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ORIGINAL ARTICLE

Effect of tube potential and image receptor on the detection of natural proximal caries in primary teeth

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Abstract The aim of this study was to assess the detection of proximal caries in primary teeth at three different tube potentials using Ektaspeed films, storage phosphor plates (SPPs), and a charge-coupled device (CCD). Fifty-three extracted human primary molars with natural proximal caries were radiographed with three different imaging modalities—Digora Optime SPP system, RVGui CCD system, and Ektaspeed films—at 50-, 65-, and 70-kV tube potentials. Three observers scored the resultant images for the presence or absence of caries. The definitive diagnosis was determined by stereomicroscopic assessment. The diagnostic accuracy for each imaging modality was expressed as the area under the receiver operating characteristic curves (A_z). Differences among the A_z values were assessed using two-way ANOVA and t tests. Kappa was used to measure inter- and intra-observer agreement. Higher accuracy was found for SPPs compared to film and CCD images at all tube potentials. Accuracy was significantly different only at 50-kV tube setting in favor of SPPs ($p<0.05$). Inter- and intra-observer agreement was high for all systems. A SPP system can be recommended for dental peadodontic clinics particularly with 50-kV tube potential for the diagnosis of proximal caries since further advantages include the elimination of chemical processing, image enhancement, and a better low-contrast detectability performance.

Keywords Radiology · Digital · Caries detection · Tube potential

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Introduction

The accuracy of different digital receptors for caries detection in permanent teeth has been compared respectively and with conventional film systems in the past 20 years [1, 2]. It is well-known that digital images generated with charge-coupled sensors or storage phosphor plates (SPPs) were comparable to film images for caries detection [3, 4]. Among many other factors, the most important factor affecting diagnostic information in intra-oral radiographs is the X-ray tube potential [5]. It was established that the presence of caries is more easily detected in radiographs with high contrast; thus, low tube potential settings are generally recommended for detection of dental caries [6]. However, contrary to the aforementioned, a recent study reported an equal diagnostic accuracy for film and digital images of permanent teeth when tube potential was increased from 60 to 90 kV [7].

Proximal caries detection in primary teeth is of great importance because of the rapid rate of caries progression due to peculiar morphologic characteristics [8, 9]. Nevertheless, the number of studies that have evaluated the efficiency of different image receptors for caries detection in primary teeth is rather limited [10, 11]. Besides, there is no published data comparing different sensors with conventional films for the detection of proximal caries in primary teeth at different tube potentials.

Therefore, the aim of the present study was to assess the visibility of proximal caries in primary teeth at three different tube potential settings using Ektaspeed Plus films, SPPs, and a charge-coupled device (CCD).

Material and methods

Specimens

Fifty-three extracted human primary first molars without fillings and with sound surfaces or proximal surfaces representing different stages of enamel and/or dentine caries were used in the study. Before radiography, the roots of the teeth were cut off. Primary first molars from each side of a young dry human mandible were removed and replaced with a test tooth for each exposure. The original teeth created natural contact points at either end. All 53 teeth were radiographed with three different imaging modalities—RVGui charge-coupled device system (RVGui ver 4.2d, Trex-Trophy Radiology Inc, Marne-la-Vallée, France), Digora® Optime (Soredex Corporation, Helsinki, Finland) image plate system, and Ektaspeed Plus film (Eastman Kodak, Rochester, NY, USA; Fig. 1).

Radiographic technique

Film and digital images of the teeth were acquired by using bite-wing projection geometry at a focus-receptor distance of 25 cm. Mandibular specimen was mounted in a block of silicone paste to ensure a reproducible geometry. While the vinyl polysiloxane putty was still soft, the CCD sensor was pressed into it. Once hardened, the putty allowed quick realignment of specimen as well as CCD, SPP, and Ektaspeed Plus film. Heliodent (Sirona DentalSystem GmbH, Bensheim, Germany) dental X-ray unit was used for all exposures operating at 7 mA with 1.5 mm Al equivalent filtration at three different tube potential settings (50, 65, 70 kV). A 20-mm-thick soft tissue equivalent Plexiglas block was placed close to the mandible and facing the X-ray tube to simulate scatter radiation and beam attenuation from soft tissues [12–15].

