
Alveolar Ridge Preservation in Severely Damaged Molar Socket Using a Polylactic Acid Membrane Without Primary Wound Closure: A Case Series

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Purpose: Untreated severely damaged molar sockets often complicate implant placement. This study evaluated membrane degradation, soft tissue healing, and alveolar crest dimensional changes after alveolar ridge preservation (ARP) in severely damaged molar sockets using a polylactic acid membrane (PLA) and xenograft without primary wound closure. **Materials and Methods:** A total of 14 damaged molar sockets in 12 patients were grafted with deproteinized bovine bone mineral, which was covered with a PLA membrane without primary wound closure. Wound healing was evaluated at set times. Three sets of CBCT data taken before surgery, at 1 to 2 weeks, and at 6 to 12 months after surgery were reconstructed and superimposed to analyze dimensional changes of the alveolar crest with volumetric imaging software. **Results:** Two weeks after ARP, no degradation of PLA membrane was present, and the xenograft had either no exfoliation (7 sites, 50%) or mild exfoliation (6 sites, 42.9%). One to 2 months following ARP, the membrane was partially degraded in 6 sites (42.9%) and completely degraded in 8 sites (57.1%). Nine sites (64.3%) presented with mild graft particle exfoliation, and four sites (28.6%) had granulation tissue covering the bone graft. All sites were fully covered by keratinized mucosa by 6 to 12 months. Compared with baseline measurements, the vertical bone graft height decreased by 2.2 ± 2.2 mm, and central alveolar ridge thickness measured at the level of the virtual implant platform decreased by 5.0 ± 5.1 mm after 6 to 12 months. **Conclusion:** The exposed PLA membrane maintains some barrier function for at least 3 to 4 weeks after ARP in severely damaged molar extraction sites. This technique allowed for implant placements without additional grafting. Future studies should include histologic assessment of the augmented bone and nongrafted control sockets. *Int J Oral Maxillofac Implants* 2021;36:XXX-XXX. doi: 10.11607/jomi.8989

Keywords: alloplastic membrane, alveolar ridge preservation, osseous defects, wound healings

Natural postextraction alveolar healing results in soft and hard tissue resorption that may impede placement of an implant in a prosthetically ideal position, compromising final functional and esthetic outcomes. To minimize adverse consequences from such dimensional changes, many studies have proposed alveolar ridge preservation (ARP) techniques.^{1,2} A systematic review reported that ARP diminishes horizontal, vertical midbuccal, and vertical midlingual socket resorption by a mean of 1 to 2 mm compared with no intervention.³ Most studies on ARP have focused on nonmolar

extraction sites or freshly extracted sockets without any defects.⁴⁻⁷

Alveolar atrophy is more pronounced in severely damaged sockets compared with those with four intact walls. This phenomenon has been demonstrated in a canine model in which buccal bone-deficient alveolar sockets were reduced in width by 62%, whereas intact sites decreased by 35% during the first 6 months of healing.^{8,9} Socket wall destruction impairs the healing capacity of the socket, causing delayed and unpredictable healing; complete repair may be unattainable.⁸⁻¹² Because molar morphology is more complex than that of single-rooted teeth, ARP for severely damaged molar sockets (SDMSs) is more challenging than grafting nonmolar sites or those with intact walls.

It is unclear if primary wound closure for ARP to promote socket healing is necessary. Primary wound closure may help retain graft in the socket and prevent salivary and bacterial contamination, providing a stable environment for healing.¹³ However, obtaining primary closure over molar sites may involve extensive flap elevation using releasing incisions, which increases surgical and postoperative risk and reduces the width of keratinized mucosa.^{14,15} To avoid these drawbacks, some clinicians

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cover the bone graft used in ARP with an absorbable xenogeneic collagen membrane or acellular dermal matrix and leave the soft tissue to granulate over the unprotected collagen. Because certain types of absorbable collagen degrade within 1 to 2 weeks when exposed to the oral environment, particulate graft exfoliation may result.^{16–18} To prevent extrusion of graft material in an ARP procedure with intentional nonclosure, the degradation rate of the absorbable occlusive membrane must match that of bone integration. One alloplastic bioabsorbable polylactic acid (PLA) membrane with a bilayer matrix configuration begins resorbing at approximately 3 months and fully resorbs in 6 to 12 months^{19,20}; this rate is slower than that of xenogeneic barriers and is contingent on complete mucosal coverage. When exposed to the oral environment, the membrane completely resorbs in approximately 4 to 8 weeks.^{19,20}

There have been few clinical studies on SDMS treated with ARP, especially with an intentionally exposed absorbable membrane.^{21–24} This study followed 12 patients with SDMS who underwent ARP using deproteinized bovine bone mineral (DBBM) overlaid with PLA membrane without primary closure. Postsurgical soft tissue and crestal bone dimensional changes were analyzed.

MATERIALS AND METHODS

Subjects


This study was approved by the Institutional Review Board of the Peking University School of Stomatology (reference number: PKUSSIRB-202054030) and was conducted in accordance with the Helsinki Declaration of 1975, as revised in 2013. From February 1, 2018, to June 1, 2020, 19 patients with 24 SDMSs were treated with ARP using a PLA membrane and xenograft without primary closure after obtaining informed consent. An SDMS lesion was clinically defined as a fresh molar extraction socket demonstrating a cyst-like bone defect or extensive periradicular bone resorption with or without bone plate dehiscence or fenestration caused by advanced chronic periodontitis, radicular cyst, osseous dysplasia, and/or resorption from an adjacent impacted third molar. These patients were screened according to the following criteria.

The inclusion criteria were as follows: (1) age \geq 19 years, (2) molar with postextraction SDMS and hopeless prognosis, (3) healthy or stable periodontal status in other sites, and (4) clinical image showing post-ARP soft tissue healing taken during scheduled follow-up.

