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Accuracy of volumetric measurement of simulated root resorption lacunas based on cone beam computed tomography

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Structured Abstract

Objectives – To evaluate the accuracy of volumetric measurement of simulated root resorption cavities based on cone beam computed tomography (CBCT), in comparison with that of Micro-computed tomography (Micro-CT) which served as the reference.

Setting and Sample Population – The State Key Laboratory of Oral Diseases at Sichuan University.

Material and Methods – Thirty-two bovine teeth were included for standardized CBCT scanning and Micro-CT scanning before and after the simulation of different degrees of root resorption. The teeth were divided into three groups according to the depths of the root resorption cavity (group 1: 0.15, 0.2, 0.3 mm; group 2: 0.6, 1.0 mm; group 3: 1.5, 2.0, 3.0 mm). Each depth included four specimens. Differences in tooth volume before and after simulated root resorption were then calculated from CBCT and Micro-CT scans, respectively. The overall between-method agreement of the measurements was evaluated using the concordance correlation coefficient (CCC).

Results – For the first group, the average volume of resorption cavity was 1.07 mm^3, and the between-method agreement of measurement for the volume changes was low (CCC = 0.098). For the second and third groups, the average volumes of resorption cavities were 3.47 and 6.73 mm^3 respectively, and the between-method agreements were good (CCC = 0.828 and 0.895, respectively).

Conclusions – The accuracy of 3-D quantitative volumetric measurement of simulated root resorption based on CBCT was fairly good in detecting simulated resorption cavities larger than 3.47 mm^3, while it was not sufficient for measuring resorption cavities smaller than 1.07 mm^3. This method could be applied in future studies of root resorption although further studies are required to improve its accuracy.

Key words: cone beam computed tomography; Micro-computed tomography; tooth root resorption

Introduction

External root resorption is a common side effect of orthodontic treatment. Radiography is the only way to detect the condition in the clinic. According to previous studies (1, 2), conventional intraoral radiography is not an adequate technique for the detection of root resorption cavities, particularly when situated on the buccal or lingual root surfaces. Many studies have reported the difficulties and inaccuracy in evaluating orthodontic-induced external root resorption (OIERR) with conventional 2-D radiography (3–7). Follin reported that 2D radiography was an inaccurate diagnostic tool for the detection of lingual root resorption (8). In recent years, studies have shown that cone beam computed tomography (CBCT), which provides 3-dimensional (3-D) images of dental structures, is an excellent method for detecting simulated root resorption lacunas (9, 10).

Essentially, OIERR is a kind of tooth volume loss associated with orthodontic force. Precisely detecting volume changes in 3-D images pre- and post-orthodontic treatment will be superior to evaluating the root length changes in 2-D images. Qualitative or semi-quantitative scoring systems were generally used for root resorption grading on panoramic (OPT) and periapical radiographs. Additionally, these methods are unable to determine root resorption on the lingual and buccal aspects, and root resorption may therefore be underestimated by OPT or periapical radiography (11). Theoretically, for the diagnosis of OIERR, 3-D and quantitative volumetric measurement, which could precisely detect the volume changes pre- and post-orthodontic treatment, will be superior to the current 2-D qualitative or semi-quantitative methods. In the latest studies (12, 13), volumetric measurement of teeth based on CBCT showed excellent accuracy. It does not logically guarantee, however, that this method also has enough accuracy to detect the tooth volume changes occurring in external root resorption.

Therefore, in this study, the accuracy of the volumetric measurement of simulated external root resorption lacunas based on CBCT was evaluated in comparison with that of Micro-CT, which served as a reference method.

Materials and methods

Specimens

Eight fresh adult bovine maxillas containing approximately six to eight intact teeth were obtained from a local slaughterhouse and were included in this study. They were stored in 10% formalin immediately after dissection.

CBCT scanning before simulating external root resorption

All of the bovine maxillas underwent CBCT scanning [MCT-1 (EX-2F), J Morita Manufacturing, Kyoto, Japan; Scan parameters: voxel size resolution: 125 μm; tube voltage: 90 kV; tube current: 4.5 mA; field of view: 60 $\times$ 60 mm).

The bovine teeth were then extracted by an experienced oral surgeon. A minimally invasive technique was used during the tooth extraction. The extracted bovine teeth were sterilized in 10% formaldehyde for approximately 10 h and rinsed in flowing water for 30 min and bench-dried for a minimum of 48 h (14, 15). Each tooth was fully examined under a stereo-microscope, particularly around the apical area. A total of 48 bovine teeth were collected, and 32 bovine teeth were finally included in the study; the other 16 teeth were excluded due to surface damage.

