RESEARCH

Performance of a photostimulable storage phosphor digital system with or without the sharpen filter and cone beam CT for detecting approximal enamel subsurface demineralization

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Objectives: The aim of this study was to assess the performance of photostimulable storage phosphor (PSP) radiographs with or without using the sharpen filter and cone beam CT (CBCT) for detecting enamel subsurface demineralization.

Methods: Enamel subsurface demineralization was induced on one of the approximal surfaces of 120 sound human teeth. Standardized images of all teeth were acquired after the demineralization phase using the Digora[®] Optime (Orion Corp./Soredex, Helsinki, Finland) (PSP) and the i-CAT[™] (Imaging Sciences International, Hatfield, PA) (CBCT) systems. Three calibrated observers interpreted the images using a five-point scale (1, demineralization definitely absent; 2, demineralization probably absent; 3, unsure; 4, demineralization probably present; and 5, demineralization definitely present). Diagnoses were validated by cross-sectional microhardness profiling in the test areas of the approximal surfaces. Interobserver agreement was analysed using kappa statistics. Accuracy was estimated by the areas under the receiver operating characteristic curves (A_z), which were compared using the Kruskal–Wallis test ($\alpha = 5\%$).

Results: Interobserver agreement was higher for CBCT ($\kappa = 0.7\text{--}0.8$), followed by sharpen-filtered ($\kappa = 0.6\text{--}0.7$) and original ($\kappa = 0.5\text{--}0.6$) images. CBCT presented the highest accuracy value ($A_z = 0.897$) compared with the original ($A_z = 0.792$) and sharpen-filtered ($A_z = 0.712$) images. However, no statistical differences were observed between the imaging modalities ($p = 0.0794$).

Conclusions: It can be concluded that PSP radiographs with or without using the sharpen filter and the CBCT images may be useful adjuncts for detecting subtle approximal enamel demineralization.

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Introduction

Dental caries is a dynamic process that develops from biochemical and ultrastructural alterations, which culminate in characteristic signs and symptoms.^{1,2} Considering that, in the initial stages, this disease can

be controlled through non-invasive treatments, the major goal in clinical practice should be the early detection of enamel subsurface demineralization.² However, the diagnosis of approximal caries lesions still represents a challenge in dentistry.³ The main difficulty in the early diagnosis of these lesions arises from their location, usually below the contact areas, impairing direct visual inspection. When the approximal caries lesions become clinically apparent, tooth

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demineralization may be irreversible, requiring restorative intervention.³

The assessment of approximal caries lesions in posterior teeth often requires a combination of diagnostic methods.^{4,5} Radiographic examination is widely used and easy to perform for the diagnosis of approximal caries.^{5–9} In the early 1990s, digital radiographic systems were launched, yielding the great possibility of manipulating image brightness and contrast to improve diagnosis.¹⁰ Nevertheless, the radiographic diagnosis of caries lesions depends on the contrast and, therefore, demineralization has to encompass at least 30–40% of the enamel layer to be observed, implying an irreversible mineral loss.^{8,11} Cone beam CT (CBCT) was developed to address the demand for three-dimensional (3D) information obtained by CT.^{12–20} The applicability of CBCT images for detecting approximal caries lesions has already been investigated.^{4,9,13,18,19,21,22} However, few studies have focused on the diagnostic performance of CBCT for the detection of subtle subsurface enamel demineralization.

The aim of this study was to evaluate the diagnostic performance of photostimulable storage phosphor (PSP) radiographs with or without the sharpen filter and CBCT images for detecting *in vitro* approximal enamel subsurface demineralization. The study hypothesis considered that CBCT, if clinically requested for other diagnostic purposes, could also be useful in the detection of incipient and reversible enamel demineralization. On the other hand, the null hypothesis stated no differences between imaging modalities, which also would not preclude the search for incipient caries lesions in CBCT images. Although this study reports on the performance of observers analysing images of blocks containing a single tooth, its practical relevance is associated with the comparison between CBCT and radiographs with the sharpen filter, which is the correct way to improve fine details.

Materials and methods

This research protocol was approved by the Institutional Review Board of the Faculdade de Odontologia de Piracicaba—UNICAMP, São Paulo, Brazil (protocol no. 148/2009) and conforms with the ethics principles for research on humans.

Sampling

80 human third molars and 40 premolars, having at least two-thirds of the roots already formed, were selected after extraction for orthodontic and surgical reasons. After extraction, the teeth were washed in a 0.9% sodium chloride solution to remove blood residues and then polished with pumice and thoroughly cleaned with distilled water.

