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ORIGINAL ARTICLE

A three-in-one alveolar process reconstruction protocol for maxillary molar sites with severe residual bone height deficiency: A proof-of-concept pilot study

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Abstract

Background: Implant placement in maxillary molar sites with severe height deficiency often requires multiple surgeries, which was time-consuming, invasive, and subject to serious postoperative complications.

Purpose: To introduce and assess a three-in-one technique (extraction, alveolar ridge preservation [ARP], and sinus elevation) for augmenting deficiency maxillary molar alveolar ridges.

Material and Methods: Fourteen patients with severe posterior maxillary ridge height deficiency underwent extraction, sinus elevation via an intrasocket window and ARP using sticky bone and then covered with acellular dermal matrix (ADM). Primary closure was intentionally not obtained. Cone-beam computed tomography and periapical radiography were used to measure dimensional ridge changes over time. Bone biopsies were taken at implant placement 7–21 months after surgery, which proceeded without additional grafting. Peri-implant soft tissue was assessed after 8–12 months of functional loading.

Results: Maxillary molar sites (13 first molars, 1 second molar) with a mean sinus floor height of 1.73 ± 0.86 mm and mean buccal plate thickness of 1.62 ± 1.15 mm were elevated and grafted. Immediately after surgery, the mean sinus floor height was 14.03 ± 1.97 mm and the alveolar thickness at virtual implant platform level was 12.99 ± 1.88 mm. After 5–9 months healing, those measurements decreased by 2.45 ± 1.73 mm ($p = 0.000$) and 3.88 ± 3.95 mm ($p = 0.006$), respectively. Healed ridges were composed of 18.74% ± 4.34% mean vital bone and 19.08% ± 9.10% mean residual graft. After 8–12 months of functional loading, the peri-implant tissue appeared healthy, and there was a mean marginal bone loss of 0.12 ± 0.11 mm.

Conclusions: For maxillary first molar sites with severe sinus floor height deficiency, this minimally invasive three-in-one treatment allows for uncomplicated implant placement and short-term functional stability.

KEYWORDS

alveolar process, bone regeneration, cone-beam computed tomography, sinus floor augmentation, tooth extraction

What is known

Implant placement in severely damaged maxillary molar sites often requires substantial ridge augmentation performed over multiple surgeries.

What this study adds

Simultaneous extraction, alveolar ridge preservation, and crestal approach through socket sinus elevation with open healing may streamline the therapeutic process and may be a valid alternative to orthodox staged therapies for ridge development at severely compromised maxillary molar sites.

1 | INTRODUCTION

Vertical deficiency in the posterior maxilla results from sinus pneumatization and resorption of the alveolar crest,[1–3] which contribute to 12%–30% and 70%–88% of height loss, respectively.[4,5] Alveolar ridge preservation (ARP) of posterior extraction sockets effectively promotes tissue regeneration and maintains bone dimensions.[1,3,6,7] Although ARP-treated sockets demonstrate a significantly greater post-extraction bone height than nongrafted sockets (7.30 vs. 4.83 mm, respectively), 16.7%–57.1% of ARP-treated maxillary molar sites require additional sinus augmentation.[1] Lateral window sinus elevation has been the conventional treatment of choice for implant site development of severely damaged ridges.[8,9] However, the lateral window approach may be time-consuming, invasive, and subject to serious postoperative complications.[6,10,11]

Biological additives such as platelet-rich fibrin (PRF) have been proposed as an adjunctive for ARP.[12,13] For example, L-PRF was found to accelerate neo-angiogenesis,[14,15] stimulate the local environment for differentiation and proliferation of surrounding cells,[16] and even accelerate new bone formation within the socket.[17] When a bone graft combined with PRF (so called sticky bone) is thought to help graft handling properties by making it easy to stick around the defect, as well as to promote vascularization and soft tissue healings,[17] therefore, protecting graft integrity.

This proof-of-concept study proposes a single-step, minimally invasive "three-in-one" treatment regimen combining maxillary molar extraction, intrasocket sinus elevation, and alveolar ridge preservation (ARP) using sticky bone for severely compromised sites, to avoid the need for further bone augmentation. The sinus-lifted socket is grafted using deproteinized bovine bone mineral (DBBM) mixed with platelet-rich fibrin (PRF) covered with acellular dermal matrix that is left exposed. The short-term clinical, radiographic, and histologic outcomes of this protocol are presented here.

2 | MATERIALS AND METHODS

This observational proof-of-concept study was prospectively performed in accordance with the 1975 Declaration of Helsinki and its revision in 2013. The study protocol was approved by the Institutional Review Board of Peking University School and Hospital of Stomatology, Beijing, China (approval number: PKUSSIRB-202054030) and registered in the Chinese Clinical Trial Registry (register number: ChiCTR2000034630). The STROBE guidelines were followed. The protocol of this study was summarized in Figure 1.

2.1 | Study population

From August 2019 to July 2020, 16 patients with one nonretainable but nonsuppurating first or second maxillary molar treatment planned for extraction and delayed implant placement were recruited from the Department of Oral and Maxillofacial Surgery at the Peking University School and Hospital of Stomatology. The inclusion–exclusion criteria included (1) age ≥ 19 years; (2) a first or second maxillary molar planned for extraction and implant placement; (3) severe bone height deficiency (<4 mm) caused by sinus hyperpneumatization, severe periodontitis, and/or periapical lesions; and (4) a healthy status of all other teeth. Exclusion criteria included (1) medical contraindication for oral surgery; (2) sinusitis; (3) ongoing immunosuppressant, corticosteroid, or bisphosphonate therapy; and (4) smoking >10 cigarettes per day.

