

Histologic and Clinical Evaluation of Ridge Augmentation of Extraction Sockets with Severe Bone Defects: A Clinical Prospective Study

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Purpose: To primarily evaluate the dimensional changes of bone and soft tissue following ridge augmentation in compromised molar regions. The secondary objective was to evaluate the histologic composition of augmented sites. **Materials and Methods:** The study included 27 patients who underwent augmentation of extraction sites with grafts covered by a collagen membrane. CBCT was taken immediately after augmentation (T2) and after 8 months of healing, before implant placement (T3). The width and height of the extraction sites were recorded at extraction (T1) and reentry surgery (T4). A histomorphometric analysis was performed. Data were evaluated in terms of bone crest level, implant survival rates, and change in mucogingival junction. **Results:** According to clinical measurement, horizontal and vertical bone gain was 10.15 ± 1.00 mm and 8.80 ± 1.86 mm, respectively. Radiographic measurement showed that the horizontal width changes were 1.46 ± 0.52 mm, 0.98 ± 1.29 mm, and 1.29 ± 0.82 mm, respectively, at 1, 3, and 5 mm apical to the crestal level. Vertical bone change was 2.34 ± 0.90 mm in the center of the socket. Histomorphometric analysis showed that percentages of mineralized bone, nonmineralized tissue, and bone substitute were $32.31\% \pm 13.25\%$, $25.36\% \pm 12.24\%$, and $42.34\% \pm 9.54\%$, respectively. The mucogingival junction shift was 0.6 ± 1.1 mm. **Implant survival rates and crestal bone resorption were 100% and 0.78 ± 0.58 mm, respectively, after 1 year of loading.** **Conclusion:** Ridge augmentation can be performed successfully to manage extraction sockets. Membrane coverage combined with primary wound closure could be conducive to new bone regeneration and peri-implant tissue health. *Int J Oral Maxillofac Implants* 2022;37:778–783. doi: 10.11607/jomi.9651

Keywords: bone regeneration, ridge preservation, tooth extraction

Bone remodeling following tooth extraction results in increasing demand for further bone augmentation for prosthetically driven implant placement.^{1,2} Ridge preservation and/or augmentation aimed to preserve and/or reconstruct the alveolar ridge volume is performed immediately after tooth extraction to provide a scaffold for regenerated bone ingrowth.³ Previous animal model and clinical studies have shown that ridge preservation could effectively reduce the postoperative contour shrinkage of extraction sockets with intact walls or partial labial defects due to trauma or carious lesions.^{3,4} Findings from a systematic review revealed that ridge preservation could reduce the bone resorption by 2.19 mm in width and 1.72 mm in height,

respectively. Thus far, most studies have involved the anterior and premolar sites, but the role of ridge preservation in molar sites has rarely been studied.⁵

According to the study by López-Martínez,⁶ in extraction sites with advanced bone loss due to severe periodontal or endodontic lesions constituting the reason for tooth extraction (accounting for 69.2% and 25.67%, respectively), more bone resorption occurs prior to or after tooth extraction. If the fresh extraction socket is not managed, more invasive bone augmentation surgery is required to obtain adequate alveolar bone. Unlike the intact or dehiscence-defect socket, in which the bony walls provide a stable scaffold and healing sources for bone formation, the healing pattern in compromised extraction sockets has been reported to be variable and unpredictable.⁷ In such anatomical conditions, conventional ridge preservation is insufficient to obtain favorable alveolar ridge architecture; hence, ridge augmentation is required to obtain large amounts of regenerated bone.