Tooth preparation

The root portion of each tooth was embedded in a rectangular block of utility wax. The crowns were coated

with a fast-drying acid-resistant red varnish (Colorama Express®; Colorama/CEIL, São Paulo, Brazil), leaving only a 7 mm² circular window of exposed enamel in one of the approximal surfaces.^{2,23} Specimens were numbered and then randomly assigned to 2 groups (*control*—without enamel subsurface demineralization and *experimental*—with enamel subsurface demineralization) of 60 specimens.

Demineralization regimen

A buffer solution, 50% saturated in relation to dental enamel, was tested through pilot studies and used to induce enamel subsurface demineralization.^{2,23,24} This demineralizing solution contained 0.05 M acetate buffer, pH 4.8, 1.12 mM calcium, 0.77 mM phosphate and 0.03 p.p.m. fluoride. For its formulation, 286.8 mg of calcium chloride dihydrate (CaCl₂·2H₂O), 159.39 mg of monobasic sodium phosphate (NaH₂PO₄·H₂O) and 0.45 ml of 100 p.p.m. fluoride standard solution were added to 4.29 ml of concentrated acetic acid, resulting in a homogeneous mixture.²³ To attain a final volume of 1500 ml, distilled and deionized water was added, and the pH was then set at 4.8. Approximately 1 g of thymol crystals was also added to avoid fungal growth.²³ Phosphorus and calcium concentrations were determined in samples of the demineralizing solution to exclude possible errors resulting from inadequate formulation.

The ratio recommended for use is 2 ml of demineralizing solution to 1 mm² of exposed enamel.^{2,23,24} Since the exposed enamel area was approximately 7 mm², the experimental specimens were kept individually immersed in 14 ml of the demineralizing solution and incubated at 37 °C for 120 days. The demineralizing solutions of the specimens in the experimental group were replaced 60 days after immersion to avoid supersaturation, resulting from constant ionic exchanges occurring between the enamel and the fluid. If supersaturation occurs, demineralization does not progress, as the kinetics of ionic exchange becomes too slow.

The specimens in the control group were separated into two subgroups. 30 specimens were individually kept in plastic recipients, consisting of a pellet of cotton moistened with distilled and deionized water at 37 °C for 120 days. The exposed enamel area was thus maintained under humid conditions, but without direct contact with water, avoiding ionic exchanges. The other 30 teeth had their crowns totally coated with a fast-drying acid-resistant red varnish and were kept immersed in the demineralizing solution for 120 days at 37 °C.

Imaging procedure

Standardized radiographs of all specimens were taken after 120 days using the Digora® Optime system size 2 plates (Orion Corp./Soredex, Helsinki, Finland), selecting super-resolution mode (pixel pitch, 0.04 × 0.04 mm; bit depth, 14-bit greyscale, *i.e.* 16 384 shades of grey ranging from 0/black to 16 383/the lightest shade of grey). The specimens were radiographed using a GE 1000® X-ray unit (General Electric Co., Milwaukee, WI), operating

at 65 kVp, 10 mA, 2.5 mm total aluminium filtration and a 32 cm focus–receptor distance. The exposure time selected was 0.16 s. An acrylic device was manufactured to hold the specimen, X-ray beam indicator device and image receptor in a reproducible relationship (Figure 1). With this support, a constant specimen–receptor distance of 2 cm was maintained, and the X-ray tube vertical and horizontal angulations were set at 0° and 90°, respectively. A 1.5 cm thick acrylic plate was positioned in front of the specimens to simulate the soft tissues. The image receptors were scanned at a standard resolution of 397 d.p.i. Digital radiographs were then exported in tagged image file format (TIFF), 8 bits, to Digora for Windows 2.6 software (Orion Corp./Soredex). Then, the sharpen filter included in the Digora for Windows 2.6 package was applied to the images, and the enhanced images were recoded and stored in TIFF (8 bits). According to the Digora for Windows 2.6, the matrix sizes for the original and enhanced images were 480×632 and 476×632, respectively.

