Vol. 128 No. 5 November 2019

Comparison of in situ cone beam computed tomography scan data with ex vivo optical scan data in the measurement of root surface area

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Objective. The aim of this study was to compare root surface area (RSA) measurements of single-root teeth in a sheep mandible based on cone beam computed tomography (CBCT) with measurements made with an optical scanner.

Study Design. Eight anterior teeth of a sheep cadaver mandible were scanned in situ by using CBCT with 3 different exposure parameters, followed by treatment with smoothing software. The teeth were then extracted and scanned individually with an optical scanner. Three-dimensional digital models of the teeth were reconstructed on the basis of CBCT and optical scanner data. RSA data were calculated, and an equivalence test was used to statistically compare the measurements with significance of difference established at $\alpha = 0.05$.

Results. The means of the differences between RSA measurements from CBCT and optical scanning ranged from 0.33% to 3.01%. There were no statistically significant differences between the 2 methods. The smoothing parameters for good fitness of the linear regression were determined to be 0.8 for the smooth factor, 8 for iterations, and 0 for compensate shrinkage.

Conclusions. The proposed CBCT technique to measure RSA is feasible. RSA data obtained from CBCT in situ are as accurate as optical scanner measurements ex vivo. (Oral Surg Oral Med Oral Pathol Oral Radiol 2019;128:552−557)

The contact area of a tooth root with its surrounding bone plays an important role in periodontal and prosthodontic therapies. It can help assess the severity of periodontal disease and the prognosis of treatment.[1,2] In addition, Ante's law is always considered when missing teeth are restored with fixed dental prostheses because the bony support over the root surface area (RSA) of abutment teeth is of clinical significance.[3,4] Klock et al.[5] used extracted permanent teeth to investigate the relationship between linear and area measurements of periodontal attachment loss and to determine the RSA on different tooth types. A moderate correlation (r = 0.78) between linear loss and area loss was determined for single-root teeth. The typical values of the RSAs of the permanent dentition were estimated on the basis of a meta-analysis of 22 published studies and reported to be between 65 cm^2 and 86 cm^2.[6] Pan et al.[7] compared the true thickness of the extracted single-root teeth with the thickness estimated from the digital image to estimate the RSA data. They concluded that the differences relied on the accuracy of the estimated thickness data from digital dental radiography. Yamamoto et al.,[8] using a dissecting microscope and image analysis software, reported that a linear function was the best fit for the net RSA measurement.

Gu et al.[9] used micro-computed tomography (micro-CT) data to measure RSAs on reconstructed digital models of extracted teeth and revealed that the data corresponding to attachment level were fitted to a linear function. Unfortunately, the micro-CT scan technique cannot be used in human patients for in situ examination because of the unacceptably high radiation exposure. Cone beam computed tomography (CBCT) has been widely used in dental practice since the 1990s.[10,11] CBCT collects data at high spatial resolution compared with multidetector CT and generates 3-dimensional (3-D) data at both lower cost and lower radiation exposure compared with micro-CT.[12] 3-D CBCT images show the surrounding bony support of tooth roots, and they can be reliable tools for diagnostic purposes.[13] Results from recent studies have proven that fields of view (FOVs), number of frames, and voxel size affect

Statement of Clinical Relevance

A technique for measuring root surface area in situ with cone beam computed tomography may be used in clinical practice to assess the severity of periodontal disease and to make treatment plans.

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Received for publication Nov 3, 2018; returned for revision Apr 27, 2019; accepted for publication May 13, 2019.