The exclusion criteria were as follows: (1) smoking $>$ 10 cigarettes per day, (2) poorly controlled diabetes (HbA1c level $>$ 7%), or (3) systemic disease that would preclude implant surgery and bone grafting.

Out of 19 patients, 12 patients with 14 SDMSs met the aforementioned criteria and were subjected to data analysis.

Surgical Procedures and Follow-up

All surgical procedures were performed under local anesthesia by two experienced oral surgeons (D.H.D. and E.B.W.). A systemic antibiotic (amoxicillin 1 g or, in the case of penicillin allergy, erythromycin 300 mg) was administered 30 minutes preoperatively to prevent surgical infection. The ARP technique was performed as follows. An envelope flap extending one adjacent tooth away mesially and distally was made by creating intra-sulcular incisions maintaining the papillae around each molar to be extracted. Buccal vertical releasing incisions were made in two cases to visualize the buccal plate: One case required lateral window sinus floor elevation at the time of extraction, and another case required apical root surgery of an adjacent tooth. Extraction of each hopeless molar was performed, and the interradicular septa were removed as needed to access all alveolar aspects of the socket, which was essential to ensure elimination of pathologic tissue, including any periapical cyst, granulomatous tissue, impacted third molar, or osseous dysplasia (Table 1). After curettage was performed to denude pathologic tissue from all alveolar walls, the extraction socket was filled with DBBM (Bio-Oss, Geistlich Pharma) alone (nine sites) or combined with autograft (two sites) or platelet-rich fibrin (PRF, three sites) according to Dohan et al's protocol²⁵ to a level 1 to 2 mm coronal to the buccal and lingual alveolar ridge. The coronal portion of bone graft was covered by a PLA membrane (GUIDOR, Sunstar Americas) alone in 11 cases; in one case, the coronal portion of bone graft was covered with both PLA and bovine acellular dermal matrix membrane (ADM, Heal-Full, Zhenghai Bio-tech) with ADM extending palatally to cover the bone plate dehiscence defects (Table 1). In all cases, the PLA membranes were sutured directly to mucosa, and the gingival flap was repositioned and secured with 3-0 absorbable sutures, intentionally leaving the underlying membrane exposed. Postoperative management included amoxicillin plus clavulanic acid 1 g or, in the case of penicillin allergy, erythromycin 300 mg every 12 hours for 6 days; ibuprofen 600 mg every 8 hours for 4 to 5 days; and 0.2% chlorhexidine oral rinse every 12 hours for 1 week. [AU: Editing oka The International Journal of Oral & Maxillofacial Implants 3