As shown in Figure 2, two subsamples of radiographs were generated: the Digora original images (Figure 2a) and those with the sharpen filter (Figure 2b). The specimen in Figure 2 was randomly selected on the basis of a high degree of interobserver agreement as well as the true presence of enamel demineralization, according to the cross-sectional microhardness profiling. The filtered image (Figure 2b) appears to have increased contrast, thus evidencing enamel demineralization. The sharpen filter was tested because it might compensate for the loss of image quality, which could hide the signal of subtle approximal enamel demineralization.²⁵ Filters would be welcomed in cases where the dentist needs to post-process an image, for instance to better display caries lesions after image capture. In the Digora for Windows 2.6, the sharpen filter is a unique tool that yields non-linear filtering. It was developed with an algorithm that enables computer-assisted manipulation of

the input image data array or matrix, grouping high-contrast pixels together in a submatrix, thus evidencing subtle changes in the output image.^{26,27} Additionally, the specimens were scanned with a flat-panel CBCT system (Figure 2c), the i-CAT™ (Imaging Sciences International, Hatfield, PA), selecting high-resolution mode (pixel pitch, 0.125 × 0.125 mm; bit depth, 14-bit greyscale, *i.e.* 16 384 shades of grey ranging from 0/black to 16 383/the lightest shade of grey). All the specimens were placed in the centre of the field of view (FOV), and a scan was completed. The exposure factors were 120 kVp, 8 mA, 6×17 cm FOV selection and 40 s for image acquisition. The scanner was set to 0.125 mm voxel resolution and then calibrated. The CBCT images were saved in Digital Imaging and Communications in Medicine 3 file format and loaded into the Xoran CAT™ software (Xoran Technologies, Ann Arbor, MI). All the images were coded to be displayed in a random order.

Image assessment

Three blinded and experienced observers evaluated the digital radiographs using the Digora for Windows 2.6 software. The CBCT data sets were assessed using the Xoran CAT software. Following a calibration session, the observers were instructed to analyse each image and score the approximal surfaces using a five-point confidence rating scale (1, enamel subsurface demineralization definitely absent; 2, enamel subsurface demineralization probably absent; 3, unsure; 4, enamel subsurface demineralization probably present; and 5, enamel subsurface demineralization definitely present). Images were presented in a random order on a 48 cm (19 inch) liquid crystal display monitor screen (W1952TQ; LG Electronics, Taubaté, SP, Brazil), with a resolution of 1440×900 pixels, in true colour (24 bits). All viewing was performed under uniform subdued lighting in a quiet and secluded room. The analogue brightness and contrast controls on the monitor were kept constant during the assessments. The observers assessed each CBCT data set,

Figure 1. Acrylic device holding the X-ray beam indicator, acrylic plate (soft-tissue-equivalent material), specimen and image receptor in the standardized position

Figure 2. Images of an experimental specimen after the demineralization phase. On the left, there is approximal enamel subsurface demineralization: (a) original Digora[®] (Orion Corp./Soredex, Helsinki, Finland) radiograph, (b) sharpen Digora radiograph and (c) cone beam CT image

scrolling axial, sagittal and coronal slices interactively, searching for a radiolucent image in the approximal surfaces. During image analysis, the observers were positioned from 50 cm to 70 cm away from the monitor. The duration of the interpretation session was not preset, but the observers were instructed to examine 20 radiographs or 20 CBCT images in each session to avoid visual fatigue. All image data sets were viewed twice with an 18 day interval between the assessments.

Validation

The Knoop cross-sectional microhardness profiling has been used to measure enamel demineralization, providing both microscopic visualization and measurement of mechanical resilience.^{2,23,28} In the present study, the enamel test areas were submitted to Knoop cross-sectional microhardness profiling. The crowns were sectioned from the roots and cut into two halves vertically through the centre of the test areas. The halves of each crown were embedded together in methyl-methacrylate resin, so that the cut section was exposed. This surface was serially polished and placed in an FM Series[™] digital microhardness tester (Future-Tech Corp., Tokyo, Japan). Microhardness testing was carried out using the FM-ARS[™] 7000 software (Sun-Tec Corp., Novi, MI). Indentations were made with the long axis of a Knoop diamond indenter parallel to the outer enamel surface, under a 25 g load for 5 s. Two rows spaced 200 μ m apart were established to allow enamel indentations at different depths inwards from the external anatomical surface. Based on the width of each indentation, a Knoop microhardness number (KHN) was automatically calculated by the FM-ARS 7000 software. One independent and well-trained operator carried out the microhardness measurements.

Statistical analyses

Kappa coefficients were estimated to assess intra- and interobserver agreement,¹⁸ according to the following criteria: poor agreement (0–0.19), fair agreement (0.20–0.39), moderate agreement (0.40–0.59), substantial agreement (0.60–0.79) and almost perfect agreement (0.80–1.00).²⁹ Sensitivity (true positive ratio), specificity (true negative ratio) and overall accuracy [(number of true positives + number of true negatives)/all recordings] values were calculated. Accuracy was estimated by receiver operating characteristic (ROC) analysis. The Kruskal–Wallis test ($\alpha = 0.05$) was used to compare the areas under the ROC curves (A_z) for the different imaging modalities. The statistical analyses were carried out using the SAS[™] 9.2 system (SAS Institute Inc., Cary, NC).