2212-4403/$-see front matter
https://doi.org/10.1016/j.oooo.2019.05.004

the diagnostic accuracy of CBCT images in clinical applications.[14–16] Pinheiro et al.[17] reported that the results of pericircumferential implant crestal bone defect assessment varied with FOVs and number of acquisition frames, as well as voxel dimensions. The 3-D digital model reconstructed from CBCT data was reported to have high linear, volumetric, and geometric accuracy in surface reconstructions of in vivo teeth.[18]

Sheep cadaver mandibles have been used for oral surgical procedure training[19] and implant osseointegration studies.[20,21] Compared with pig mandible, which is more commonly used, sheep cadaver mandible usually consists of well-developed anterior single-root teeth that are amenable to radiographic examination. The purpose of this study was to measure the RSAs of single-root teeth in situ by using CBCT and to assess the accuracy of these measurements in comparison with ex vivo optical scanner measurements of these teeth after extraction. The null hypothesis stated that there is no significant difference between CBCT and optical scanner measurements of RSAs.

MATERIALS AND METHODS

The study used a mandible with 8 intact anterior teeth from a freshly slaughtered sheep. The sample size was determined by a pilot study and power analysis and was calculated with $\alpha = 0.05$ and power = 0.90. It was determined that a sample of 4 specimens per group was needed for a 20% effect size change to represent a significant difference in RSA values. Scans of the sheep mandible with teeth in situ were obtained by using a CBCT scanner (NewTom VG, QR s.r.l., Verona, Italy), at 110 kV and 1.24 mA, with different combinations of FOVs and reconstructed layer thickness, as well as voxel size either 0.15 mm or 0.30 mm. All teeth were scanned 3 times with different exposure parameters:

Group 1: FOV = 12 cm × 8 cm; layer thickness = 0.30 mm

Group 2: FOV = 12 cm × 8 cm; layer thickness = 0.15 mm

Group 3: FOV = 8 cm × 8 cm; layer thickness = 0.15 mm.

Frames with 360 degrees of projection images were used for all groups.

The CBCT data were imported into the medical imaging software Mimics (Quotation Mimics 17.0; Materialise Dental, Leuven, Belgium). The contour of each tooth was determined manually from every 3 layers on the cross-sectional and sagittal plane images during segmentation of each tooth. The cementoenamel junction (CEJ) was determined and formed from the coronal plane images during segmentation of the crown and root portions separately. Furthermore, the *masks* (a term used in Mimics software for section selection) of the single-root tooth were assembled according to the selected boundary. The final 3-D objects were then calculated from the masks and smoothed. After segmentation procedures, the 3-D images of the surface of the crown and the root portion of each tooth were measured with the software (Figure 1). Initially, 3 parameters were set while being smoothed in the software: smooth factor, iterations, and compensate shrinkage. Altogether, there were 30 groups of data resulting from combinations of 0.5, 0.8, and 1 for the smooth factor, 4, 8, 16, 32, and 64 for iterations, and 1 (for yes) and 0 (for no) for compensate shrinkage. Linear regression analysis was performed to determine a set of optimal parameters to be used in the study. As a result of this analysis, the parameters selected to smooth the objects were: smooth factor = 0.8; iterations = 8; and compensate shrinkage = 0. The software could show only the surface area of the enclosed shapes but not the surface area of the crown and the root separately. Therefore, the crown and the root portions were divided along the CEJ on the objects by a fictitious truncation surface technique by using the software to separate the crown and root portions. The surface areas of the whole crown portion and the root portion, including the truncation surface area, could be measured with the software. The results of the truncation surface area (S_{S1}) and the RSA (S_R) were calculated and determined by using the following formulas:

$$S_{S1} = (S_{MC} + S_{MR} - S_{MT}) \times 1/2$$

$$S_R = S_{MR} - S_{S1}$$

where S_{MC} was the surface area of the crown object, S_{MR} was the surface area of the root object, and S_{MT} was the surface area of the whole tooth (Figure 2). All the measurements were made in duplicate by the 2 examiners, who were radiologists with more than 5 years of clinical experience. The measurements of the 2 examiners were averaged for data analysis. Cronbach's alpha value was calculated and used to determine the internal reliability between the first and second measurements for each individual examiner. The intraclass correlation coefficient was calculated to test the level of interexaminer reliability. Variance analysis was performed to compare the differences between the data obtained from the 3 tested groups of CBCT scan parameters.

