Comparing the diagnostic efficacy of intraoral radiography and cone beam computed tomography volume registration in the detection of mandibular alveolar bone defects

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Objectives. The aim of this study was to (1) compare bone loss detection accuracy with intraoral radiography and registered cone beam computed tomography (CBCT); (2) assess repeatability with both modalities; (3) determine factors affecting defect detection; and (4) determine the effect of buccolingual bone thickness on defect detection.

Study Design. Six observers viewed intraoral radiographs and CBCT scans before and after the defect to determine defect presence and extent. Receiver operating characteristic (ROC), sensitivity, specificity, logistic regression, odds ratio, intraclass correlation coefficient, and weighted kappa were used.

Results. CBCT and intraoral radiography mean ROC area under the curve values were not statistically different (0.90 vs 0.81; $P = .06$). CBCT had higher sensitivity compared with intraoral radiography (0.85 vs 0.63; $P = .01$) but similar specificity (0.91 vs 0.84; $P = .45$). Bone thickness, imaging modality, and observer had significant effects on defect detection ($P < .001$). Odds ratios for CBCT vs intraoral radiography were 2.29 for diagnostic accuracy and 1.52 for buccolingual bone thickness. There was moderate interobserver agreement for detection of defects and substantial intraobserver agreement for measurement of extent.

Conclusions. CBCT showed equivalent diagnostic efficacy and specificity for defect detection and higher sensitivity compared with intraoral radiography. CBCT increases the odds of accurate defect assessment more than 2-fold compared with intraoral radiography. The odds of bone loss detection increase by approximately 50% per millimeter of buccolingual alveolar bone loss. (Oral Surg Oral Med Oral Pathol Oral Radiol 2019;128:176−185)

Chronic periodontitis affects millions of Americans. Mild, moderate, and severe forms affect 1 in every 2 adult Americans age 30 years or greater. Among adults age 65 years or greater, the prevalence increases to 70.1%.[1] A number of diagnostic markers are used to determine the presence and severity of periodontitis. One of these markers is the amount of alveolar bone loss resulting from inflammatory mediators in the periodontal tissues. The presence and extent of alveolar bone loss as well as the rate of change in bone levels are important diagnostic and prognostic markers. Traditionally, dentists monitor alveolar bone levels by using intraoral radiography as an adjunctive diagnostic tool, along with both probing of pocket depth, measurement of attachment level, and other clinical parameters. Although inexpensive and easy to use, intraoral radiography is limited in its diagnostic ability because it does not offer the ability to assess bone defects in 3 dimensions and is not very sensitive for detecting mild demineralization of hard tissue. A substantial amount of bone loss or bone demineralization must be present (30%−50%) before it can be detected on an intraoral radiograph.[2-5] Furthermore, the buccolingual width of the defect cannot be visualized or quantified. Two-dimensional (2D) imaging is hindered by superimposition, which may mask bone defects, particularly those containing walls of bone buccal and lingual to the defect.

Although it is typical for clinicians to compare intraoral radiographs at 2 different time points side by side, this

Statement of Clinical Relevance

Registration of cone beam computed tomography scans provides a novel way to assess alveolar bone changes surrounding teeth with periodontal defects. Superimposition of the scans aids in visualizing the location and extent of demineralization in 3 dimensions without the need for rigid patient positioning.

Early data analysis results were presented in poster format at the American Academy of Oral and Maxillofacial Radiology Annual Sessions meeting at Scottsdale, AZ, September 29, 2016.

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is a challenging cognitive task further hampered by lack of standardization. Digital subtraction radiography was developed to improve detection sensitivity and defect quantification. Alveolar bone mineralization changes as small as 5% can be detected with this modality.[6,7] To obtain a digital subtraction image, 2 serial intraoral radiographs with near-identical projection geometry, image density, and image contrast are registered.[8,9] Exact reproduction of the projection geometry leads to the best subtraction results; however, a small margin of error can be tolerated.[10] Although reproduction of the projection geometry and image density improve the reliability of serial assessments and are prerequisites for the success of digital subtraction radiography, it takes time and effort to meet these requirements.[11] Thus, the application of digital subtraction radiography in dentistry has been limited to research studies and is not being used in clinical practice.