2.2 | Treatment procedures

2.2.1 | Preparation of the mixed bone graft

Before surgery, four tubes of venous blood were collected from each patient according to the standard protocol.[18] After centrifugation, the resulting PRF clots were cut into small pieces using scissors and then mixed with DBBM (Bio-Oss, 1.0–2.0 mm, Geistlich AG, Wolhusen, Switzerland) at a ratio of four membranes per 0.75–1.00 g DBBM.

2.2.2 | Surgical procedures and follow-up

An antibiotic (amoxicillin 1 g or, in the case of penicillin allergy, erythromycin 600 mg) was administered to each patient 30 min preoperatively. All surgical procedures were performed by one experienced oral surgeon (DHD) under local anesthesia. First, an intrasulcular, papilla-maintaining incision was made around the tooth to be extracted and extended to the adjacent teeth. The tooth was

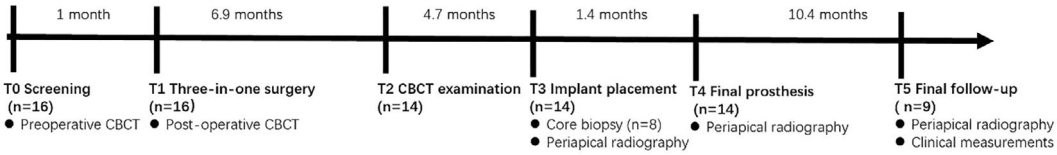

FIGURE 1 Flowchart of patient enrollment, allocation, and analyses

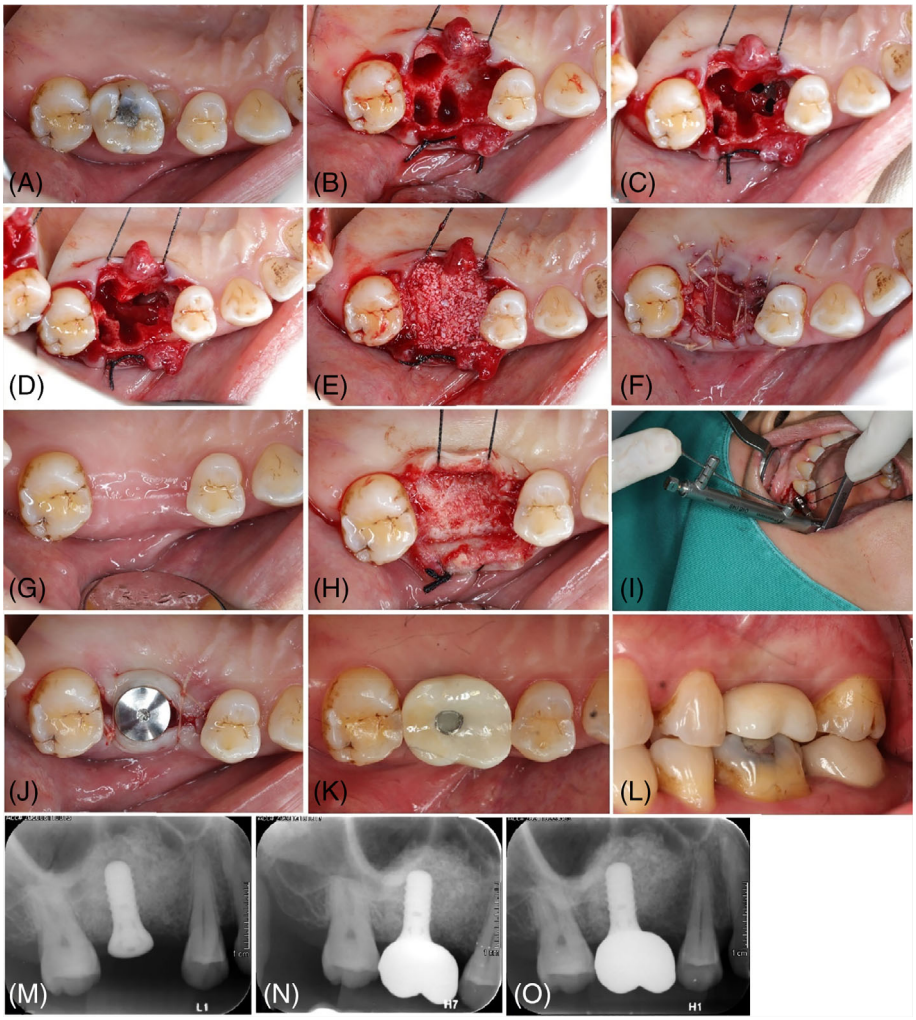

FIGURE 2 The three-in-one treatment regimen and follow-up (Case 5). (A) This right maxillary first molar has external resorption from the impacted second premolar. (B) The buccal and palatal gingival flaps were fixed to adjacent tissue to improve surgical access. (C) A sinus membrane perforation occurred during sinus elevation through an intrasocket window. (D) The perforation was sealed with a collagen membrane. (E) The elevated space and socket were filled with deproteinized bovine bone mineral mixed with pieces of platelet-rich fibrin. (F) The bone graft was overlaid with acellular dermal matrix. The site was sutured without primary wound closure. (G–J) An implant was placed with primary stability 8 months after three-in-one surgery. (K, L) The occlusal and lateral view of the final prosthesis, respectively. Periapical radiographs taken at T3 (M), T4 (N), and T5 (O) showed a stable marginal bone level

