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Changes in alveolar process dimensions following extraction of molars with advanced periodontal disease: A clinical pilot study

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Abstract

Objective: To use cone beam computed tomography (CBCT) to assess the alterations of socket dimensions after a 6-month healing period following molar extraction.

Materials and methods: Seventeen molars were extracted due to advanced periodontitis. CBCT scans were taken immediately after extraction and once more 6 months later. Superimposition of CBCT images was used to measure the following: horizontal changes at extraction sites at three corono-apical levels (−1, −3, and −5 mm) below the bone crest, three mesio-distal levels (mesial, central, and distal), vertical changes at nine regions of the alveolar crest, and alveolar bone volume.

Results: The width of the central crests at −1 mm decreased by 0.59 and 0.72 mm in the buccal and 0.27 and 0.02 mm in the lingual, in the maxilla and mandible, respectively. No statistically significant decreases in the ridge height were observed except in the disto-palatal region with a 1.11 mm decrease in the maxilla ($p < 0.05$). Heights of the buccal and lingual bone plates decreased significantly and ranged from 0.56 to 1.38 mm in the mandible after 6 months of healing ($p < 0.05$). Overall, ridge height changes were not significantly different between the maxilla and mandible ($p > 0.05$) and no significant volumetric bone loss occurred in either maxillary or mandibular sockets after 6 months of healing.

Conclusions: Socket dimensions of molars with advanced periodontal disease showed a significant increase at the middle-central portion, although there were no significant changes of horizontal width 6 months following the procedures.

KEYWORDS
bone, cone beam computed tomography, flapless, resorption, socket healing

1 | INTRODUCTION

The alveolar process is a tooth-dependent bone tissue that develops in conjunction with the eruption of a tooth (Marks & Schroeder, 1996). After tooth extraction, alveolar processes exhibit atrophic changes along with a reduction in vertical height and a decrease in width of the residual ridge (Araujo & Lindhe, 2005; Cardaropoli, Araujo, & Lindhe, 2003; Pietrokovski & Massler, 1967; Pietrokovski, Starinsky, Arensburg, & Kaffe, 2007). Lekovic et al. (1998, 1997) studied alveolar process changes at anterior extraction sites after a 6-month healing period, using both clinical and model measurements. Their results indicated that the width of the alveolar process decreased by 60% (mean value = 4.4 mm) and the height decreased by 40% (mean value = 1.2 mm). Results of previous studies have demonstrated that bone loss in the single anterior tooth extraction site is more prominent in the buccal rather than the lingual/palatal bone plates and that ridge width changes are generally greater than loss in height (Botticelli, Berglundh, & Lindhe, 2004; Iasella et al., 2003; Sanz et al., 2010; Tomasi et al., 2010). Schropp, Wenzel, Kostopoulos, and Karring (2003) investigated contour changes of the alveolar processes of posterior extraction sites by measuring stone casts and discovered a reduction in width of the residual alveolar ridge of up to 50% (5.0–7.0 mm) during a 12-month healing period, of which two-thirds of the reduction occurred within the first 3 months of healing. Systematic reviews of mixed anterior and posterior extraction socket changes indicated an approximate 3.8 mm horizontal reduction, more than the observed vertical reduction which ranged from 1.24 to 1.67 mm (Tan, Wong, Wong, & Lang, 2012; Van der Weijden, Dell'Acqua, & Slot, 2009). The aforementioned studies reported measuring and analyzing anterior teeth only or mixed extraction sockets; however, the morphological characteristics of alveolar processes of anterior and posterior teeth are different. In fact, the dimension of the extraction socket and the thickness of the alveolar bone plate may influence changes of the alveolar process during healing. Consensus exists that the thickness of the buccal bone plate at the time of extraction is an important predictor for the resorption of the alveolar process; thin bone resorbs more severely than thick bone (Chappuis et al., 2013; Chen, Darby, & Reynolds, 2007; Ferrus et al., 2010).

Numerous studies have investigated alterations in alveolar process dimensions after tooth extraction, often with results presented as qualitative and quantitative changes at extraction sites free of infection (non-inflammatory sockets), where teeth were removed due to root fracture or caries (Araujo, Silva, Mendonca, & Lindhe, 2015; Walker et al., 2017). The healing process for infected sockets, however, is likely delayed compared with that of non-inflammatory sockets (Ahn & Shin, 2008; Kim, Song, Ben Amara, Kyung-Rim, & Koo, 2016; Marcaccini, Novaes, Souza, Taba, & Grisi, 2003; Marcaccini, Miguel, Torroba, & Garcia-Valverde, 2003). By contrast, when Lindhe et al. (2012) evaluated the tissues of fully healed extraction sites in subjects with missing teeth 5 months to several years post-extraction, no significant differences were observed in the tissue composition of post-extraction sites when comparing periodontitis-susceptible subjects and non-periodontitis subjects. In general, tooth extraction has been linked to periodontal disease reported at a rate of approximately 70%, both in teaching institutes and in private clinics (Lopez-Martinez et al., 2015). Further understanding of the healing pattern of extraction sockets for molars exhibiting advanced periodontal disease will be crucial for informed decision-making and comprehensive treatment planning, especially for future implant-supported restoration cases (Tan et al., 2012).

Regarding instrumentation, cone beam computed tomography (CBCT) have proved adequate for the evaluation of post-extraction wound changes (Agbaje, Jacobs, Michiels, AbuTaa, & Steenberghe, 2009; Pinsky, Dyda, Pinsky, Misch, & Sarment, 2006; Vandenberghe, Jacobs, & Bosmans, 2010). Araujo, Silva, Mendonca, and Lindhe (2015) investigated dimensional alterations of the alveolar ridge of caries-caused or fractured single root-caused extraction sites using CBCT and revealed that, after 4 months of healing, the height of the buccal bone plate was more reduced than that of the palatal plate. To our knowledge, no studies measuring the dimensional changes of alveolar processes of diseased molar extraction sites using CBCT have been published, and currently, little is known about ridge changes of sockets following periodontally diseased molar extraction.