Cone beam computed tomography (CBCT) provides a 3-dimensional (3D) view of the maxillofacial complex. CBCT is able to provide improved visualization of the periodontal ligament space compared with traditional intraoral radiography.[12] Visualization of periodontal bone defects in 3 dimensions can be valuable because it has been shown that the healing of these defects is highly dependent on defect anatomy, such as those contained within bone (3-wall) vs those involving the facial or lingual cortical plates (2- or 1-wall defects). Therefore, developing the surgical plan and choosing periodontal regenerative materials that yield the most optimal outcome is predicated on an accurate examination of the defect's anatomy.[13]

Recent advancements in CBCT software allow for 3D assessment of bone changes over time, and this has implications for multiple areas of dentistry. This is achieved by superimposing CBCT scans, a process known as *3D volume registration*. The process of registration overlays the second scan on top of the first, thus allowing the clinician to view both scans simultaneously or to toggle between the 2 scans. Viewing registered CBCT scans is somewhat similar to digital subtraction radiography in that this facilitates superimposition of radiographic data. However, for 3D volume registration, there are no additional prerequisites for image acquisition because the projection geometry is reproduced accurately from the first scan to the next. The technique of CBCT volume registration can be accomplished in a matter of minutes, making it a viable option in clinical practice. Registered volumes have the potential to provide more accurate and comprehensive information to clinicians and can have implications for multiple areas in dentistry. It is hypothesized that the registration of 2 CBCT volumes from different time points can yield greater sensitivity in the detection and visualization of alveolar bone defect.

The objectives of the present study were to (1) compare bone loss detection accuracy with intraoral radiography and registered CBCT; (2) assess repeatability of detection with both modalities; (3) determine factors affecting defect detection; and (4) determine effect of buccolingual bone thickness on defect detection. The null hypothesis stated that there were no significant differences between intraoral radiography and CBCT for any of these parameters.

MATERIALS AND METHODS

An ex vivo model was used to simulate clinical conditions as closely as possible while controlling the actual changes of the specimens. Institutional review board approval (No. 15-1771) was obtained to collect deidentified, dried human mandibles and carry out observation sessions at the University of North Carolina at Chapel Hill School of Dentistry (Chapel Hill, NC). The study followed the guidelines set forth by the Helsinki Declaration. Twenty-two mandibles were collected. Each mandible was assessed visually to determine the presence of molar and premolar teeth. Mandibles that were edentulous, containing only anterior teeth, teeth broken up to the alveolar crest, or teeth with large metallic restorations that could induce metal artifacts in the CBCT scan were excluded from the study. After the exclusion process, 14 mandibles were identified to be used for this study. To simulate the attenuation characteristics of soft tissue, each mandible was covered with Play-Doh (Hasbro, Inc., Pawtucket, RI) at approximately 0.5 cm thickness around alveolar bone, ascending ramus, and tongue space before predefect and postdefect imaging (Figure 1). This material has been shown to have radiographic attenuation characteristics that closely resemble those of soft tissue.[14]

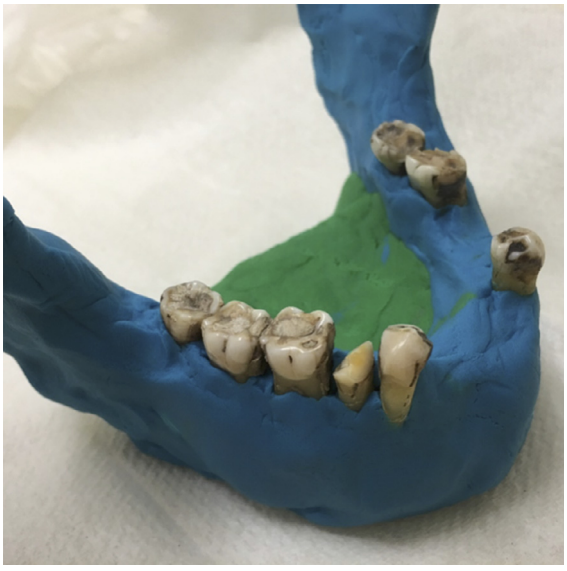

Fig. 1. Photograph of a dried mandible with Play-Doh, which is a soft tissue equivalent material.