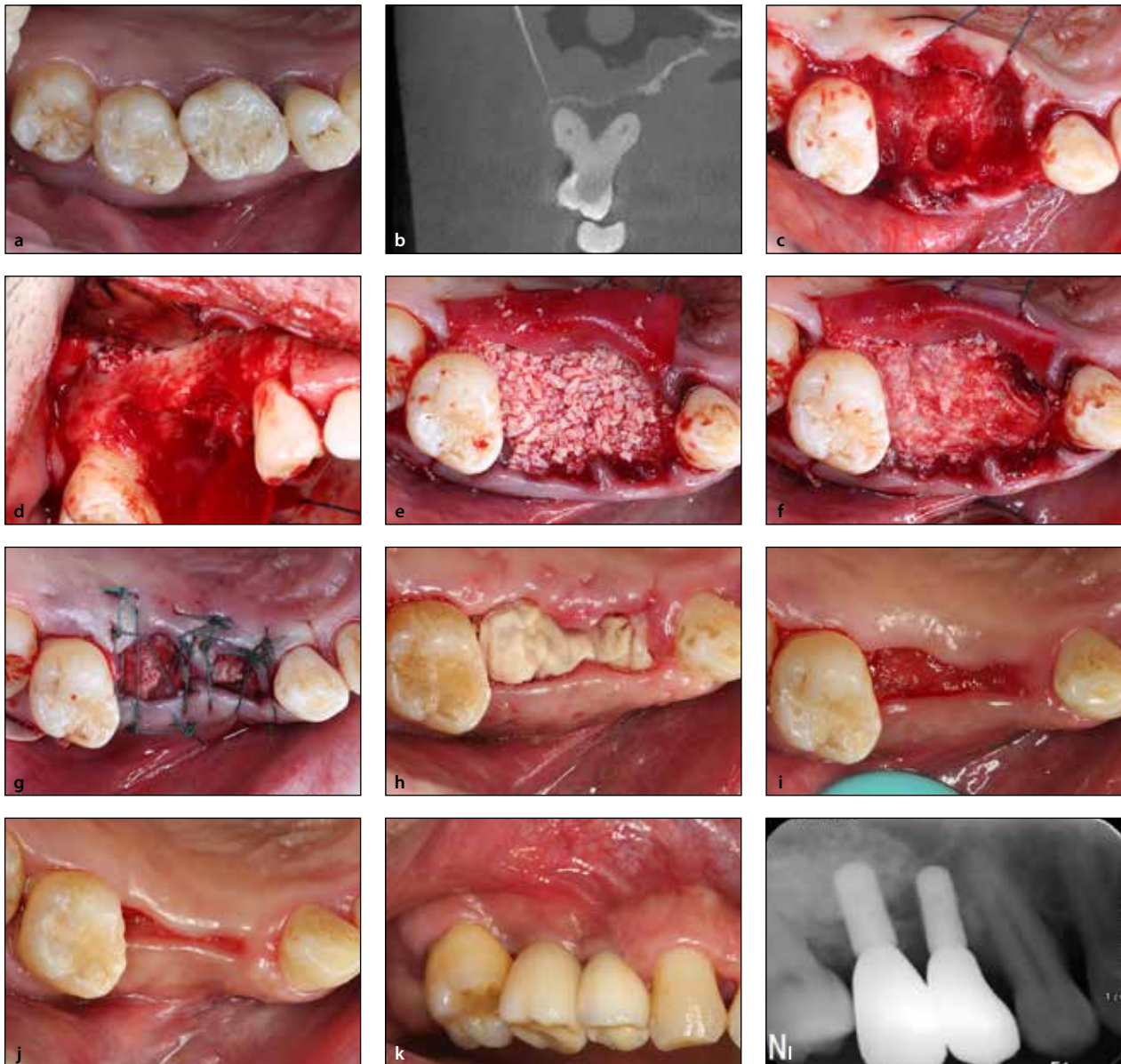


Fig 1 Alveolar ridge preservation in a severely damaged maxillary molar socket (case #9). (a) Occlusal view of hopeless maxillary right second premolar and first molar. (b) A preoperative CBCT scan showed advanced chronic periodontitis of maxillary right first molar. (c) The sockets presented with periradicular bone resorption with palatal and distobuccal dehiscence. (d) A bovine ADM barrier was sutured to the palatal flap. (e) The SDMS was filled with deproteinized bovine bone mineral. (f) PRF and ADM membranes were overlaid on the bone graft. (g) A PLA membrane was overlaid on the ADM membrane without primary closure. (h) Two weeks after alveolar ridge preservation and concomitant lateral window sinus elevation, the membrane had partly split off from the peripheral mucosa (MD1), and the bone graft appeared contained within the socket by the membrane (GE1). (i) Eight weeks following ARP, the surgical sites exhibited complete membrane degradation and granulation tissue coverage of the bone graft (MD4, GE4). (j) Ten months following ARP, sites were completely covered by keratinized mucosa (MD4, GE4). (k) Three months after restoration of the maxillary right second premolar and first molar, the peri-implant mucosa appeared noninflamed. (l) A periapical radiograph of the maxillary right second premolar and first molar revealed adequate peri-implant bone and interimplant distances. [AU: Please check that teeth names are correct]

Evaluation of Soft Tissue Healing

Patients were recalled at 14 days, 1 to 2 months, and 6 to 12 months post-ARP for clinical examinations and

photography to assess soft tissue healing, membrane degradation, and graft exfoliation.

Membrane degradation scores were categorized as follows:

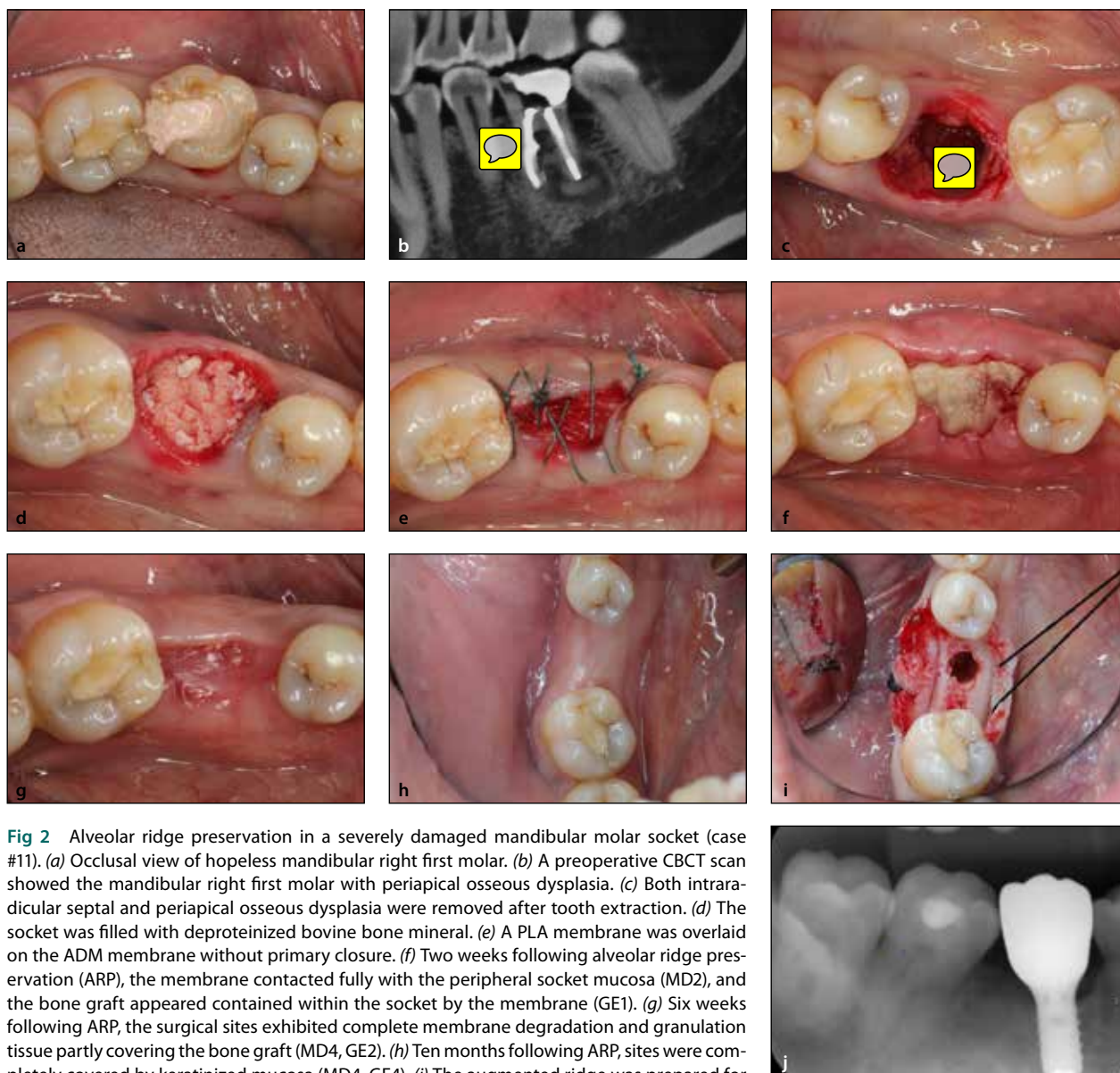


Fig 2 Alveolar ridge preservation in a severely damaged mandibular molar socket (case #11). (a) Occlusal view of hopeless mandibular right first molar. (b) A preoperative CBCT scan showed the mandibular right first molar with periapical osseous dysplasia. (c) Both intraradicular septal and periapical osseous dysplasia were removed after tooth extraction. (d) The socket was filled with deproteinized bovine bone mineral. (e) A PLA membrane was overlaid on the ADM membrane without primary closure. (f) Two weeks following alveolar ridge preservation (ARP), the membrane contacted fully with the peripheral socket mucosa (MD2), and the bone graft appeared contained within the socket by the membrane (GE1). (g) Six weeks following ARP, the surgical sites exhibited complete membrane degradation and granulation tissue partly covering the bone graft (MD4, GE2). (h) Ten months following ARP, sites were completely covered by keratinized mucosa (MD4, GE4). (i) The augmented ridge was prepared for implant placement. (j) A periapical radiograph of the mandibular right first molar immediately after crown restoration. [AU: Please check that teeth names are correct]

- MD1: The membrane contacts partly with the peripheral socket mucosa.
- MD2: The membrane contacts fully with the peripheral socket mucosa.
- MD3: The membrane degrades centrally and is integrated with the peripheral socket mucosa.
- MD4: The membrane degrades completely.

Graft exfoliation scores were categorized as follows:

- GE1: The bone graft appears to be secured within the socket by the membrane.
- GE2: Mild bone graft exfoliation that does not extend apical to the presumptive alveolar ridge.

- GE3: Severe bone graft exfoliation that extends apical to the presumptive alveolar ridge.
- GE4: The bone graft appears to be secured within the socket by granulation tissue or keratinized mucosa.

Evaluation of Alveolar Crest Changes

Nine patients had CBCT scans (Morita) taken preoperatively, at 1 to 2 weeks, and at 6 to 12 months after ARP; 10 socket sites were evaluated with CBCT software (i-Dixel One Volume Viewer, J. Morita). All images were taken at 90 kV, 5 mA, 17.5 seconds with a field of view (FOV) of 6 × 6 cm and a slice thickness of 1 mm. The DICOM data from each CBCT scan of an intact hopeless molar were

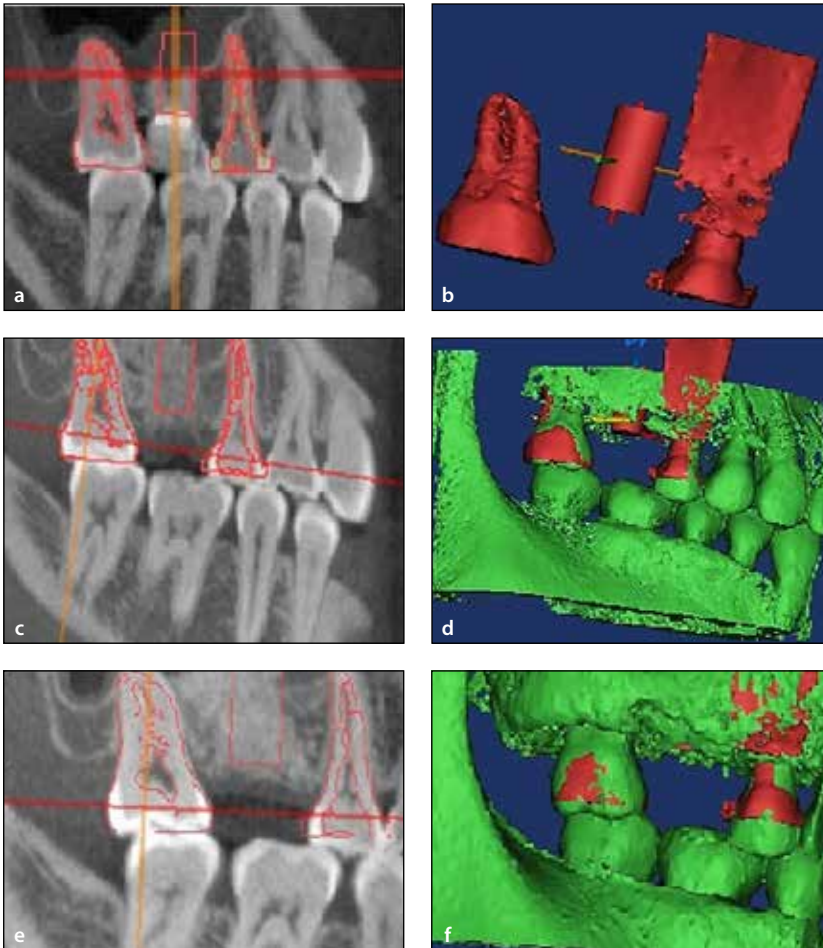


Fig 3 Description of CBCT measurements. (a and b) Images of a virtually placed implant together with two adjacent natural teeth based on a pre-extraction CBCT scan were created and exported as an STL file. (c and d) Images of the virtual implant and adjacent teeth were superimposed onto CBCT data taken 1 to 2 weeks following alveolar ridge preservation. (e and f) Images of the virtual implant and adjacent teeth were superimposed onto CBCT data taken 6 to 12 months after alveolar ridge preservation.