The purpose of this prospective study was to use CBCT imaging to evaluate the potential linear and three-dimensional volumetric alterations of alveolar processes of advanced periodontal disease molar extraction sites. Measurements were taken both at baseline (immediately after tooth extraction) and at 6 months after tooth extraction. The null hypothesis was that no significant changes were expected in socket dimensions immediately following extraction vs. socket dimensions after a 6-month healing period.

2 | MATERIAL AND METHODS

This study was conducted in accordance with the World Medical Association Declaration of Helsinki (revised in 2013), registered at Chinese Clinical Trial Registry (ChiCTR-ONN-16009433), and approved by the local ethical committee (Institutional Review Board of Peking University School and Hospital of Stomatology, Approval Number: PKUSSIRB-201310068). Written informed consents were obtained from all participants following the guidelines of the committee for the research process. CONSORT guidelines were observed for this manuscript.

Patients who were scheduled for a molar extraction due to severe periodontal disease and who planned to have the extracted tooth replaced with an implant-retained prosthesis were included in the study.

Inclusion criteria:

1. Age 25 years or older, motivated to have periodontal disease controlled within 6 months, and compliant with study procedures and recall visits;
2. Good general health according to the American Society of Anesthesiologists, either ASA I or ASA II; and
3. The ailing tooth had at least two socket walls with 3 mm of alveolar bone height and one adjacent proximal tooth.

Exclusion criteria:

1. Any form of tobacco use;
2. Missing both adjacent teeth;
3. Suffering from bone disease or using medication that interferes with bone healing or metabolism;
4. History of head and neck radiotherapy; and
5. The ailing tooth at acute inflammatory stage.

All patients received both a radiographic and a periodontal examination to confirm diagnosis of the ailing tooth, in addition to scaling, root planning, oral hygiene instruction, and any periodontal treatment necessary to assure an oral environment favorable to wound healing at least 1 week before tooth extraction. Extraction was performed by the same experienced periodontist (WH) for all samples and used a minimum invasive and flapless tooth extraction procedure. All patients received prophylactic antibiotic therapy (amoxicillin, 1.0 g, or erythromycin 0.3 g for patients with penicillin allergies) 1 hr before tooth extraction and rinsed with a 0.2% chlorhexidine solution for 1 min prior to the procedure. Under local anesthesia using the flapless procedure, an internal bevel incision was situated 0.5–1 mm below the buccal and the lingual free gingival margins of the tooth in order to remove the inner lining of periodontal pockets Teeth were extracted atraumatically with periotomes and extraction forceps, separating the roots with diamond fissure burs and allowing root separation within the socket, if necessary to avoid unwarranted trauma to the surrounding alveolar bone walls. Sockets were carefully inspected, and meticulous bone curettage was performed using surgical curettes to remove residual granulation tissue inside the socket. Silk sutures were used on extraction with no attempt at primary closure, allowing for natural healing; sutures were removed after 1 week.

A comprehensive periodontal examination was performed before the extraction procedure, and a 6-month healing period was allowed. The following data were recorded to the nearest 0.5 mm and collected by the same periodontist (WH) using a UNC-15 probe (Hu Friedy®, Chicago, IL, USA): Probing depth (PD) and gingival recession (GR) were measured, and clinical attachment loss (CAL) was calculated. The PD, GR, and CAL were obtained from six sites/tooth, and the width of keratinized tissue (WKT) from mucogingival junction to gingival margin was determined on the mid-buccal aspect of the tooth assigned for extraction. The examiner reliability was confirmed in a previous pilot study showing intra-examiner differences for PD, GR, and WKT were within 1 mm.

To assess changes in dimensions of alveolar processes, CBCT scans were taken immediately after the tooth extraction and repeated after 6 months of healing time. All scans were taken with 0.125 mm slice thickness, 8 × 8 cm field of view, 360 degrees, and pixel size of 0.125 mm with the same imaging unit (NewTom VG, Aperio Services, Italy); exposure parameters were as follows: 15 s, 110 KVP, and 12–17 mAs. 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 (3-D) reconstruction was conducted. On an axial image, the threshold level was determined individually for each CBCT dataset on the basis of a profile line made crossing from the adjacent alveolar bone through the alveolar socket as described by Linderup, Küseler, Jensen, and Cattaneo (2015). Using the profile line, the profile of the gray values was visualized to find an optimal threshold for segmentation. Based on the minimal and maximal threshold values, a layer of the hard tissue (bone tissue and teeth) was semi-automatically defined and color-coded to create a mask; the threshold value for hard tissue ranged between 300 and 4,200. Noise reduction was accomplished by removing the floating pixels near the region-growing algorithm to recreate a new mask.