Film images were acquired using size 0 (22×35 mm) films. Digital images were obtained with a size 1 CCD sensor and a size 0 (22×31 mm) blue storage phosphor plates. The RVGui system provides three types of diagnostic modes (dentoenamel, periodontal, and endodontic) at two levels (high and low) of spatial resolution. In this study, the exposures with the RVGui sensor were performed in the

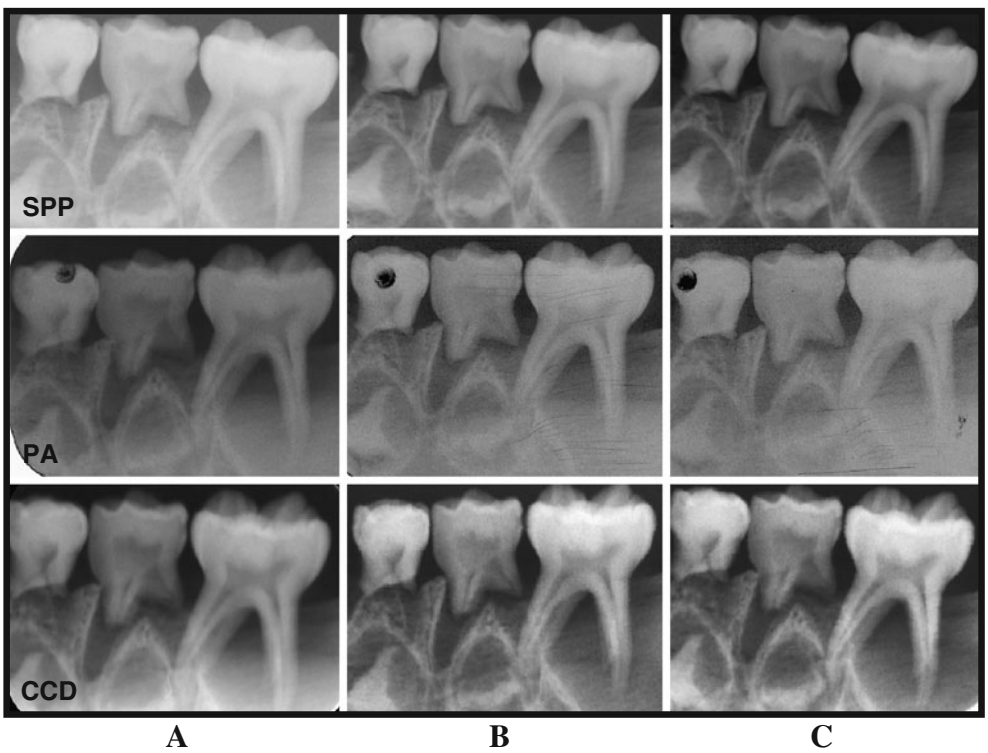

Fig. 1 Images of storage phosphor plate (*SPP*), charge-coupled device (*CCD*), and Ektaspeed periapical film (*PA*) obtained at 50 (**A**), 65 (**B**), and 70 kV (**C**) tube settings

"dentoenamel" high-resolution mode, which was recommended by the manufacturer to provide high-contrast images for caries detection.

The Digora Optime system was used for acquisition of phosphor plate images. The plates were stored in lightproof envelopes during the exposure and scanned immediately after exposure using the Digora Optime scanner. "High-resolution" mode of scan was selected from the scanner setup menu as recommended by the manufacturer for most diagnostic tasks. Ektaspeed Plus films were exposed for 0.25 s while SPPs and CCD sensor were exposed at 0.12 s to generate subjectively an optimal density for caries detection [1, 16]. All films were developed using an AP-200 (PLH Medical Ltd, Watford, UK) automatic film processor using fresh solutions.

Image evaluation

Two oral radiologists and one specialist in restorative dentistry independently evaluated the resultant 477 images and 954 approximal sites for the presence or absence of proximal caries using a five-graded scale: (1) caries definitely absent, (2) caries probably absent, (3) unsure whether caries is absent or present, (4) caries probably present, and (5) caries definitely present. Observers were instructed to assess only proximal surfaces coronal to the cementoenamel junction at both sides of each test tooth.

Films were mounted in non-transparent frames, placed on a masked light box with a ×2 magnifying viewer, and examined in a room where the light was dimmed. Digital images were displayed on a 15-in. high-resolution (XGA) color liquid crystal monitor with a resolution of 1,024× 768 pixels and 256 gray levels (Toshiba Satellite 1900, Toshiba Corp., Tokyo, Japan). Digital images were displayed using the dedicated software of each imaging system incorporated into the same computer. Observation conditions were optimized through use of the same computer monitor when the images were displayed and the display ratio was 1:1. Viewing distance was kept constant to about 50 cm for all observers, and the lights were subdued during observations. The observers were not given the option to perform any image enhancements to avoid the production of variety of different digital images.