extracted atraumatically, and pathological tissue within the socket was removed. To maximize access, miniature buccal and palatal flaps were elevated and fixed via sutures to adjacent mucosa. A piezosurgery unit with hydraulic pressure (Ultra-surgery Inc., Guilin, China) was used to prepare a precise bone window through which the bluish sinus membrane could be visualized while preserving the interradicular septae. The sinus membrane was detached and lifted from the sinus floor using hand instruments (Urban sinus lift instruments, Hu-Friedy, Chicago, IL, USA). A collagen membrane (Bio-Gide, Geistlich AG, Wolhusen, Switzerland) was patched over any membrane perforation. The sticky bone (mixed DBBM-PRF graft) was inserted into the socket and gently compacted to raise the sinus membrane. Acellular dermal matrix (ADM) was laid over the graft (Heal-All Oral Biofilm, Zhenghai Bio-tech, Yantai, China). 4-0 absorbable sutures (Vicryl Rapide, Ethicon, Somerville, MA; Figure 2A–F) were used to secure the socket without primary closure. The postoperative regimen included antibiotics (amoxicillin 1 g BID, or, in the case of penicillin allergy, erythromycin 600 mg BID) for 5 days, oral rinsing (0.2% chlorhexidine 15 ml TID) for 1 week, and analgesics (ibuprofen 600 mg) as needed. After 1–2 weeks, sutures were removed. After 7–21 months, implants were placed flush with the alveolar crest according to the manufacturer's instructions (Straumman, Basel, Switzerland). A bone biopsy sample was collected with a trephine at the time of implantation. All implants were restored with single screw-retained zirconia crowns 1–2 months after implant placement (Figure 2G–L).

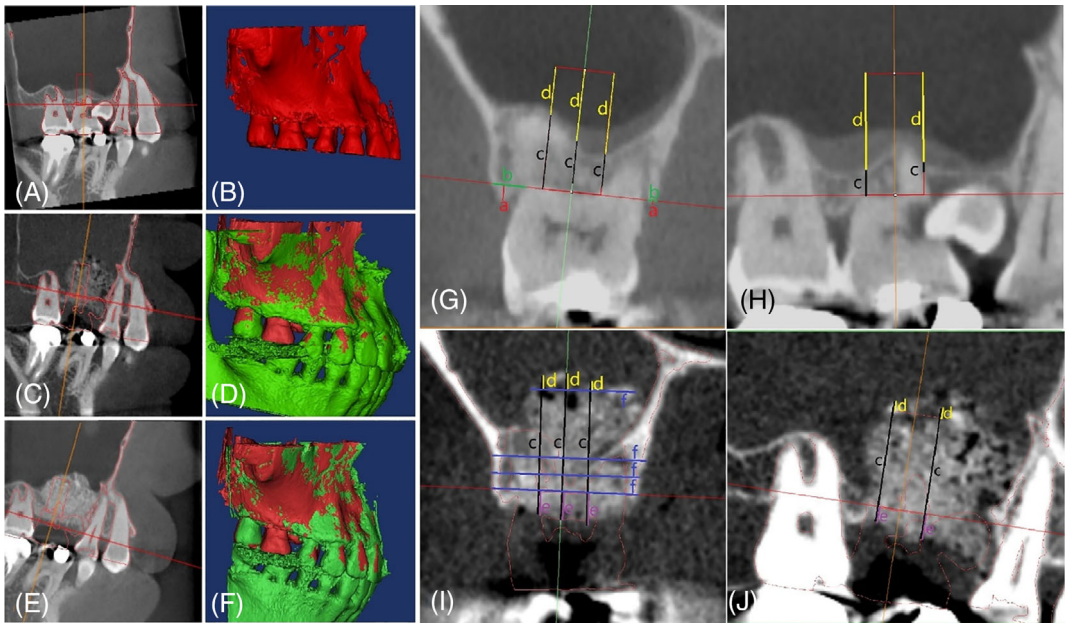

FIGURE 3 Description of CBCT registration and alveolar ridge measurements (A–J) (Case 5). (A, B) Images of a virtually placed implant and the maxilla on a pre-extraction CBCT scan were created and exported as an STL file. (C, D) Images of the virtual implant and maxilla were superimposed onto T1 CBCT data. (E, F) Images of the virtual implant and upper jaw were superimposed onto T2 CBCT data. Preoperative (T0) and postoperative (T1) alveolar ridge parameters were measured with respect to the virtual implant on the coronal (G, I) and sagittal (H, J) sections: socket bone plate height above the virtual implant platform (a); socket bone plate thickness (b); sinus floor height (c); implant protrusion height (d); crestal bone height above the virtual implant platform (e); and alveolar ridge/bone graft thickness (f) at 0, 2, 4, and 10 mm below the virtual platform

2.3 | Radiographic evaluation

Cone-beam computed tomography (CBCT) scans were acquired (3DX Accuitomo, Morita, Kyoto, Japan) prior to (T0), 1–14 days after (T1), and 5–9 months (T2) after three-in-one surgery and exported as DICOM-format files. To determine morphological changes to the alveolar bone during healing, volumetric imaging software (Mimics 15.0, Materialise, Leuven, Belgium) was used. A protocol previously reported by our group was used.[19] Briefly, the presurgical set of DICOM data was transferred into the Mimics software, and a 4.8 × 10 mm columnar implant mock-up was placed in the digital space in a restoratively driven position with the platform at the level of the root furcation. This three-dimensional model of the ideally placed implant and adjacent anatomy was saved and superimposed on postsurgical CBCT scan data for comparison (Figure 3A–F). The virtual implant mock-up and superimposing was performed by one calibrated examiner (DHD). Alveolar ridge parameters were measured as illustrated in Figure 3G–J.