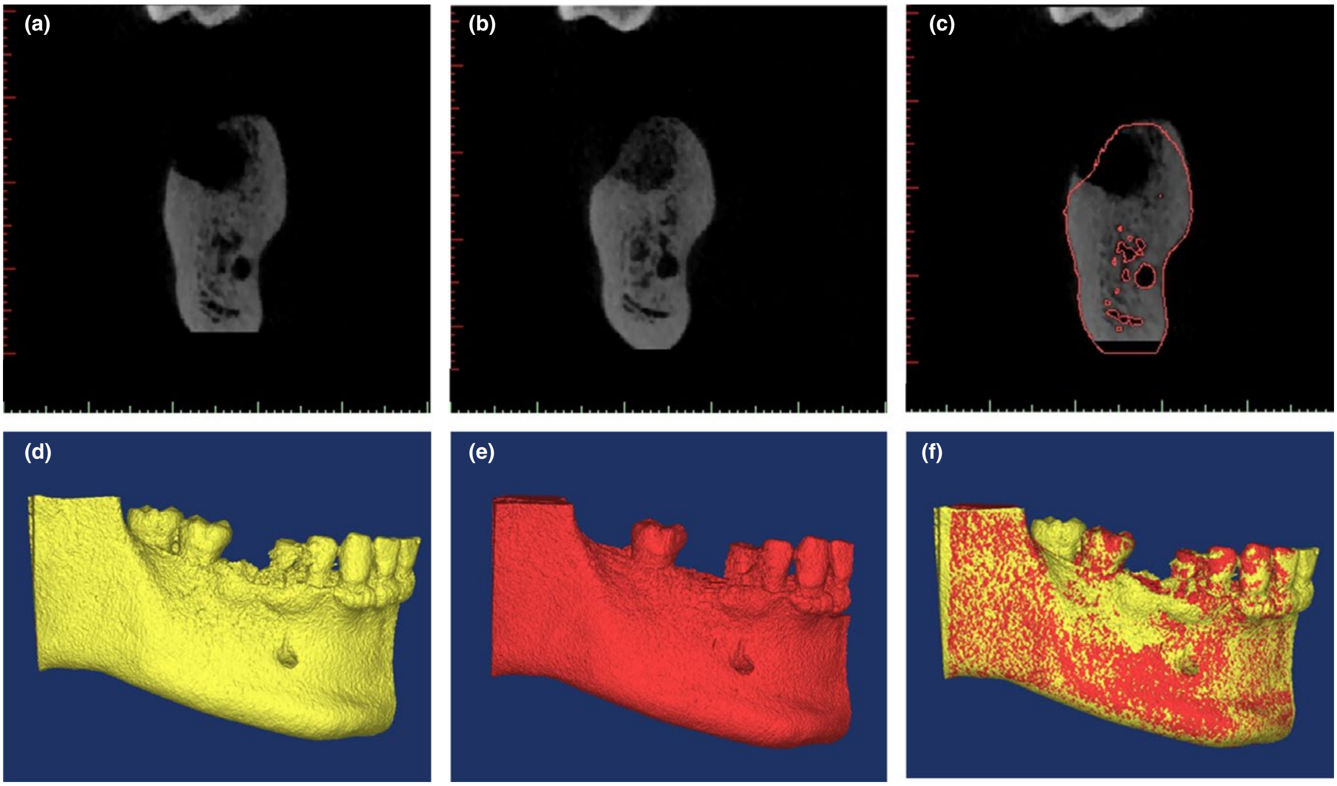

FIGURE 1 Coronal slices in the middle of the extraction site (a, b, c) and corresponding three-dimensional virtual mandible (d, e, f). (a) and (d) are images of the socket immediately after tooth extraction; (b) and (e) are images of the socket after a 6-month healing period; (c) and (f) are images derived from superimposing the socket images of both immediate and 6-month recall time frames [Colour figure can be viewed at wileyonlinelibrary.com]

The new mask was interpolated using the "multiple slice edit" and "edit mask in 3D" functions in three planes. When the segmentation was completed, a 3-D model of the mandible/maxilla was generated from the series of 2D masks by using the "Calculate 3D" function of the volumetric imaging software (Mimics 17.0; Materialise). Three-dimensional rendered images were then analyzed by superimposing virtual models with selected areas of the dataset using identified landmarks at which no changes had taken place during the 6-month healing period, such as the inferior border of the mandible and the palatal vault of the maxilla (Figure 1). If necessary, manual adjustment was applied to assure a perfect match. To establish a reproducible and precise measurement, and to determine the 3-D changes of the horizontal and vertical bone loss immediately after extraction and the 6-month healing period, locations at different levels and sites on the alveolar process were assigned and drawn; measurements were made using the same reference points and lines as described by Jung et al. (2013) (Figure 2). CBCT measurements of ridge width changes were conducted at the following three coronal sections: (a) in the center, (b) in the mesial at one-sixth of the mesio-distal socket distance, and (c) in the distal at one-sixth of the mesio-distal socket distance.

2.1 | Baseline thickness and height of alveolar wall measurements

The thicknesses of the residual buccal and lingual (or palatal) bone plate in the center of the socket at three levels below the bone crest (−1, −3, and −5 mm) were located and measured in the coronal section of the CBCT images taken immediately after extraction (Figure 2a). Using the baseline CBCT images, the heights of the residual bone walls were measured from the crest to the horizontal reference line in the mesial, central (Figure 2b), and distal coronal sections. At the central sagittal plane of the socket, the height of the alveolar process in the center of the mesial and distal margin of the socket was measured (Figure 2a).

2.2 | Ridge width changes measurement

Horizontal socket width changes were determined by comparing the three levels below the initial bone crest (−1, −3 and −5 mm) on the CBCT images taken immediately after extraction and after a 6-month healing period. Keeping the baseline CBCT images on the computer screen, the software switched to the 6-month images in the same plane so the measurements could be obtained at exactly the same locations for two points in time. In the center of the sockets, the horizontal ridge width was measured relative to the initial crest of the buccal and lingual bone plates (Figure 2b). Ridge widths at the mesial and distal one-sixths of the socket were measured relative to the initial buccal bone crest only. If the buccal or lingual/palatal plate was missing at peak level, the ridge width at this level corresponded to the thickness of the residual lingual/palatal or buccal alveolar wall. Width changes were calculated 1, 3, and 5 mm below the most coronal aspect of the initial bone crest at the mesial, central, and distal regions.