After CBCT scanning and data analysis, the 8 mandibular anterior single-root teeth were extracted smoothly and atraumatically with forceps. The extracted teeth were immediately immersed in 5.25% sodium hypochlorite solution for 20 minutes to dissolve the residual soft tissue attached to the root surface (Figure 3). The clinical crown of each extracted tooth was embedded in baseplate wax with the CEJ and the root portion exposed (Figure 4). The root surfaces were coated by spraying them with a visible dye penetrant flaw detection material (Eco-Check ED-ST; Marktec Co., Tokyo, Japan) to facilitate the optical

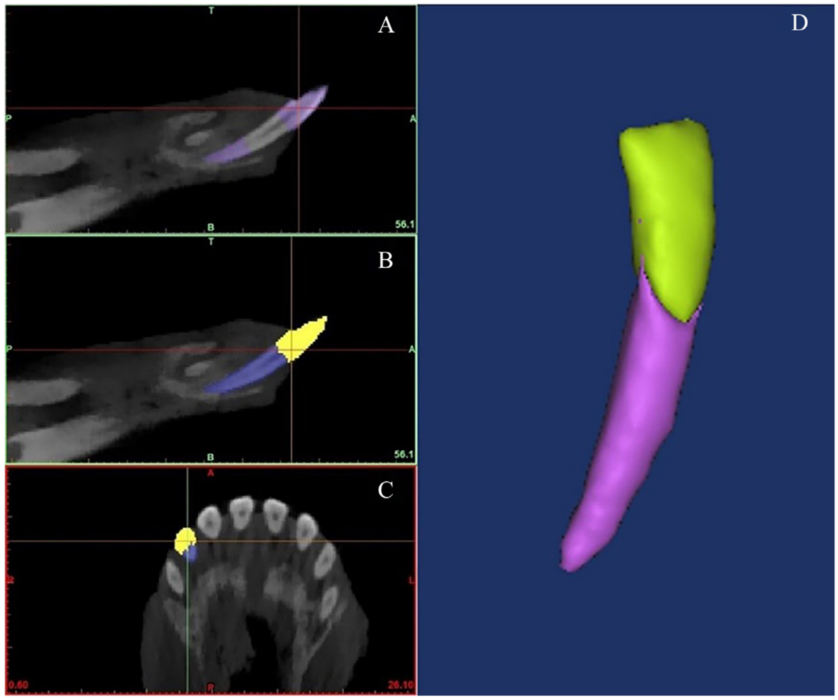

Fig. 1. Masks and images of crowns and roots. **A**, The cementoenamel junction (CEJ) was determined on the sagittal plane. **B**, Masks of the crown and root on the sagittal plane. **C,** Masks of the crown and root on the axial plane. **D**, The 3-dimensional object consists of a crown and a root.

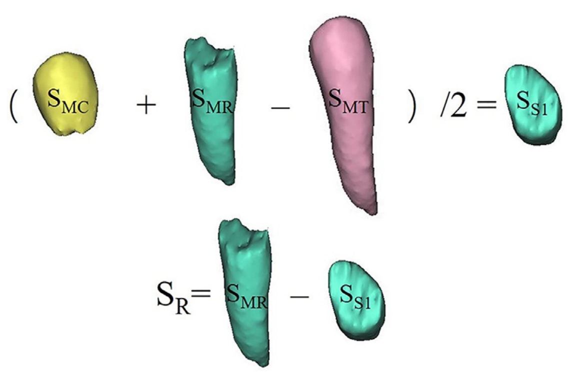

Fig. 2. Schematic drawing of the calculation of root surface area measured by cone beam computed tomography. S_{MC}, surface area of the crown object; S_{MR}, surface area of the root object; S_{MT}, surface area of the whole tooth; S_{S1}, truncation surface area; S_R, root surface area. The calculation used the following formulas: (1) $S_{S1} = (S_{MC} + S_{MR} - S_{MT})$ (2) $S_R = S_{MR} - S_{S1}$.