Results

The mean KHN values in the test area of each crown were averaged within the study groups (Table 1). No difference was found between the cross-sectional microhardness mean values obtained for the specimens kept in individual recipients without demineralizing solution, *i.e.* in the humidified environment, and those immersed in demineralizing solution but totally coated with acid-resistant varnish. Their KHN mean values were considered as control means and served as comparative parameters for the experimental specimens. The mean KHN in the control group ranged from 310.8 to 371.9, compared with 145.2–276.4 in the experimental specimens, thus evidencing mineral loss in the latter group. Furthermore, microscopic examination showed that the approximal enamel outer surfaces in the test areas of the

Table 1 Mean Knoop hardness number for approximal enamel test areas in the study groups

Group	Minimum value	Maximum value
Control—kept in humidified environment ($n = 30$)	311.5	371.9
Control—immersed in the demineralizing solution ($n = 30$)	310.8	371.1
Experimental—immersed in the demineralizing solution ($n = 60$)	145.2	276.4

experimental specimens were not disrupted but presented great porosity and discoloration.

In 85.71% of the cases, intraobserver agreement ranged from substantial to almost perfect ($\kappa = 0.6$ – 0.9).²⁹ In the remaining cases, it was moderate ($\kappa = 0.5$ – 0.56).²⁹ Interobserver agreement was higher for CBCT ($\kappa = 0.7$ – 0.8 , *i.e.* substantial to almost perfect) followed by sharpen-filtered ($\kappa = 0.6$ – 0.7) and original ($\kappa = 0.5$ – 0.6) images, indicating moderate to substantial reproducibility (Table 2).²⁹ The CBCT higher reproducibility was corroborated by the data shown in Table 3, which presents the distribution of correct diagnoses performed based on the mean KHN values. According to pooled data from the assessments performed by all three observers, enamel subsurface demineralization was detected in 92% of the CBCT data sets from experimental specimens. In addition, absence of demineralization was observed in a higher percentage with CBCT (83.1%). The use of the sharpen filter was also related to high percentages of correct diagnoses for true presence (83%) or absence (79%) of enamel subsurface demineralization. As shown in Table 4, higher numbers of specimens were categorized with a score of 5 (demineralization definitely present) than those with a score of 1 (demineralization definitely absent).

Although not statistically significant, average sensitivity and overall accuracy values for detecting enamel subsurface demineralization were higher using CBCT (0.880 and 0.878, respectively) than the corresponding means for original (0.654 and 0.687) and sharpen-filtered (0.670 and 0.674) images (Table 5). The average A_z values and the corresponding percentages of the total area for each imaging modality are given in Table 6. No statistically significant differences were found between imaging modalities, even though the highest A_z value was obtained using the CBCT images (0.897) in relation to the original (0.792) and sharpen-filtered (0.712) radiographs ($p = 0.0794$). As shown in Table 6 and

Table 2 Interobserver agreement by imaging modality

Imaging modality	Observer 1 vs Observer 2	Observer 1 vs Observer 3	Observer 2 vs Observer 3
Cone beam CT	0.7	0.8	0.8
Original Digora®	0.6	0.6	0.5
Sharpen Digora	0.6	0.6	0.7

Digora Optime is manufactured by Orion Corp./Soredex, Helsinki, Finland.

Table 3 Absolute numbers and percentages of correct diagnoses for the specimens with or without enamel demineralization, based on microhardness data, performed by the panel of three observers

Demineralization	Cone beam		
	CT	Original Digora®	Sharpen Digora
Present	152 (92.1)	133 (80.6)	137 (83)
Absent	162 (83.1)	135 (69.2)	154 (79)

Digora Optime is manufactured by Orion Corp./Soredex, Helsinki, Finland.

demonstrated in Figure 3, the ROC curves for CBCT images had the greatest area under the curve on ROC analysis (83.7%) and, hence, yielded the best combination between sensitivity and specificity, compared with both the original and the sharpen-filtered radiographs.

Discussion

Besides its promising clinical applicability in many circumstances that require 3D data, CBCT demands a relatively low dose of irradiation, as compared with CT used in medical radiology, and provides satisfactory resolution for dentomaxillofacial diagnosis.^{20,30} Considering that radiography is the most feasible method for detecting approximal caries lesions and that the clinical use of CBCT should be optimized, it would be justifiable to compare the diagnostic accuracy of digital radiographs with an enhancement filter and CBCT images.