2.3 | Ridge height change measurements

Using the method described above, vertical ridge height was determined by measuring the CBCT images taken immediately after extraction. Vertical ridge changes were assessed at 9 points on both the baseline and 6-month CBCT scan images: mesial, central, and distal over the buccal and lingual/palatal crests as well as the center of the socket in the coronal plane, and the center of the mesial and distal margin of the socket in a sagittal plane.

(a) (b)

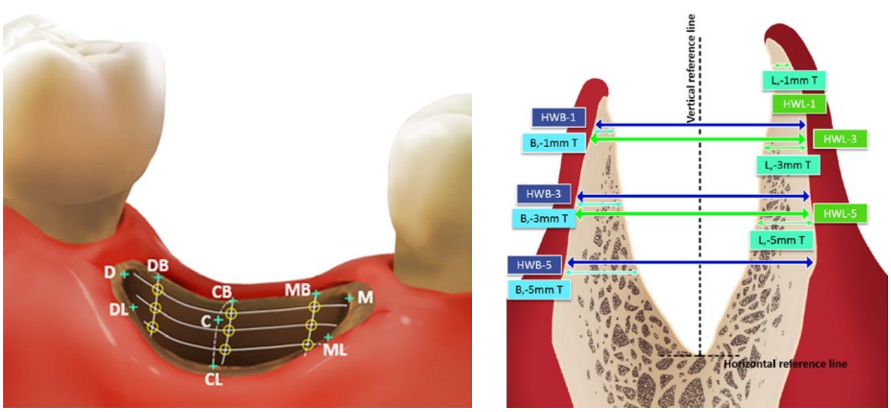

FIGURE 2 Illustration of a representative lower first molar extraction socket at baseline (immediately after tooth extraction). (a) Lingual view, three-dimensional representation of 9 ridge height measurement points (+) on the crest and nine horizontal measurement points (O) 1, 3, and 5 mm below buccal crest. (b) Coronal section view at the center of the socket: HWB/L-1, HWB/L-3, and HWB/L-5 represent horizontal ridge width measured at three levels (−1, −3, −5 mm) below the buccal and lingual bone crest, respectively. B/L −1 mm T, B/L −3 mm T, and B/L −5 mm T represent the thickness of the buccal and lingual plate measured at three levels (1, 3, and 5 mm below the buccal and lingual crest). The HWL-1 corresponds to the L, 1 mm T since the buccal plate is missing 1 mm apical to the lingual bone crest. B: buccal; C: central; D: distal; H: horizontal; L: lingual; M: mesial; T: bone plate thickness; W: width [Colour figure can be viewed at wileyonlinelibrary.com]

2.4 | Ridge volume change measurements

Standard tessellation language (STL) files of the 3-D-rendered volumes of the alveolar bone at baseline and at 6 months, generated in Mimics 17.0 software, were imported into the reverse engineering software, Geomagic Studio 2013 (Raindrop, Rock Hill, SC, USA). They were then superimposed using semi-automatic registration wizard, which allowed for volumetric evaluation. Volumetric differences were assessed for a defined region of interest (ROI), starting at the mesial and distal interproximal bone and extending from the alveolar crest to the root tip. The volumes of the sectioned sockets were calculated individually in cubic millimeters using a volumetric analysis tool. The vertical reference plane was identified through the center of the socket at the baseline (mesial–distal direction), thus dividing the socket into one buccal and one lingual/palatal aspect. Volumetric changes were also assessed from the buccal and lingual/palatal aspects. Relative alveolar volume changes were evaluated by subtracting the baseline value from the 6 months of healing period; those results were divided to calculate the baseline volume.

A research investigator (LZ) made all the radiographic measurements to the nearest 0.01 mm. Intra-examiner calibration was conducted by measuring the variables twice with an interval of 7 days on CBCT images of 5 randomly selected samples prior to the final data measurement, and the intra-examiner reliability was analyzed by paired t test at $\alpha = 0.05$.

All measurement data from CBCT images of baseline and 6-month recall were entered into an Excel 2007 (Microsoft Corporation, Redmond, WA, USA) spreadsheet and transferred to SPSS 22.0 (IBM Corporation, Armonk, NY, USA) for statistical analysis. Descriptive statistical analysis of all data was performed, and the normality of the data was tested using the Shapiro–Wilk test. Within group differences between baseline and 6 months, data that were not normally distributed were analyzed by paired Student's t test or using a Wilcoxon signed-rank test. If data were not normally distributed between group maxilla and mandible differences at baseline and after 6 months of healing, it was analyzed using Student's t test or Mann–Whitney U test. For all tests, $\alpha = 0.05$.

3 | RESULTS

Sixteen subjects participated in this study. Each patient contributed a single molar extraction site, with the exception of one patient who contributed two sites (one maxillary first molar and one mandibular second molar). The extracted teeth included the following: seven maxillary first molars, one maxillary second molar, five mandibular first molars, and four mandibular second molars; no post-operative complications were recorded. All patients completed the study, complied with a 6-month follow-up visit, and kept periodontal disease under control. With respect to intra-examiner error, no statistically significant differences were observed between the first and second sets of measurement data ($p > 0.05$).

