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Accuracy of Proximal Caries Depth Measurements: Comparison of Two Computed Cone Beam Tomography and Storage Phosphor Plate Systems

Arayüz Çürük Derinliği Ölçüm Doğruluğunda Farklı Dental Volümetrik Tomografi ve Fosfor Plak Sistemlerinin Karşılaştırılması

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Abstract

Objective: The aim of this study was to compare the accuracy of NewTom 9000 [cone beam computerized tomography (CBCT)], Accu-I-Tomo [limited CBTC (LCBCT)] and Digora Optime [storage phosphor plate (SPP)] imaging systems in assessing the depths of defects with different shapes and sizes on the proximal surfaces of teeth.
Materials and Methods: Thirty out of 50 incisive teeth with sound proximal surfaces were divided into three equal groups. Mechanical defects of different sizes and depths were created on their proximal surfaces and teeth were placed in acrylic blocks with approximal contacts. Radiographs of the blocks were obtained with CBCT, LCBCT and SPP systems. The depth measurements of 60 artificial defects were performed by 3 radiologists in the digital radiographs. The gold standard (true measure) was defined as the mean of the 2 observers' measurements on the microscopic sections. Results from imaging systems and true depths were compared using Bland-Altman plots. The agreement was determined with intra-class correlation coefficient.
Results: Maximum deviation from the true length in axial and sagittal slices of CBCT system was 2 mm [95% confidence interval (CI) 2.60-0.60] and 1.5 mm (95% CI 0.30-2.30) respectively while the deviation of LCBCT was 0.66 mm (95% CI 0.53-2.22) and 0.37 mm (95% CI 0.50-2.25). The deviation from truth for SPP was 0.66 mm (95% CI 0.33-2.25). Correlation among observers was 0.487 and 0.700 respectively, for CBCT axial and sagittal slices; while it was 0.979 and 0.985 for LCBCT and 0.979 for SPP.
Conclusion: Images obtained with the Accu-I-Tomo LCBCT system were more accurate than Newtom CBCT and Digora SPP system for measurement of caries lesion depth. Correlation among observers was higher for LCBCT and SPP systems compared with CBCT system.

Öz

Amaç: Bu çalışmanın amacı, NewTom 9000 [konik ışınlı bilgisayarlı tomografisi (CBCT)] ve Accu-I-Tomo [sınırlı CBTC (LCBCT)] dental volümetrik tomografi sistemleri ile Digora Optime [Depolama fosfor tabakası (SPP)] fosfor plak görüntüleme sistemini, dişlerin ara yüzeylerinde oluşturulan farklı şekil ve boyutlardaki defekt derinlikleri açısından karşılaştırmalı olarak değerlendirmektir.

Gereç ve Yöntemler: Çürük lezyonu bulunmayan 50 adet kesici dişin 30 tanesi 3 eşit gruba bölündü. Ara yüzeylerinde mekanik olarak farklı şekil ve boyutlarda defekt oluşturulan dişler aproksimal kontakta olacak şekilde akrilik bloklara yerleştirildi. Blokların CBCT, LCBCT ve SPP görüntüleme sistemleri ile görüntüleri alındı. Altmış adet defektin derinlik ölçümleri dijital görüntüler üzerinde 3 gözlemci tarafından gerçekleştirildi. Ölçümlerin altın standardı, mikroskobik kesitler üzerinde 3 gözlemcinin yaptığı ölçümlerin ortalaması alınarak belirlendi. Mikroskobik kesitler üzerinde hesaplanan gerçek ölçümler (altın standart) ile dijital görüntüler üzerinde yapılan ölçümlerin karşılaştırması aşamasında Bland-Altman yönteminden yararlanıldı. Gözlemciler arası uyum grup içi korelasyon katsayısı kullanılarak saptandı.

Bulgular: CBCT sisteminde aksiyel ve sagittal kesitlerde gerçekleştirilen ölçümlerde, altın standarttan maksimum sapma sırasıyla 2 mm [%95 güven aralığı (GA) 2,60-0,60] ve 1,5 mm (%95 GA 0,30-2,30) iken, LCBCT sistemi için bu değer 0,66 mm (%95 GA 0,53-2,22) ve 0,37 mm (%95 GA 0,50-2,25) olarak bulundu. CBCT sisteminin aksiyel ve sagittal kesitlerine ait gözlemciler arası uyum değeri sırasıyla 0,487 ve 0,700 iken, LCBCT sistemi için bu değer 0,979 ve 0,985 olarak saptandı. SPP görüntüleme sistemi için ise bu değer 0,979 idi.