Microhardness profiling evidenced mineral loss in the test areas of the experimental specimens (Table 1), providing support to the assumption that this *in vitro* model was adequate to induce caries-like enamel subsurface demineralization in agreement with previous studies.^{2,23} In terms of reproducibility, most kappa coefficients expressed intraobserver substantial to almost perfect agreement, indicating that the observers could be considered well trained and calibrated for detecting enamel subsurface demineralization in PSP radiographs and CBCT images. As shown in Table 2, interobserver agreement was higher using CBCT images (substantial to almost perfect) than using the sharpen Digora (substantial) and original Digora (moderate to substantial) radiographs. It seemed that the observers were more confident in diagnosing enamel subsurface

Table 4 Absolute numbers of specimens identified with scores corresponding to enamel subsurface demineralization definitely present (presence) or absent (absence) by imaging modality

Observer	Demineralization					
	Cone beam CT		Original Digora®		Sharpen Digora	
	Presence	Absence	Presence	Absence	Presence	Absence
1	41	11	19	8	23	11
2	35	12	27	10	31	12
3	36	12	24	8	30	12

Digora Optime is manufactured by Orion Corp./Soredex, Helsinki, Finland.

Table 5 Mean sensitivity, specificity and overall accuracy values for the detection of enamel subsurface demineralization by imaging modality

Imaging modality	Sensitivity	Specificity	Overall accuracy
Cone beam CT	0.880	0.867	0.878
Original Digora®	0.654	0.879	0.687
Sharpen Digora	0.670	0.692	0.674

Digora Optime is manufactured by Orion Corp./Soredex, Helsinki, Finland.

demineralization presence or absence using the CBCT images (Table 3). On the other hand, the lowest interobserver kappa coefficients (Table 2) and percentages of correct diagnoses (Table 3) were obtained for the original Digora images. These results are sustained by previous studies carried out with another PSP system (Vistascan®; Dürr Dental, Beitigheim-Bissingen, Germany), which recommended that original images should be filtered before interpretation.^{25,31} The sharpen filter included in the Digora for Windows 2.6 package may have enhanced the subjectively judged image quality for viewing anatomical tooth structures. Presumably, the sharpen filter mode improved visualization of subtle radiolucent areas on the approximal surfaces by increasing contrast.²⁶ In fact, high contrast and visual perception might be closely related to a subjective response during caries diagnosis, because even a very sharp edge will be poorly visible if the contrast is too low.

It is desirable that diagnostic imaging modalities have high and balanced values for sensitivity and specificity. As shown in Table 5, sensitivity was higher for the CBCT images (0.880), without jeopardizing specificity (0.867). Conversely, high specificity and low sensitivity for detecting approximal caries lesions were registered using a CBCT system with a charge-coupled device image detector (3DX Accuitomo™; J. Morita Mfg Corp., Kyoto, Japan).²¹ According to the findings of this study, specificity and sensitivity were relatively high using a CBCT system with a flat-panel image detector. Flat-panel detectors are less complicated, less bulky and offer greater dynamic range than image intensifiers and charge-coupled device detectors connected to some CBCT units.²⁰ These performance indices were slightly lower for the sharpen Digora (sensitivity, 0.670; specificity, 0.692) and original Digora (sensitivity, 0.654; specificity, 0.879) radiographs (Table 5). Data summarized in Table 3 correlate directly with sensitivity and specificity, which in turn corroborate the findings of this study. However, as

reported in a previous study,¹⁸ none of the imaging modalities significantly outperformed the others.

As shown in Table 5, overall accuracy was higher using CBCT images (0.878) than using original Digora (0.687) and sharpen Digora (0.674) radiographs ($p > 0.05$). These data are in accordance with the results from ROC analysis (Table 6 and Figure 3). Although not statistically significant, the mean A_z value was highest for CBCT images (0.897), followed by the original Digora (0.792) and sharpen Digora (0.712) radiographs. In a previous study, the A_z value for a CBCT system with a flat-panel image detector was higher (0.84) than that for digital radiographs acquired using the Digora Optime system (0.64).²² Another study reported that the highest A_z values for all three observers in the diagnosis of approximal caries lesions were obtained with the CBCT images, acquired using a system with a flat-panel image detector.¹⁸ Nevertheless, the differences between imaging modalities (CBCT, conventional radiography and digital radiographs acquired with a charge-coupled device (CCD) system and the Digora Optime system) were not statistically significant.¹⁸ Similarly, no statistically significant differences were found between the A_z values obtained using conventional radiography, the Digora Optime system and two CBCT systems (with complementary metal oxide semiconductor and amorphous silicon flat-panel image detectors) for the detection of non-cavitated proximal caries lesions.¹⁹ The results of the present study are in agreement with the earlier studies comparing proximal caries detection in digital radiographs and CBCT images.^{9,18,19} However, the CBCT systems and some of the intraoral image receptors used in those studies were different from those investigated herein.

