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Comparative Analysis of the Bone Dimensional Changes after Extraction of Maxillary Molars: A CBCT Study

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ABSTRACT

Aims & Hypotheses: The goals of this retrospective CBCT study were to: (1) compare the area of the alveolar process before and after molar extraction; (2) compare the height and width of the alveolar process before and after molar extraction, and (3) identify the pattern of bone remodeling according to the initial relation between the molar roots, alveolar bone position, and the sinus cavity. Three hypotheses were proposed: (1) there are significant dimensional bone changes at the site of maxillary molars following extraction; (2) the magnitude of the dimensional bone change is associated with root divergence, and (3) the magnitude of the dimensional bone change is associated with initial bone position.

Materials & Methods: Twenty-five teeth samples from 17 subjects were analyzed with two CBCT scans (before and after the molar extraction). Then, the scans were segmented to reconstruct 3D models. Two models were superimposed in computer planning software using specific anatomical landmarks. The MB-P, Mid-P, and DB-P cross-section planes were established to measure the dimensional change in horizontal bone width, vertical bone height, and the area of the alveolar bone.

Results: Overall, the average reduction in horizontal bone width was 65.10%. The average reduction in vertical bone height and the area of alveolar bone were 35.23% and 18.89%, respectively. The associations of bone change with either root divergence or initial bone location were not statistically significant ($p > 0.05$).

Conclusions: Despite all the limitations of this study, the results showed that after maxillary posterior tooth extraction, dimensional changes in the alveolar process occurred in both the vertical and horizontal directions. The vertical changes in the majority of the subjects were

attributable to remodeling of the alveolar bone, and only two subjects presented signs of sinus pneumatization.

DEDICATION

I thank my parents, Chien-ming Chen and Cheng-shi Chen, my first teachers, who taught me to be strong and face anything in this life, for their ultimate love and support. I could not have done this without you. I am grateful for your efforts to overcome anything to allow me to achieve my goals.

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LIST OF ABBREVIATIONS

Cone beam computed tomography = CBCT

Cementoenamel junction = CEJ

Mesiobuccal = MB

Distalbuccal = DB

Palatal = P

Mesiobuccal to palatal = MB-P

Middle of palatal = Mid-P

Distobuccal to palatal = DB-P

(Joint Photographic Experts Group) = JPEG

Standard deviation = SD

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Introduction

The tooth is supported by attachment tissues that establish a functional unit including root cementum, periodontal ligament, and bundle bone. Following tooth extraction, this unit is lost and the bundle bone loses its function and disappears through the process of bone modeling.[1] Consequently, after tooth extraction, significant dimensional changes in the alveolar process can be observed. Several factors, including facial bone wall thickness, tooth angulation, and other anatomical differences at the different tooth sites might influence the bone remodeling process following tooth extraction.[2] Several studies have reported that the greatest amount of bone loss after tooth extraction occurs in the horizontal dimension, primarily on the facial aspect of the ridge. There also is loss of vertical ridge height, which has been reported to be more pronounced on the facial aspect.[3]

In a previous preclinical study in a dog model, the modelling process at the site of mandibular premolars resulted in substantial reduction of the alveolar process.[1] 8 weeks following tooth extraction, the relative reduction in the height of the facial bone was, on average, 2.2 mm. When flapless extractions were compared to extractions after raising the flap, the alveolar process area was reduced by approximately 17% six months after tooth extraction when a flapless extraction was performed. This value, however, was significantly higher in the coronal portion of the alveolar ridge, with a reduction of 35% in both groups and no significant difference between them.[4] Consequently, the alveolar ridge develops a sloped and triangular outline, which makes implant rehabilitation more challenging.

In the clinical scenario, studies have indicated that bone remodeling after tooth extraction can be 2 to 3.5 times more severe compared to pre-clinical findings, and such factors as the thickness of the facial bundle bone appears to determine the pattern of bone remodeling in the anterior maxilla. In a clinical cone beam computed tomography (CBCT) study that evaluated the amount of bone loss 8 weeks after a single tooth extraction in the anterior maxilla, a progressive bone resorption pattern was observed at sites with a facial bone wall thickness of 1 mm or less. The study outcomes revealed a median vertical bone loss of 7.5 mm, or 62% of the former facial bone height 8 weeks after extraction.[5] Thus, it is known well that after tooth extraction in the anterior maxilla, significant bone remodeling occurs, especially in the coronal portion of the ridge. Accordingly, these sites should be subjected to socket grafting to reduce the amount of bone loss or plans made for immediate or early implant placements with simultaneous bone grafting to allow a more predictable and less invasive surgical procedure.

While several studies have evaluated the alterations in hard tissue in the anterior maxilla, only a few have reported dimensional changes after tooth extraction at posterior sites. In a clinical CBCT study, Nunes et al. evaluated the bone dimensions of 122 patients with posterior maxillary edentulism, and demonstrated that more than 90% of the patients presented alveolar bone heights of more than 6 mm in the molar area. In contrast to the anterior area, the alveolar bone in the posterior maxilla presents thicker facial and lingual walls, which may impair significant bone remodeling in the coronal portion of the ridge. However, the study also demonstrated that 90 to 95% of the same sites presented a mean bone height of less than 8 mm. Thus, most of the edentulous areas would require a bone grafting procedure to achieve appropriate implant rehabilitation.[6] Some possible reasons for the significant bone height reduction are the intimate contact of the alveolar process with the sinus cavity, as well as the molars' morphology.[7] Further, understanding the relation between the molar roots and the sinus cavity seems to be crucial to predict the amount of bone remodeling after tooth extraction in molar areas.