Demographic and clinical measurements at baseline in the maxilla and mandible are presented in Table 1. At baseline, WKT

TABLE 1 Demographics of maxilla and mandible subject groups

	Maxilla	Mandible	*p* value
Age (years)			
Median (range)	50 (34–65)	51 (35–60)	
Mean ± *SD*	51 ± 10 (n = 8)	50 ± 8 (n = 9)	$p > 0.05^{a}$
Gender (M:F)	5:3	6:3	$p > 0.05^{b}$
Clinical attachment loss (mm)(			
Median (range)	6.4 (5.8–8.0)	7.1 (4.0–11.1)	
Mean ± *SD*	6.7 ± 0.8	7.2 ± 1.9	$p > 0.05^{a}$
Probing depth (mm)			
Median (range)	5.3 (4.7–7.5)	6.0 (4.0–7.3)	
Mean ± *SD*	5.7 ± 1.1	6.0 ± 1.2	$p > 0.05^{a}$
Gingival recession (mm)			
Median (range)	0.5 (0.0–2.3)	0.5 (0.0–4.1)	
Mean ± *SD*	0.9 ± 0.8	1.2 ± 1.6	$p > 0.05^{a}$
Width of keratinized tissue (mm)			
Median (range)	6.0 (4.5–7.0)	3.5 (0.0–5.0)	
Mean ± *SD*	5.7 ± 1.1	3.0 ± 2.4	$p = 0.02^{a,*}$
Healing time (months)			
Median (range)	6.0 (5.0–12.0)	6.0 (5.0–9.0)	
Mean ± *SD*	6.8 ± 2.2	6.3 ± 1.1	$p > 0.05^{a}$

[a]Student t test. [b]Chi-square test. *Indicates a statistically significant ($p < 0.05$) difference in width of keratinized tissue between maxilla and mandible.

data in the maxilla and mandible were 5.7 ± 1.1 and 3.0 ± 2.4 mm, respectively, $p = 0.02$. Initial thickness and height of alveolar bone plate after tooth extraction at the maxillary and mandibular alveolar processes are listed in Table 2. Regarding the maxillary and mandibular alveolar processes, the thickness of the buccal bone plate in the center of the socket at 3 mm apically to the crest produced a mean of 1.88 ± 1.37 and 3.96 ± 1.77 mm, respectively, $p = 0.017$. Tables 3 and 4 present the changes in the width of extraction sites at baseline and after 6 months, located at 1, 3, and 5 mm apically from the alveolar crest of the maxillary and mandibular sockets. A statistically significant decrease in alveolar crest width (approximately 0.6 mm) was located 1 mm apically at the mesial side of maxillary socket, and at both 1 and 3 mm apically at the mesial side of mandibular sockets (means of 1.2 mm at 1 mm and 0.7 mm at 3 mm apically), $p < 0.05$.

Table 5 gives values for ridge height changes in maxillary sockets over the 6-month healing period. No statistically significant differences were observed except in the palatal side at the distal region of the socket with a 1.11 ± 1.26 mm decrease. A significant increase in ridge height was observed (6.06 ± 2.64 mm) at the middle-central portion of maxillary sockets, $p < 0.05$. In general, bone loss at the palatal side of the crest was greater than that at the buccal side in the mesial, middle, and distal regions. Table 6 presents ridge height changes measured in the mesial, middle, and distal regions of the mandibular molar sockets. The decreases in buccal and lingual vertical bone height ranged from 0.69 to 1.38 and 0.56 to 1.18 mm, respectively. Increases in ridge height were observed at all central regions, especially at the middle-central portion of mandibular sockets which increased by 7.84 ± 3.52 mm, $p < 0.05$. Changes in ridge height over the 6-month healing period were not significantly different between the maxilla and the mandible ($p > 0.05$); however, ridge height decrease was generally greater at the buccal plate in mandibular sockets than in maxillary sockets (Table 7). Volumetric analysis showed no statistically significant changes in the total volume either in the maxilla or mandible, with a decrease of 66.56 ± 164.87 mm^3 and 9.61 ± 102.31 mm^3, respectively (Table 8). Volume at the buccal aspect increased by 25.59 ± 90.82 mm^3 (8.66%) and 12.14 ± 69.79 mm^3 (2.42%), and volumetric diminutions at the lingual/palatal aspect were 92.14 ± 150.65 mm^3 (2.98%) and 17.76 ± 84.35 mm^3 (0.76%) in maxilla and mandible, respectively.

TABLE 2 Baseline measurements of hard tissues (mean ± standard deviation) in the maxillary and mandibular sockets (mm)

	Maxillae (*n* = 8)	Mandible	
Parameters#	*n* = 8	*n* = 9	*p* value
Thickness of buccal bone, −1 mm	1.62 ± 1.37	2.06 ± 0.97	0.457
Thickness of buccal bone, −3 mm	1.88 ± 1.37	3.96 ± 1.77	0.017*
Thickness of buccal bone, −5 mm	2.19 ± 2.94	3.22 ± 3.42	0.516
Thickness of palatal/lingual bone, −1 mm	1.95 ± 1.38	1.89 ± 1.93	0.936
Thickness of palatal/lingual bone, −3 mm	1.91 ± 1.49	2.63 ± 1.80	0.386
Thickness of palatal/lingual bone, −5 mm	1.56 ± 1.50	2.31 ± 2.56	0.477
Height of buccal bone in the center	5.79 ± 3.00	7.19 ± 3.19	0.368
Height of palatal/lingual bone in the center	5.86 ± 2.43	7.73 ± 3.43	0.220
Height of buccal bone in the mesial	3.79 ± 3.61	5.77 ± 2.63	0.211
Height of bone in the center of the mesial side	7.18 ± 2.72	9.27 ± 3.42	0.188
Height of palatal/lingual bone in the mesial	5.32 ± 3.71	6.44 ± 3.60	0.536
Height of buccal bone in the distal	4.74 ± 2.97	7.26 ± 3.90	0.094
Height of bone in the center of the distal side	4.64 ± 2.67	6.79 ± 3.96	0.216
Height of palatal/lingual bone in the distal	6.06 ± 2.61	7.27 ± 3.90	0.472

Notes. n: sample size;
−1 mm: 1 mm apical from the crest; −3 mm: 3 mm apical from the crest; −5 mm: 5 mm apical from the crest.
*Indicates a statistically significant difference in thickness of the buccal bone plate at 3 mm apical from the crest between maxilla and mandible ($p < 0.05$) using Student *t* test.