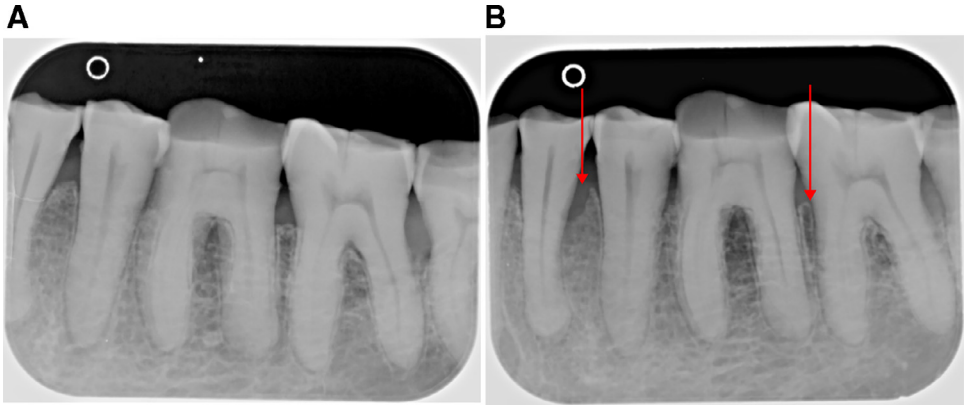

Fig. 2. Intraoral radiographs of the same site predefect **(A)** and postdefect **(B)**. In the postdefect radiograph, the left red arrow points to notable bone loss distal to tooth #21. The right red arrow points to bone loss mesial to tooth #18, which remains obscured by anatomic superimposition and greater buccolingual bone thickness.

The mandibles were imaged with an intraoral imaging modality and with CBCT before defect preparation and after defect preparation. Photostimulable phosphor plates (PSPs) (Gendex, Hatfield, PA) were used to produce the intraoral images. Premolar and molar intraoral radiographs were acquired with a size-2 PSP plate stabilized in the Play-Doh before (Figure 2A) and after (Figure 2B) defect creation. Intraoral radiographs were acquired with a Focus X-ray source (Instrumentarium Dental, Tuusula, Finland) at 70 kVp, 8 mA, 0.32 seconds, and 40-cm source-to-image receptor distance by using a rectangular beam limiting device. Because only mandibles were imaged, a bitewing XCP (Extension Cone Paralleling) device was not used to stabilize the PSP plate with opposing dentition. The central X-ray beam was projected perpendicular to teeth, similar to a bitewing radiograph projection, such that alveolar bone between adjacent teeth could be adequately visualized. Imaging stents traditionally used in studies involving preoperative and postoperative radiographs were not used, but care was taken to closely mimic the projection geometry between the preoperative and postoperative images. Stents were not used so that a typical clinical situation could be mimicked, similar to previous studies.[15] The exposed PSP plates were scanned in a ScanX IO ILE scanner (Air Techniques, Melville, NY) at a resolution of 18 lp/mm via the MiPACS Dental Enterprise Viewer 3.1.1401 operating ScanX Plugin Version 1.2.8 (Medicore Imaging, Charlotte, NC).

CBCT scans of each mandible were then acquired by using the Orthophos XG 3D CBCT unit with an 8×8 cm field of view at 85 kV, 7 mA, and 14.3 seconds (Dentsply Sirona, Inc., Long Island, NY). Each mandible was placed on a round imaging platform, which fit into the CBCT field of view. A foam block was used to raise the mandibles above the metallic platform to prevent metal artifacts. The CBCT volumes, with a 0.3-mm isotropic voxel size, were exported as Digital Imaging and Communications in Medicine files from the Dentsply Sirona Sidexis software.

Potential sites for periodontal defects included the mesial and distal surfaces of each molar and premolar tooth. These locations were logged into an Excel 2013 spreadsheet (Microsoft Corp., Redmond, WA) and totaled 75 sites (Table I). A random number generator program in Excel was used to determine which sites would serve as control sites (no bone loss) and which sites as experimental sites (periodontal bone defect). A total of 34 control sites and 41 experimental sites were identified for the purpose of this study. Bone defects between 2.5 mm and 10 mm were created in the experimental sites by an experienced periodontist (A.J.M.), using a diamond-tipped bur and air-driven handpiece. Each defect left the facial and lingual cortical plates intact. The defects were then measured with a UNC-15 periodontal probe to the deepest portion of the defect (Figure 3A). No defects that were smaller than 2.5 mm were created because a connective tissue attachment of approximately 2 mm exists between the most inferior portion of a periodontal pocket and the most inferior portion of a periodontal bone defect.[16] Defect depths of less than 2 mm may not extend apically to the level of the alveolar crest and would not be considered an intrabony defect; therefore, these depths were not used in the present study. The ground truth of presence or absence of the created defects, as well as their measured depths, was recorded. The facial and lingual bone thicknesses of the walls surrounding the defects