Fig. 3. The extracted mandibular anterior teeth after cleaning with 5.25% sodium hypochlorite solution for 20 minutes.

scanning procedures. Each tooth specimen was scanned with a 3-D optical scanner (Smart Optics 880; Smartoptics, Bochum, Germany), with scanning accuracy set at 0.01 mm. Optical scanner data were collected and imported into the software Geomagic Studio & Qualify 2012 (Raindrop Geomagic Co., Morrisville, NC) to construct a 3-D digital model (Figure 5). The RSA of each tooth was measured and used as a control and coded as S_T.

Statistical analysis was performed with the software SPSS v. 20.0 (SPSS Inc., Chicago, IL). An equivalence test was designed to compare the S_T and S_R values. The confidence interval method was used to evaluate the equivalence. Equivalence bounds were set at ± 5%, with $\alpha = 0.05$.

RESULTS

Raw data of S_R and S_T values are listed in Table I. The 95% confidence intervals of $(S_R - S_T) / S_T \times 100\%$ were calculated and are presented in Table II. The 95% confidence intervals and equivalence bounds (± 5%) were compared, and the results of all 3 tested groups were within the −5% to +5% range. A dependent variable, *y*, was defined as the difference between S_R and S_T. The smoothing parameters—smooth factor (a), iterations (b), and compensate shrinkage (c)—were then used as independent variables. Multiple linear

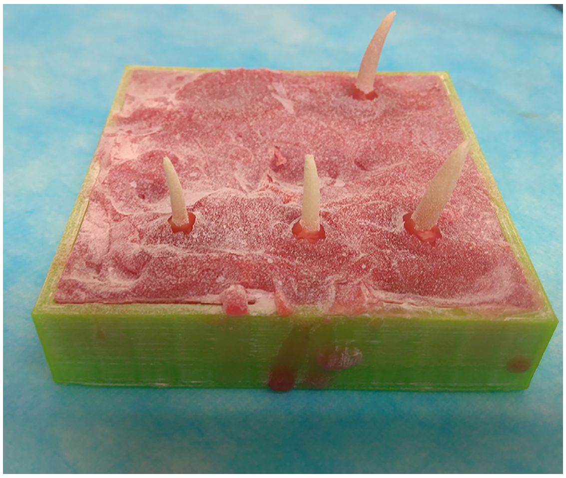

Fig. 4. The crown portions of extracted single-root teeth embedded in wax, with the root portions exposed.

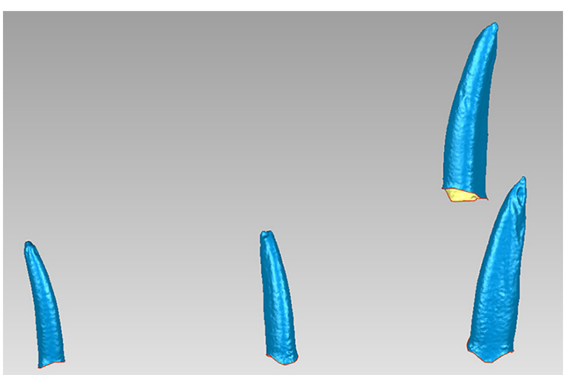

Fig. 5. Digital models of roots constructed by the 3-dimensional optical scanner and software.

regression analysis using the stepwise method was performed, and the regression equation with the best fitness results is shown below with R = 0.875.

$$y = -17.187\,a - 0.513\,b + 35.516\,c + 11.023$$

Factors were determined as: a = 0.8; b = 8; and c = 0. The means of the difference between S_R and S_T ranged from 0.33% to 3.01%, as shown in Table II. In the equivalence test, the intraexaminer correlation test determined the Cronbach's alpha value to be 0.997, and the interexaminer correlation test showed a correlation coefficient value of 0.995. Variance analysis of compatibility design was performed for the tested groups. The results indicated that there were no statistically significant differences ($F = 0.021$; $P = .979$) between the results of the CBCT technique using combined FOVs and reconstructed layer thickness parameters and the results from the optical scanner in assessing the RSAs of single-root teeth.