Sonuç: Accu-I-Tomo LCBCT sistemi ile elde edilen görüntüler üzerinde gerçekleştirilen çürük derinliği ölçümleri; Newtom CBCT ve Digora SPP sistemlerine kıyasla daha doğru sonuçlar vermiştir. Gözlemciler arası uyum, LCBCT sistemi için CBCT ve SPP sistemlerine kıyasla daha yüksektir.

Introduction

Radiographic evaluation have traditionally been used for estimating depth of carious lesions (1,2). The rapid advances in computer technology have had a significant impact on dental radiography. Since the diagnostic accuracy of digital systems is comparable with conventional dental films, digital imaging systems are becoming common in clinical dental practice (3,4).

The technical efficacy of detectors which are continuing to improve results in higher image quality at lower exposure levels. However, the two-dimensional representation of a caries lesion discards valuable information. A radiographic image of a demineralized area corresponding to a carious lesion is not a well defined radiolucency as the degree of calcification increases towards the periphery of the lesion, therefore detecting the true extent of caries is difficult (5,6). For this reason, measurements of the extent of a carious lesion are difficult to perform accurately. Small lesions go undetected when the relative amount of mineral loss is low, resulting in low subject and image contrast. Besides, the changes in the projection geometry can seriously effect the radiographic appearance and accordingly detection of a lesion (1,7).

Although it has been shown that digital manipulations of radiographic images have the potential to increase the validity of radiographic assessment of interproximal caries (8,9), the replacement of film by digital detectors does not address these fundamental limitations. These limitations of radiographic detection encourages studies that compare the diagnostic accuracy of different imaging systems and the search for improved image processing techniques (10). With the development of cone beam computerized tomography (CBTC), it is now possible generating three-dimensional images of a limited volume with a high level of detail without increasing the patient dose to unacceptable levels (11,12). A number of studies have been conducted to compare the efficacy of different digital intraoral systems and CBCT units for caries diagnosis showed that it appears to be a promising tool for monitoring especially small caries lesions (13-16). However, previous caries-related CBCT researchs have focused mainly on proximal and occlusal caries detection (14-16). The number of the studies comparing caries depth measurements using different imaging modalities is limited (17,18). The results of a recent study evaluating the accuracy of occlusal caries depth measurements obtained with using film, CCD, two different CBCT units showed that CBCT units performed similarly and better than intra-oral modalities. However, there seem to be no studies published to date comparing approximal caries lesion depth measurements using images obtained with different CBCT units (18).

The aim of this study was to compare the accuracy of a CBCT (NewTom 9000), a limited CBCT (LCBCT) (Accu-i-Tomo) and a storage phosphor plate (SPP) (Digora Optime) imaging systems in assessing the depths of mechanically created defects with different shapes and depths on the proximal surfaces of extracted teeth.

Materials and Methods

Fifty incisive teeth with sound proximal surfaces will be used for this study. Mechanical defects of different shapes and depths were created on proximal surfaces of 30 teeth using 3 different (round, fissure and flame) burs. Two different sizes of mechanical defects were created using two different round burs: one was 0.66 mm in diameter and the other was 0.75 mm in diameter on each proximal surfaces of 10 experimental teeth. Mechanical defects of 2 different depths (1 and 2 mm) were also created with a fissure bur 0.90 mm in diameter on each proximal surfaces of 10 separate experimental teeth, and with a flame bur 1.25 mm in diameter on the latter 10 experimental teeth. This resulted in 60 artificial defects on the proximal surfaces of 30 teeth.

The 30 experimental teeth and 20 teeth with sound proximal surfaces were divided into 10 groups and three experimental and 2 sound teeth on both sides were mounted in acrylic blocks. Each block with 5 teeth which had 6 contacting proximal surfaces was placed in the center of a plexiglass device to ensure a reproducible geometry between the X-ray unit, object, and film/sensor.