Table I. Alveolar bone defect ground truth

0 mm (no defect)	34
0–2.4 mm	0
2.5–4.9 mm	11
5–7.4 mm	27
7.5–10 mm	3
Total	75

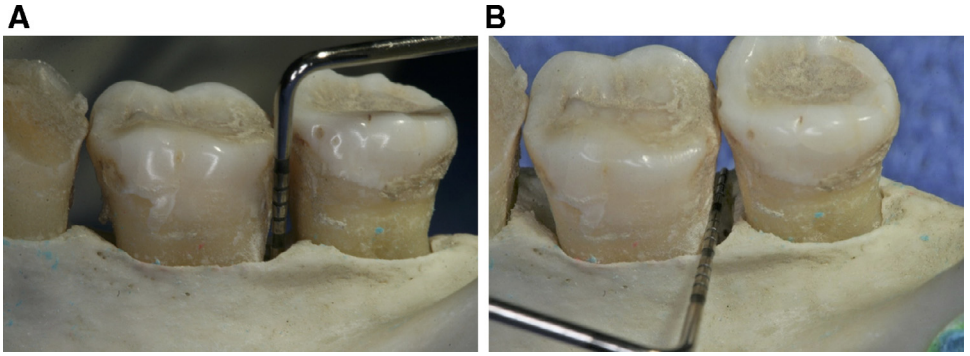

Fig. 3. Measuring the alveolar bone defect depth **(A)** and width of the facial and lingual bone **(B)** clinically with a UNC-15 periodontal probe.

were then measured at the level of the crestal bone perpendicular to the cortical plates (Figure 3B).

After creating the alveolar bone defects, the soft tissue equivalent material was readapted to the mandibles and a postdefect series of radiographs with the use of PSP plates and a CBCT scan were acquired for each mandible. The CBCT scans were registered with InVivo software version 5.4.5 (Anatomage, San Jose, CA), using a combination of 2 registration techniques. With use of the InVivo (Anatomage, San Jose, CA) point-based registration method, at least 5 landmarks on the 3D predefect mandible were manually selected, and those same landmarks were selected on the postdefect mandible as well. These points were then used by the software to register the predefect and postdefect CBCT scans. Surface-based registration, the second registration option in the InVivo software (Anatomage, San Jose, CA), was then used to automatically match the rendered surfaces of both predefect and postdefect mandibles to further minimize their distances (Figures 4A and 4B).

Six observers were recruited to analyze the images. All observers had several years of training in oral and maxillofacial radiology and clinical experience in assessing alveolar bone levels on radiographs. Five of the observers were oral and maxillofacial radiology residents, and 1 observer was a board-certified oral and maxillofacial radiologist. An orientation session was provided to review the study's purpose, various bone morphology characteristics, methods to use the MiPACS viewing software (Medicore Imaging, Charlotte, NC) and to view the registered CBCT volumes with the InVivo software (Anatomage, San Jose, CA), and the proper use of a 5-point confidence rating scale. Informed consent was obtained from the observers before the orientation session.

The observers were asked to indicate their confidence regarding the presence or absence of alveolar bone loss between the images from time point 1 and