All of the included teeth and their corresponding alveolar sockets were coded in a set from No. 1 to No. 32 by another investigator.

Micro-CT scanning before simulating external root resorption

Those teeth without the alveolar socket were referred to Micro-CT scanning (μ80, Scanco

Medical, Bassersdorf, Switzerland; Scan parameters: Voxel size resolution: 37 μm; Tube voltage: 70 kV; Tube current: 114 μA).

Simulating external root resorption

Thirty-two bovine teeth were randomly divided into three groups (Table 1). Artificial external resorptive cavities were then prepared according to the classification of Alqerban et al. (9), using a low-speed handpiece with International Organization for Standardization round diamond burs of 1.2 mm in diameter and water as a coolant. Artificial external resorptive cavities were located at the available lingual, labial, mesial, and distal wall of the apical third of the root. All of the tooth crowns were placed in plaster bases to ensure stability during drilling. All of the defects were made by the same investigator, and the defect sizes were verified by another investigator using magnified vision.

CBCT scanning after simulating external root resorption

All of the bovine teeth were repositioned in their corresponding alveolar sockets, and the whole bovine maxillas were referred to CBCT scanning again, using the same parameters as the first time CBCT scanning.

Table 1. **Thirty-two Bovine teeth were divided into three groups according to different depth of root resorption cavities, which were 1.2 mm in diameter**

Depth of simulated root resorption cavity (mm)	Group 1	Group 2	Group 3
0.15	4		
0.2	4		
0.3	4		
0.6		4	
1.0		4	
1.5			4
2.0			4
3.0			4
Total	12	8	12

Micro-CT scanning after simulating external root resorption

After the preparation of the artificial cavity, each tooth was then removed carefully from the plaster and was referred to Micro-CT scanning again, using the same parameters as the first time Micro-CT scan.

Data processing and statistical analysis

All of the scanning data were saved in DICOM (digital imaging and communications in medicine) format. Mimics (version 10.0; Materialise, Leuven, Belgium) was used for tissue segmentation, 3-D reconstruction, and volumetric measurement. From CBCT data, the teeth were tissue segmented, and 3-D reconstructed, and the volumetric measurements were then performed. This method was described in detail in our pilot study (12). While from Micro-CT data, the teeth were 3-D reconstructed and the volumetric measurement was then performed directly. The 3-D images reconstructed from the CBCT data pre- and post-simulating different degrees of root resorption are shown in Fig. 1. Figure 2 shows the corresponding 3-D images reconstructed from the Micro-CT data.

The changes in the tooth volumes after the artificial cavities were made were then calculated. The accuracy of the volumetric measurement of the simulated root resorption cavities based on CBCT was evaluated in comparison with that of Micro-CT, which served as the reference method.

The reliability of the CBCT method was examined using the records of ten randomly selected subjects by repeating the tissue segmentation, 3-D reconstruction, volumetric measurement, and calculation of tooth volume changes, after a 4-week interval by the same investigator. The reliability was analyzed by calculating the method error using the formula proposed by Dahlberg (16):

$$\mathrm{ME} = \sqrt{\Sigma(x_1 - x_2)2}/2n$$

where x_1 is the first measurement, x_2 is the second measurement, and n is the number of repeated records.

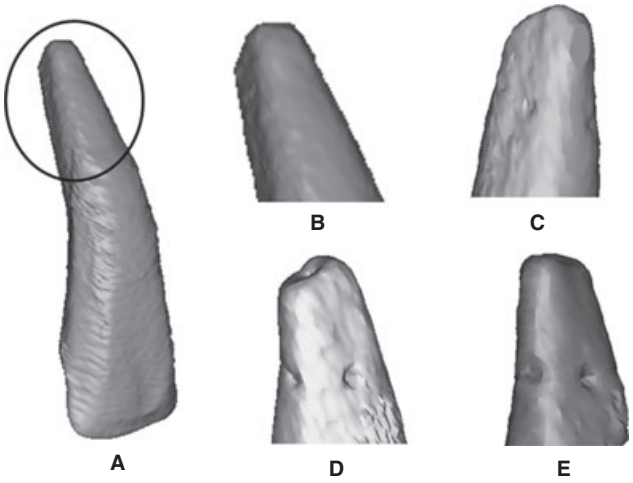

Fig. 1. (A) 3-D images of bovine teeth reconstructed from concordance correlation coefficient (CBCT) data. (B) Magnification of apex portion of the intact root. (C–E) Magnification of root apex portion of the first, second, and third group.