A recent systematic review evaluated the anatomical variations in maxillary sinuses through a CBCT analysis.[8] The study revealed that the most common variations included increased thickness of the sinus membrane, the presence of sinus septa, and sinus pneumatization.

Pneumatization of the maxillary sinus is a physiological process that occurs in all paranasal sinuses during growth and causes them to increase in volume.[9] In addition to the resorption pattern of the alveolar process after tooth extraction in the posterior maxilla, this expansion of the sinus area also compromises implant placement. The vertical deficiency combined with local alveolar bone resorption and sinus pneumatization makes the implant placement more challenging.

Aim and Hypothesis

To our knowledge, there are no tomographic studies in the literature that describe the pattern of bone remodeling after molar extraction in the posterior maxilla. Thus, the goals of this retrospective CBCT study were to: (1) evaluate the area of the alveolar process before and after molar extraction; (2) evaluate the height and width of the alveolar process before and after extraction, and (3) identify the pattern of bone remodeling according to the initial relation between the molar roots, alveolar bone position, and sinus cavity.

Hypotheses:

1. There are substantial dimensional bone changes at the site of maxillary molars following extraction.
2. The magnitude of the dimensional bone change is associated with root divergence.
3. The magnitude of the dimensional bone change is associated with initial bone position.

Research Design

Implant planning before tooth extraction relies on accurate diagnosis of the alveolar bone process changes after the healing period. By knowing the remodeling pattern of the alveolar process and whether the pre-existing anatomy influences the pattern of remodeling, a clinician is able to make a more accurate prediction in implant planning and potentially will face fewer complications during the implant surgery.

A 3D method using digital model superimpositions of two consecutive CBCTs was used to characterize the extent of bone loss post-extraction and identify risk zones as well as the respective modulating factors in hard tissue alteration. This project provided a better understanding of the underlying tissue biology and facilitated treatment planning and the selection of the surgical approach to implant placement.

Materials and Methods

This study was designed to analyze retrospectively records of patients who had two CBCT scans taken for the purposes of diagnosis or implant planning at Tufts University School of Dental Medicine. The study was approved by the Tufts Health Science Campus Institutional Review Board (process number 12723). Upon approval, a request was made to the Dental Clinical Services of Tufts Technology Service (TTS) to supply the data. Records of patients who had two CBCT scans taken with ADA code D0366 or D0367 from May 1, 2014 to May 24, 2017 in axiUm were eligible for the study. An example case is shown in Figure 1.

Inclusion Criteria

- Patients who had a CBCT taken previously for various purposes (endodontics, periodontics, or dental implant procedures)
- Patients with a CBCT with a maxillary tooth (or teeth) present before extraction and a subsequent CBCT of the edentulous site in the same area after tooth extraction

Exclusion Criteria

- Patients who presented with teeth with large periapical lesions, substantial periodontal bone loss (> 3 mm), and/or root resorption
- Patients with molar teeth that required an osteotomy for their extraction
- Patients with a CBCT with invisible bone contours
- Patients with a CBCT with a significant number of radiographic artifacts that were unsuitable for analysis

CBCT Analysis

All images were obtained from the same tomographic machine (i-CAT®, Imaging Sciences, Hatfield, PA, USA) and taken by a single radiologist. Both pre- and post-extraction CBCTs were imported from MiPACs medical imaging software (Medicor Imaging, North Carolina, USA) into the computer planning software (coDiagnostiX, Dentalwings, Montreal, Canada) as DICOM files. For the three-dimensional image reconstruction, segmentation was performed by adjusting the Hounsfield value, and unnecessary images (e.g., scatter) were removed to obtain the clearest 3D image of the maxillary anatomy.

To standardize the radiographic measurements before and after tooth extraction, the teeth and bone outlines in the first radiographic image (before extraction) were segmented and superimposed based on unchanged anatomical landmarks, such as virgin teeth, tuberosities, palatal bone, incisive canal, or zygoma. The export level of detail was set to "Fine" (as shown in Figure 2). All measurements were made on the radiographic image, and the 3D reconstruction was used for reference purposes only.

The planes for the measurement were established as follows: the long axis of the molar was set as the vertical axis in the "Align patient coordinate system" option. The area of interest was set as the axial view. Three cross-section views (Figure 3) were determined (DB-P, Mid-P, MB-P) by adjusting the reference line in tangential view.

Area of the alveolar process at pre-extraction sites

The area of the alveolar process at the pre- and post-extraction sites was determined with three different cross-sectional views as described below (Figure 4):

1. Section 1: the plane created by the section from the mesiobuccal root to the palatal root of the maxillary molar (MB-P)

2. Section 2: the plane created by the section from the mid-portion of the two buccal roots to the palatal root of the maxillary molar (Mid-P)
3. Section 3: the plane created by the section from the distobuccal root to the palatal root of the maxillary molar (DB-P)

The cross-sectional planes were established from the pre-extraction CBCT.

Horizontal linear measurement of the bone width at the extraction site

In each cross-sectional plane, the cemento-enamel junction (CEJ) of the tooth was identified. The line connecting the CEJ on each side was set as a reference horizontal baseline. In CoDiagnostix, a distance 3 mm perpendicular to the reference horizontal line was marked as 3mm below the CEJ line (Line A). A distance 5 mm perpendicular to the reference horizontal line was marked as 5mm below the CEJ line (Line B). Finally, a distance 7 mm perpendicular to the reference horizontal line was marked as 7mm below the CEJ line (Line C), as illustrated in Figure 5.