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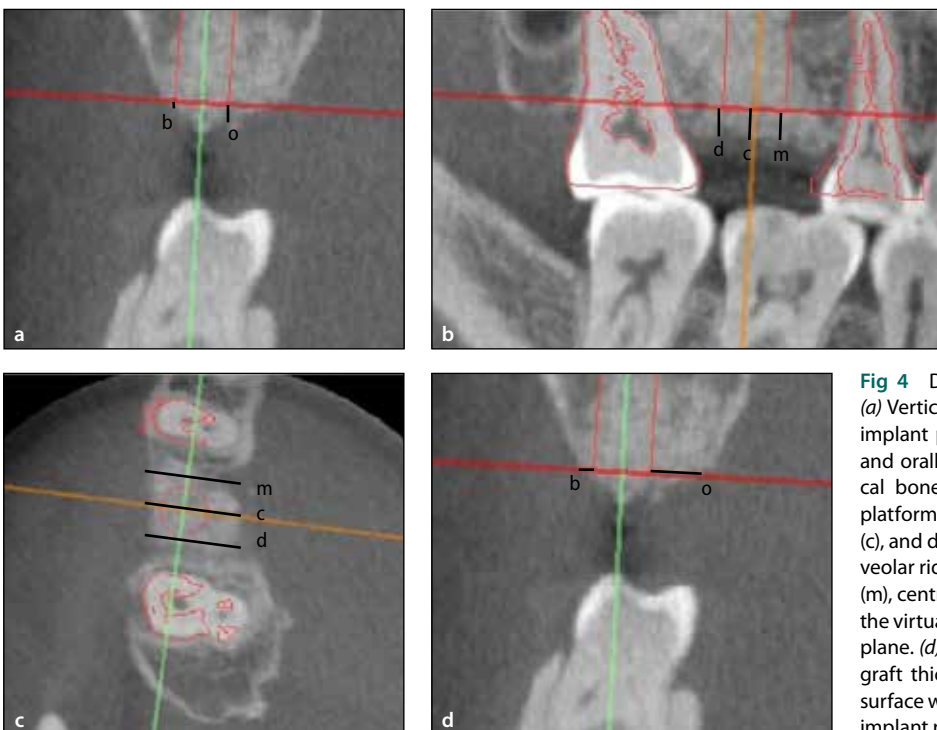


Fig 4 Description of CBCT measurements. (a) Vertical bone height coronal to the virtual implant platform was measured buccally (b) and orally (o) on the coronal plane. (b) Vertical bone height above the virtual implant platform was measured mesially (m), centrally (c), and distally (d) on the sagittal plane. (c) Alveolar ridge thickness was measured mesially (m), centrally (c), and distally (d) at the level of the virtual implant platform on the transverse plane. (d) Midbuccal (b) and midoral (o) bone graft thickness lateral to the virtual implant surface was recorded at the level of the virtual implant platform on the coronal plane.

transferred into volumetric imaging software (Mimics 19.0, Materialise), and a 4.8×10 -mm bone-level columnar implant mock-up was virtually placed following a restoratively driven approach with the implant platform positioned at a level 3.5 mm apical to the cementoenamel junction of the hopeless tooth. Data on the virtually placed implant and two adjacent natural teeth were segmented, exported, and saved as an STL file. To evaluate hard tissue morphologic changes around implant sites, the pre-extraction STL file and DICOM data were transferred into the Mimics software and 3D superimposed onto the postoperative CBCT images taken at 1 to 2 weeks and 6 to 12 months after ARP surgery (Fig 3).

Radiographic measurements on the superimposed pre-extraction (with virtual implant placement) and post-ARP CBCT images were performed twice by one investigator (D.H.D.), and mean values were calculated. Intraexaminer reproducibility was tested in 10 random samples at an interval of 2 weeks. Intraclass correlation coefficients for CBCT were 0.82 to 0.93 ($P < .05$). CBCT measurements were described as follows (Fig 4):

- **Vertical bone height:** Linear measurements from the height of the bone graft to the virtual implant platform were performed at three locations (central, mesial, and distal) on the coronal plane and at two locations (buccal and lingual) on the sagittal plane.
- **Alveolar ridge thickness:** The distance between the lateral border of the virtual implant and the external aspect of the buccal and oral alveolar plate at three lines was calculated at the 0-, 2-, 4-, and 6-mm levels apical to the virtual implant platform. On the transverse plane at each level, three parallel lines perpendicular to the buccal and oral plates that passed through mesial, central, and distal aspects of the virtual implant were drawn using CBCT software; the bucco-oral distance between the intersection of these parallel lines and the external alveolar plates was measured as the alveolar ridge thickness.
- **Midbuccal and midoral bone thickness:** On the transverse plane, the distance from the lateral aspect of the virtual implant to the border of the bone graft material or to the external border of the buccal or oral plate (whichever border was positioned more laterally), was recorded at 0-, 2-, 4-, and 6-mm levels apical to the implant platform at the midbuccal and midoral locations.

Statistical Analysis

Data were analyzed using SPSS version 22.0 software (IBM). Descriptive statistics including the mean and standard deviation (SD) were calculated. The independent-sample *t* test and one-way analysis of variance (ANOVA) were performed to compare mean differences

between groups. Statistical significance was set at $P < .05$.

RESULTS

Twelve patients with 14 SDMSs treated with ARP were included in this study (Table 1). Out of 12 patients, 5 were men (41.7%) and 7 were women (58.3%); the mean age was 41.1 ± 9.7 years (range: 27 to 56 years). Out of 14 SDMS sites, 8 (57.1%) were of maxillary first molars, 3 (21.4%) were of mandibular first molars, 2 (14.3%) were of maxillary second molars, and 1 (7.1%) was of a mandibular second molar. Reasons for extraction included advanced chronic periodontitis (six sites), periapical cyst (three sites), periapical osseous dysplasia (two sites), external root resorption by unerupted wisdom tooth (two sites), and periapical granuloma (one site; Table 1).

At the first examination following ARP (14 days after), all sites demonstrated edematous marginal mucosa and crimped PLA membranes. Seven sites (50%) presented with MD1; 6 of these demonstrated GE2, whereas 1 site had GE3. In addition, 3 out of 7 sites showed wound infection with gray-appearing xenograft and exudate. The other 7 sites (50%) presented with MD2 and GE1.