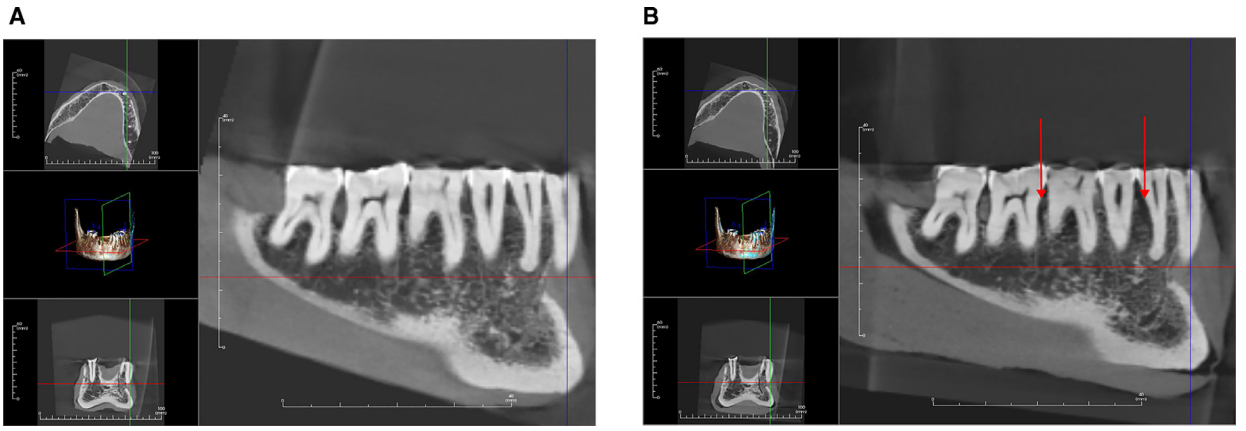

Fig. 4. **A,** Superimposition window in Anatomage Invivo v. 5.4.5, with registered cone beam computed tomography (CBCT) scans showing the same quadrant as in Figures 2A and 2B without bone defects. **B,** Superimposition window in Anatomage Invivo v. 5.4.5, with registered CBCT scans showing the same quadrant as in Figures 2A and 2B with alveolar bone defects mesial to tooth #18 and distal to tooth #21 *(red arrows)*. The defect mesial to tooth #18 was not visualized on the 2-dimensional radiograph. Defect depth mesial to tooth #18 was 5 mm with a remaining buccolingual bone wall thickness of 5 mm. Defect depth distal to tooth #21 was 6 mm, with a remaining buccolingual bone wall thickness of 3.5 mm.

the images from time point 2 by using the following Likert scale: 1 = definitely no bone loss; 2 = probably no bone loss; 3 = unsure if bone loss is present or absent; 4 = bone loss probably present; and 5 = bone loss definitely present. The observers recorded their answers on an anonymized score sheet. This process was completed for the intraoral radiographs and then for the registered CBCT volumes. All images and CBCT volumes were randomized, and the observers viewed the intraoral images first and then the registered CBCT volumes with a washout period of at least 2 weeks. Randomization of images and the washout period helped mitigate any order or recognition bias.

In a dimly lit radiology reading room, the observers viewed the time point 1 and time point 2 intraoral radiographs simultaneously on workstations with Lenovo LT2252p dual monitors (Lenovo, Beijing, China) by using MiPACs Dental Enterprise Viewer 3.1.1401 software (Medicore Imaging, Charlotte, NC). Registered CBCT volumes were examined under the same ambient light conditions on a Lenovo W540 ThinkPad (Lenovo, Beijing, China) by using the Superimposition feature of the InVivo software (Anatomage, San Jose, CA) (see Figures 4A and 4B). A TCG-18 test pattern quality control check was performed on each of the monitors before the observation sessions to ensure adequate brightness and contrast. The principal investigator was on site during all observation sessions to answer any questions that arose. After a washout period of 2 to 3 weeks, each observer viewed approximately half of the images a second time to calculate intraobserver agreement.

The observers' scores and ground truth data were used to create receiver operating characteristic (ROC) curves utilizing a web-based ROC analysis computer program from Johns Hopkins University School of Medicine (www.jrocfit.org). Area under the curve (AUC) values were obtained, and sensitivity and specificity were calculated in Excel. For detection of the presence of alveolar bone loss, a response of 4 or 5 was considered a positive response. A response of 1, 2, or 3 was considered a negative response. Differences between the sensitivity and specificity of the 2 modalities were analyzed by using paired *t* tests. To assess the effect of modality, bone thickness, and observer on defect detection and quantification in 1 model, a type 3 analysis of effects (logistic regression) was conducted with the Wald test, which also allowed for calculation of odds ratios. Intraclass correlation coefficients were calculated as a measure of overall agreement among the 3 observers. For intraobserver agreement, linear weighted kappa values were computed for each observer. Intraobserver agreement and logistic regression were performed by using SAS software version 9.4 (SAS Institute, Inc. Cary, NC). A P value of $< .05$ was considered statistically significant.

RESULTS

The ROC AUC for alveolar bone loss detection was 0.90 for CBCT and 0.81 for intraoral radiography, which was not significantly different ($P = .06$). The ROC curves derived from pooled observer data for CBCT and intraoral radiography are depicted in Figure 5. CBCT had a significantly higher sensitivity (0.85) compared with intraoral radiography (0.63) ($P = .01$). The difference in specificity between CBCT and intraoral radiography (0.91 and 0.84, respectively) was not statistically significant ($P = .45$; Table II).

Bone thickness, imaging modality, and observer all had a significant effect on the ability to detect bone loss ($P < .001$) (Table III). Type 3 analysis of effects showed a statistically significant difference in the detection of bone loss between the 2 imaging modalities after controlling for observer and bone thickness ($P < .001$) (see Table III). The odds ratio for CBCT vs intraoral radiography was 2.29, and for buccolingual bone thickness, it was 1.52 (Table IV).