In the cross-sectional view, both the horizontal bone width in the pre- and post-extraction distance at Lines A, B, and C were recorded individually in millimeters. If bone was present at the horizontal baseline, it was recorded as “0.”

Vertical linear measurements of the bone height at the extraction site

In the Mid-P plane, vertical linear measurements from the sinus floor to the furcation of the extracted tooth were recorded in millimeters at the pre-extraction bone height. The post-extraction bone height was measured from the sinus floor to the existing alveolar ridge. With the superimposition, the measurements were calibrated to use the exact same reference (Figure 6). The difference in pre- and post-extraction height was calculated, and the percentage loss in vertical bone height was computed. In addition, the presence of sinus pneumatization was recorded and measured.

Area measurements of the alveolar process in the extraction sites

The volume of the septum bone was quantified individually for the pre- and post-extraction scans in each section. To calculate the area, the cross-sectional view was saved as a .jpeg file that was opened in Photoshop CC 2015 (Adobe Systems, CA, USA) to perform the measurements. Before each measurement, the measurement scale was set according to the scale in the bottom left corner of the picture. The area of measurement began from Line A, as mentioned previously (3 mm from CEJ). The number of pixels was counted in Photoshop by selecting the area of the alveolar process at the pre-extraction sites, and then was converted to square millimeters. The areas of the alveolar process at the post-extraction sites were measured in the same manner. The change in the area of the alveolar bone in each section (sections 1, 2 and 3) and the mean bone change for all 3 sections were calculated.

Initial bone location

In each section, the highest position of the alveolar bone beneath the maxillary molar in the pre-extraction model was located. This location was compared with the maxillary molar's palatal root tip. According to the relation between the initial bone location and root tip, a binary variable was defined with the categories "above" and "below," and associations between this binary variable and mean vertical and area bone changes were evaluated.

Root divergence

In each section, the degrees of angulation of the two roots were measured. The root divergence in each section was compared with the change in the area of bone in each section, as well as the average change in bone height.

Statistical Analysis

Sample Size

A convenience sample was used. A total of 124 records during the period of 5/1/2014 to 5/24/2017 were reviewed. After excluding the ineligible samples, 17 patients (34 CBCT images imported) with a total of 25 teeth (34 CBCT images analyzed) were included in the study.

A sample size calculation was conducted using nQuery Advisor (Version 7.0). Assuming a standard deviation of 4.2 mm for the vertical change in bone height[10] and an intracluster correlation coefficient of 0.02[11], the sample size of 17 subjects with 25 teeth was adequate to obtain a two-sided 95% confidence interval with a margin of error of 1.7 mm.

Analysis

Descriptive statistics (frequencies and percentages for categorical variables, means and standard deviations for continuous variables) were computed for all of the measurements. Associations between root divergence and vertical change in bone height, root divergence, and the change in the area of the alveolar bone, initial bone location and vertical change in bone height, and initial bone location and change in the area of the alveolar bone were assessed using mixed-effects modeling due to the fact that some tooth samples were from the same subject. Because it was known previously that the dimension of the alveolar ridge would decrease after tooth extraction, formal hypothesis testing to compare the data before and after extraction was unnecessary. Instead, attention focused on quantifying the magnitude of the change, as well as reporting the precision of the change estimated. Therefore, 95% confidence intervals of the vertical linear change in the bone height and horizontal linear change in the bone width at extraction sites were calculated. SPSS v. 24 (IBM, NY, USA) and SAS v. 9.4 (SAS Institute, NC, USA) were used in the analysis.

Results

One hundred twenty-four patient samples were collected during the designated period, and a total of 249 CBCT records were imported to coDiagnostix software. After applying the inclusion and exclusion criteria, 17 patients were included with a total of 25 teeth consisting of 17 first and 8 second molars.

Horizontal Linear Measurement of Bone Width at Extraction Site

Table 1 displays the means and standard deviations of horizontal linear measurements of bone width at the extraction sites. In all cases, the mean bone width decreased after extraction. The average percentage of reduction over the 9 conditions overall was 65.10%.

Section 1 (MB-P)

The mean (SD) horizontal bone widths before extraction at lines A (3mm below CEJ), B (5mm below CEJ), and C (7mm below CEJ) were 13.33 (2.03), 13.72 (1.89), and 14.37 (2.41) mm, respectively. The mean (SD) horizontal bone widths after extraction at lines A, B, and C were 2.43 (3.42), 4.98 (4.58), and 7.22 (4.21) mm, respectively. The mean (SD) changes in the horizontal bone width at lines A, B, and C were 10.90 (3.77), 8.74 (4.75), and 7.16 (4.63) mm, respectively. The mean (SD) percentages of change in bone width were 82.99 (28.25)%, 63.47 (33.91)%, and 48.85 (29.90)%. At line A, the 95% confidence interval of the change in bone width was (8.85, 12.52) mm. At line B, the 95% confidence interval of the change in bone width was

(6.27, 10.70) mm. At line C, the 95% confidence interval of change in the bone width was (4.70, 9.13) mm.

Section 2 (Mid-P)

The mean (SD) horizontal bone widths before extraction at lines A, B, and C were 12.90 (1.58), 13.36 (1.81), and 13.84 (1.79) mm, respectively. The mean (SD) horizontal bone width after extraction at lines A, B, and C were 3.58 (2.89), 5.45 (4.06), and 7.86 (3.86) mm, respectively. The mean (SD) changes in the bone width at lines A, B, and C were 9.33 (3.71), 7.92 (4.66), and 5.98 (4.45) mm, respectively. The mean (SD) percentage of changes in the bone width were 72.87 (29.38)%, 59.36 (34.90)%, and 42.42 (30.41)%, respectively. At line A, the 95% confidence interval of change in the bone width was (7.49, 11.08) mm. At line B, the 95% confidence interval of the change in bone width was (5.68, 9.98) mm. At line C, the 95% confidence interval of change in the bone width was (3.58, 7.67) mm.