1. Socket bone plate height (SBPH), which was the distance from the alveolar crest to the virtual implant platform on the buccal and palatal sides as seen on the coronal view (Figure 3G-a). A measurement was given a negative value if the virtual platform was coronal to the crest and a positive value if the virtual platform was apical to the crest. Measured at T0.

2. Socket bone plate thickness (SBPT), which was the distance from the lateral aspect of the virtual implant to the respective buccal or palatal plate at the level of the virtual implant platform as seen on the coronal view (Figure 3G-b). Measured at T0.

3. Sinus floor height (SFH), which was the distance from the alveolar crest to the sinus floor at five sites (mesial, distal, central, buccal, and palatal) as seen on the coronal (Figure 3G-c,I-c) and sagittal views (Figure 3Hc,Jc). The combined mean value of SFH was used in data analysis. Measured at T0, T1, and T2.

4. Virtual implant protrusion height (VIPH), which was the distance from the apex of the virtual implant to the sinus floor at five sites (mesial, distal, central, buccal, and palatal) as seen on the coronal (Figure 3G-d,I-d) and sagittal views (Figure 3H-d,J-d). A measurement was given a negative value if the virtual implant apex was coronal to the sinus floor and a positive value if the virtual implant apex was apical to the sinus floor. The combined mean value of VIPH was used in data analysis. Measured at T0, T1, and T2.

5. Crestal bone height (CBH), which was the distance from the virtual implant platform to the coronal-most extent of the pristine bone or bone graft at five sites (mesial, distal, central, buccal, and palatal) as seen on the coronal (Figure 3G,I) and sagittal views (Figure 3H,J). A measurement was given a negative value if the virtual implant platform was coronal to the height of the graft or bone and a positive value if the virtual implant platform was apical to the height of the graft or bone. The combined mean value of CBH was used in data analysis. Measured at T1 and T2. The combined mean value of buccal and palatal SBPH was used as CBH at T0.

6. Alveolar ridge width (ARW), which was the postoperative buccopalatal ridge dimension at 0, 2, 4, and 10 mm apical to the virtual implant platform on the coronal view (Figure 3I). Please note that the 10 mm mark corresponds to the level of the virtual implant apex. Measured at T1 and T2.

Standardized periapical radiographs were performed using the long-cone paralleling technique at the following time points: implant placement (T3), prothesis placement (T4), and 8–12 months following restoration (T5). The marginal bone level (MBL), which was the distance between the implant platform of a bone-level implant or the smooth/rough interface of a tissue-level implant to the first bone-to-implant contact point, was measured mesially and distally using ImageJ software (Java, National Institutes of Health, Bethesda, MD), and the mean of these measurements was calculated. The measurement was calibrated with the known distance of the thread pitch to avoid radiographic distortion. Measured at T3 and T5.

2.4 | Clinical measurements

Clinical measurements were recorded at six sites around each implant 8–12 months after functional loading using a CP15 periodontal probe (Hu-Friedy, Chicago, IL) and included the plaque index (PI),[20] bleeding on probing (BOP), probing depth (PD), mucosal recession (MR), clinical attachment level (CAL), and width of keratinized tissue (KT).

2.5 | Histomorphometric assessments

All biopsy samples were fixed in 4% paraformaldehyde solution for 2 days. Serial sections were stained using hematoxylin and eosin. One slide from the central of paraffin-embedded block was used for histological analyses. Histologic slides were observed under a light microscope (BX51, Olympus, Tokyo, Japan) and digitally scanned. The scanned images were analyzed histomorphometrically using ImageJ software (Java, National Institutes of Health, Bethesda, MD, USA). The percentage of vital bone, residual graft, and nonhard tissue were identified and calculated in each sample core.

2.6 | Data calibration

The radiographic, clinical, and histomorphometric data measurements were performed twice within 1 h by one investigator (DHD, QY, and DHD, respectively) and mean values were calculated. Intraexaminer repeatability was assessed using intraclass correlation coefficients of 10 pairs of randomly selected recordings.[21] The coefficients of intraexaminer repeatability for socket bone plate thickness, MBL, PD, and vital bone (%) were at least 0.95.

2.7 | Statistical evaluation

Data were exported into SPSS (version 22.0, IBM, Armonk, NY) for statistical analysis. Results of the descriptive analyses were expressed as the mean ± standard deviation and range. Since our data met the criteria for normal distribution, parametric tests (paired *t*-test) were applied to test the equality of alveolar ridge dimension at T0, T1, and T2. For all tests, a p value <0.05 was considered significant.

