or were virtually absent, and the height of the buccal plate was lower than its lingual/palatal counterpart in most of the samples (Tables 3 and 8). By contrast, buccal bone plates were frequently intact in the samples presented by Araujo.[33]

Brownfield and Weltman[54] reported a significant correlation between buccal plate thickness and loss of vertical ridge height, for example, sites with a mean buccal plate thickness of 1.3 mm lost a mean of 0.2 mm, whereas sites with a mean buccal plate thickness of 0.9 mm lost a mean of 1.7 mm. We also noticed that ridge height changes (decreased by 0.85 mm, Table 6) in the control group in the present study were lower than those reported by Walker,[38] in which buccal ridge height decreased by 2.60 ± 2.06 mm following molar extraction and the buccal plate thickness was 0.71 ± 0.32 mm, while the thickness of the buccal plate 1 mm apical to the crest in the control groups of the present study was 1.97 ± 1.09 mm.

Vertical changes in the mesial and distal were assessed in the present study, and ridge height changes at mesiobuccal and distobuccal aspects of the sockets were significantly different between test and control groups (Table 6) with the test group experiencing a vertical gain of 1.00 mm and 1.04 mm, respectively, whereas vertical bone loss of 0.89 mm and 0.66 mm was reported for the control group, respectively. This finding is consistent with Willenbacher,[18] who reported that mesial and distal bone loss could be prevented by ridge preservation, ranging from -0.3 ± 0.76 mm to -0.1 ± 0.7 mm on mesial reference points and from -0.4 ± 0.9 mm to -0.1 ± 0.7 mm distal, and that the mesial ridge decreased by -1.0 ± 0.8 mm to -0.4 ± 1.2 mm and that the distal ridge decreased by -1.0 ± 0.8 mm up to -0.5 ± 1.0 mm in the control group. Avila-Ortiz also reported that ridge preservation sites showed 0.48 mm and 0.24 mm less reduction in mesial and distal height, respectively.[24]

Soft tissue changes also were examined in the present investigation and while the width of keratinized tissue decreased in both the control and in the test groups (-0.7 ± 1.4 and -1.1 ± 1.7 mm, respectively), the difference between the two groups was not statistically significant (Table 4, $P = .535$). The reduction in width of keratinized tissue in the test group is consistent with a previous study which revealed a reduction of 1.7 ± 0.6 mm when a GBR technique was combined with a coronally advanced flap for primary closure.[48]

The present study used careful collection of data and a high level of precision in measuring alveolar bone changes using CBCT in examining patients with similar extraction defect morphologies. Furthermore, because residual morphologies of the alveolar process are irregular due to variation in the extent and rate of destruction, we measured ridge changes at mesial, medium, and distal locations of the socket. Scheyer and colleagues[41] reported that baseline extraction bony wall thickness and extraction socket depth were related to ridge preservation outcomes; these measurements were not significantly different between test and control groups in the present study (Table 3). Limitations of this study included small sample size, lack of histological analysis and short follow-up period. Histological analysis, implant-related outcomes, and long-term survival and success of implant treatment were not evaluated herein but will be provided in a subsequent report.

5 | CONCLUSIONS

Within the limitations of this study, results of the prospective clinical trial suggest that alveolar ridge preservation/augmentation in periodontally compromised molar sockets with severe plate destruction is safe and results in greater regeneration of the plate and maintenance of ridge dimensions 6 months after extraction. Grafted sites showed a significant gain in width 1 mm apical from both the buccal and the lingual crest bone in the center of the sockets, whereas width reduction was observed for the control, and though not statistically significant, reduced height changes were observed in the center of the sockets.

Assessment of bone defect geometry prior to tooth extraction could be clinically relevant for evaluation of the need for ridge preservation/augmentation. These preliminary findings should be confirmed by further RCTs on a larger sample size over a longer follow-up period.

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CONFLICT OF INTEREST

The authors declare no conflict of interest related to this study.

ORCID

Liping Zhao DDS http://orcid.org/0000-0001-8133-8609

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