Radiographic Technique

Ten acrylic blocks containing 3 test teeth with artificial defects with different shape and depth and 2 teeth with sound proximal surface at both sides were radiographed using NewTom 9000 CBCT (Quantitative Radiology, Verona, Italy), Accu-I-Tomo (3DX) (Morita Co Ltd, Tokyo, Japan) and the Digora® Optime (Soredex Corporation, Helsinki, Finland) image plate system with the optimal exposure time recommended for each system.

Blue SPPs, later to be scanned in a Digora® Optime scanner, were exposed with a Gendex Oralix DC (Gendex Dental Systems, Milan, Italy) dental x-ray unit operating at 60 kVp, 7 mA, and 1.5 mm Al equivalent filtration at a focus-receptor distance of 25 cm. A 15 mm thick soft tissue equivalent material was placed facing the x-ray tube and acrylic blocks. After exposing SP plates for 0.12 s. They were scanned in the Digora Optime scanner. Digora for Windows software was used to save the resulting images.

The LCBCT images were taken at 80 kV and 1.5 mA using Accu-I-Tomo (3DX) (Morita Co Ltd, Tokyo, Japan). The filtration was 3.1 mm Al equivalent and the exposure time 17.5 s. A circular soft tissue substitute was used to simulate the effect of soft tissue and acrylic blocks were placed in the center of this circular substitute. The LCBCT technique consisted of a cone-shaped X-ray beam, an image intensifier and a solid-state sensor. Images were captured with 360-degree rotation around the patient and tomographic layers of 0.125-2 mm were created.

The NewTom 9000 CBCT (Quantitative Radiology, Verona, Italy) system was used for acquisition of CBCT images. The device was operated at 7 mA and 85 kV in a field of view of 23 cm (voxel size 0.29) with a single scan time of 70 s. Upon completion, the acrylic block and circular soft tissue substitute were removed from the equipment and the image was processed with NewTom QR-DVT 9000 software. The images were obtained from 2 mm-CTs axial section and sagittal or coronal reconstructions.

Image Evaluation

It would be loss of time to view the defects on all slices of CBCT and LCBCT images. To avoid having the observers view all these images, three axial and three sagittal sections, were chosen by an investigator where the depth of the defects was clearly seen for the measurement procedure.

The resulting images were analyzed with the software program provided for each system and 3 radiologists performed the depth measurements of 60 artificial defects from the enamel surface to the deepest part of the defects. The depth measurements regards to the CBCT and LCBCT systems were recorded as one sagittal and one axial value as the mean of measurements of three axial and three sagittal sections. Thus, 780 depth measurements (60 SPP, 60x2x3 CBCT and 60x2x3 LCBCT images) were performed by each evaluator, and total of 2340 measurements were performed for 3 different imaging systems.

Histology

After the radiographic exposures, each test tooth was embedded in acrylic and 100µm-thick sections were cut in the mesiodistal direction using an Exact 300 CL (Exakt Apparatebau GmbH, Norderstedt, Germany) diamond saw. Two observers (experienced with microscopic inspection) validated the tooth sections using a light microscope and selected the section in which the defect was deepest. The depth measurements were performed on these selected sections and the gold standard (true measure) was defined as the mean of the 2 observers' measurements on the microscopic sections.

Statistical Analysis

Gold standard measurements were compared with the measurements obtained from each of the radiographic systems using Bland-Altman plots (19). This analysis consists of a graph in which the difference between the measurements of each method (e.g. method A - method B) is plotted on the y-axis, against their mean difference, i.e. (method A + method B)/2 plotted on the x-axis. The 95% limits of individual agreement (confidence intervals CI) between the two methods were calculated as the mean difference between two methods ±2.0 standard deviations. Horizontal lines are drawn at the mean difference and at the mean difference ±1.96 times the standard deviation of the differences.

The repeated-measures ANOVA was used to calculate the overall comparisons. Inter-rater agreement was assessed with the calculation of average measure intraclass correlation coefficients.

Results

Table 1 showed the mean difference between observers' measurements from the true length for each of the three modalities tested. The mean difference was smallest for measurements made using the sagittal slices of LCBCT system and greatest for axial slices of CBCT system. Although the mean difference values for SPP and axial slices of LCBCT system were equal, 95% limits of agreement were narrowest for LCBCT system.