3 | RESULTS

A total of 16 subjects with a mean age of 42.21 ± 9.94 years (range: 24–57 years) were recruited. Two subjects did not return for implant placement after three-in-one surgery. Data analysis was performed on the 14 patients (7 males, 7 females) who completed implant placement (13 first maxillary molar sites and 1 second maxillary molar site). During three-in-one surgery, membrane perforation occurred in 42.86% of sites (cases 2, 4, 5, 7, 8, and 11). All patients had no signs of bone graft infection or sinusitis except for one (Case 2, representing 7.14% of sites) who had nasal discharge up to 10 days post-extraction. A mean 11.6 ± 4.2 months after three-in-one surgery, ten 4.8 × 10 mm implants and four 4.8 × 8 mm implants were placed; additional bone augmentation was not needed. Detailed subject characteristics are presented in Table 1.

The dimensional ridge changes with respect to the virtual implant are summarized in Tables 1–3 and Figure 4. At baseline (T0), the mean SFH was 1.73 ± 0.86 mm; mean VIPH was 4.35 ± 1.99 mm; mean SBPT was 1.62 ± 1.15 mm buccally and 0.95 ± 1.23 mm palatally with mean CBH of 0.23 ± 2.02 mm; and mean SBPH was 0.90 ± 2.29 mm buccally and 1.62 ± 1.15 mm palatally. Nine patients (representing 64.3%) had buccal or palatal crests positioned apical to the virtual implant platform (negative SBPH values). Immediately after three-in-one surgery (T1), the mean SFH was 14.03 ± 1.97 mm, mean CBH was 3.21 ± 1.47 mm, and mean VIPH was −1.11 ± 2.35 mm. All these vertical parameters were significantly higher than those at T0. After 5–9 months, from T1 to T2, the mean SFH decreased significantly by 2.45 ± 1.73 mm ($p = 0.00$) and the mean CBH decreased by 1.71 ± 2.02 mm with significance ($p = 0.01$). The VIPH did not change significantly between T1 and T2 ($p = 0.06$). Immediately after three-in-one surgery, the ARW was 12.99 ± 1.88, 14.36 ± 1.29, 15.37 ± 1.71, and 6.99 ± 3.91 mm at 0, 2, 4, and 10 mm apical to the virtual implant platform, respectively. After 5–9 months, from T1 to T2, significant decreases in ARW occurred at 0 mm (by 3.88 ± 3.95 mm, $p = 0.006$), 2 mm (by 2.81 ± 3.86 mm, $p = 0.028$), and 4 mm (by 1.53 ± 2.05 mm, $p = 0.025$). No significant change in the ARW occurred at the implant apex, that is, the 10 mm mark ($p = 0.252$).

After 8–12 months (mean 10.38 ± 1.38 months) of functional loading, the peri-implant tissue health of nine patients was evaluated (Figure 2M–O and Table 4). Stable marginal bone levels were present, with a marginal bone loss of 0.12 ± 0.11 mm from T3 to T5. Mean PI was 0.71 ± 0.76, mean BOP was 30.95% ± 36.55%, mean PD was 2.48 ± 0.59 mm, mean CAL was 0.36 ± 0.44, and mean KT was 3.86 ± 2.12 mm.

Biopsies from eight patients were available for histological analyses. Newly formed bone was observed in close contact with residual DBBM particles. The mean values of vital bone, residual graft, and nonhard tissue were 18.74% ± 4.34% (range: 13.29%–29.18%),

TABLE 1 Demographic and radiographic characteristics of included cases

Case numbers	Gender/age (years)	Tooth number	SFH (mm)	VIPH (mm)	SBPT (mm)		SBPH (mm)[a]	
					Buccal	Palatal	Buccal	Palatal
1	M, 47	26	1.93	1.73	0.00	0.00	−1.54	−3.93
2	F, 57	16	3.14	5.13	3.01	0.00	1.54	−0.62
3	M, 30	26	2.54	6.41	2.23	2.53	3.01	2.60
4	M, 40	16	3.16	4.32	2.79	2.13	3.12	2.47
5	F, 52	16	1.84	6.46	2.19	0.97	1.49	0.67
6	F, 52	16	1.15	6.13	2.35	0.00	2.28	−3.00
7	M, 48	26	1.51	2.48	0.00	0.00	−5.41	−3.57
8	M, 38	16	1.45	6.97	2.47	1.99	1.56	2.13
9	F, 24	16	0.00	2.72	2.02	0.00	2.25	−0.59
10	M, 44	16	0.77	3.42	1.44	0.00	1.37	−3.32
11	F, 30	26	2.24	5.99	2.76	0.00	2.78	−1.60
12	F, 52	26	1.42	1.28	0.00	0.00	−0.67	−1.06
13	F, 43	26	1.44	5.63	1.43	2.28	1.20	1.91
14	M, 34	27	1.58	2.25	0.00	3.35	−0.36	1.65

Abbreviations: SBPH, socket bone plate height with respect to the virtual implant platform; SBPT, socket bone plate thickness at the level of the virtual implant platform; SFH, Sinus floor height at the level of the virtual implant platform; VIPH, virtual implant protrusion height.
[a]A negative value means that the height of the plate is apical to the level of the virtual implant platform, that is, a virtual dehiscence is present.