At the second examination following ARP (1 to 2 months after), six (42.9%) sites presented with MD3, whereas the other eight sites (57.1%) presented with MD4. Nine sites (64.3%) presented with GE2, four sites (28.6%) presented with GE4, and one site (7.1%) presented with GE3.

Three patients (cases no. 3, 4, and 8 in Table 1) with three sites failed to attend the final examination following ARP (6 to 12 months after). All 11 sites that were assessed at the final follow-up visit presented with MD4 and GE4. More information on both membrane degradation and graft exfoliation during healing is summarized in Fig 5.

Table 2 summarizes the vertical ridge changes of ARP-reconstructed SDMS 1 week to 12 months post-grafting. The mean vertical bone graft height apical to the virtual implant platform including five measurement sites was 3.2 ± 1.7 mm 1 to 2 weeks following ARP. At 6 to 12 months, the mean vertical graft height decreased to 0.9 ± 1.6 mm, resulting in a mean difference of 2.2 ± 2.2 mm, which was statistically significant ($P < .05$).

Tables 3 and 4 [AU: No Table 4 was included. Should this just be Table 3?] summarize the horizontal ridge changes of ARP-reconstructed SDMS 1 week to 12 months post-grafting. The magnitude of changes in alveolar ridge thickness between 1 to 2 weeks to 6 to 12 months following ARP significantly differed between measurements at the virtual implant platform

Table 1 Case Descriptions						
Case no.	Sex/ Age (y)	Tooth position (FDI)	Causes of tooth extraction	SDMS characteristics	Graft material	Additional procedures
1	F/50	27	External root resorption	Cystoid defect with buccal plate fenestration	DBBM	Third molar extraction
2	M/48	16	Advanced chronic periodontitis	Extensive periradicular bone resorption with palatal plate dehiscence	DBBM + mandibular ramus bone	Lateral window sinus floor elevation
		26	Advanced chronic periodontitis	Extensive periradicular bone resorption with palatal and mesiobuccal plate dehiscence	DBBM + mandibular ramus bone	
3	F/45	36	Advanced chronic periodontitis	Extensive periradicular bone resorption	DBBM	
4	M/56	16	Periapical cyst	Cystoid defect	DBBM + PRF	Tooth extraction (#15)
5	F/49	26	Advanced chronic periodontitis	Extensive periradicular bone resorption	DBBM	
		27	Advanced chronic periodontitis	Extensive periradicular bone resorption	DBBM	
6	M/30	16	Periapical cyst	Cystoid defect with palatal plate fenestration	DBBM + PRF	Apical root surgery (#16)
7	F/27	36	Periapical osseous dysplasia	Cystoid defect	DBBM	
8	F/47	26	Periapical cyst	Cystoid defect with mesiobuccal plate dehiscence	DBBM	
9	M/36	16	Advanced chronic periodontitis	Extensive periradicular bone resorption with palatal and disto-buccal dehiscence	DBBM + PRF	Lateral window sinus floor elevation + tooth extraction (#15)
10	M/36	16	Periapical granuloma	Cystoid defect with sinus floor fenestration	DBBM	
11	F/42	46	Periapical osseous dysplasia	Cystoid defect	DBBM	
12	F/27	37	External root resorption	Cystoid defect	DBBM	Third molar extraction

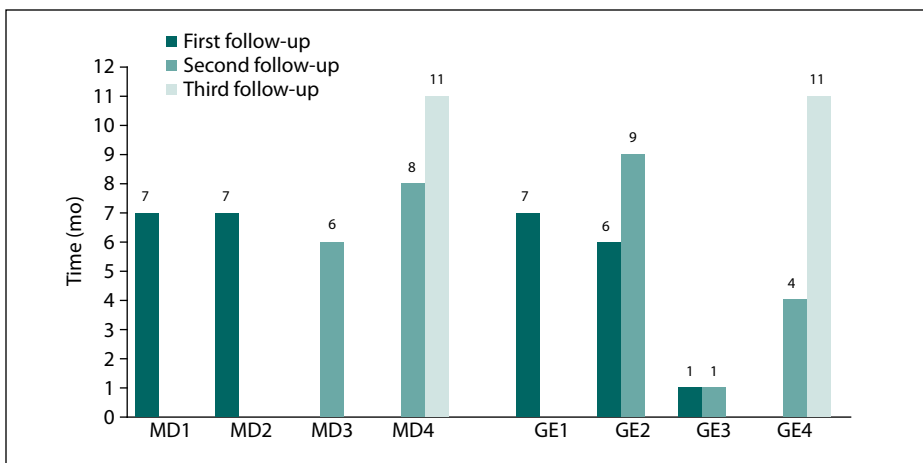


Fig 5 Membrane degradation (MD) and graft exfoliation (GE) status at 14 days, 1 to 2 months, and 6 to 12 months following alveolar ridge preservation.

and those at the other levels (2, 4, and 6 mm apical to the virtual platform; $P < .05$). The greatest decrease in alveolar thickness occurred at the level of the virtual implant platform (Appendix Table 2; see Appendix in online version of this article at quintpub.com); [AU: Where should Appendix Table 2 be called out in the text?]

there, mean alveolar ridge thickness values significantly decreased by 4.7 ± 3.8 mm mesially, 5.0 ± 5.1 mm centrally, and 4.5 ± 4.2 mm distally between the two post-operative CBCT scan time points. The mean midbuccal and midoral bone thickness lateral to the virtual implant trended downward over time and was the thinnest at

Table 2 Vertical Dimensions of the Reconstructed SDMS (Mean ± SD)