Table 1. Maximum deviation from the true length in for three different imaging modalities

	Mean difference (mm)	Deviation range (95% CI)
CBCT axial	2 mm	2.60-0.60
CBCT sagittal	1.5 mm	2.30-0.30
LCBCT axial	0.66 mm	2.22-0.53
LCBCT sagittal	0.37 mm	2.25-0.50
SPP	0.66 mm	2.25-0.33

CBCT: Cone beam computerized tomography, LCBTC: Limited cone beam computerized tomography, SPP: Storage phosphor plate, CI: Confidence interval

The Bland-Altman plots for each radiographic modality showed an equal distribution around the mean and within 2 standard deviations of the mean difference (Figure 1-3). Repeated-measures ANOVA revealed that there were significant differences among the CBCT and LCBCT systems ($p<0.05$), while the differences between LCBCT and SPP system were non-significant ($p>0.05$). No differences were found in measurements' for both imaging modalities as regards to the different shape of artificial defects ($p>0.05$).

Results from the intra-class correlation coefficients can be followed in Table 2. Correlation among

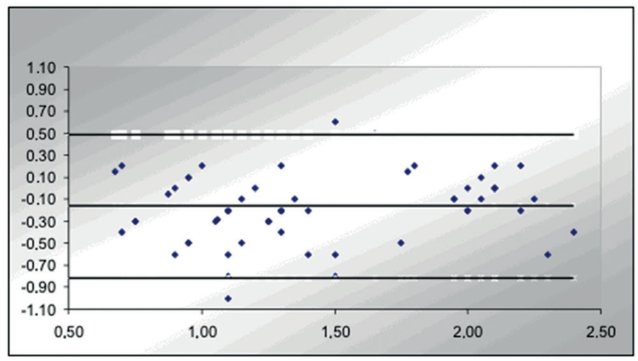

Figure 1. Bland-Altman plots for cone beam computerized tomography

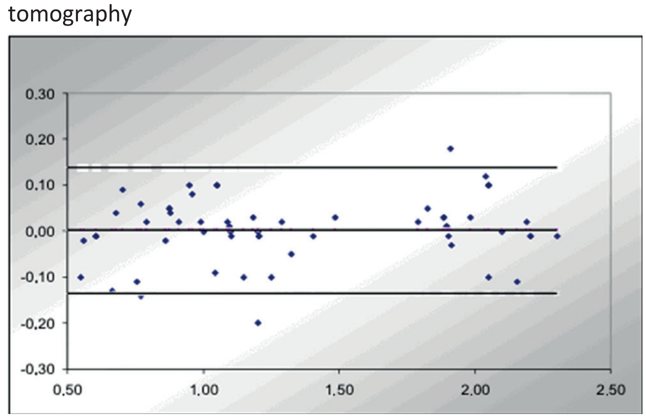

Figure 2. Bland-Altman plots for limited cone beam computerized tomography

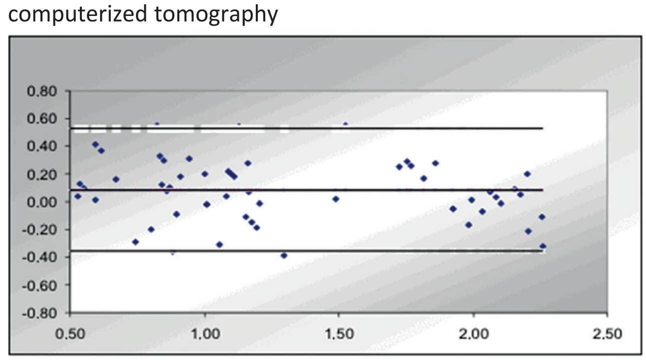

Figure 3. Bland-Altman plots for storage phosphor plate

observers was 0.487 and 0.700 respectively, for CBCT axial and sagittal slices; while it was 0.979 and 0.985 for LCBCT and 0.979 for SPP.

Discussion

CBCT systems have been used by many disciplines in dentistry over the last decade, including tasks such as diagnosis, prognosis and treatment planning (20-22). In 2012, guidelines for the application of CBCT have been elaborated by the SEDENTEXCT project in Europe (23).