TABLE 2 Vertical changes in the reconstructed alveolar ridge contour analyzed by Paired *t*-test (mm)

Dimension	T0	T1	T2	P (T0–T1)	P (T1–T2)	P (T0–T2)
VIPH[a] (range)	4.35 ± 1.99 (1.28–6.97)	−1.11 ± 2.35 (−5.67–2.41)	−0.20 ± 2.89 (−5.19–3.36)	0.00	0.06	0.00
CBH[b] (range)	0.90 ± 2.29[c] (−5.41–3.12)[c]	3.21 ± 1.47 (0.93–5.7)	1.49 ± 1.85 (−2.00–4.23)	0.00	0.01	0.00
SFH (range)	1.73 ± 0.86 (0–3.16)	14.03 ± 1.97 (9.68–17.10)	11.70 ± 1.91 (8.61–15.01)	0.000	0.00	0.00

Abbreviations: CBH, crestal bone height at the level of the virtual implant platform; SFH, sinus floor height from the alveolar crest to the sinus floor; VIPH, Virtual implant protrusion height.
[a]A negative value means that the sinus floor is apical to the virtual implant apex.
[b]A negative value means that the bone height is apical to the level of the virtual implant platform, that is, a virtual dehiscence is present.
[c]The combined mean value of buccal and palatal socket bone plate height was used as CBH at T0.

TABLE 3 Horizontal changes in the reconstructed alveolar ridge contour analyzed by Paired *t*-test (mm)

Dimension	T1	T2	T1–T2 difference	*P*
Alveolar ridge thickness at:				
0 mm apical to the virtual implant platform (range)	12.99 ± 1.88 (9.11–17.01)	9.09 ± 4.99 (0.00–16.83)	3.88 ± 3.95 (0.18–12.89)	0.006
2 mm apical to the virtual implant platform (range)	14.36 ± 1.29 (12.21–17.09)	11.50 ± 4.22 (2.37–17.39)	2.81 ± 3.86 (−0.3–12.55)	0.028
4 mm apical to the virtual implant platform (range)	15.37 ± 1.71 (13.04–18.25)	13.93 ± 3.06 (7.25–18.29)	1.53 ± 2.05 (−0.04–7.51)	0.025
At the virtual implant apex (range)	6.99 ± 3.91 (0.00–15.08)	5.60 ± 5.30 (0.00–14.13)	1.29 ± 3.70 (−5.22–6.73)	0.252

19.08% ± 9.10% (range: 3.33%–32.35%), and 62.20% ± 9.48% (range: 49.27%–79.57%), respectively (Figure 5 and Table 4).

4 | DISCUSSION

Our report may be the first to document maxillary molar extraction with immediate sinus elevation through an intrasocket window and alveolar ridge preservation performed without primary coverage in cases with severe height deficiency (mean SFH of 1.73 ± 0.86 mm, 64.3% patients with buccal and/or palatal plate height defects). This three-in-one approach produced a posthealing mean sinus floor height of 11.70 ± 1.91 mm and generated 18.74% ± 4.34% of vital bone, allowing for prosthetically driven implant positioning and circumventing additional ridge augmentation. Hard tissue stability around implants was present in the short term (MBL of 0.12 ± 0.011 mm after loading).