The concordance correlation coefficient (CCC) (17–19) was used to inspect the agreement of measurement of tooth volume changes by CBCT and Micro-CT methods. CCC was calculated as:

$$\mathrm{CCC} = \frac{2S_{12}}{S_1^2 + S_2^2 + (\overline{Y}_1 - \overline{Y}_2)^2}$$

$$S_{12} = \frac{1}{n}\sum_{i=1}^{n}(Y_{i1} - \overline{Y}_1)(Y_{i2} - \overline{Y}_2)$$

$$S_j^2 = \frac{1}{n}\sum_{i=1}^{n}(Y_{ij} - \overline{Y}_j), \quad j = 1, 2$$

$\overline{Y}_1$ and $\overline{Y}_2$ are the sample means of Y_1 and Y_2, respectively; n is the sample size.

The statistical analysis was processed with Microsoft Excel (Microsoft, Redmond, WA, USA) and SPSS (Release 13.0, standard version; SPSS, Chicago, IL, USA).

Results

The result of the reliability assessment of the method is shown in Table 2. A low method error (ME = 0.296 mm^3) was indicated. The volumes of the simulated root resorption lacunas of three groups calculated from micro-CT and CBCT data are presented in Tables 3–5.

Figures 3–5 show the data for the three groups when the results of teeth volume changes from

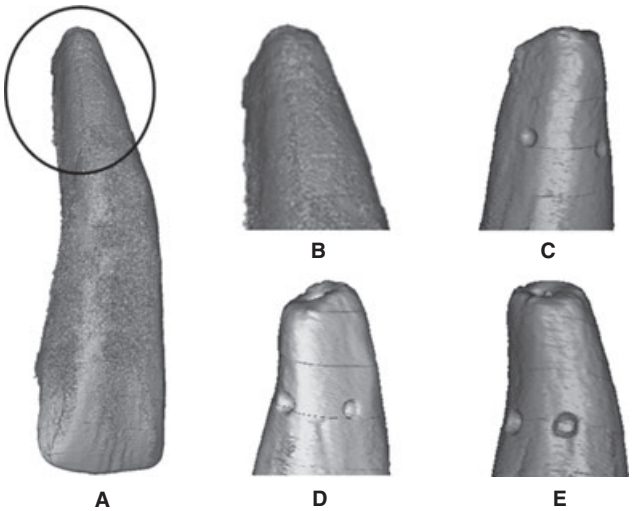

Fig. 2. (A) 3-D images of bovine teeth reconstructed from Micro-CT data; (B) Magnification of apex portion of the intact root; (C–E) magnification of root apex portion of the first, second, and third group.

CBCT method were plotted against those from Micro-CT method. The estimated regression line is drawn through the midst of the points, which has a slope of 0.370, 0.881, and 1.027, respectively. CCC1 is 0.098; CCC2 is 0.828; CCC3 is 0.895. The agreement for the group 1 (average volume of resorption cavity is 1.07 mm^3) between CBCT method and Micro-CT method was poor. For the groups 2 and 3 (average volume of resorption cavity was 3.47 and 6.73 mm^3, respectively), the agreements were fairly good.

Discussion

Methodologically, the best way to study the measurement accuracy of OIERR is to create root resorption lacunas by applying orthodontic force *in vivo*. Many studies have evaluated the relationship between orthodontic forces and root resorption. However, no definite conclusion has been reached regarding this issue (14, 20, 21). It is therefore difficult to control the degree of root resorption when orthodontic forces are applied *in vivo*. In this study, we chose to simulate different degrees of root resorption cavities precisely *in vitro*, referring to the criteria developed by Alqerban et al. (9).