A total of 1,431 observations were made by three observers. The evaluation was repeated at least a week later with the same observers in order to obtain intra-rater agreement.

For the validation of the true presence of caries, the test teeth were hemi-sectioned in the mesiodistal direction perpendicular to the proximal surfaces from their central fossas by a diamond disk under water cooling. Two observers with experience in microscopy validated the both sides of each tooth section under a stereomicroscope (Leica S8APO, Leeds, UK) at ×10 magnification using the following scale: (1) sound, (2) caries in enamel, (3) caries in dentoenamel junction, (4) caries in the outer half of the dentin, and (5) caries in the inner half of the dentin. The observers assessed the tooth sections individually, and in case of disagreement, a joint assessment was performed to establish an agreement.

Statistical analysis

Receiver operating characteristic (ROC) analysis was used to evaluate the diagnostic accuracy of three imaging systems under three different kilovoltage settings by averaging the scores over all three observers. The diagnostic accuracy for three different kilovoltage settings on images acquired with different imaging modalities was expressed as the area under the ROC curves (A_z). A_z values were calculated for each observer (SPSS package—version 10.0 for Windows; SPSS Inc., Chicago, IL, USA) on images from the systems using three different kilovoltage settings. The A_z values were analyzed by two-way analysis of variance, while pair-wise comparisons of A_z values of three different imaging modalities obtained at each different kilovoltage setting was performed using post hoc t test (SPSS package, GLM—version 10.0 for Windows; SPSS Inc., Chicago, IL, USA). The level of significance was established as $p=0.05$. Cohen's kappa was used to measure the level of agreement in and between observers and the results interpreted using the six-point scale as proposed by Landis and Koch [17].

Results

The histological examination of 106 proximal surfaces in 53 primary molar teeth confirmed that 40 (37.7%) proximal surfaces being evaluated were not carious, whereas 63 (62.3%) had caries with different depths (Table 1).

The mean A_z values and standard deviations for three image receptors at each kilovoltage setting and results of

Table 1 Distribution of sound and carious proximal surfaces of primary teeth assessed by histological validation

Scores	Number of tooth surfaces	Percent
Score 1: sound	40	37.7
Score 2: caries in enamel	8	7.54
Score 3: caries in dentoenamel junction	12	11.32
Score 4: caries in the outer half of the dentin	20	18.86
Score 5: caries in the inner half of the dentin	26	24.5

pair-wise comparisons were presented in Table 2. The highest A_z was obtained with the SPPs, followed by Ektaspeed Plus film and CCD sensor for all kilovoltage settings (Table 2). Pair-wise comparisons revealed that the significant difference was only present between SPP–film (p=0.0009) and SPP–CCD (p=0.0001) and only at 50-kV tube setting (Table 2). Using 50 kV, the detection efficiency obtained with the SPP system was significantly higher than those found with CCD and film; however, the difference between the CCD system and film was not significant (p> 0.05). The detection accuracy ranking of the three imaging systems was exactly the same for the remaining kilovoltage settings (65 and 70 kV) used in this study. No statistically significant difference was observed among three image receptors for the detection of proximal caries in primary teeth at 65 and 70 kV (p>0.05).

Kappa analysis indicated that inter-rater agreement among evaluators' detection of proximal caries ranged between moderate and substantial for SPP images (range between 0.46 and 0.67) and Ektaspeed Plus films (range between 0.51 and 0.79) while it was between fair and substantial for CCD sensor images (range between 0.36 and 0.73). There was a high level of intra-rater agreement between the two assessments of the observers as expressed by mean kappa values in the range of 0.87–0.91 (almost perfect).

Discussion

Comparison of relatively higher tube potentials (65 and 70 kV) used in the present study for examination of radiographs obtained with two digital receptors and film radiographs showed no significant difference in the detection of proximal caries in primary teeth. This finding is in accordance with the results of previous studies, in which the effect of tube potential was studied in relation to diagnostic accuracy of proximal caries in permanent teeth [18, 19]. The intra- and inter-observer agreements obtained are also in line with the reported agreements for caries diagnosis and contributed to this result [7, 20–22].