Indeed, CBCT may have improved the diagnosis of enamel subsurface demineralization because it enables the visualization of many tooth slices by multiplanar reconstruction, avoiding the overlap of 3D anatomical structures as seen in two-dimensional images.^{19,22} The observers appeared to be more confident about attributing a score of 5 (enamel subsurface demineralization definitely present) using the CBCT images than using the Digora Optime radiographs (Table 4). Additionally, contrast and image resolution features may have favoured the CBCT system. Firstly, the CBCT images were acquired using 120 kVp as opposed to 65 kVp for the Digora Optime system. Higher kilovoltages are related to better contrast resolution. Secondly, pixel pitch (the linear distance between adjacent pixels) was smaller for the Digora Optime radiographs. However, greater pixel pitch results in not only lower resolution but also lower noise because more X-ray photons per pixel are used. Despite these advantageous characteristics, from the statistical standpoint, the CBCT images did not surpass the Digora Optime radiographs. Maybe this equivalence in performance for detecting enamel subsurface demineralization is owing to the display conditions. Bit depth defines the maximum number of individual grey values that an image can contain. Bit depth had the same

Table 6 Area under the receiver operating characteristic curve (A_z) mean values for the detection of enamel subsurface demineralization by imaging modality

Imaging modality	A_z	Relative percentage of area (%)
Cone beam CT	0.897	83.7
Original Digora®	0.792	69.7
Sharpen Digora	0.712	63.3

Digora Optime is manufactured by Orion Corp./Soredex, Helsinki, Finland.

Figure 3. Receiver operating characteristic curves based on pooled data for cone beam CT (CBCT) images, original Digora® (Orion Corp./Soredex, Helsinki, Finland) radiographs and sharpen Digora radiographs

magnitude for both imaging modalities (14 bit). An increase in bit depth results in more available shades of grey in an image, which is more shades than the naked eye can see, and more than contemporary computer monitors can support at a time (most monitors support 8-bit grey shade images = 256 levels).³²

The sharpen filter is a diagnostic tool that uses mathematical algorithms to highlight specific characteristics and compensates for the loss of image quality.²⁵ Based on data shown in Tables 2–4, it may be assumed that the use of an enhancement filter improved the diagnostic performance of digital radiography and, hence, should be advocated during approximal caries detection. The use of the sharpen filter was related to lower observer variability, even though it was not statistically different from the original images. On the other hand, it also may be inferred that the CBCT system with a flat-panel image detector used in this study improved the detectability of small approximal enamel demineralization.

The i-CAT system has a flat-panel image detector, in which the sensor components are embedded in a thin layer of amorphous silicon. This sensor consists of a screen of caesium iodide scintillator and a set of photosensors (photodiodes and transfer devices).²⁰ The scintillator converts the X-ray beam into an optical signal, which is converted into an electrical signal by the photodiodes and, then, it is registered by the set of transfer devices. Probably, the higher accuracy of the

CBCT images observed in this study may be attributed to the flat-panel detector.^{20,33} Nevertheless, other authors using CCD-based image detector systems⁹ and flat-panel detector systems other than the i-CAT system¹⁹ found that CBCT images did not surpass conventional and digital radiography for caries diagnosis.

The diagnosis of caries lesions may be carried out on radiographs or CBCT image data sets.¹⁴ However, the extent of caries demineralization could be better assessed using CBCT.¹⁴ Sensitivity for detecting caries lesions in dentin was higher with CBCT images than with Digora Optime radiographs with or without enhancement filters.⁹ In the present study, enamel sub-surface demineralization was produced to simulate incipient caries lesions, which may be radiographically detected only after a mineral loss of around 40% takes place in the dental tissues.³⁴ Two major factors may be associated with the radiographic diagnosis of dental caries, namely operator experience and intensity of the differences in shades of grey within the demineralized tissues. Perhaps, subtle differences in shades of grey would be better displayed in CBCT images because the noise level may be reduced by slicing.