	Mesial	Central	Distal	Buccal	Oral	Mean
1–2 mo post	3.5 ± 2.0	3.3 ± 1.8	3.7 ± 1.7	2.7 ± 1.6	2.7 ± 1.50	3.2 ± 1.7
6–12 mo post	1.6 ± 1.5	1.1 ± 1.6	1.2 ± 1.6	0.4 ± 1.7	0.3 ± 1.8	0.9 ± 1.6
Dimensional change	2.0 ± 2.6	2.2 ± 2.5	2.4 ± 2.3	2.3 ± 1.8	2.4 ± 2.1	2.2 ± 2.2

Table 3 Horizontal Dimensions of Reconstructed SDMS (Mean ± SD)

	Alveolar ridge thickness			Bone thickness lateral to implant	
	Mesial	Central	Distal	Midbuccal	Midoral
0 mm below implant platform					
1–2 mo post	11.1 ± 1.9	11.3 ± 2.4	10.8 ± 2.9	2.9 ± 1.5	3.1 ± 1.4
6–12 mo post	6.4 ± 3.9	6.2 ± 3.6	6.3 ± 3.4	1.6 ± 1.4	1.1 ± 1.7
Dimensional change	4.7 ± 3.8	5.0 ± 5.1	4.5 ± 4.2	1.3 ± 2.0	2.0 ± 1.6
2 mm below implant platform					
1–2 mo post	12.1 ± 1.7	12.4 ± 2.0	12.1 ± 2.1	3.9 ± 1.6	3.7 ± 1.3
6–12 mo post	10.5 ± 1.4	10.6 ± 1.5	10.7 ± 1.7	3.2 ± 1.9	2.7 ± 0.9
Dimensional change	1.6 ± 1.5	1.8 ± 1.4	1.44 ± 2.2	0.7 ± 1.3	1.1 ± 1.3
4 mm below implant platform					
1–2 mo post	13.1 ± 1.6	13.5 ± 1.6	13.9 ± 2.0	4.4 ± 1.7	4.2 ± 1.2
6–12 mo post	12.0 ± 1.8	12.4 ± 1.6	13.0 ± 1.6	3.9 ± 1.7	3.7 ± 1.4
Dimensional change	1.1 ± 0.6	1.1 ± 0.8	0.8 ± 1.1	0.5 ± 0.6	0.5 ± 0.9
6 mm below implant platform					
1–2 mo post	13.5 ± 1.7	14.2 ± 1.9	14.9 ± 2.4	4.70 ± 1.8	4.6 ± 1.2
6–12 mo post	13.0 ± 1.9	13.4 ± 1.8	14.4 ± 2.0	4.4 ± 1.7	4.2 ± 1.5
Dimensional change	0.5 ± 0.5	0.8 ± 0.7	0.6 ± 0.8	0.3 ± 0.6	0.4 ± 0.9

the level of the virtual implant platform 6 to 12 months following ARP, measuring 1.6 ± 1.4 mm buccally and 1.1 ± 1.7 mm orally (Table 3).

DISCUSSION

Primary closure has been considered a prerequisite for bone regeneration that is partially based on studies documenting infection from prematurely exposed expanded polytetrafluoroethylene (e-PTFE) membranes used around furcations and implants.¹³ The need for primary closure for socket preservation is questionable. Darby et al indicated that primary closure may not be necessary for socket grafting, though most of the articles they reviewed obtained it, and Engler-Hamm et al did not observe any significant ridge width differences between cases with primary closure and those with intentional collagen membrane exposure.^{14,26} A meta-analysis reported that flapped extractions result in less horizontal socket resorption than flapless extractions, a

finding that the study's authors ascribed to the ability to achieve primary closure using flaps.²⁷

Leaving a membrane exposed after alveolar ridge preservation makes the site susceptible to infection, premature barrier loss, and graft exfoliation; any of these complications may compromise outcomes, especially at the coronal portion of SDMS that frequently has thin to no bone and a wide orifice. Coronally, a mean vertical bone height decrease of 2.2 ± 2.2 mm was observed despite graft containment within the socket and complete coverage by keratinized mucosa 6 to 12 months post-ARP (Table 2). From the first CBCT scan (1 to 2 months post-ARP) to the second (6 to 12 months post-ARP), the mean central alveolar ridge thickness decreased by 5.0 ± 4.8 mm, 1.9 ± 2.8 mm, 0.8 ± 1.9 mm, and 0.0 ± 0.9 mm at the 0-, 2-, 4-, and 6-mm levels, respectively, apical to the virtual implant platform; these changes corresponded to final radiographic central alveolar ridge thickness values of 6.4 ± 3.9 mm at the platform and 10.5 ± 1.4 mm, 12.0 ± 1.8 mm, and 13.0 ± 1.9 mm at the 2-, 4-, and 6-mm levels, respectively, apical to the

platform. The results of this study were consistent with the studies by Scheyer et al and Sun et al.^{10,28} In a multicenter clinical study on buccal bone-deficient socket grafting, the horizontal change from the baseline to 6 months was 6.71 ± 2.07 mm using xenograft with native collagen membrane and 4.95 ± 2.65 mm using allograft with cross-linked collagen membrane using a surgical stent as a reference.¹⁰ In a study by Sun et al, damaged sockets were filled with allograft and covered with a dPTFE membrane. Four months postgrafting, the molar sites exhibited dimensional decreases of 4.1 ± 1.9 mm horizontally and 2.5 ± 1.6 mm vertically at a level 1 mm apical to the alveolar crest.²⁸