Section 3 (DB-P)

The mean (SD) horizontal bone width before extraction at lines A, B, and C were 12.57 (1.56), 13.34 (1.64), and 13.65 (2.06) mm, respectively. The mean (SD) horizontal bone width after extraction at lines A, B, and C were 2.58 (3.31), 4.84 (3.80), and 7.16 (3.28) mm, respectively. The mean (SD) changes in the bone width at lines A, B, and C were 9.99 (3.67), 8.50 (4.56), and 6.49 (4.48) mm, respectively. The mean (SD) percentage of changes in the bone width were 80.82 (29.87)%, 64.44 (34.11)%, and 46.26 (28.63)%, respectively. At line A, the 95% confidence interval of the change in bone width was (8.07, 11.69) mm. At line B, the 95% confidence interval of the change in bone width was (6.06, 10.46) mm. At line C, the 95% confidence interval of the change in bone width was (4.05, 8.21) mm.

Vertical Linear Measurements of Bone Height at Extraction Site

Table 2 displays the means and standard deviations of vertical linear measurements of the bone height at extraction sites. Overall, the mean bone height decreased following extraction.

In the mid-P cross-section, the mean (SD) vertical bone height before extraction was 8.01 (1.82) mm, while it was 5.40 (2.75) mm after extraction. The mean change in bone height was 2.61 (1.76) mm. The mean (SD) percentage of loss in the total bone height was 35.23 (26.60)%. Two tooth samples, one a first molar and the other a second molar, presented signs of pneumatization, with 0.1mm (of total 1.4 mm) and 0.3 mm (of total 0.4 mm) in bone reduction, respectively. The 95% confidence interval of the change in bone height was (1.67, 3.31) mm.

Measurement of the Area of the Alveolar Process at Extraction Site

Table 3 shows the means and standard deviations of the measurements of the area of the alveolar process at extraction sites. All of the samples exhibited a decrease in area following the extraction, with an average percentage reduction of 18.89%.

Section 1 (MB-P)

The mean (SD) area of the alveolar process before extraction was 327.10 (147.45) mm^2. The mean (SD) area of alveolar process after extraction was 271.30 (252.28) mm^2. The mean (SD) change of the area was 55.80 (41.91) mm^2. The 95% confidence interval of the change in the area was (37.74, 74.22) mm^2. The mean (SD) percentage of the change in the area was 19.42 (14.35)%.

Section 2 (Mid-P)

The mean (SD) area of the alveolar process before extraction was 327.18 (106.47) mm^2. The mean area of the alveolar process after extraction was 266.48 (111.77) mm^2. The mean change in the area was 60.70 (46.80) mm^2. The 95% confidence interval of the change in the area was (37.81, 88.58) mm^2. The mean (SD) percentage of the change in the area was 19.67 (17.82)%.

Section 3 (DB-P)

The mean (SD) area of the alveolar process before extraction was 309.29 (119.81) mm^2. The mean (SD) area of the alveolar process after extraction was 257.57 (121.11) mm^2. The mean (SD) change in the area was 51.72 (45.21) mm^2. The 95% confidence interval of the change in area was (30.62, 77.84) mm^2. The mean (SD) percentage of the change in the area was 17.59 (17.49)%.

Association Between Root Divergence and Percentage Change in the Area of the Alveolar Process

Section 1 (MB-P)

The mean (SD) root divergence was 32.64 (12.21) degrees. One of the tooth samples exhibited fusion of the mesio-buccal root and palatal root. Table 4 shows the results of the mixed-effects model predicting the percentage change in the area of the alveolar process associated with root divergence; there was no significant association between root divergence and the percentage of the change in the area ($p = 0.19$).

Section 3 (DB-P)

The mean (SD) root divergence was 38.26 (15.81) degrees. One of the tooth samples exhibited fusion of the distal-buccal root and palatal root. Table 4 shows the results of the mixed-effects model predicting the percentage of change in the area of the alveolar process associated with root divergence. There was no significant association ($p = 0.98$).

Association Between Root Divergence and the Percentage of Change in Vertical Bone Height

Section 1 (MB-P)

Table 4 displays the results of the mixed-effects model predicting the change in the percentage of the area of the vertical bone height associated with root divergence; no significant association was found (*p* = 0.30).

Section 3 (DB-P)

Table 4 displays the results of the mixed-effects model predicting the change in the percentage of the area of the vertical bone height associated with root divergence; no significant association was identified (*p* = 0.59).

Association Between Initial Bone Location and the Change in the Percentage of the Area of the Alveolar Process

Table 5 shows the results of the mixed effects model predicting the change in the percentage of the area of the alveolar bone associated with root divergence.

Section 1 (MB-P)

Among the 25 tooth samples, the location of the tip of the palatal root in 16 samples (64%) was below the highest position of the alveolar bone. In 9 samples (36%), the tip of the palatal root was above the highest position of alveolar bone. There was no significant association between initial bone location and the change in the percentage of the area of the alveolar bone (*p* = 0.39).

Section 2 (Mid-P)

As above, the location of the tip of the palatal root in 16 samples (64%) was below the highest position of the alveolar bone. In 9 samples (36%), the tip of the palatal root was above the highest position of the alveolar bone. There was no significant association between initial bone location and the change in the percentage of the area of the alveolar bone ($p = 0.83$).