The use of CBCT for the detection of caries has been the subject of several laboratory research studies on extracted teeth. Although most of the studies of proximal caries detection concluded that there was no significant difference in diagnostic performance between the CBCT systems and intraoral radiography (15,24,25), couple of studies found higher sensitivity for detection of proximal dentine caries with a limited volume, high resolution CBCT systems (11,12). It has been recognized that CBCT units with limited field of view (LCBCT) coupled with a substantially higher resolution can be useful for various dental applications including the detection of small caries lesions (23). The findings of the present study confirmed this statement by revealing the superiority of LCBCT system for the detection of mechanically created proximal defects. The LCBCT system used in the present study provided more accurate lesion depth estimates with less variation when compared with measurements obtained with a CBCT system providing larger field of view. Accuracy of measurements in CBCT devices is controlled with few major factors. One of those factors is the spatial resolution, which is closely related to the acquired voxel volume (26,27). Smaller voxel sizes increase clinicians' ability to visualize greater levels of detail because smaller voxels produce high resolution images. Another factor affecting the measurement accuracy is the field-of-view (FOV) of images (28). Larger number of scattered photons was produced with larger FOVs, which in turn reduce the image resolution as compared to smaller FOVs (29).

Table 2. Intraclass correlation coefficients levels for three different imaging modalities

	Correlation coffecient (ICC)
CBCT axial	0.487
CBCT sagittal	0.700
LCBCT axial	0.979
LCBCT sagittal	0.985
SPP	0.979

CBCT: Cone beam computerized tomography, LCBTC: Limited cone beam computerized tomography, SPP: Storage phosphor plate

The size of the FOV is further important regarding the radiation dose delivered to the patient and staff. Reducing the size of the X-ray beam to the minimum size needed to image the object of interest results in an obvious means of limiting dose to patients, as well as improving image quality by scatter reduction (30,31). Decrease in the scatter also makes it easier to delineate small lesions and is another factor for the superiority of limited FOV CBCT for detection of small mechanically created defects.

Despite the possible advantages in diagnostic outcome of 3-dimensional imaging, the radiation doses (and hence risks) from dental CBCT are generally higher than two-dimensional dental radiography. Clinicans' choices do not only affect the diagnostic quality of images but also the amount of radiation exposure that their patients receive. Thus, it should be borne in mind that the benefits of acquiring high resolution images must outweigh the risks of radiation dose (31).

According to the results of the present study, LCBCT system yielded a significantly higher performance than both SPP and CBCT modalities in measuring proximal caries depth. This result is in accordance with a recent report comparing conventional, digital intraoral receptors and two different CBCT devices for caries depth measurement (18). Although more than five different imaging modalities and two different CBCT units were included to the above-mentioned study, they aimed to evaluate the accuracy of occlusal caries depth measurement, not proximal cavities. To date, only a single study compared the accuracy of proximal caries depth measurements using CBCT images. Akdeniz et al. (17) compared a LCBCT system, a SPP system and F-speed film for measuring depth of proximal caries lesions. According to the results LCBCT performed better than other imaging modalities in proximal caries depth measurements. Although these results are similar to the results of the present study, our study seems to be the first one comparing the performance of two different CBCT units in proximal caries depth measurements.

However, it should be remembered that this study was performed at ideal *ex vivo* conditions. In a true clinical situation, various fillings or other metallic restorations as well as possible patient movement during the examination may affect the quality of CBCT images and thus the diagnostic performance (32). Besides, it should be emphasized that current results were obtained with the early generations of both CBCT and LCBCT machines using image intensifiers providing a smaller dynamic range and also lower spatial resolution than that of today's flat panel detectors (33). Further studies using the recent advanced CBCT technology are needed and would probably exceed the results obtained in this study.

Conclusion

Based on the results of the current study, it is concluded that the Accu-I-Tomo LCBCT system was more accurate than Newtom CBCT system and Digora SPP images for measurement of mechanically created lesion depth and observers are better in assessing the depths of the defects with LCBCT than both CBCT and SPP imaging systems. However, clinical studies would be needed to support this conclusion.

Ethics

Ethics Committee Approval: It was not taken.

Informed Consent: It was not taken.

Peer-review: Externally and internally peer-reviewed.

Authorship Contributions

Concept: B.G.B., Design: H.G.G., Data Collection or Processing: E.Ş., Analysis or Interpretation: T.K., Literature Search: S.H., Writing: E.Ş.

Conflict of Interest: No conflict of interest was declared by the authors.

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