The only significant relationship among three receptors was found at the lowest kilovoltage setting (50 kV). It was previously reported that observers evaluating natural proximal caries lesions at 65 and 90 kVp made more total errors at the higher tube potential [23]. It was advocated that this difference in favor of the low tube potential may be due to the higher subject contrast associated with lower tube potentials. In a study that has evaluated the diagnostic accuracy at four different tube potentials, significant difference was found in the detection of caries favoring 60 kVp over 90 kVp [6]. In another study, diagnostic accuracy was found to be better with low kilovoltage for radiography of premolars [24]. Similar results with regard to the better performance of digital detectors were obtained due to either an increase in detail detectability or improved signal-to-noise ratio when images were acquired with lower voltage [25, 26].

Current published report of European Commission on radiation protection (RP 91) recommended that tube voltage should be at least 50 kV (http://ec.europa.eu/energy/nuclear/radiation_protection/doc/publication/091_en.pdf). On the other hand, in the updated consultation draft (RP 162), it was suggested that the operating tube voltage should not be <60 kV (http://ec.europa.eu/energy/nuclear/radiation_protection/consultations/doc/rp_91_update_2009_draft_for_consultation.pdf). Nevertheless, studies evaluating the quality of radiological equipment in different countries reported that 8–56% of dental X-ray machines have either 50 or lower kilovoltage [27–31]. Since 50-kV machines are still widely used in many developing countries including our country, 50-kV tube potential is included to the parameters of the present study.

The results demonstrate high diagnostic accuracy at all kilovoltage settings for all image receptors used in this study. Hence, all receptors may be regarded as considerably adequate for proximal caries diagnosis in primary teeth. It is well-known that one of the most important factors that influence the efficiency of caries detection is the size and depth of the lesion [5]. Since 43% of the proximal surfaces evaluated in this study had caries extending to dentin and due to the different grades of carious lesions, high diagnostic accuracy may be naturally expected. As already known, the depth of caries affects the attenuation of radiation and accordingly the density and contrast by which it is represented in an image [32]. Therefore, another reason for high diagnostic accuracy may be the relatively thinner structure of dentin in primary teeth giving rise to rapid rate of caries progression resulting in emergent profound defects extending deeper in dentin (lesions that are shaped like a cone with their base inward), and accordingly, their detection is highly efficient with all receptors used in this

Table 2 Mean A_z values and SD of three receptors at three tube potentials

Receptor type	Mean A_z values ± SD		
	50 kV	65 kV	70 kV
SPP	0.98±0.10	0.93±0.02	0.94±0.02
Film	0.88±0.03[a]	0.90±0.03	0.93±0.03
CCD	0.83±0.03[a]	0.88±0.03	0.88±0.02

Film–SPP (p=0.0009), CCD–SPP (p=0.0001)

SPP storage phosphor plate, *Film* Ektaspeed Plus film, *CCD* charge-coupled device

[a] Indicates significance between SPP

study. Anyhow, the accuracy obtained for all types of images/sensors in the present study were comparable to the previous reports for primary teeth [7, 33–35]. Considering that the number of carious lesions extending into dentine is large and intra-observer agreements were high in the present study, it may be possible to recommend the use of either of the digital receptors or a fast analog film for diagnosis of relatively deep proximal caries in primary teeth since all systems provided high accuracy at the tube potentials used in this study.

Contrast resolution and low-contrast detectability are considered as the primary factors for the comparison of diagnostic accuracy of different imaging systems/receptors [36]. Caries detection is a contrast-limited task; thus, high contrast is a more important prerequisite for providing an optimal basis for caries diagnosis [37]. The density, contrast, and noise characteristics of the final image are affected by the choice of diagnostic mode; however, both softwares used in this study did not allow access to the original non-processed image data. The selection of spatial and/or contrast resolution at the time of image acquisition resulted in the application of image processing procedures that could not be reversed. According to the manufacturers, high-resolution mode of the SPP system provides high-contrast images with 14-bit depth [38] whereas caries (dentoenamel) mode of the CCD system provides 12-bit high-contrast images [39]. Therefore, higher-contrast resolution of storage phosphor plate images as well as their better low-contrast detectability may be associated with better performance with regard to the proximal caries detection in primary teeth [40].