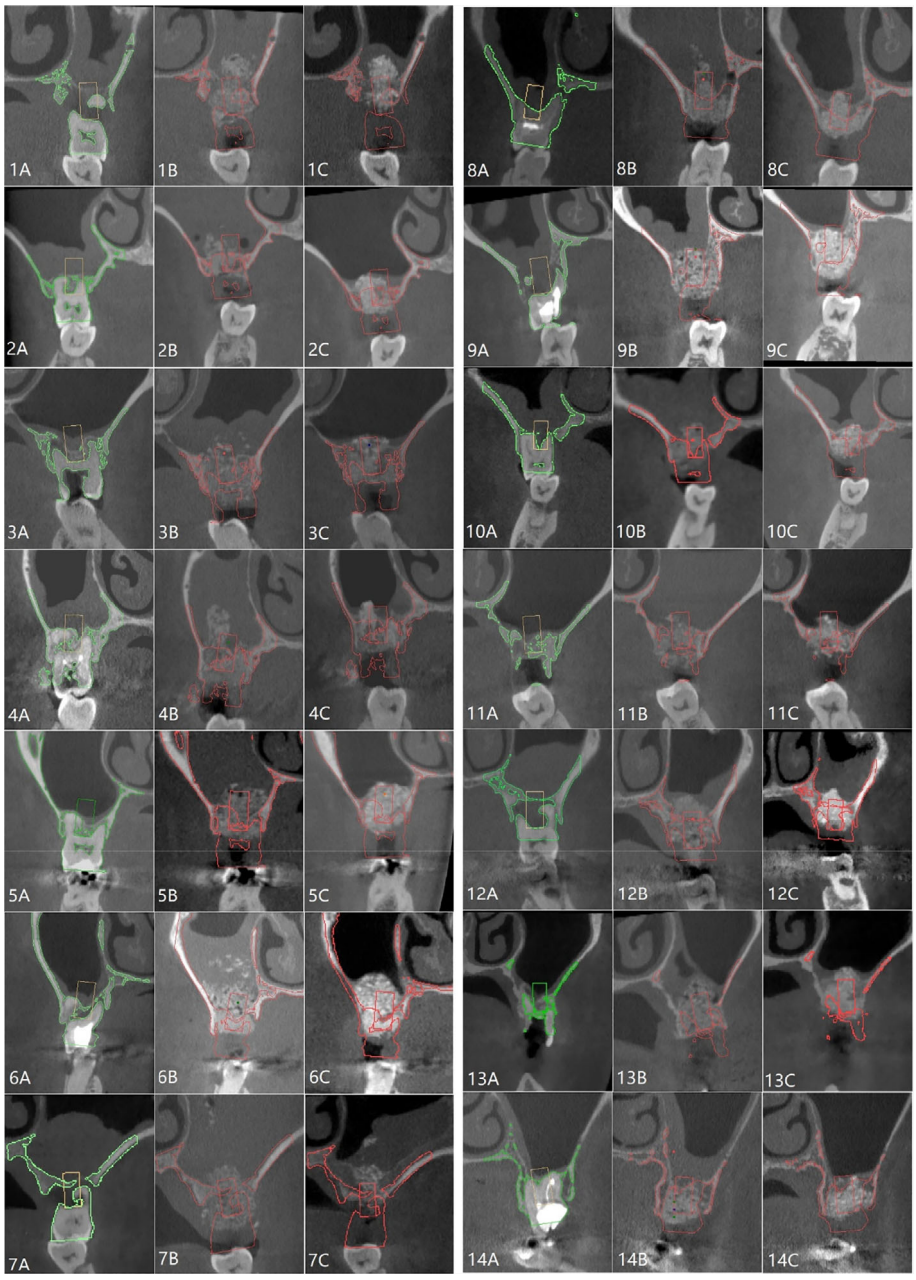

FIGURE 4 Alveolar ridge morphology at T0 (A), T1 (B), and T2 (C) in 14 cases

TABLE 4 Histomorphologic bone analysis measured at the time of implant placement and clinical parameters measured after 8–12 months of functional loading

	Vital bone (%)	Residual graft (%)	Nonhard tissue (%)	BOP (%)	PD (mm)	MR (mm)	CAL (mm)	KT (mm)	MBL[a](mm)
Mean	18.74	19.08	62.20	30.95	2.48	2.17	0.36	3.86	0.12
SD	4.34	9.10	9.48	36.55	0.59	0.75	0.44	2.12	0.11
Minimum	13.29	3.33	49.27	0.00	1.77	0.67	0.00	2.00	0.00
Maximum	29.18	32.35	79.57	100.00	3.33	3.17	1.17	7.00	0.30

[a]Marginal bone loss from implant placement to final follow-up.

The regimen proposed here may be a valid alternative to orthodox staged therapies for ridge development at severely compromised maxillary molar sites.

To increase bone height after maxillary molar extraction, several transcrestal sinus elevation modalities have been proposed, such as the crestal core technique in which osteotome-mobilized residual

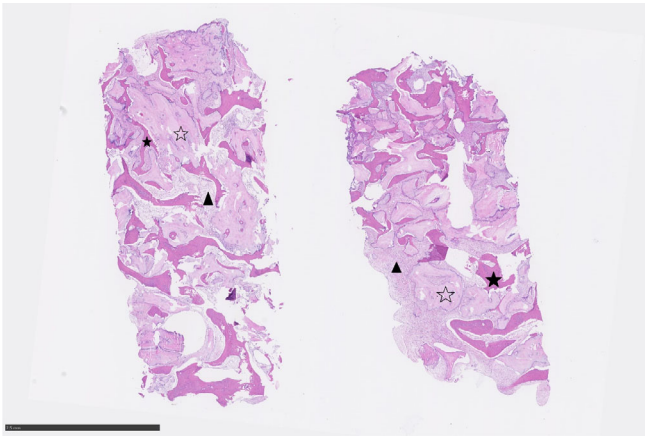

FIGURE 5 Representative histological image (hematoxylin and eosin stain) of a bone core biopsy (Case 5). Residual graft (hollow pentagram) was surrounded by newly formed bone (solid pentagram) and soft tissue (solid triangle). The bone core fractured when it was taken out of the trephine; the left image is the apical portion of the core, the right image is the coronal portion

ridge bone is positioned apically, tenting the sinus membrane up, and the created space is filled with bone substitute.[22–25] As the crestal core can potentially puncture the sinus membrane and be resorbed, a second sinus augmentation may be needed, so that technique is best suited for sites with moderate residual bone heights (4–5 mm).[22,23,25] The difference between the crestal core elevation technique proposed by Kolerman et al[25] and ours is that the crestal core elevation technique may potentially perforate the sinus membrane during the procedure and cause the placed grafts being resorbed. If this occurs, then a second sinus augmentation is often needed, therefore, the crestal core elevation technique may be best suited for sites with moderate residual bone heights (4–5 mm) to avoid any potential membrane perforation. However, our proposed "Three-in-One Alveolar Process Reconstruction" can be applied in cases with minimal residual bone heights (around 2 mm) with minimal chance of causing membrane perforation. By using intrasocket approach with a piezotome instrument that operated in a controlled manner to avoid membrane perforation while achieving an adequate amount of elevation (5.46 mm), that is, the difference in VIPH between T0 and T1.