TABLE 3 Ridge width changes of maxillary sockets from baseline to 6 months of recall obtained at 1, 3, and 5 mm apical from the crestal bone

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
Sample size	*N* = 7	*N* = 6	*N* = 6	*N* = 8	*N* = 8	*N* = 7	*N* = 8	*N* = 7	*N* = 5	*N* = 8	*N* = 8	*N* = 5
Baseline	7.89 ± 5.23	10.11 ± 5.67	11.44 ± 6.09	8.15 ± 6.02	11.18 ± 6.46	10.62 ± 5.98	9.74 ± 5.75	10.43 ± 6.38	10.07 ± 6.30	9.47 ± 7.35	11.00 ± 6.94	8.74 ± 6.56
6-month	7.31 ± 5.26	9.60 ± 5.08	10.75 ± 5.57	7.55 ± 5.45	10.71 ± 5.55	10.65 ± 5.54	9.47 ± 4.79	11.24 ± 3.62	11.91 ± 3.77	9.32 ± 5.49	10.96 ± 5.43	9.45 ± 5.99
Difference	−0.58 ± 0.52	−0.52 ± 0.93	−0.70 ± 0.74	−0.59 ± 2.07	−0.47 ± 2.02	+0.03 ± 1.53	−0.27 ± 3.24	+0.80 ± 3.15	+1.85 ± 5.25	−0.5 ± 2.61	−0.04 ± 2.61	+0.71 ± 2.42
p value	0.026*	0.232	0.070	0.446	0.530	0.964	0.823	0.525	0.476	0.873	0.968	0.551

*Statistically significant difference ($p < 0.05$) using paired t test.

TABLE 4 Ridge width changes of mandibular sockets from baseline to 6 months of recall obtained at 1, 3, and 5 mm apical from the crestal bone

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
Sample size	*N* = 9	*N* = 8	*N* = 8	*N* = 9	*N* = 9	*N* = 8	*N* = 9	*N* = 7	*N* = 6	*N* = 9	*N* = 9	*N* = 8
Baseline	10.30 ± 5.18	13.84 ± 1.32	14.77 ± 1.09	10.06 ± 6.10	15.17 ± 1.67	15.94 ± 1.43	9.97 ± 5.85	13.57 ± 4.50	15.83 ± 1.87	11.25 ± 4.78	15.67 ± 1.19	16.75 ± 1.01
6-month	9.09 ± 5.06	13.16 ± 1.42	14.72 ± 1.17	9.35 ± 5.17	14.56 ± 1.92	15.73 ± 1.55	9.96 ± 4.84	13.49 ± 3.01	15.04 ± 2.53	11.17 ± 4.19	15.63 ± 1.10	16.70 ± 1.00
Difference	−1.21 ± 0.62	−0.68 ± 0.52	−0.05 ± 0.15	−0.72 ± 2.45	−0.61 ± 0.99	−0.22 ± 0.31	−0.02 ± 3.84	−0.07 ± 1.86	−0.80 ± 1.08	−0.08 ± 1.27	−0.04 ± 0.51	−0.05 ± 0.14
p value	<0.001[a,*]	0.008[a,*]	0.391[a]	0.161[b,a]	0.103[a]	0.109[b,a]	0.989[a]	0.921[a]	0.131[a]	0.849[a]	0.821[a]	0.351[a]

[a]Paired t test. [b]Wilcoxon signed-rank test. *Statistically significant difference ($p < 0.05$).

TABLE 5 Ridge height changes (mean ± standard deviation) measured in the mesial, middle, and distal aspects of maxillary molar sockets between baseline and 6 months post-extraction

	Mesial			Middle			Distal		
	Buccal	Central	Palatal	Buccal	Central	Palatal	Buccal	Central	Palatal
Height changes	+0.48 ± 2.48	−0.06 ± 0.35	−0.58 ± 2.14	−0.26 ± 3.16	+6.06 ± 2.64	−1.55 ± 2.04	+0.01 ± 2.43	+0.31 ± 0.67	−1.11 ± 1.26
p value	0.601	0.631	0.470	0.822	<0.001*	0.068	0.996	0.228	0.042*

*Statistically significant difference ($p < 0.05$) using paired *t* test.

4 | DISCUSSION

This study was designed to assess the alveolar process changes of sites where molars were extracted because of advanced periodontitis. Our research hypothesis proposed that no significant changes of socket dimension would be observed after 6 months of natural healing. The null hypothesis was partially rejected for some socket dimensions but not for others. Results of this study revealed significant decreases in ridge width at both the mesial side and the central-buccal region of maxillary and mandibular sockets. Significant increases in the ridge height at the middle-central portion of both maxillary and mandibular sockets were also observed; yet, there were no statistically significant differences between maxillary and mandibular sockets in ridge height changes (Table 7).

In contrast with previous studies (Araujo, Silva, Mendonca et al., 2015; Jung et al., 2013) in which measurements of horizontal and vertical socket bone loss were only performed in the center of the extraction sockets, the current study collected more detailed data on ridge changes as measured at mesial, middle, and distal locations of the socket. Furthermore, because the extent and rate of destruction of the alveolar bone due to periodontal disease vary, the morphologies of the remaining alveolar processes are difficult to standardize. In order to understand the form of the alveolar process at baseline, we measured the thickness of buccal and lingual (or palatal) alveolar bone plates in the center of the sockets and the initial height of the alveolar process at the mesial, middle, and distal regions. Horizontal measurements in the current study were measured at three levels (−1, −3, and −5 mm) below the crest on both the buccal and lingual (or palatal) sides along the coronal section through the center of the socket. This design is different from previous studies (Fickl, Zuhr, Wachtel, Bolz, & Huerzeler, 2008; Fickl, Zuhr, Wachtel, Stappert et al., 2008; Sisti et al., 2012) in that all horizontal measurements were related only to the position of the palatal alveolar bone wall. Recognizing that the buccal and lingual (or palatal) bone plates may have already been destructed before the tooth extraction due to advanced periodontitis is valuable information to consider as is knowing that not only buccal but also lingual bone plates reveal vertical changes after tooth extraction (Araujo, Silva, Mendonca et al., 2015; Jung et al., 2013).