Section 3 (DB-P)

The location of the tip of the palatal root in 18 samples (72%) was below the highest position of the alveolar bone. In 7 samples (28%), the tip of the palatal root was above the highest position of the alveolar bone. There was no significant association between initial bone location and the change in the percentage of the area of the alveolar bone ($p = 0.72$).

Association Between Initial Bone Location and the Percentage of Vertical Change in Bone Height

Table 5 shows the results of the mixed effects model predicting the percentage of the vertical change in bone height associated with root divergence.

Section 1 (MB-P)

There was no significant association between initial bone location and the percentage of the vertical change in bone height ($p = 0.99$).

Section 2 (Mid-P)

There was no significant association between initial bone location and the percentage of the vertical change in bone height ($p = 0.44$).

Section 3 (DB-P)

There was no significant association between initial bone location and the percentage of the vertical change in bone height ($p = 0.63$).

Discussion

This study compared two CBCT scans with the aid of 3D image reconstruction. The segmentations from the scans were created by adjusting the Hounsfield values. Two reconstructed models from pre- and post-extraction records were superimposed to analyze the dimensional alterations in the alveolar bone. The CBCT scan provides valuable 3D information that facilitates implant planning prior to surgery, and the superimposition of CBCTs provides diagnostic value, as the anatomical variation and limitation, particularly in the maxillary posterior region, increase the difficulty in placing the implant.

CBCT scans comparing the pre- and the post-extraction situations were obtained to investigate the dimensional changes in the alveolar bone. The results of the study indicated that bone height and width at the maxillary molar sites decreased substantially following tooth extraction. The coronal portion exhibited more horizontal bone change than did the apical portion. However, the associations between the bone change and both root divergence and initial bone location were not statistically significant. Further, the vertical change in bone height exhibited was attributable predominantly to the loss of the alveolar process. Only two patients presented sinus pneumatization.

The width and height of the changes in the alveolar bone at maxillary molar sites were measured, and changes in the area were calculated as well. Pramstraller et al.[12] reviewed a total of 127 CBCT scans of the edentulous maxillary posterior region. They found that bone height was 5.4 mm (3.1–7.35 mm) at the first molar sites and 6.6 mm (4–9.1mm) at second molar sites. The mean height was similar to that found in our study. However, both studies had large standard deviations attributable to the variations in anatomical structures, and the difficulty of categorizing the maxillary posterior region. The measures of bone width in Pramstraller's study were 1, 3, and

7 mm, respectively, from the top of the alveolar crest. The mean widths were 5.7/6.6, 9.6/10, 11.6/11.9, and 9.49 mm at the first molar and second molar sites, respectively. The difference in width between the two studies might be because the baselines were set differently. However, both studies showed a trend, in that the closer the measurement was to the sinus, the greater the bone width. Nunes et al.'s study[6] reported that the mean bone height was 5.04 and 5.08 mm at first molar and second molar sites, respectively, based on a review of 122 CBCT scans.

Tooth extraction initiates a remodeling process of the alveolar bone that causes alveolar bone loss.[13] A systematic review reported that horizontal bone loss ranged from 29 to 63%, while vertical bone loss ranged from 11 to 22% 6 months following extraction.[14] In our study, the horizontal bone change ranged from 46.26 to 82.99%, while the vertical bone change was between 35.23 to 38.04%. These percentages of linear bone change were higher than those reported in the review mentioned above. This might be attributable to the difference in observation timelines, and the fact that anterior teeth were included in the review. Remarkably, reduction in vertical bone height is especially prominent in the facial aspect of the maxillary posterior ridge.[15] On the other hand, the palatal bone morphology maintained nearly the same contour when compared in superimpositions.

This study used CBCT superimposition innovatively to compare the dimensional changes in the posterior maxillary region after molar extraction. Some studies have used contralateral teeth in CBCTs to compare bone alterations following extraction, and several studies have adopted different baselines. In Misawa et al.'s[16] study, the extraction site was compared with the contralateral tooth position. They found that in the maxillary anterior region, the cross-sectional area decreased overall from 99.1 to 65.0 mm^2, and the width of the alveolar process decreased markedly as well. Other studies have used an imaginary line parallel to the CT scan plane passing through the CEJ of the canine as the baseline.[12,17] Using the actual tooth position from the extraction sites rather than that from the contralateral sites or the projecting lines eliminated the risks of increasing errors attributable to anatomical variations or abnormal tooth positions. Moreover, the method used in our study increased the accuracy of measurements because the superimposition truly reflected the original dimensions of the pre-extraction contour. Chappuis et al. conducted a similar study in which the authors superimposed two CBCT scans that also were matched with the intraoral scan and investigated soft tissue alterations related to the underlying bone in the maxillary anterior region.[5,18]

The primary outcome in this study was the change in vertical bone height after tooth extraction. The mean bone height after extraction was 5.40 mm. A sinus augmentation procedure is required to place a regular implant (length > 8 mm). In addition, the study attempted to discover whether any specific factors were associated with the changes in the bone. However, the associations between bone changes and both the initial bone location and root divergence were not statistically significant. Thus, the study failed to predict bone changes attributable to any of the factors. This might be because of the limited number of samples available for the study.