Both digital receptors have a linear relationship between relative exposure and optical density. However, SPPs have a wider exposure range than that of both films and CDD sensors, producing good-quality images at low and high exposures [41]. On the contrary, it was reported that employing 70 kVp, in CCD sensors, tended to reduce the dynamic range even further [42]. The large dynamic range presented by the photostimulable storage phosphor imaging plates could have made it possible for a greater number of images acceptable for diagnosis at all tube settings used in this study [33, 40–42]. On the other hand, narrower dynamic range of the CCD sensor may be the reason for the insignificant difference between diagnostic accuracy of CCD and film images since films also have similar restrictions regarding density at both ends of the exposure range.

The number of examiners and number of examined surfaces are important factors in the design of in vitro studies for the statistical power to demonstrate a difference in diagnostic accuracy between systems. Bader et al. have concluded that a small number of observers are a limiting factor for those studies which compare the radiographic methods for caries detection [43]. On the contrary, Rockenbach et al. have postulated that it is more productive to compare the findings of one observer to the gold standard, and the evaluation carried out by a single well-calibrated observer with good intra-observer agreement is the ideal situation [4]. Finally, Hintze et al. demonstrated that as long as the data are analyzed by a two-way analysis of variance, that study designs for comparing the accuracy of several systems can be composed freely in relation to the number of surfaces and observers provided that the total number of evaluations per system are identical [44]. In the present study, the same number of evaluations was done for each system under investigation, two-way analysis of variance was used for the statistical analysis, and the intra-observer agreement ranged between 0.87 and 0. 91, indicating a good concordance among the evaluations performed by the observer. Therefore, according to the aforementioned study, the results of the present study may be regarded as reproducible and may be generalized as regards the diagnostic performance of different systems in primary teeth [45].

In vitro studies comparing the diagnostic accuracy of different imaging modalities for detection of proximal caries have generally used dental stones for mounting of teeth. In the present study, a young dry mandible was preferred to mimic clinical settings and to maintain a reproducible receptor positioning. The presence of bone trabeculae in the bony specimens provided more realistic "noise" presenting images imitating natural in vivo conditions and providing a chance to interpolate our results to clinical settings [46]. However, further clinical studies are needed to validate this assumption.

There are several update studies concerning the accuracy of caries detection either using different types of image receptors [47] or different tube potentials for permanent [6, 25], mixed [11], and primary dentitions [32, 48]. However, this is the first study fulfilling the three different conditions together. The present study compared the accuracy of proximal caries detection for different digital intra-oral receptors with conventional films on primary teeth using different tube potentials. However, it should be remembered that this article focused only on kilovoltage. Tube potential is just one of the many factors that influence the patient dose, image quality, and accordingly the diagnostic accuracy of different receptors/systems.

When choosing the ideal imaging system/receptor for proximal caries detection in pediatric dental practice, the accommodation of positioning of the sensor in the children's mouth, image quality, and the dose received by the patient should be equally considered. In this context, the manipulation of CCD sensor is not easy in children, and further, active surface area of CCDs is smaller than the outer surface and requires more exposures to cover the

same area often resulting in retakes [49]. On the other hand, analog films have a thin metal foil which tends to prevent backscatter radiation thereby avoiding the deterioration of the resultant image as well as dose to the patient. Accordingly, when the factors frequency of retakes, number of images to cover a region of interest, and dose for a single exposure are combined, it may be speculated whether a dose reduction is obtained with a digital receptor. In recent years, analog films have also increased in sensitivity, and the difference between the radiation sensitivity for film and digital receptors is smaller [50]. Nevertheless, further dose saving for an exposure with SPP system compared to film was reported which could be further maximized with the use of image enhancement options [51]. It should be kept in mind that, due to the wide dynamic range of SPP systems, unnecessary high doses could be readily used since clinicians tend to prefer dark radiographs [50].

In conclusion, no difference was found among SPP, CDD sensor, and Ektaspeed Plus film images for the diagnostic accuracy of proximal caries in primary teeth at tube potentials of 65 and 70 kV, but significant difference was observed at 50 kV in favor of SPP images. Therefore, considering the pros and cons of each receptor/system, one may prefer to use a storage phosphor plate system particularly with 50-kV tube potential for the diagnosis of proximal caries in primary teeth since further advantages include the elimination of chemical processing, image enhancement, and a better low-contrast detectability performance.

Conflict of interest The authors declare that they have no conflict of interest.

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