CBCT has gained broad acceptance in dentistry, and mainly has diversified applications in orthodontic treatment planning and implantology. The use of CBCT in clinical practice offers a number of potential advantages over conventional imaging modalities, including easier image acquisition in the three spatial planes (axial,

sagittal and coronal) and higher accuracy. Even though CBCT is not the method of choice for diagnosing caries lesions, dentists should be aware of its usefulness for detecting incipient demineralization, whenever this kind of examination is needed.^{19,20} If the patient already has undergone CBCT scans, the images should be better analysed because they can serve as diagnostic adjuncts for a multitude of pathologies, including dental caries. In some clinical situations, no other imaging modalities need to be requested, if the CBCT scans are available and well interpreted. This study pointed out that CBCT may

be a suitable imaging modality for detecting approximal caries lesions. On the other hand, whenever the sharpen filter is clinically available, dentists should try this image-enhancement tool in an attempt to improve the diagnosis of subtle approximal caries lesions.

In conclusion, no significant differences were found in the diagnostic performance of CBCT images, original Digora and sharpen Digora radiographs. Accordingly, these imaging modalities may be useful adjuncts for detecting incipient and reversible approximal enamel demineralization.

References

1. Pine CM, ten Bosch JJ. Dynamics of and diagnostic methods for detecting small carious lesions. *Caries Res* 1996; **30**: 381–388.
2. Haiter-Neto F, Ferreira RI, Tabchoury CPM, Bóscolo FN. Linear and logarithmic subtraction for detecting enamel subsurface demineralization. *Dentomaxillofac Radiol* 2005; **34**: 133–139. doi: [10.1259/dmfr/92119765](https://doi.org/10.1259/dmfr/92119765).
3. Hala LA, Mello JB, Carvalho PL. Evaluation of the effectiveness of clinical and radiographic analysis for the diagnosis of proximal caries for different clinical experience levels: comparing lesion depth through histological analysis. *Braz J Oral Sci* 2006; **5**: 1012–1017.
4. Tsuchida R, Araki K, Okano T. Evaluation of a limited cone-beam volumetric imaging system: comparison with film radiography in detecting incipient proximal caries. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2007; **104**: 412–416.
5. van Rijkom HM, Verdonschot EH. Factors involved in validity measurements of diagnostic tests for approximal caries—a meta-analysis. *Caries Res* 1995; **29**: 364–370.
6. Sanden E, Koob A, Hassfeld S, Staehle HJ, Eickholz P. Reliability of digital radiography of interproximal dental caries. *Am J Dent* 2003; **16**: 170–176.
7. Jacobsen JH, Hansen B, Wenzel A, Hintze H. Relationship between histological and radiographic caries lesion depth measured in images from four digital radiography systems. *Caries Res* 2004; **38**: 34–38.
8. Ferreira RI, Haiter-Neto F, Tabchoury CP, de Paiva GA, Bóscolo FN. Assessment of enamel demineralization using conventional, digital, and digitized radiography. *Braz Oral Res* 2006; **20**: 114–119.
9. Haiter-Neto F, Wenzel A, Gottfredsen E. Diagnostic accuracy of cone beam computed tomography scans compared with intraoral image modalities for detection of caries lesions. *Dentomaxillofac Radiol* 2008; **37**: 18–22.
10. Isidor S, Faaborg-Andersen M, Hintze H, Kirkevang LL, Frydenberg M, Haiter-Neto F, et al. Effect of monitor display on detection of approximal caries lesions in digital radiographs. *Dentomaxillofac Radiol* 2009; **38**: 537–541.
11. Wenzel A, Haiter-Neto F, Gottfredsen E. Risk factors for a false positive test outcome in diagnosis of caries in approximal surfaces: impact of radiographic modality and observer characteristics. *Caries Res* 2007; **41**: 170–176.
12. Sukovic P. Cone beam computed tomography in craniofacial imaging. *Orthod Craniofac Res* 2003; **6**: 31–36; discussion: 179–182.
13. Akdeniz BG, Gröndahl HG, Magnusson B. Accuracy of proximal caries depth measurements: comparison between limited cone beam computed tomography, storage phosphor and film radiography. *Caries Res* 2006; **40**: 202–207.
14. Kalathing SM, Mol A, Tyndall DA, Caplan DJ. In vitro assessment of cone beam local computed tomography for proximal caries detection. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2007; **104**: 699–704. doi: [10.1016/j.tripleo.2006.08.032](https://doi.org/10.1016/j.tripleo.2006.08.032).