Several studies have investigated the symptoms and causes of pneumatization. Sharan et al.[9] identified the symptoms of sinus pneumatization following maxillary molar extraction, while Tolstunov et al.[19] classified sinus pneumatization based on the alveolar height that could accommodate straight implant placement. Saccucci et al.[20] reported 3D analyses to identify the volume of the maxillary sinus, but found no statistically significant relation between gender and the severity of pneumatization. Levi et al.[21] stated that socket preservation with xenografts may be beneficial to reduce sinus pneumatization. However, the study was conducted only with 2D measurements from panoramic radiographs. Luz et al.[22] reviewed 64 CBCT scans to identify the surface and volume of the sinus, but failed to find an association between the dimensions of the sinus and patient age or state of the dentition. Conversely, in a recent study, Schriber et al.[23] compared the dimensions of maxillary sinuses in dentate and edentulous patients with CBCT scans. They concluded that the loss of the alveolar bone height was caused primarily by crestal bone resorption rather than pneumatization. This finding coincided with that in our study, as only 2 subjects presented vertical bone loss attributable to a drop of the sinus floor.

This study has several limitations. First, the small sample size, as mentioned previously, resulted in limited statistical power. Second, as is characteristic of most retrospective studies, it was impossible to standardize the time between the CBCT before and after extraction. Third, the study design excluded the possibility of measuring the thickness of buccal plate or palatal plate, which might also be a critical factor of alveolar bone remodeling. Lastly, some subjects presented with dramatic alveolar bone remodeling following tooth extraction. These cases with extreme resorption affected the statistical results substantially. Further studies with better controlled research designs and methods will be needed to confirm the findings of this initial study.

Conclusion

Despite the limitations of this radiographic retrospective study, it used a novel protocol of superimposing two CBCT scans and measured the dimensional changes following the extraction of maxillary molars. The results showed: (1) a dimensional decrease in every cross-sectional view for all subjects; (2) only 2 subjects presented vertical dimensional changes in the sinus floor, and the remainder presented vertical changes attributable to resorption of the alveolar ridge, and (3) associations between root divergence and bone changes, and initial bone location and bone changes were not statistically significant. This study may help improve our understanding of the dimensional changes in the alveolar bone following maxillary molar extraction. It also may be beneficial for the design of future studies, which should use larger sample sizes and controlled designs to verify the magnitude of the bone remodeling process in the maxillary posterior region.

APPENDICES

Appendix A: Tables

Appendix B: Figures

Appendix A: Tables

Table 1. Descriptive analysis of horizontal linear measurements of bone width at extraction sites (based on 25 teeth from 17 subjects)

		Before	After	Change	95% CI for Change	Percentage Change
MB-P	3mm	13.33 (2.03)	2.43 (3.42)	10.90 (3.77)	(8.85, 12.52)	82.99 (28.25)%
	5mm	13.72 (1.89)	4.98 (4.58)	8.74 (4.75)	(6.27, 10.70)	63.47 (33.91)%
	7mm	14.37 (2.41)	7.22 (4.21)	7.16 (4.63)	(4.70, 9.13)	48.85 (29.90)%
Mid-P	3mm	12.90 (1.58)	3.58 (2.89)	9.33 (3.71)	(7.49, 11.08)	72.87 (29.38)%
	5mm	13.36 (1.81)	5.45 (4.06)	7.92 (4.66)	(5.68, 9.98)	59.36 (34.90)%
	7mm	13.84 (1.79)	7.86 (3.86)	5.98 (4.45)	(3.58, 7.67)	42.42 (30.41)%
DB-P	3mm	12.57 (1.56)	2.58 (3.31)	9.99 (3.67)	(8.07, 11.69)	80.82 (29.87)%
	5mm	13.34 (1.64)	4.84 (3.80)	8.50 (4.56)	(6.06, 10.46)	64.44 (34.11)%
	7mm	13.65 (2.06)	7.16 (3.28)	6.49 (4.48)	(4.05, 8.21)	46.26 (28.63)%

Before: mean (SD); After: mean (SD); Change: mean (SD). (unit: mm)

Table 2. Descriptive analysis of vertical linear measurement of bone height at extraction sites (based on 25 teeth from 17 subjects)

	Before	After	Change	95% CI for Change	Percentage Change
Mid-P	8.01 (1.82)	5.40 (2.75)	2.61 (1.76)	(1.67, 3.31)	35.23 (26.60)%

Before: mean (SD); After: mean (SD); Change: mean (SD). (unit: mm)

Table 3. Descriptive analysis of area measurement of alveolar process at extraction sites (based on 25 teeth from 17 subjects)

	Before	After	Change	95% CI for Change	Percentage Change
MB-P	327.10 (147.45)	271.30 (252.28)	55.80 (41.91)	(37.74, 74.22)	19.42 (14.35)%
Mid-P	327.18(106.47)	266.48 (111.77)	60.70 (46.80)	(37.81, 88.58)	19.67 (17.82)%
DB-P	309.29(119.81)	257.57 (121.11)	51.72 (45.21)	(30.62, 77.84)	17.59 (17.49)%

Before: mean (SD); After: mean (SD); Change: mean (SD). (unit: mm^2)

Table 4. Association between root divergence and change in area/vertical change in bone height

	Cross-section	Intercept	Slope	95% CI (Slope)	*p*
Area change	**MB-P**	8.10	0.35	-0.22, 0.91	0.19
	DB-P	18.73	-0.01	-0.36, 0.35	0.98
Vertical change	**MB-P**	48.56	-0.43	-1.35, 0.49	0.30
	DB-P	40.81	-0.13	-0.69, 0.42	0.59

Mixed-effects modeling was used with root divergence as the independent variable and change in area or vertical change as the dependent variable.