Sinus membrane perforation is the most frequent intraoperative complication of maxillary lateral sinus augmentation, occurring in 7%–44% of cases.[26,27] It is strongly linked to postoperative complications, such as sinusitis, edema, bleeding, loss of bone graft material, and implant failure.[28,29] In this study, perforated membranes occurred in 42.86% that was higher than the average rate of 19.5% in lateral approach[30] or 3.8% in transcrestal approach.[31] The reason for this high percentage of membrane perforation is probably due to the learning curve. However, no signs of sinusitis or bone graft infection were observed during healing except in one case (representing 7.14%) of nasal discharge persisting for 10 days. This low postperforation complication rate may be attributed to three factors. First, we repaired any perforation with collagen membrane, a predictable sinus membrane perforation treatment.[32,33] Second, sockets were treated with PRF, which slowly releases growth factors—for example, bone morphogenetic protein, platelet-derived growth factor, insulin-like growth factor, and vascular endothelial growth factor—that promote soft tissue healing, encourage angiogenesis, modulate inflammation, stimulate differentiation and proliferation of surrounding cells, and control infection.[14,15,34–36] PRF may accelerate the transformation of the blood clot overlying the bone graft into provisional connective tissue, better securing the graft in the socket and impeding early exfoliation. Third, using an intrasocket rather than lateral window limited the area of sinus manipulation and preserved membrane elasticity, which restricts graft scattering and provides a more stable environment for healing.

Leaving a membrane covered after ARP may prevent premature loss of the barrier and graft exfoliation.[19] Approximately 1.53 mm of vertical and 2.87 mm of horizontal ridge resorption were observed after ARP in damaged molar sockets where primary wound closure was obtained by coronally advanced flap.[37] However, obtaining primary closure involves extensive flap elevation and/or releasing incisions, which increases intra- and postoperative complications.[38] To reduce surgical trauma, we opted for an open healing approach and chose ADM matrix with relatively long degradation time to delay the exposure of bone graft.[39] Reductions in vertical (mean CBH decreased by 1.71 ± 2.02 mm) and horizontal (mean ARW decreased by 2.81 ± 3.86 mm) dimensions occurred in this study. These-dimensional changes were in line with those in molar ARP sites with primary healing approach,[37] but more than the approximately 1–1.2 mm of vertical and 2–2.5 mm of horizontal ridge resorption was observed by two studies performing molar ARP with exposed dense polytetrafluoroethylene (d-PTFE) membrane.[40,41] D-PTFE membrane maintains barrier function longer than ADM does, however, by adding platelet-rich fibrin as we did may enhance graft handling capacity, enhance angiogenesis,[14,15] and promote soft tissue healing and socket healing,[16] therefore, protecting graft integrity. Nonetheless, study has shown there was no difference between d-PTFE and ADM when it was used for ARP.[42]

Although vital bone is considered a key factor for bone-to-implant contact, there is no consensus regarding the threshold value of vital bone needed for integration or long-term success. Tissue regeneration in ARP depends on preexisting socket bone; the defect morphology greatly affects healing.[43–45] A healed intact molar socket grafted without primary wound closure may be composed of 26.1% new bone,[46] whereas a healed damaged molar socket grafted similarly may be composed of only 11.3%–18.5% new bone, which aligns with our observation (18.74% mean vital bone).[44,47] However, implants placed in sites with less new bone (11.3% ± 7.4%) can demonstrate stable implant bone levels after 1 year.[47] In this study, all implants survived and functioned well with stable marginal bone levels after at least 6 months of loading.

Although the proposed "Three-in-One Alveolar Process Reconstruction" can achieve favorable clinical outcomes while saving time, but the major limitation of this approach is "technique-sensitive," hence clinicians with minimal experience should not attempt this

approach until they have gained more experience. Secondly, the following clinical conditions: presence of sinus membrane peroration (either previous or during the procedure), and residual infection cannot be completely eradicated are the potential contraindications for this proposed technique.

Other than its proof-of-concept nature, this study has some major limitations. First, the three-in-one protocol introduced here is technique sensitive. Sinus elevation through an intrasocket window is a delicate operation, as limited visualization and irregular sinus floor morphology can complicate matters. Second, the sample size is limited. Third, extensive time difference in periods T1 (1–14 days) and T2 (5–9 months), short time of evaluation after implant placement, and the difference in time between the biopsy samples in histomorphometric evaluation (7–21 months), due to the COVID-19 pandemic, make it difficult to determine the optimal timing for implantation and to document this protocol's treatment course shortening advantage.

5 | CONCLUSIONS

For maxillary first molar sites with severe height deficiency, a minimally invasive three-in-one treatment regimen may achieve sufficient hard tissue to preclude further grafting and permit stable implant bone and function in the short term. Long-term randomized controlled clinical trials with large samples are required to confirm its safety and efficacy.

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CONFLICT OF INTEREST

All authors do not have any financial interests, either directly or indirectly, in the products or information listed in the article.

AUTHOR CONTRIBUTIONS

Deng-Hui Duan contributed to the surgical conception and design; data acquisition, analysis, and interpretation; and drafting of the manuscript. En-Bo Wang contributed to the surgical conception and design, interpretation of important intellectual content, and final approval. Jian-Yun Zhang contributed to biopsy treatment and analysis. Qiao Yuan contributed to the periodontal evaluation. Hom-Lay Wang contributed to the critical revision of the manuscript and final approval.

DATA AVAILABILITY STATEMENT

The data sets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

ETHICS STATEMENT

Ethical approval was obtained from the ethics committee of Peking University School and Hospital of Stomatology.

CLINICAL TRIAL REGISTRATION

Minimally invasive reconstruction of alveolar ridge with severe defect of extraction socket in maxillary molar area. http://www.chictr.org.cn/edit.aspx?pid=136686&htm=4. Clinical trial registration number: ChiCTR2100053254.

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