Owing to the morphologic and anatomical differences in posterior regions, ridge augmentation could be more of a challenge because of the difficulty of primary closure, a reduction in keratinized tissue width, and the delay in bone regeneration.⁸

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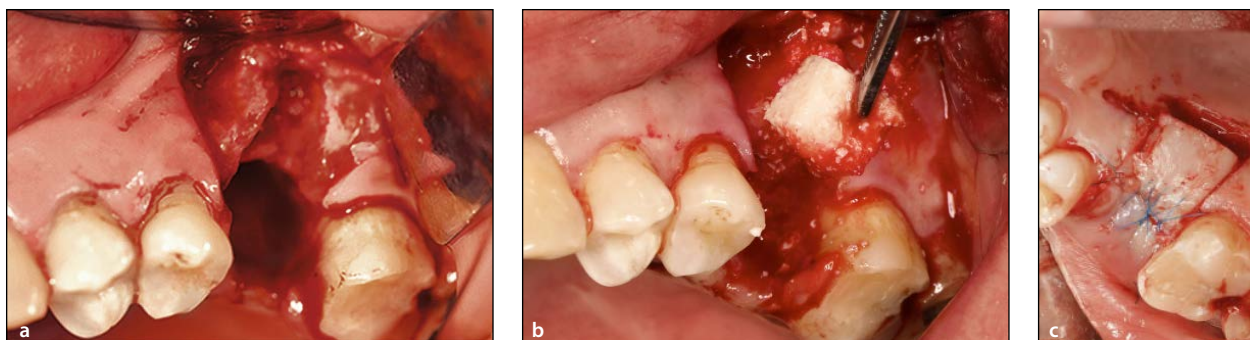


Fig 1 Clinical photographs of ridge augmentation of the compromised extraction socket. (a) Complete bony wall defect following molar removal. (b) Socket grafted with Bio-Oss Collagen. (c) Primary wound closure with palatal island flap.

The primary purpose of the current study was to assess the dimensional changes of bone and soft tissue following ridge augmentation in compromised molar sites. The secondary objective was to evaluate the histologic composition of grafted sites. The null hypothesis was that ridge augmentation could be effectively conducive to new bone regeneration and contour maintenance of compromised extraction sockets.

MATERIALS AND METHODS

The present prospective clinical study was conducted from May 2017 to December 2020 at Peking University Hospital of Stomatology, fourth division. Patients who needed molar replacement owing to severe periodontal or endodontic disease were eligible for this study. CBCTs were carried out to evaluate the bone volume available for implant placement. Patients were included according to the inclusion criteria: (1) adult patients (age 20–80 years); (2) hopeless molar teeth requiring extraction; (3) complete resorption of at least one socket wall; and (4) minimum 2 mm of keratinized buccal gingiva. The exclusion criteria were: (1) any condition that precluded oral surgery such as uncontrolled diabetes mellitus or history of radiation therapy to the neck and head; (2) teeth extracted as a consequence of endodontic failures or fracture; and (3) a smoking habit of > 10 cigarettes per day.

The institutional ethics committee of the Peking University School of Stomatology approved this study (PKUSSIRB-202163057).

Clinical Procedure

Preoperative procedures. All patients were assessed and received necessary oral hygiene instructions until acceptable oral hygiene was achieved.

Surgical procedure. All the surgical operations were performed by two surgeons (Q.L.X. and Y.H.J.).

After administering 4% articaine for local anesthesia, a full-thickness flap was elevated over the completely resorbed socket wall (Fig 1a). After meticulous debridement of granulation tissue followed by tooth extraction, the extraction socket was augmented with Bio-Oss Collagen (Geistlich) to reconstruct the alveolar bone with overcontouring (Fig 1b). A bioabsorbable collagen membrane was applied to cover the socket and then tucked under the buccal/palatal flap. Primary wound closure was accomplished. A palatal island flap in the maxilla and lingual flap advancement in the mandible were applied to assist wound closure (Fig 1c).⁹

Patients were instructed to rinse with 0.2% chlorhexidine for 20 seconds three times a day for 1 week and were evaluated after 2 weeks.

Reentry. After an 8-month healing period, a reentry surgery was performed (Fig 2a). After a mucoperiosteal flap was elevated (Fig 2b), the implant (Thommen Medical) was placed (Fig 2c). If necessary, additional bone graft was used to cover the local bone defect surrounding the implant. After another 3 months of healing, the final restoration was completed.