Table I. Data measured with CBCT in situ (S_R) and optical scanner (S_T)

No.	*S_R (mm^2)*			*S_T (mm^2)*
	Group 1	*Group 2*	*Group 3*	
1	138.13	137.93	135.73	135.24
2	120.44	123.61	118.64	119.77
3	94.82	95.678	91.69	91.71
4	71.64	72.94	72.50	72.82
5	140.40	139.80	135.87	140.18
6	125.45	124.37	120.59	119.21
7	85.16	91.72	91.93	87.96
8	71.98	73.78	70.31	69.54

$F = 0.021$; $P = 0.979$, variance analysis between group 1, group 2, and group 3.
CBCT, cone beam computed tomography; *S_R,* root surface area measured by CBCT in situ; *S_T,* root surface area measured by optical scanner in vitro.

DISCUSSION

Various factors may influence the accuracy of the 3-D model construction based on CBCT scan data, such as FOV size, voxel thickness, number of frames, tube voltage, and amperage.[22] Proper selection of CBCT acquisition parameters to evaluate the periodontal condition of abutment teeth, including RSA measurement, requires a balance between optimal image quality and radiation dose.[17] Combinations of different exposure parameters were assessed in this study. Using this sheep model with commonly employed parameters of FOV, voxel size, and number of frames, 3-D model images constructed from CBCT in situ data demonstrated equivalent quality compared with optical scanner ex vivo images for measurement of RSAs of single-root teeth. High accuracy for smooth parameter settings in measurement by CBCT was found with a relatively low RSA discrepancy for group 3 (FOV = 8 cm × 8 cm; voxel size = 0.15 mm; 360 frames) compared with the optical scanner ex vivo measurement. Pinheiro et al.[17] reported significantly better peri-implant bone loss detection and good intra- and interobserver agreements for CBCT imaging with the use of the smallest FOV (4 × 4 cm), the smallest voxel size (0.08 mm), and the maximal number of projection images (1009 frames) compared with 2 alternative protocols: (1) the same FOV and voxel size, but a reduced number of projection images (512 frames); and (2) similar frame numbers but a larger FOV (14 × 5 cm) and voxel size (0.25 mm). In the present study, we used a fixed number of projection images (360 frames) for all experimental groups. Sang et al. assessed the accuracy of 3-D reconstructions of ex vivo teeth from CBCT data and found that a smaller voxel size and a fixed FOV (12 × 8 cm) obtained significantly smaller differences in tooth length between the 3-D reconstruction model and the physical measurement.[18] In addition, different CBCT devices using the

Table II. Results of root surface area measurement by CBCT and optical scanner

	Mean of $(S_R - S_T)/S_T$ *(%)*	*Standard deviation of* $(S_R - S_T)/S_T$ *(%)*	*95% confidence intervals of* $(S_R - S_T) / S_T$	
			Lower limit (%)	*Upper limit (%)*
Group 1	1.28	2.83	−1.09	3.64
Group 2	3.01	2.22	1.16	4.87
Group 3	0.33	2.16	−1.47	2.13

CBCT, cone beam computed tomography; S_R, root surface area measured by CBCT in situ; S_T, root surface area measured by optical scanner in vitro.

same voxel size with various FOVs, tube voltages, and tube currents resulted in significant differences in the linear measurements of 3-D reconstructed models.

CBCT has been used for implant osseointegration and periodontal defect assessments.[16,23,24] Kamburoglu et al.[23] tested the influence of various FOVs in the detection of peri-implant defects and compared their results with those from studies with the identical device and FOV sizes. They concluded that there was no difference in detection rates among the various FOV sizes. In our investigation, the major difference between group 2 and group 3 was the FOV size of 12 × 8 cm and 8 × 8 cm, respectively. The RSA measurement data from group 2 and group 3 were determined to be equivalent, a finding that is consistent with the conclusion reported by Kamburoglu et al.[23]