The interobserver reliability for CBCT bone loss detection and defect size assessment, as measured by the intraclass correlation coefficient, was 0.59 and 0.56, respectively. For intraoral radiography, the values were 0.56, and 0.58, respectively (Table V). The average intraobserver agreement, measured by weighted kappa values, was 0.62 both for the detection of bone loss and for defect size assessment in CBCT scans, which indicates substantial agreement (Tables VI and VII). The intraobserver average weighted kappa value for detection of bone loss and defect size assessment on intraoral radiography was 0.52 and 0.59, respectively. Both values indicate moderate intraobserver

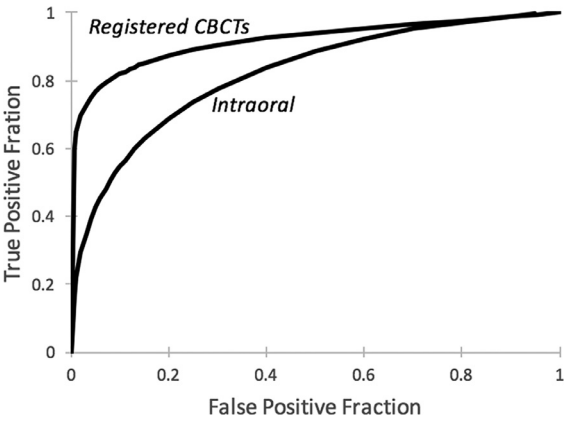

Fig. 5. Receiver operating characteristic (ROC) curves based on pooled data from registered cone beam computed tomography (CBCT) scans and intraoral radiographs for detection of alveolar bone loss.

Table II. Receiver operating characteristic (ROC) area under the curve (AUC), sensitivity, and specificity based on pooled data with paired *t* tests

Imaging modality	*AUC*	*Sensitivity*	*Specificity*
Registered cone beam computed tomography (CBCT) scans	0.90	0.85	0.91
Intraoral radiographs	0.81	0.63	0.84
Paired *t* test			
Mean difference	0.09	0.21	0.07
Standard deviation	0.09	0.12	0.21
P value	.06	.01	.45

Table III. Type 3 analysis of effects

Effect	*Wald's χ^2 test*	*P value*
Buccolingual bone thickness	30.64	<.0001
Imaging modality	15.24	<.0001
Observer	66.27	<.0001

agreement (see Tables VI and VII). Differences in the tests for equal kappa coefficients were not significant for 5 of the 6 observers ($P > .08$) (see Tables VI and VII). There were significant differences ($P < .01$) between CBCT and intraoral radiography for Observer 5 in both bone loss detection and defect size (see Tables VI and VII).

DISCUSSION

Posterior interdental areas of the maxilla and the mandible are challenging for patients to keep biofilm-free, and this leads to an increased risk for persistent inflammation and consequent loss of alveolar bone. The broad, flat architecture of the posterior interdental bone between mandibular molars may predispose the area to formation of an osseous crater. Craters are contained by the mandible's thick cortical plates, which may preclude their discovery with intraoral radiographic examination. Additionally, soft and hard tissue vasculature may easily allow inflammatory factors to enter the area.[17-19] In the present study, defects that did not penetrate the cortical plates were created. The reason for this was 2-fold: (1) These defects are generally more difficult to detect radiographically because demineralization is difficult to ascertain before cortical plate involvement, and (2) one of the aims of the study was to determine the amount of buccolingual bone loss that must occur before defects are visualized with 2D imaging.

The average AUC value for CBCT was larger than that for intraoral radiography, but the difference was not statistically significant. The lack of statistical difference may be attributed to the relatively small number of observers and the variability among the observers. It should also be noted that the average AUC value for intraoral radiography was high. This may have been the result of the way in which the defects were created or because of the controlled, benchtop conditions of this study, which do not fully compare with a clinical setting. The level of expertise of the observers may also have contributed to this. We compared our results with those of a similar study by Mol et al., who achieved CBCT mean AUC values of 0.82 and 0.79 for molars and premolars, respectively.[20] Mean AUC values for intraoral radiography in Mol et al.'s study were 0.45 and 0.52 for molars and premolars, respectively.[20] The CBCT AUC values in our investigation were possibly higher because a contemporary scanner was used and image quality likely had improved after nearly a decade of technologic development. The AUC values for intraoral radiography were higher in the present study, possibly because no defects were created buccal and lingual to teeth, in contrast to the study by Mol et al. The present study did not include buccal or lingual defects because such inclusion would likely yield results biased in favor of