Follow-up and Clinical Assessments

Primary healing of the surgical region was characterized by absence of any infection, tissue necrosis, or wound dehiscence. CBCT was recorded after augmentation (T2) and 8 months of healing, before implant insertion (T3). Panoramic radiographs were recorded immediately and 1 year after crown placement. The follow-up protocol included patient assessment at 2 weeks and 3 months after the first surgery, 2 weeks and 3 months after the second surgery, and 3 months and 1 year after crown placement.

Bone gain measurements. In the case of one missing socket wall, bone width was evaluated using a caliper 1 mm apical to the remaining bony wall crest, while in the case of two socket walls with bone defects, the initial width was considered zero. The vertical bone defect was measured as the length from the apex of the socket

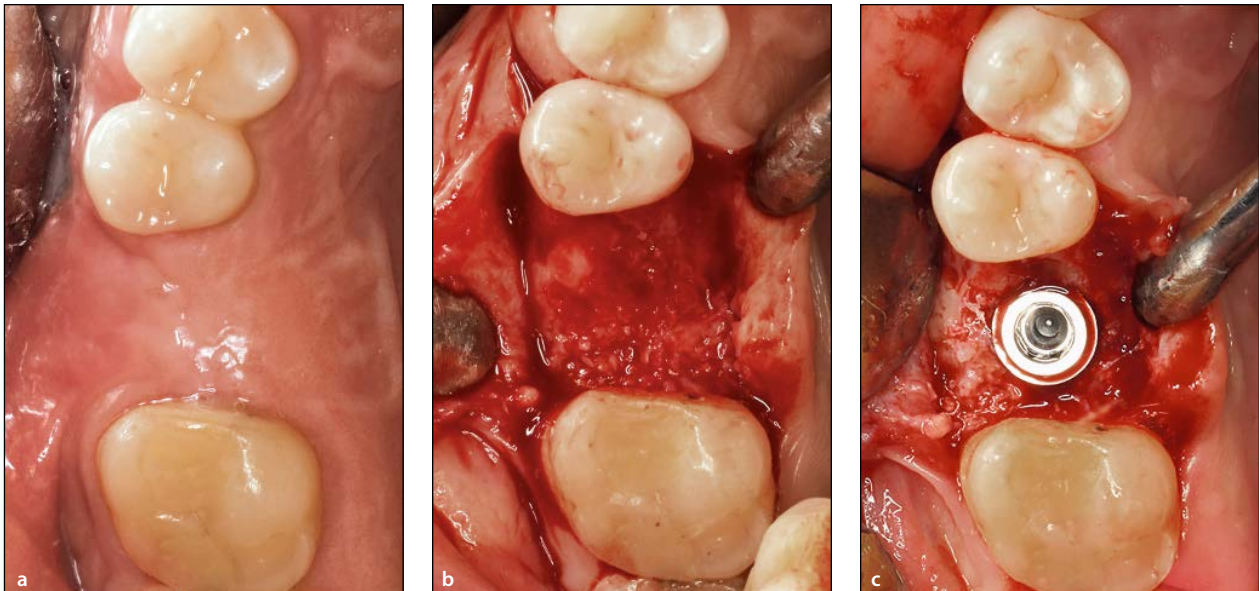


Fig 2 Reentry procedure after an 8-month healing period. (a) Site evaluation. (b) Intraoperative view showing hard tissue regeneration. (c) Implant placement.

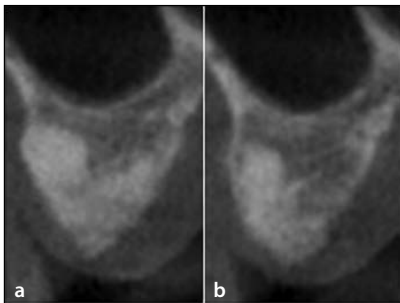


Fig 3 CBCT evaluation of the site at T2 (a) and T3 (b).



to the imaginary line that connected the mesial and distal neighboring teeth's cemento-enamel junction. During the second-stage surgery, all the measurements of bone width and height were repeated. In the case of two socket walls with bone defects, the midpoint between two adjacent teeth and 1 mm apical to the ridge were used for horizontal measurements.