Other studies have reported results inconsistent with this study, which recorded twice as much alveolar ridge shrinkage as those did.^{16,28,29} These disparities may be attributed to socket location, degree of socket damage, surgical techniques such as flap reflection, healing time, concomitant procedures performed, and evaluation methodology (reference line and measurement level). Romano et al showed significant horizontal shrinkage of 2.57 ± 1.32 mm at 1 mm apical to the buccal alveolar crest 12 months post-ARP using DBBM and collagen membrane.²⁹ A randomized controlled trial by Lee et al on damaged extraction sockets demonstrated a similar horizontal reduction (2.67 ± 3.42 mm) as well as a 1.45 ± 1.92 -mm vertical diminution 4 months after ARP using DBBM and collagen membrane.¹⁶ In contrast to the present study, Romano et al examined only nonmolar sites (incisors and premolars), made vertical releases adjacent to the extraction socket, and gained partial barrier coverage (it is the central portion of the socket that was left exposed).²⁹ Lee et al included analysis of 23.4% nonmolar extraction sites, which may have dampened any impact from molar resorption.¹⁶

Compared with coronal bone width changes after ARP of intact nonmolar sockets without primary closure, the alterations after such treatment for SDMS tend to be greater.^{3,8,10,16,28} The present study showed that at least 1 mm of hard tissue lateral to the virtual implant existed buccally and orally 6 to 12 months following ARP, and implants were placed without further augmentation in all sites. This finding can be partly explained by the maintenance of the barrier function through the healing period. A PLA membrane with a slow resorption rate was used. Two weeks following ARP, each membrane appeared crimped but without signs of degradation. One to two months following ARP, membrane had degraded partially in six (42.9%) sites and completely in eight sites (57.1%). These findings mean that the exposed PLA membrane maintained barrier function to some extent for at least 3 to 4 weeks as claimed by the manufacturer.

Two weeks following ARP, three sites showed bone graft infection that caused loss of graft material to the level of the presumptive alveolar ridge. It is possible that the bone graft beneath the infection had vascularized up to the presumptive alveolar ridge so that despite premature membrane removal at this 14-day follow-up visit, alveolar ridge preservation still produced clinically acceptable results; Fotek et al described spontaneous exfoliation of all ePTFE membranes a mean 16.6 days following socket graft but reported no major ridge dimensional changes in affected sites or differences compared with retained ADM barriers after 16 weeks.¹⁷ These findings suggest that a barrier that endures for 3 to 4 weeks, such as the one employed in the present study, would be sufficient for clot stability, graft containment, ridge preservation, and uncomplicated implant placement.

This investigation has two major limitations. It is a case series; a randomized controlled trial would better evaluate the effectiveness of the investigated procedure. Also, the surgical approach was not standardized: The flap design was either an envelope or a trapezoidal configuration with two buccal releasing incisions; additional procedures, including lateral window sinus floor elevation, apical root surgery, and third molar extraction, were performed in some cases; the extraction socket was augmented with xenograft alone or in combination with an autograft or platelet-rich fibrin; a polylactic acid membrane was used alone or combined with a bovine acellular dermal matrix membrane. Such heterogeneity affects the relevance and generalizability of this study.

CONCLUSIONS

Alveolar ridge preservation of severely damaged molar sockets using an exposed PLA membrane overlying DBBM generated adequate ridge dimensions for uncomplicated implant placement. The uncovered membrane maintains some barrier function for at least 3 to 4 weeks. Future studies should include histologic assessment of the augmented bone and nongrafted control sockets.

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APPENDIX

Appendix Table 1 Soft Tissue Healing of Orifice

Case no.	Tooth no.	1st follow-up			Second follow-up			Third follow-up		
		Time	Membrane degradation	Graft exfoliation	Time	Membrane degradation	Graft exfoliation	Time	Membrane degradation	Graft exfoliation
1	27	2 wk	MD1	GE2	4 wk	MD3	GE4	7 mo	MD4	GE4
2	16	2 wk	MD2	GE1	6 wk	MD3	GE2	8 mo	MD4	GE4
	26	2 wk	MD2	GE1	6 wk	MD3	GE2	8 mo	MD4	GE4
3	36	2 wk	MD2	GE1	4 wk	MD4	GE2	Follow-up failure		
4	16	2 wk	MD1	GE3	4 wk	MD4	GE3	Follow-up failure		
5	26	2 wk	MD1	GE2	6 wk	MD4	GE4	10 mo	MD4	GE4
	27	2 wk	MD1	GE2	6 wk	MD4	GE2	10 mo	MD4	GE4
6	16	2 wk	MD1	GE2	8 wk	MD4	GE4	7 mo	MD4	GE4
7	36	2 wk	MD2	GE1	4 wk	MD3	GE2	11 mo	MD4	GE4
8	26	2 wk	MD2	GE1	4 wk	MD3	GE2	Follow-up failure		
9	16	2 wk	MD1	GE2	4 wk	MD4	GE2	12 mo	MD4	GE4
10	16	2 wk	MD2	GE1	4 wk	MD3	GE4	8 mo	MD4	GE4
11	46	2 wk	MD2	GE1	6 wk	MD4	GE2	10 mo	MD4	GE4
12	47	2 wk	MD1	GE2	4 wk	MD4	GE2	6 mo	MD4	GE4

Appendix Table 2 ANOVA Analysis of Alveolar Ridge Thickness and Graft Thickness Lateral to the Virtual Implant at Different Levels

	Alveolar ridge thickness						Graft thickness lateral to the virtual implant			
	Mesial		Central		Distal		Midbuccal		Midoral	
	Difference (mm)	P	Difference (mm)	P	Difference (mm)	P	Difference (mm)	P	Difference (mm)	P
0 mm										
2 mm	3.12	.00	3.22	.01	3.05	.01	0.67	0.24	0.93	.10
4 mm	3.61	.00	3.90	.00	3.66	.00	0.86	0.14	1.50	.01
6 mm	4.24	.00	4.20	.00	3.90	.00	1.06	0.07	1.57	.01
2 mm										
4 mm	0.50	.60	0.68	.58	0.61	.59	0.19	0.74	0.57	.30
6 mm	1.13	.24	0.98	.42	0.84	.45	0.39	0.50	0.64	.25
4 mm										
6 mm	0.63	.51	0.30	.80	0.24	.83	0.20	0.73	0.07	.89