Table 5. Association between initial bone location and change in area / vertical change of bone height

	Cross-section	Intercept	Slope	95% CI (Slope)	*p*
Area change	**MB-P**	22.07	-3.99	-14.22, 6.25	0.39
	Mid-P	33.52	-1.51	-17.96, 14.94	0.83
	DB-P	36.80	-3.71	-27.55, 20.13	0.72
Vertical change	**MB-P**	35.44	-0.11	-21.08, 20.85	0.99
	Mid-P	22.11	-4.42	-17.09, 8.26	0.44
	DB-P	17.83	3.16	-11.60, 17.92	0.63

Mixed-effects modeling was used with the initial bone location as the independent variable (with "initial bone location below the root tip" as the reference category, and "initial bone location above the root tip" as the test category) and the change in area or vertical change as the dependent variable.

Appendix B: Figures

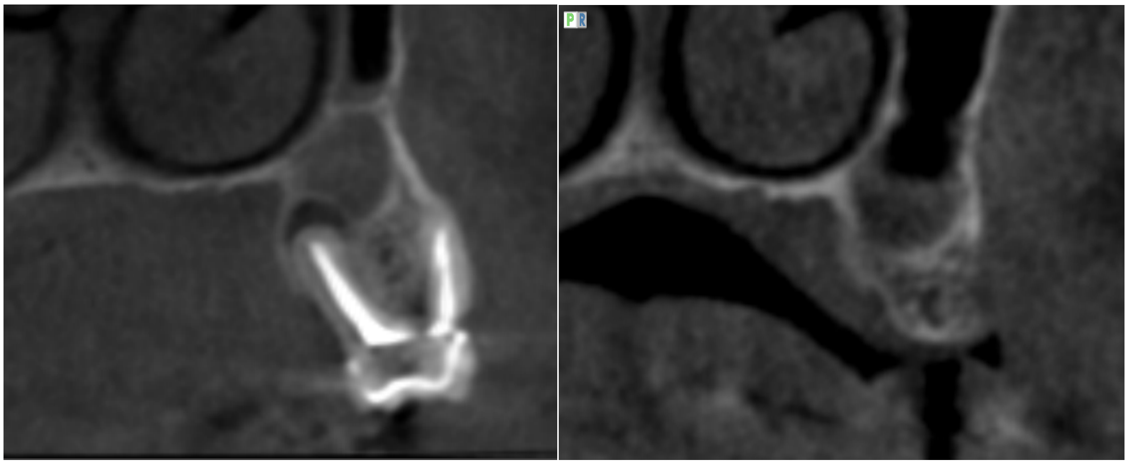

Figure 1. Cross-sectional MB-P view before (left) and after tooth extraction (right). Note that width and height of the alveolar bone have decreased.

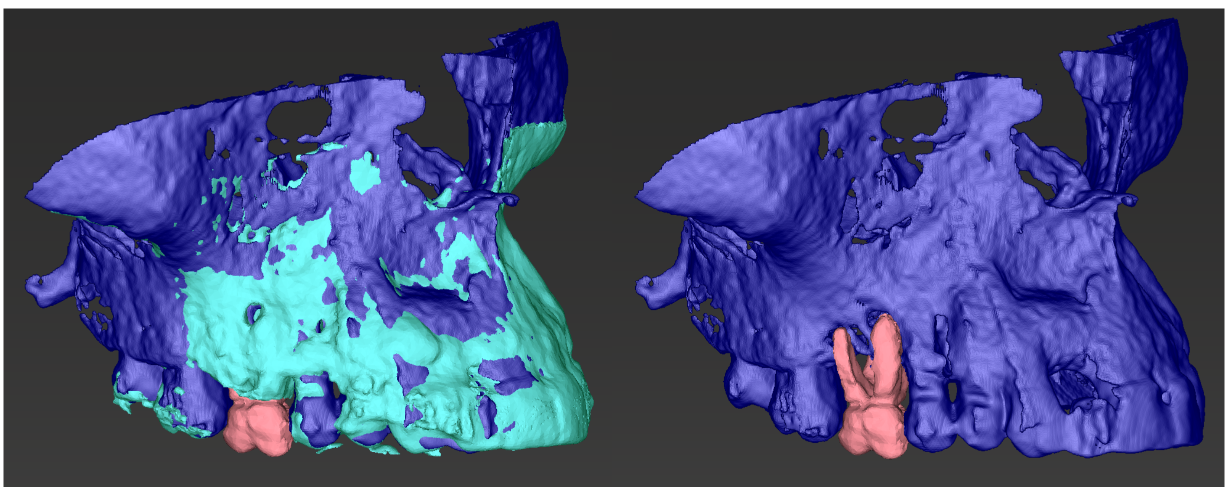

Figure 2. Superimposition of a 3D reconstruction image from the CBCT.

Left: Superimposition with pre-extraction segmentation (teal), and extracted molar (red) and post-extraction segmentation (blue). Right: Superimposition of post-extraction segmentation (blue) and extracted molar (red).