Radiographic assessment. Measurements were made by a clinical examiner blinded to the study protocol.

CBCT measurements. For standardized radiographic measurements, two sets of DICOM data at T2 and T3 were generated and adjusted with at least three anatomical landmarks. The width of the bone was measured 1, 3, and 5 mm apical to the most coronal point of the initial palatal or buccal bony wall, and then the horizontal dimension difference was calculated between T2 and T3 (Fig 3). The height difference at T3 was measured as the distance from the most coronal level to the base of the socket. If both buccal and palatal bony walls showed a defect at any level, the horizontal measurement at 8 months was identified to assess the dimensional change in width.

Peri-implant bone loss. Digital radiographs of implants were taken at the time of definitive restoration placement and 1 year after restoration delivery. Peri-implant bone loss was measured as the distance from the implant shoulder to the most apical point of bone-implant contact. The scale of each image was calibrated according to the 1-mm distance between two implant threads. **Marginal bone loss** was calculated as the difference between the two measurements.

Histomorphometric analysis. Bone specimens were harvested from the implant preparation site at reentry. A bone core measuring 2 mm in diameter and at least 6 mm in length was harvested. The sections were fixed, demineralized, and embedded in paraffin. Consecutive horizontal sections with 4- μ m thickness were obtained along the axis of the bone core. Several central sections of each bone specimen were obtained and subjected to eosin staining. Histomorphometric analysis was performed to evaluate the proportions of mineralized bone, residual graft material, and nonmineralized tissue.

Sections were examined by light microscopy (Leitz Laborlux 12) at 4 \times magnification. Calculation of the

proportions of mineralized bone, residual graft material, and nonmineralized tissue was performed using Image-Pro Plus 6.0 software (Media Cybernetics). The proportion of each component was measured. Counting was repeated three times per bone core.

Shift of mucogingival junction. Analysis of the change in the keratinized mucosa width was performed. A roll technique was applied to determine the mucogingival junction. Distance between the mucogingival junction and the gingival margin or midcrestal region was measured using a periodontal probe.

Complications. Biologic and technical complications were recorded at every patient visit.

RESULTS

A total of 30 patients underwent ridge augmentation of the extraction socket. The 27 included patients (17 male and 10 female; mean age: 52.85 ± 9.82 years) completed the 1-year observation period. A total of 34 molar extraction sockets were included. The demographic characteristics of the included patients are shown in Table 1. Further, 18 out of 34 extraction sockets displayed complete buccal socket wall resorption, 8 showed complete loss of the palatal/labial wall, and 8 showed defects of both socket walls. All implants were inserted as planned and remained stable during follow-up. Accordingly, implant survival rate was considered to be 100%.

Bone Reconstruction Data

Table 2 provides detailed information regarding the actual measurement of the initial ridge and ridge volume after socket augmentation. During the reentry procedure, all grafted sites appeared as normal bone during site preparation, although bone graft particles still could be observed. After an 8-month healing period, the augmentation procedure was effective with a height increase of 8.80 ± 1.86 mm and a width increase of 10.15 ± 1.00 mm.

All implants could be inserted with adequate primary stability. Except for three implants (8.82%) that needed minor additional grafting, all other augmented sites allowed implant placement (at least 4.5 mm in diameter) without any further bone augmentation.

Radiographic Measurement Data

The horizontal and vertical bone changes following ridge augmentation are shown in Table 3. At the horizontal aspect, an average resorption of 1.46 ± 0.52 mm, 0.98 ± 1.29 mm, and 1.29 ± 0.82 mm occurred at 1, 3, and 5 mm, respectively, apical to the crest. An evident bone resorption (2.34 ± 0.90 mm) was observed in the vertical direction.