Table 2. **Reliability analysis of the CBCT method**

First measurement (mm^3)	Measurement 4 weeks later (mm^3)	Method error
1.68	1.29	$ME = \sqrt{\Sigma(x_1 - x_2)2/2n} = 0.296\ mm^3$
2.06	2.49	
2.05	1.98	
3.56	3.84	
3.52	3.94	
5.95	5.12	
4.82	4.63	
7.01	7.45	
5.78	5.36	
8.18	8.32	
8.03	8.50	

Table 3. **Measurements of simulated root resorption lacunas by cone beam computed tomography (CBCT) and micro-computed tomography (Micro-CT) methods for group 1. All volumes in mm^3**

Depth of simulated root resorption cavity(mm)	CBCT (mm^3)	Micro-CT (mm^3)
0.15	2.05	0.45
0.15	0.94	0.39
0.15	1.65	0.56
0.15	1.97	0.64
0.2	2.08	0.82
0.2	1.68	1.22
0.2	1.90	0.94
0.2	2.70	1.07
0.3	2.06	1.38
0.3	1.94	1.31
0.3	1.83	2.23
0.3	2.05	1.82
Mean ± SD (mm^3)	1.90 ± 0.403	1.07 ± 0.56

Table 4. **Measurements of simulated root resorption lacunas by cone beam computed tomography (CBCT) and micro-computed tomography (Micro-CT) methods for group 2. All volumes in mm^3**

Depth of simulated root resorption cavity (mm)	CBCT (mm^3)	Micro-CT (mm^3)
0.6	2.39	2.68
0.6	2.60	2.40
0.6	3.56	2.71
0.6	3.98	3.43
1	3.65	4.04
1	5.20	4.90
1	3.52	4.10
1	4.01	4.49
Mean ± SD (mm^3)	3.56 ± 0.87	3.47 ± 0.93

In most studies related to simulating root resorption, a round bur was applied to simulate root resorption cavities (9, 22) because it could precisely simulate different degrees of irregular and three-dimensional root resorption cavities. These types of simulated cavities were fit in with the features of OIERR. Moreover, during ortho-

Table 5. **Measurements of simulated root resorption lacunas by cone beam computed tomography (CBCT) and micro-computed tomography (Micro-CT) methods for group 3. All volumes in mm^3**

Depth of simulated root resorption cavity (mm)	CBCT (mm^3)	Micro-CT (mm^3)
1.5	5.32	4.89
1.5	5.95	5.23
1.5	4.82	5.02
1.5	5.81	4.91
2	6.05	5.87
2	7.01	6.36
2	5.78	6.2
2	6.93	6.32
3	9.82	8.36
3	8.18	8.94
3	9.02	9.78
3	8.03	8.83
Mean ± SD (mm^3)	6.89 ± 1.56	6.73 ± 1.77

dontic treatment, the apex portion of the roots is the primarily affected area in OIERR because of the stress concentrated in the area. In this study, therefore, simulated root resorption cavities were also located at the apical portion of the root.

As Figs 4–5 show, the CBCT and Micro-CT methods demonstrated good agreement for groups 2 and 3, indicating the good accuracy of this CBCT method for these degrees of root resorption lacunas. For group 1, the agreement between the CBCT and Micro-CT results was low (Fig. 3), indicating that such kind of minimum volume loss is not able to be precisely calculated by this CBCT method, although this type of resorption cavity could be detected by CBCT (Fig. 1C). This might partly be explained by the systematic error existing in this CBCT method, particularly in the procedure of manual tissue segmentation, which was used to eliminate the artifacts resulting from the insufficient automatic tissue segmentation by the software. Although this type of systematic error is too small to affect the accuracy of the volumetric measurement of resorption cavities similar in size to those in groups 2 and 3, it is large enough to compromise

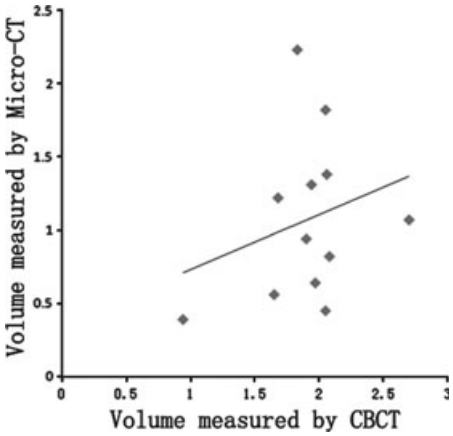

Fig. 3. A scatterplot of the results from two methods in group 1 (mean volume of the resorption cavity is 1.07 mm^3), which shows the agreement between the concordance correlation coefficient (CBCT) method and the Micro-CT method. The slope of the solid line is 0.370. If there were perfect agreement between the two methods, then the slope of the line should be close to 1.