Table IV. Odds ratio estimates

Effect	*Point estimate*	*95% confidence intervals (CIs), Wald's test*	
Cone beam computed tomography (CBCT) vs intraoral radiography	2.29	1.51	3.46
Buccolingual bone thickness	1.52	1.31	1.77

Table V. Interobserver reliability (intraclass correlation coefficient)

Imaging modality	*Confidence of detection*	*Measurement of extent*
Registered cone beam computed tomography (CBCT) scans	0.59	0.56
Intraoral radiographs	0.56	0.58

Table VI. Weighted kappa values for confidence of bone loss detection

	Observer	*Cone beam computed tomography (CBCT) kappa*	*CBCT 95% confidence interval (CI)*		*Intraoral radiography, kappa*	*Intraoral radiography, 95% CI*		*P value*
	1	0.76	0.62	0.90	0.60	0.46	0.74	.12
	2	0.43	0.23	0.63	0.60	0.46	0.74	.19
	3	0.56	0.35	0.77	0.51	0.35	0.68	.72
	4	0.63	0.45	0.81	0.51	0.36	0.66	.30
	5	0.70	0.55	0.86	0.22	0.03	0.41	<.01
	6	0.62	0.45	0.80	0.66	0.51	0.82	.73
Mean		0.62	0.44	0.79	0.52	0.36	0.67	.35
SD		0.11	0.14	0.09	0.16	0.17	0.14	.31

Table VII. Weighted kappa values for measurement of bone loss extent

	Observer	*Cone beam computed tomography (CBCT), kappa*	*CBCT 95% CI*		*Intraoral radiography, kappa*	*Intraoral radiography, 95% CI*		*P value*
	1	0.80	0.63	0.98	0.82	0.65	1.00	.88
	2	0.47	0.21	0.72	0.73	0.57	0.90	.08
	3	0.48	0.31	0.66	0.59	0.44	0.75	.37
	4	0.56	0.37	0.75	0.35	0.18	0.52	.11
	5	0.78	0.66	0.91	0.29	0.08	0.49	<.01
	6	0.64	0.42	0.85	0.78	0.64	0.92	.28
Mean		0.62	0.43	0.81	0.59	0.42	0.76	.34
Standard deviation		0.15	0.18	0.12	0.23	0.24	0.21	.32

CBCT. If buccal and lingual defects had been included in the present study, the difference in AUC values between the 2 imaging modalities may have been statistically significant.

The difference in sensitivity between the 2 imaging modalities was statistically significant. Observers detected 85% of the lesions with CBCT and 63% of the lesions with intraoral radiography. All of the observers demonstrated better sensitivity with CBCT, although not all to the same degree. The average difference in the specificity between the 2 modalities was 7% in favor of CBCT, but this difference was not statistically significant. It can be assumed that there is no difference in diagnostic efficacy largely attributable to variability among the observers in specificity. This variability in interobserver reliability is likely the reason for the high standard deviation, which reached 0.21 for specificity.

The logistic regression analysis showed a statistically significant difference in diagnostic efficacy between intraoral radiography and CBCT after controlling for observer and buccolingual bone thickness. Therefore, thickness of bone, imaging modality, and observer had significant effects on bone loss detection. Greater buccolingual bone thickness was more likely to hide the defects on the intraoral radiographs. The odds of making a correct decision regarding the presence or absence of bone loss with CBCT were 2.29 times greater compared with making such a decision with intraoral radiography. This finding substantiates the ability of 3D CBCT imaging to show the changes in trabecular bone without interference of the cortical bone. For every 1 mm of trabecular bone loss in the buccolingual dimension, the odds of detecting a defect increased 1.52 times after controlling for imaging modality and observer. This finding is consistent with the notion that more buccolingual bone loss leads to less X-ray attenuation and, therefore, increased contrast between the defect and the unaffected bone.

Interobserver reliability values for both imaging modalities indicated a moderate level of agreement among the 6 observers for determining the presence or absence of bone loss and for determining the amount of bone loss. Depending on the difficulty of the task, it can be expected that observers would vary in their responses. The moderate agreement suggests that interpreting the images from the 2 imaging modalities was observer specific because there was no substantial to perfect agreement.

The average intraobserver reliability, as measured by weighted kappa, was substantial for CBCT and moderate for intraoral radiography, both for determining the presence or absence of bone loss and for measurement of the defect size. For all observers except 1, there was no statistically significant difference between the weighted kappa values of the 2 imaging modalities. It seemed that the additional information from 3D imaging helped in observer 5's consistency in deciding on lesion detection and extent. For lesion detection, this observer was an outlier in terms of specificity in intraoral radiography, which implies that the observer was susceptible to distractors mimicking bone loss. However, this finding could not be generalized to all observers. Observers 2 and 6 were more reliable with regard to intraoral radiography compared with CBCT, but these differences were not statistically significant ($P \geq .19$). Given these data, it appears that the reliability of intraoral radiography and CBCT was dependent on the user.