For both maxillary and mandibular sockets, no statistically significant changes were observed for ridge width at the central and distal aspects of the sockets between the baseline and after 6 months of natural healing following tooth extraction. Ridge width in the center of the socket at 3 mm apically from buccal bone crest displayed a decrease of 0.47 ± 2.02 and 0.61 ± 0.99 mm for maxillary and mandibular sockets, respectively (Tables 3 and 4). These values are not consistent with findings from previous studies (Barone et al., 2017; Walker et al., 2017). Walker et al. (2017) studied the dimensional change of molar extraction sites during a 3-month healing period following tooth extraction using CBCT and reported a ridge width decrease of 3.11 ± 3.83 mm measured at 3 mm apically from the highest crest in the mid-socket. Similarly, Barone et al. (2017) measured the width reduction in non-grafted molar sockets clinically using a periodontal probe, and after 3 months of healing, a horizontal decrease of 3.77 ± 0.75 mm was observed. Notably, the indications for molar extractions of these previous studies included carious lesions, prosthetic failures, root fractures, and endodontic failures but not advanced periodontitis. Some studies have suggested that if the buccal plate of the alveolar process at the time of extraction is between 1.8 and 2.3 mm in thickness, minimal bone resorption is likely to occur. However, when the buccal crestal bone is <2 mm in thickness, pronounced resorption may occur (Chen et al., 2007; Qahash, Susin, Polimeni, Hall, & Wikesjo, 2008; Spray, Black, Morris, & Ochi, 2000). Buccal bone plate thickness of 0.71 ± 0.32 mm reported by Walker et al. (2017) was significantly thinner than that of 1.85 ± 1.15 mm at 1 mm below the crest as measured in the present study. Measurements made on CBCT scans in the present study

TABLE 6 Ridge height changes (mean ± standard deviation) measured in the mesial, middle, and distal aspects of mandibular molar sockets between baseline and 6 months post-extraction

	Mesial			Middle			Distal		
	Buccal	Central	Lingual	Buccal	Central	Lingual	Buccal	Central	Lingual
Height changes	−1.37 ± 1.22	+0.07 ± 1.28	−1.18 ± 1.07	−1.38 ± 1.81	+7.84 ± 3.52	−1.08 ± 0.96	−0.69 ± 0.57	+1.78 ± 3.81	−0.56 ± 0.63
p value	0.010*	0.867	0.011*	0 0.051	<0.001*	0.010*	0.007*	0.199	0.030*

*Statistically significant difference ($p < 0.05$) using paired *t* test.

indicated a progressive decrease of bone resorption moving toward the apical level in the center of the socket. In the buccal region of central coronal sections, a decrease of 0.59 and 0.72 mm at 1 mm apically from the alveolar crest, and an increase of 0.03 mm and a decrease of 0.22 mm at 5 mm apically from the alveolar crest were observed for maxillary and mandibular sockets, respectively (Tables 3 and 4). These results are consistent with the findings of Kerr et al. (2008) who reported a relative decrease in horizontal reduction with increasing distance from the alveolar crest. Equivalently, Misawa, Araujo, and Lindhe (2016) reported that greater bone resorption occurred in the marginal portion than the apical portion of the ridge. Despite the fact that the changes of ridge width were significant in the current study, the remaining width of residual ridge should be suitable for a regular platform type implant placement into molar sockets with periodontal disease after 6-month healing period.

In the present study, ridge height changes in maxillary molar sockets consisted of a 0.26 ± 3.16 mm reduction at the middle-buccal region and a 1.55 ± 2.04 mm reduction at the middle-palatal region in the center of the sockets (Table 5); these ridge height decreases are consistent with the findings of Kerr et al. (2008). For mandibular sockets, decreases in ridge height of the buccal bone plate (1.38 ± 1.81 mm) were more pronounced than in the lingual aspect (1.08 ± 0.96 mm; Table 7), consistent with previously reported findings that the amount of bone resorption is greater in the buccal aspect than in its lingual/palatal counterpart (Araujo, Silva, Mendonca et al., 2015; Pietrokovski & Massler, 1967). Ridge height changes measured in the present study were lower than those reported by Barone et al. (2017), in which ridge height changes were 2.05 ± 0.72 and 2.00 ± 0.69 mm in the buccal and lingual aspects of molar sites after a 3-month healing period following tooth extraction. Buccal height changes in the current study were also lower than the outcome of the study reported by Walker et al. (2017), in which buccal ridge height decreased by 2.60 ± 2.06 mm after a 3-month healing period following molar extraction. The key reason for the above differences between studies is most likely related to the selection criteria for tooth extraction and the corresponding baseline alveolar bone height. In the present study, all molars were extracted due to advanced periodontal disease and the associated alveolar processes were irregular and already exhibited severe bone loss before tooth extraction. Residual alveolar height in this study ranged between 3.79 and 9.27 mm instead of >10 mm of alveolar bone height observed on radiographs of non-periodontal involved tooth sockets examined by Walker et al. (2017). Although findings in the current study showed reductions in ridge height, significant increases at the middle-central portion of all sockets were observed. Results show the healing site should provide a favorable condition for future implants to achieve primary stability during the initial placement.