The diagnostic efficacy of CBCT images may be influenced by voxel size because decreasing the spatial resolution with larger voxel sizes will generate less detailed anatomic information, more noise and artifacts, and a lower-quality image.[18] Kolsuz et al.[24] concluded that a voxel size of 0.15 mm should be considered as the cutoff value for assessment of periodontal defects when using CBCT. Pinheiro et al.[17] obtained acceptable results with a voxel size of 0.25 mm regardless of the FOV protocol used in their peri-implant bone loss ex vivo study. Sang et al.[18] used CBCT to reconstruct 3-D tooth models for linear measurement and found that increasing the voxel size from 0.15 mm to 0.30 mm to construct a 3-D model did not result in increased accuracy of measurement. The results of the RSA measurements from group 1 and group 2 are consistent with the results from Sang et al.[18]

Each of the exposure protocols used in the present investigation produced potentially different radiation doses because of the different CBCT acquisition parameters. According to the manufacturer's computed tomography (CT) dose index for exposure, group 1 and group 2 had the same radiation exposure of 1.67 mGy, and group 3 had the lowest radiation exposure of 1.37 mGy, with all groups operating at a tube voltage of 110 kVp and an amperage of 1.24 mA. Pinheiro et al.[17] used 90 kVp and 5 mA with 3 protocols to investigate peri-implant bone loss in vitro. The radiation exposure ranged from 4.6 mGy to 17.6 mGy, which was 3 to 10 times higher than that in the present study.

To construct an optimal and accurate 3-D model to measure the RSA of a single-root tooth from CBCT in situ data, different combinations of smooth factor, iteration, and compensate shrinkage parameters were tried, and 30 groups of data were evaluated after calculation. The main purpose of this study was to validate the RSA measurement data and to compare them with optical scanner ex vivo measurement data. We found no previous studies providing effective data or parameters for the protocols used in this investigation. Gu et al.[25] used micro-CT to measure the total RSA of extracted permanent teeth and determined that the linear function fit perfectly in relating the mean root volume to the mean total RSA value for different types of permanent teeth.

Sonmez et al.[26] explored the accuracy of measurements of artificial external root resorption cavities through CBCT examination of ex vivo specimens. In that investigation, teeth with artificially created lesions were positioned in the alveolar sockets of a dry human skull with 1.5-cm thick wax covering the bone, acting as a soft tissue equivalent. The periodontal ligament space, hard tissue, and soft tissue were quite different from those encountered in clinical practice. In the present study, teeth were taken from cadaver mandibles with soft tissue on the bone, which more closely approximated a realistic clinical situation.

One of the major limitations of this study is that it used an animal model design (a sheep cadaver mandible and its mandibular anterior teeth) for investigating and measuring the RSA values. The thickness, density, and contour of the periodontal hard and soft tissues may not be the same as human tissues. In addition, a protocol for measuring posterior teeth with multiple roots should be different from measuring a single-root tooth. However, according to the results of this study, the CBCT in situ measurements of the RSA covered by alveolar bone did not differ significantly from the optical scanner ex vivo measurements.

CONCLUSIONS

This study proposed a method for measuring the RSA of single-root teeth in situ with CBCT imaging and determined a set of appropriate parameters to maximize accuracy. On the basis of the findings of this study, the following conclusions were drawn:

1. Data from CBCT in situ RSA measurements were not significantly different from those from the optical scanner ex vivo RSA measurements.
2. The sheep cadaver model provides a feasible and reproducible RSA measurement of single-root teeth with CBCT.

ACKNOWLEDGMENTS

The authors would like to thank the members of the Department of Periodontology, Radiology and National Engineering Laboratory for Digital and Material Technology of Stomatology, for their help in the current investigation. The technical assistance of Dr. Yushu Liu in performing the 3-D model is highly appreciated. We also acknowledge the help from Dr. Xinyue Zhang, Dr. Huifang Yang, Dr. Tao Wang, Dr. Yiping Wei, and Miss. Zichen Zhang.

FUNDING

This study was supported by research grants from Capital Medical Development and Research Fund, PRC (2011-4025-04) and National Natural Science Foundation of China (No:61876005).

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