This study had a number of potential limitations. Metal artifact is an issue in CBCT imaging, so mandibles that contained teeth with large metallic restorations were excluded from the study. It can be hypothesized that the effect of metal artifacts may be minimal because most of these artifacts are generated in the direction of the beam and, therefore, largely propagate in the axial plane above the crestal bone. It is possible, however, that metal artifacts would have predisposed the registration of CBCT volumes to error. Any large error in registration would create inaccurate detection and measurement of bone defects between the 2 CBCT scans during the sessions. Patient motion is also a factor during CBCT acquisition, and motion artifacts were not included in this ex vivo study. Furthermore, only mandibles were used for this study because of their utilization in a previous research project and because dried maxillae were not readily available. Having maxillary dentition would have made the study more clinically relevant. Additionally, the angle of a periodontal bone defect has been shown to play a role in treatment prognosis. An angle of less than 45 degrees between the root and side of the defect has been associated with a higher chance of success in regaining bone.[21] However, the present study was solely concerned with comparing defect detection and defect depth assessment between 2 imaging modalities, rather than assessing treatment outcomes. Observers were not tasked with measuring defect angles. Additionally, the method used for registration of the CBCT scans was a combination of point-based registration and surface-based registration. In the hierarchy of accuracy for aligning 3D volumes, voxel-based registration is superior, allowing for superimposition of 2 volumes at the level of voxels. Although voxel-based registration allows for slightly less variability in registration, surface-to-surface registration has proven successful in previous studies and is within an acceptable level of accuracy without any statistically significant difference from voxel-based registration.[22] Finally, we chose to artificially induce bone defects in an ex vivo

model for the benefit of close control of the changes in alveolar bone topography and in the interests of time because bone loss in live patients takes months to years to develop. However, inherent problems arise when creating and imaging bone defects in dried mandibles. Soft tissue equivalent material was adapted to the surface of the mandibles, but empty marrow spaces create high contrast, which would not be seen in live patients. Although the defects created by an experienced periodontist were contoured to mimic natural bone loss while leaving the cortical plates intact, the high contrast caused by empty marrow spaces may have made detecting bone loss easier with CBCT when examining slices through the medullary bone.

Although registered CBCT scans yielded higher sensitivity and odds of visualizing bone loss compared with intraoral radiography, some drawbacks exist in the serial acquisition of registered CBCTs for the sole purpose of assessing alveolar bone. Of all dental imaging modalities, CBCT has the highest potential radiation burden. It also takes additional time to process and register CBCT scans, a process that is not necessary when comparing intraoral radiographs. The technology still shows promise, however. Compared with a full mouth series of intraoral radiographs, acquisition of a CBCT scan is more comfortable for the patient, requires less time, and is less technique sensitive. It is inherently simple to obtain an ideal, diagnostically acceptable CBCT scan, whereas several operator-dependent factors, including projection geometry, are required for obtaining ideal intraoral radiographs. Furthermore, the development of low-dose protocols in CBCT may help lower the potential risks of radiation. Software and hardware improvements will undoubtedly lessen the time required for registering CBCT scans in the future. Additional studies are warranted to determine whether there would be significant improvements in intraoral and 3D imaging for bone loss detection to aid general dentists or periodontists. Another area of research could be the diagnostic accuracy of registered CBCT scans compared with CBCT scans displayed side by side. The comparison of registration accuracy based on exposure parameters (i.e., low dose vs higher dose) should also be investigated.

CONCLUSIONS

Registered CBCT scans were, on average, not significantly different in terms of diagnostic efficacy or specificity compared with intraoral radiography. Registered CBCT scans were, on average, found to be significantly more sensitive compared with intraoral radiographs. There was moderate interobserver agreement for registered CBCT scans and intraoral radiographs. There was substantial and moderate intraobserver agreement for registered CBCT scans and intraoral radiographs, respectively. These findings suggest that although registered CBCT proved to be more sensitive, assessment of alveolar bone loss is user-specific. Furthermore, our results suggest that in intraoral radiography, for every 1 mm of bone lost in the buccolingual dimension, the odds of detecting those defects increases 1.52 times.

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