15. Ballrick JW, Palomo JM, Ruch E, Amberman BD, Hans MG. Image distortion and spatial resolution of a commercially available cone-beam computed tomography machine. *Am J Orthod Dentofacial Orthop* 2008; **134**: 573–582.
16. Tyndall DA, Rathore S. Cone-beam CT diagnostic applications: caries, periodontal bone assessment, and endodontic applications. *Dent Clin North Am* 2008; **52**: 825–841. doi: [10.1016/j.cden.2008.05.002](https://doi.org/10.1016/j.cden.2008.05.002).
17. Wenzel A, Haiter-Neto F, Frydenberg M, Kirkevang LL. Variable-resolution cone-beam computerized tomography with enhancement filtration compared with intraoral photostimulable phosphor radiography in detection of transverse root fractures in an in vitro model. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2009; **108**: 939–945.
18. Senel B, Kamburoglu K, Üçok O, Yüksel SP, Ozen T, Avsever H. Diagnostic accuracy of different imaging modalities in detection of proximal caries. *Dentomaxillofac Radiol* 2010; **39**: 501–511.
19. Zhang ZL, Qu XM, Li G, Zhang ZY, Ma XC. The detection accuracies for proximal caries by cone-beam computerized tomography, film, and phosphor plates. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2011; **111**: 103–108.
20. Scarfe WC, Li Z, Aboelmaaty W, Scott SA, Farman AG. Maxillofacial cone beam computed tomography: essence, elements and steps to interpretation. *Aust Dent J* 2012; **57**: 46–60. doi: [10.1111/j.1834-7819.2011.01657.x](https://doi.org/10.1111/j.1834-7819.2011.01657.x).
21. Young SM, Lee JT, Hodges RJ, Chang TL, Elashoff DA, White SC. A comparative study of high-resolution cone beam computed tomography and charge-coupled device sensors for detecting caries. *Dentomaxillofac Radiol* 2009; **38**: 445–451.
22. Kayipmaz S, Sezgin OS, Saricaoglu ST, Çan G. An in vitro comparison of diagnostic abilities of conventional radiography, storage phosphor, and cone beam computed tomography to determine occlusal and approximal caries. *Eur J Radiol* 2011; **80**: 478–482.
23. Ferreira RI, Haiter-Neto F, Tabchoury CP, Bóscolo FN. In vitro induction of enamel subsurface demineralization for evaluation of diagnostic imaging methods. *J Appl Oral Sci* 2007; **15**: 392–398.
24. Argenta R, Tabchoury C, Cury JA. A modified pH-cycling model to evaluate fluoride effect on enamel demineralization. *Pesqui Odontol Bras* 2003; **17**: 241–246.
25. Haiter-Neto F, Wenzel A, Casanova MS, Frydenberg M. Task-specific enhancement filters in storage phosphor images from the Vistascan system for detection of proximal caries lesions of known size. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2009; **107**: 116–121.
26. Analoui M. Radiographic image enhancement. Part I. Spatial domain techniques. *Dentomaxillofac Radiol* 2001; **30**: 1–9. doi: [10.1038/sj/dmfr/4600562](https://doi.org/10.1038/sj/dmfr/4600562).
27. Lehmann TM, Troeltsch E, Spitzer K. Image processing and enhancement provided by commercial dental software programs. *Dentomaxillofac Radiol* 2002; **31**: 264–272.
28. Arends J, ten Bosch JJ. Demineralization and remineralization evaluation techniques. *J Dent Res* 1992; **71**: 924–938.
29. Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics* 1977; **33**: 159–174.

30. Arai Y, Tammisalo E, Iwai K, Hashimoto K, Shinoda K. Development of a compact computed tomographic apparatus for dental use. *Dentomaxillofac Radiol* 1999; **28**: 245–248. doi: [10.1038/sj/dmfr/4600448](https://doi.org/10.1038/sj/dmfr/4600448).
31. Yalcinkaya S, Kunzel A, Willers R, Thoms M, Becker J. Subjective image quality of digitally filtered radiographs acquired by the Dürr Vistascan system compared with conventional radiographs. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2006; **101**: 643–651.
32. Wenzel A, Haiter-Neto F, Gotfredsen E. Influence of spatial resolution and bit depth on detection of small caries lesions with digital receptors. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2007; **103**: 418–422.
33. Scarfe WC, Farman AG, Sukovic P. Clinical applications of cone-beam computed tomography in dental practice. *J Can Dent Assoc* 2006; **72**: 75–80.
34. Razmus TF, Parks ET, Miles DA, Van Dis ML, Williamson GF, Bricker SL. Effects of filtration, collimation, and target-receptor distance on artificial approximal enamel lesion detection with the use of RadioVisioGraphy. *Oral Surg Oral Med Oral Pathol* 1994; **77**: 419–426.