Table 1 Patient Distribution and Intervention Characteristics

Sex	Male	17
	Female	10
Mean age (y) at extraction		52.85
Location of socket wall resorption	Buccal	18
	Palatal/Labial	8
	Both	8
Extraction sites	Maxilla	24
	Mandible	10
Reason for extraction	Periodontal lesions	19
	Endodontic lesions	10
	Implant failure	5

Table 2 Ridge Augmentation Measurements (mm; mean \pm SD)

	Baseline	Reentry	Ridge changes
Ridge width	0.78 ± 0.39	10.93 ± 0.97	10.15 ± 1.00
Vertical defect ^a	12.92 ± 1.51	4.13 ± 1.14	8.80 ± 1.86

^aDistance from the apex of the socket to the line connecting the two neighboring teeth's cemento-enamel junction.

Table 3 Radiographic Assessment of Ridge Augmentation and Bone Remodeling Results (mm; mean \pm SD)

	Ridge width			Ridge height
	HW-1	HW-3	HW-5	
Baseline	11.46 ± 0.82	11.23 ± 2.03	11.60 ± 1.27	11.13 ± 1.91
8 months	9.99 ± 0.73	10.25 ± 1.53	10.31 ± 1.35	8.78 ± 2.10
Difference	1.46 ± 0.52	0.98 ± 1.29	1.29 ± 0.82	2.34 ± 0.90

HW = horizontal width at 1, 3, and 5 mm apical to the crest.

The mean change in marginal bone loss was 0.78 ± 0.58 mm.

Histomorphometric Outcome

A total of 25 bone specimens were taken during the reentry procedure, of which 3 were too damaged to undergo histomorphometric analysis. Histomorphometric analysis showed that the mean proportions of mineralized bone, nonmineralized tissue, and residual graft material were $32.31 \pm 13.25\%$, $25.36 \pm 12.24\%$ and $42.34 \pm 9.54\%$, respectively (Fig 4; Table 4).

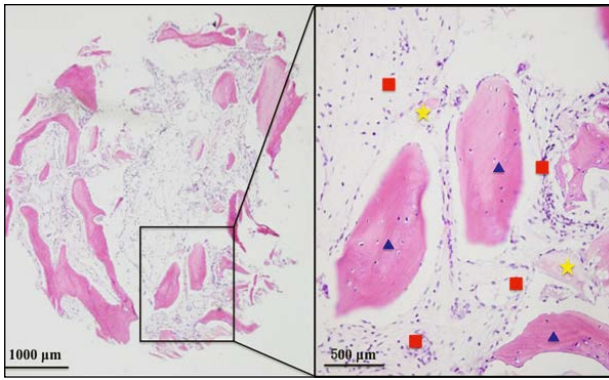


Fig 4 Histologic section of a biopsy sample (hematoxylin and eosin staining). (left) Histologic section providing an overview (original magnification $\times 4$). (right) Detailed view of the same sample at a higher magnification (original magnification $\times 10$). Blue triangles = mineralized bone; yellow stars = residual graft material; red squares = nonmineralized tissue.

Table 4 Radiographic and Histomorphometric Values (mean \pm SD)

Crestal bone loss	0.78 \pm 0.58 mm
MB	32.31% \pm 13.25%
RGM	42.34% \pm 9.54%
NT	25.36% \pm 12.24%

MB = mineralized bone; RGM = residual graft material; NT = nonmineralized tissue.

Mucogingival junction change

After the 8-month healing period, decreases of 0.6 \pm 1.1 mm were observed between pre-extraction and post-ridge augmentation.

DISCUSSION

The current study evaluated ridge augmentation for compromised molar extraction sockets with at least one completely resorbed socket wall. The results suggest that ridge augmentation using resorbable collagen membrane with primary closure can be effective in obtaining bone architecture and preventing soft tissue changes.