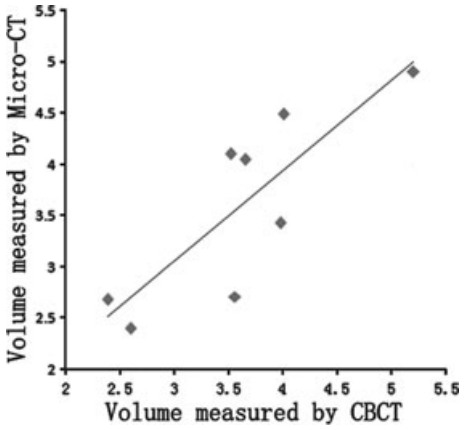

Fig. 4. The slope of the solid line for group 2 (mean volume of the resorption cavity is 3.47 mm^3), is 0.881, which is close to 1.

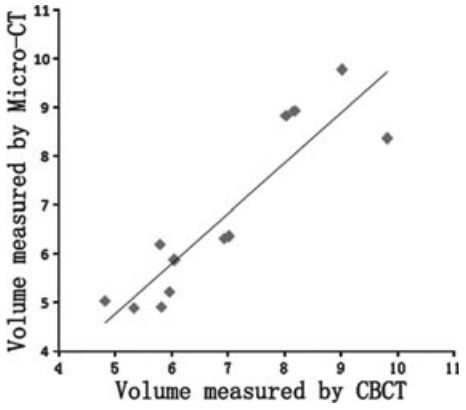

Fig. 5. The slope of the solid line for group 3 (mean volume of the resorption cavity is 6.73 mm^3), is 1.027, which is close to 1.

the accuracy of volumetric measurement of such kind of minimum root resorption cavities as small as in group 1 (average volume is 1.07 mm^3).With the improvement of the algorithm of software and the voxel size resolution of CBCT, the manual segmentation might not be needed any more. Consequently, the systematic error of this method could be decreased as minimum as possible, and the accuracy of this CBCT method might be improved enough to precisely calculate the volume of such minimum resorption cavities even though it is smaller than 1 mm^3.

In this study, we focussed on the measurement of simulated root resorption cavities, so a dentoalveolar CBCT scan (field of view: 60 × 60 mm) was sufficient. Because of the radiation exposure, CBCT cannot replace 2D-cephalograms or panoramic radiographs in pre- and post-orthodontic examinations. CBCT delivers a higher dose to the patient than panoramic and periapical radiography but a much lower dose than CT (23). CBCT, however, has advantages in the fields of 3-D cephalometry, assessment of impacted teeth and diagnosis of temporomandibular dysfunction. Improvements of CBCT devices may result in lower dose CBCT scanning and hence in its future use in pre- and post-orthodontic examinations.

The voxel size, artefacts, and image quality of CBCT may have influenced segmentation in this study. With the improvement of the voxel size resolution of CBCT, manual segmentation may become easier, and the accuracy of this method might be improved enough to precisely calculate the volume of much smaller resorption cavities. Liedke et al. (10) reported that three voxel resolutions (0.4, 0.3, and 0.2 mm) produced the same results for the diagnosis of cavities that simulate external root resorptions. However, this diagnosis was easier with the 0.3- or 0.2-mm voxel resolutions. The best radiographic examination should provide great diagnostic performance and lower patient exposure to X-rays. Further studies are still required. For studies about the etiology, pathology, and predisposing factors of OIERR, the improved accuracy of OIERR measurements may lead to more convincing conclusions. Therefore, the conventional qualitative or semi-quantitative methods should be replaced by more precise 3-D quantitative volumetric measurements, like the method we introduced in this study, although further studies are needed to improve the accuracy of this kind of volumetric measurement.

Conclusions

The 3-D quantitative volumetric measurement of external root resorption based on CBCT was introduced in this study. The accuracy of this method was fairly good in detecting simulated resorption cavities larger than 3.47 mm^3, but it was not sufficient for resorption cavities smaller than 1.07 mm^3. This 3-D quantitative volumetric measurement could be applied in future studies of OIERR, although further studies are still required to improve its accuracy.

Clinical relevance

External root resorption, which occurs around tooth roots irregularly and three-dimensionally (3-D), is a kind of volume loss. Precise 3-D quantitative measurement of volume changes pre- and post-orthodontic treatment should have greater power than the current qualitative or semi-quantitative methods. Therefore, in this study, the volumetric measurement of simulated root resorption based on CBCT was evaluated in comparison with that of Micro-CT, which served as the reference.

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