With regard to 3-D volumetric bone loss, the relative decrease in total ridge volume was 5.20% and 0.03% in the maxilla and mandible, respectively, which is less than that reported by Sbordone et al. (2016), in which bone volume loss was 31% between baseline and 6 months. In the study by Sbordone, however, the premolar and molar teeth were extracted due to untreatable caries, endodontic failures or mild/moderate periodontal disease and extraction sockets displayed alveolar height >8 mm.

The buccal and lingual/palatal volume changes measured in this study are not consistent with those reported by Tomasi et al. (2018),

TABLE 8 Ridge volume changes (mean ± standard deviation) of maxillary and mandibular molar sockets from baseline to 6 months

Parameters	Maxilla	Mandible
Total volume (mm^3)		
Baseline	1,084.56 ± 410.28	1,886.35 ± 566.48
6-month	1,018.00 ± 395.85	1,876.75 ± 537.99
Difference (mm^3)	−66.56 ± 164.87	−9.61 ± 102.31
Difference (%)	−5.20 ± 14.34	0.03 ± 5.55
p value	0.291	0.785
Buccal volume (mm^3)		
Baseline	474.97 ± 228.09	825.95 ± 223.85
6-month	500.56 ± 245.21	838.08 ± 217.94
Difference (mm^3)	25.59 ± 90.82	12.14 ± 69.79
Difference (%)	8.66 ± 37.34	2.42 ± 11.38
p value	0.452	0.616
Lingual/palatal volume (mm^3)		
Baseline	609.58 ± 357.88	1,056.34 ± 431.53
6-month	517.44 ± 265.24	1,038.58 ± 386.39
Difference (mm^3)	−92.14 ± 150.65	−17.76 ± 84.35
Difference (%)	−2.98 ± 41.2	−0.76 ± 11.46
p value	0.127	0.545

Note. No significant differences were determined ($p > 0.05$) using paired *t* test.

TABLE 7 Comparison of ridge height changes (mean ± standard deviation) between maxillary and mandibular molar sockets measured in the mesial, middle, and distal aspects

	Mesial			Middle			Distal		
	Buccal	Central	Lingual	Buccal	Central	Lingual	Buccal	Central	Lingual
Height changes									
Maxillary	+0.48 ± 2.48	−0.06 ± 0.35	−0.58 ± 2.14	−0.26 ± 3.16	+6.06 ± 2.64	−1.55 ± 2.04	+0.01 ± 2.43	+0.31 ± 0.67	−1.11 ± 1.26
Mandible	−1.37 ± 1.22	+0.07 ± 1.28	−1.18 ± 1.07	−1.38 ± 1.81	+7.84 ± 3.52	−1.08 ± 0.96	−0.69 ± 0.57	+1.78 ± 3.81	−0.56 ± 0.63
p value	0.065[a]	0.776[a]	0.200[b]	0 0.376[a]	0.500[a]	0.569[a]	0.418[a]	0.301[a]	0.289[a]

[a]Student *t* test. [b]Mann–Whitney *U* test.

in which buccal and palatal relative volume reduction was 11.0% and 9.0%, respectively. In the present study, buccal relative volume increased by 8.66% and 2.42% and lingual/palatal decreased by 2.98% and 0.76% in the maxilla and mandible, respectively. The key reason for the differences is related to the irregular and severe bone loss before tooth extraction in the present study, with height of buccal bone lower than lingual/palatal bone (Table 1). Though the width and height of buccal bone decreased, middle ridge height in socket increased, and for this reason, the buccal relative volume increased. Furthermore, Tomasi et al. (2018) reported that the thickness of buccal bone influenced the degree of volume reduction; the diminution of buccal volume at sites with thin (≤1 mm) bone plate was three times greater than at sites with a thicker (>1 mm) bone; in the present study, the buccal bone plate thickness was 1.85 ± 1.15 mm.

Results of the current study are of high importance to the treatment planning of immediate or delayed implant placement as they provide novel insights into the remodeling characteristics of alveolar processes following extraction of a single periodontally infected molar. Based on the results of this study, this process appears to proceed differently and/or to a different degree than for sockets unaffected by periodontal disease. Bone degradation due to periodontal disease may overshadow the effect of extraction, and further research will be required to determine the full impact of periodontal disease on post-extraction change in socket dimensions. Overall, this study has confirmed that the tooth socket affected by advanced periodontal disease does resorb and change 3-dimensionally in some aspects, especially at the buccal wall of the socket. Notably, however, ridge height and width changes were not as pronounced as those reported in previous studies of extraction sites not affected by periodontal disease. The decrease in ridge width changes was more pronounced in mesial regions (0.58 mm for maxillary socket and 1.21 mm for mandibular socket) than in central and distal regions. No statistically significant differences of ridge height changes were observed between maxillary and mandibular molar sockets.

The current study does have some limitations. First, the sample size was small and the statistical power might not be enough to test the true differences for all changes clinically. Second, we did not correct for the possible "false-positive" findings from multiple tests in that this investigation is a clinical pilot study only; any extrapolation of the study findings should be made in caution. Third, the clinical significance of the changes in the dimension of alveolar process following extraction needs to be validated and confirmed by future studies with a larger sample size. Nonetheless, results of the present study do provide some valuable reference points applicable to identify and quantify of socket behavior in molar extraction due to advanced periodontal disease.

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CONFLICT OF INTEREST

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

AUTHOR CONTRIBUTION

Liping Zhao conceived and designed the study, collected the data, statistically analyzed and interpreted the data, prepared the manuscript, and approved and submitted the final versions of the manuscript. Wei Yiping and Zhang Bo conceived and designed the study, collected the data, and approved and submitted the final versions of the manuscript. Tao Xu and Wenjie Hu conceived and designed the study, conducted clinical procedures, reviewed the manuscript, and approved and submitted the final versions of the manuscript. Kwok-Hung Chung conceived and designed the study, restored the consultation, edited the manuscript, and approved and submitted the final versions of the manuscript.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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