Clinically, teeth are most frequently extracted due to severe periodontal and endodontic pathology that may present different healing patterns compared to an intact socket.⁶ In such conditions, ridge augmentation, instead of ridge preservation, is recommended to restore ridge volume in molar sites to decrease the need for sinus floor elevation and other bone augmentation procedures.¹⁰ Eight months after the extraction, augmented sockets obtained a mean height increase of 8.8 mm, with a mean width change of 10.15 mm. Implants

could be placed in most cases (91.18%) without additional bone grafting, demonstrating the effectiveness of early intervention of compromised extraction sockets.

Ridge width changes presented in the present study are in accordance with other findings that reported a change from 1.3 to 2.1 mm based on CBCT measurements.^{4,11} Results of vertical ridge resorption comparable to those found in this study were reported in previous studies on socket augmentation procedures.^{4,10} However, ridge preservation in an extraction socket with an intact wall or partial bone wall defect showed less bone resorption in terms of height (0.48 to 1.18 mm).^{12,13} This difference was mainly due to the differences in degree of initial bone plate deficiency. Complete absence of one or more bone plates may not provide stable scaffolding for blood clot stabilization and prevent soft tissue from growing into grafted sites, thus resulting in decreased bone formation. Therefore, the use of a barrier membrane covering grafting materials in damaged extraction sockets is recommended.¹²

The technique applied in the present study is very similar to a guided bone regeneration (GBR) procedure, which requires a membrane to prevent epithelial cells from infiltrating into the extraction site.¹⁴ Although various graft materials were placed into the fresh socket to prevent ridge resorption,¹⁵ the Bio-Oss Collagen used in the present study facilitates the procedure, allowing good shaping and stabilization of the blood clot into the defect.^{16,17} Membrane coverage was also necessary to protect the underlying biomaterials and reduce the amount of volume loss after flap closure.¹⁷

Histomorphometric data showed consistent results with previous studies, wherein the amount of regenerated bone ranged between 19% and 33% when grafting with Bio-Oss Collagen in the mandibular molar region.^{9,16,18} Although the correlation between healing time and vital bone formation was controversial, the histologic data showed that at least 8 months of healing was necessary to acquire a "dense" tactile bone quality. Regenerated bone quality could influence implant primary stability and the amount of osseointegration from a long-term perspective.¹⁹ Bone biopsy was harvested before implant placement, thus not analyzing bone-to-implant contact. The hydrophilic implant surface (Inicell, Thommen Medical) used in the present study has been demonstrated to enhance angiogenesis and bone regeneration.²⁰ Hydrophilic titanium surfaces may have potential benefits to enhance bone formation along the implant following ridge augmentation.

Either flapless or flapped procedures could be applied for socket preservation^{16,21}; however, primary wound closure would be necessary in conditions of compromised socket augmentation based on the concept of GBR. In such compromised extraction sites,

primary wound closure is often difficult to obtain due to the insufficient soft tissue. The labial coronally repositioned flap is always accompanied by a reduction in keratinized tissue width and a shift of the mucogingival junction.²² The palatal island flap in the maxilla and lingual flap advancement in the mandible used in the present study could effectively close the wound. Additional benefits include obtaining the initial mucogingival junction (−0.6 mm), which may improve long-term peri-implant tissue health.

A limitation of the present investigation was a small sample size. Additional randomized controlled studies on different healing times after socket augmentation are warranted to evaluate the clinical and histologic outcomes.

CONCLUSIONS

Based on our findings, ridge augmentation could be successfully performed to manage compromised extraction sockets. The application of membrane coverage combined with palatal/lingual flap advancement to close the wound could be conducive to new bone regeneration and peri-implant tissue health.

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The authors declare that there are no conflicts of interest related to this article. Division of work for this study was as follows: H.Y.—data analysis, drafting article; L.N.—data collection and analysis; L.Q.—concept/design, approval of article.

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