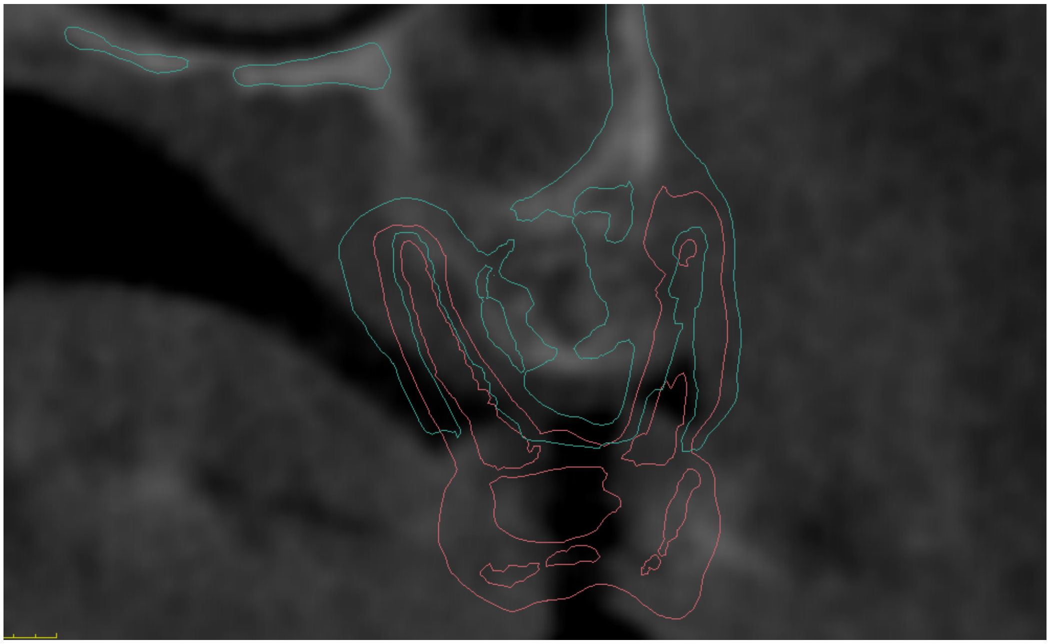

Figure 3. Cross-sectional view of CBCT.

The green contour represents the bone contour pre-extraction after the segmentation. The red contour represents the tooth contour. Superimposition was made based on related anatomical landmarks.

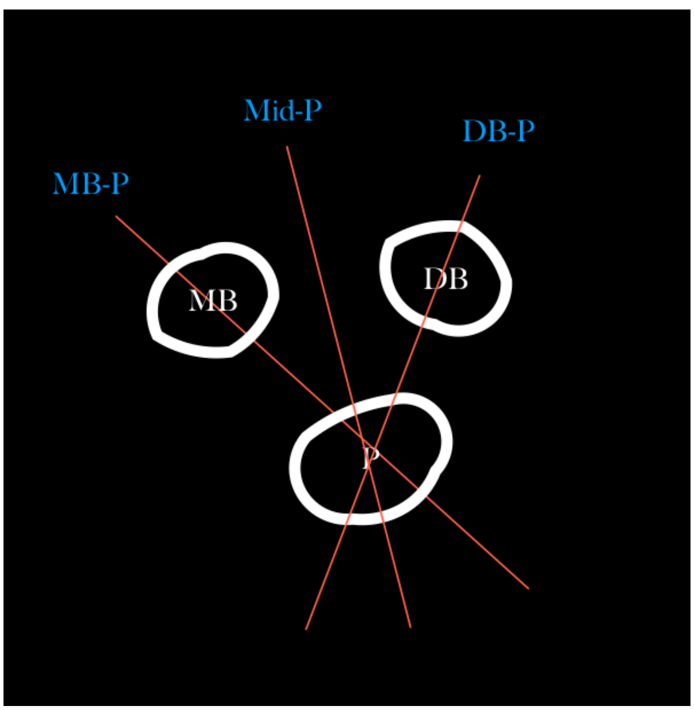

Figure 4 Diagram of cross-sectional view:
MB-P: the cross-sectional view from mesio-buccal root to palatal view.
Mid-P: the cross-sectional view from palatal root perpendicular to the arch.
DB-P: the cross-sectional view from distal-buccal root to palatal view.

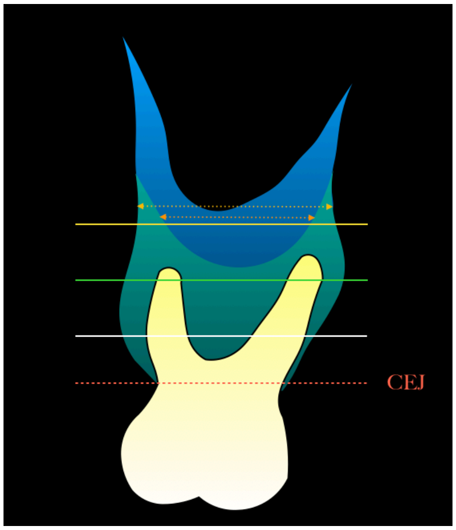

Figure 5. Diagram of horizontal measurements.

The blue area indicates the alveolar bone after extraction, while the green area indicates the bone before extraction. Line A (white line) placed 3mm vertically distant from the CEJ (red line) of extracted molar. Line B (green) placed 5mm vertically distant from the CEJ. Line C (yellow line) placed 7mm vertically distant from the CEJ.

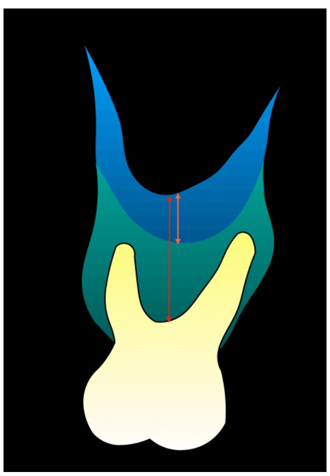

Figure 6. Diagram of vertical measurements.

The vertical heights in the blue and green regions represent the bone height pre-extraction (red double arrow), and the vertical height in the blue region represents the height post-extraction (orange double arrow).

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