Original Article

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Dentistry Section

Effect of Different Tube Potential Settings on Caries Detection using PSP Plate and Conventional Film

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ABSTRACT

Purpose: To compare intraoral Phosphor Stimulable Plate digital system and intraoral film using different tube settings on incipient proximal caries detection.

Materials and Methods: Five blocks, with five teeth each, were radiographically examined using phosphor plates and F-speed films. The images were acquired in 07 different tube potentials from 50-80 kV. The films were digitized. Three oral radiologists scored the images for the presence of caries using a 5-point rating scale. The areas under ROC curve were calculated. The influence of tube kilovoltage was verified by ANOVA and pair wise comparisons performed using Tukey test.

Results: Mean ROC curve areas varied from 0.446-0.628 for digital images and 0.494–0.559 for conventional images. The tube setting of 70 kV presented the best result both for digital and conventional images. Considering the image type separately, 70 kV scored highest followed by 75 and 65 kV for digital images (p=0.084). For conventional image modality, even though 70 kV presented the best result, it did not differ significantly from 80 kV, not differing from 60 and 55 kV, which did not differ from 75, 65 and 50 kV (p=0.53).

Conclusion: Phosphor plate digital images seem to be more susceptible to tube setting potential variations then digitized film images.

Keywords: Dental digital radiography, Diagnostic tests, Intraoral radiography, ROC analysis

INTRODUCTION

Intraoral radiography is, despite the up-to-date advanced methods, still the most commonly used radiographic technique in dental caries diagnosis [1]. It is well-known that the radiographic diagnosis of caries lesions depends on the image quality. And, among all exposure parameters, the most important one affecting diagnostic information in intraoral radiographs is the X-ray tube potential [2]. This parameter determines the contrast of the radiography in an inversely proportional way: The higher the tube potential, the lower the contrast. Image contrast is a result of the different attenuations of X-radiation photons by the exposed tissue [3]. As it was established that the presence of dental caries is more easily detected in radiographs with high contrast, low tube potential settings are generally recommended for caries detection [2].

Digital radiographic systems were introduced as an alternative to conventional radiographic films and have gained ground in dental practices worldwide [1,4]. There are many digital radiography systems commercially available for dental use and they all use one of the two basically different types of receptor: a solid-state sensor with or without a cord {charge-coupled device (CCD) or complementary metal oxide semiconductor (CMOS)} and a photostimulable storage phosphor (PSP) plate [1,5,6]. PSP technology is also called indirect digital imaging because the image is first captured in analog format and then converted into digital format [7]. The PSP plate surface is ionized when the plate is exposed and a latent image is produced. This latent image is read by a red laser beam in a scanner. The laser light stimulates the electrons, whereby energy is emitted in the form of blue light. This is recorded by a photo-multiplier, which turns light into an electronic signal that is digitized [1].

To the present moment, it has been suggested that digital systems reduce patients' exposure to radiation compared to conventional radiography. And also, digital images have been shown to be diagnostically comparable to film images for detecting caries [4]. Therefore, the aim of this study was to compare intraoral Phosphor Stimulable Plate digital system and intraoral film using different tube settings on incipient proximal caries detection.

MATERIALS AND METHODS

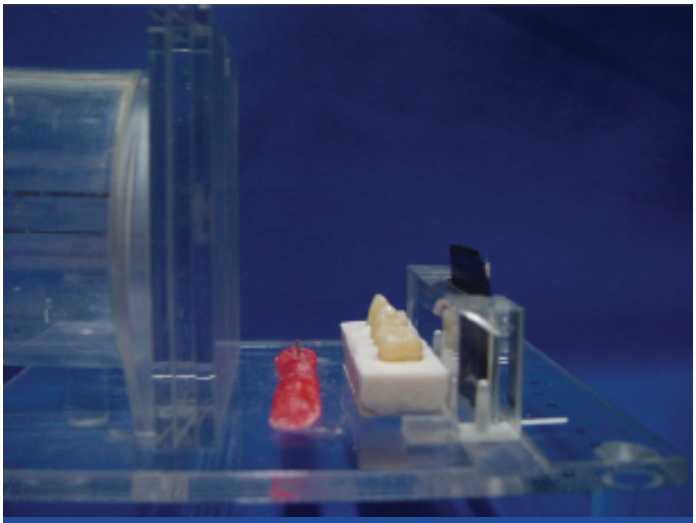
The study design was approved by the Ethical Board of Piracicaba Dental School - State University of Campinas Review Board and is in compliance with the Helsinki Declaration. This study was conducted during the period of February 2012 to February 2014. Twenty-five extracted human teeth (5 canines, 10 premolars, and 10 molars) were mounted in five blocks of silicone, with four test teeth (2 premolars and 2 molars) and one non-test tooth (canine) each. The canine tooth was only used to assure proximal contact to the first premolar.

The premolars and molars inclusion criteria were that they had either none or small demineralization in their proximal surfaces. The exclusion criteria were premolars and molars with visible dentine caries and/or restorations on proximal surfaces. All incipient proximal caries lesions presented in the sample were natural and not artificially created.

Radiographic Procedure

All test teeth of the 5 phantoms were radiographed with 2 different imaging systems: size 2 intraoral PSP digital imaging (DenOptix, Gendex Dental Systems, Milan, Italy) and size 2 F-speed intraoral films (Kodak Insight Dental Film, Eastman Kodak Company, Rochester, USA). Each tooth was imaged with a GE 1000 unit (General Electric Company, Milwaukee, USA) operating at 3 mAs. The tube potential settings varied from 50 to 80 kV with a 5 point kV interval. A total of 280 images were obtained: 20 radiographic images per tube potential setting (4 images for each phantom), per imaging system. A 1.2 cm thick acrylic plate was placed adjacent to the models as soft tissue equivalent material [8-10]. To ensure in vitro true parallel technique, the blocks of silicone were stabilized on a customized acrylic device providing a distance of 34 cm between the X-ray source and image receptor, a central

X-ray beam orientation, and 2 cm tooth-receptor distance [Table/Fig-1].



[Table/Fig-1]: Acrylic device used to ensure reproducible in vitro true parallel technique

Prior to exposure, each plate of the digital system was exposed to a LCD backlight negatoscope for 130 s, as suggested by the manufacturer. After exposure, the plates were scanned using 300 dpi resolution and saved in a personal computer. Films were processed automatically using a GPX processor (Gendex Dental Systems, Milan, Italy), using fresh Kodak RP X-OMAT processing solutions (Kodak Eastman Corp., Rochester, USA), according to the manufacturer's instructions, and were digitized into a personal computer by a scanner with transparency module (Scanjet 4C; Hewlett Packard Co., Greeley, USA) with a resolution of 300 dpi. All images were acquired in 256 shades of gray (8 bits), not manipulated, stored in a non-compressed file (tiff format) and identified by a code indicating tooth, phantom, image modality and tube potential setting.

Viewing Sessions

Images were analysed by three blinded, previously calibrated examiners. The previous calibration consisted of verbal-practical instructions and the identification of the existence of caries lesions in 40 radiographs of each modality that did not belong to the study sample.

The observers, all of them having more than 5 years' experience as oral radiologists, independently assessed all 280 images, 20 images at a time, on a 17" color monitor placed in a quiet room with dimmed light. Images were viewed as a Microsoft PowerPoint presentation (Microsoft Corporation, Redmond, USA), in order to facilitate the examiners work-flow. Enhancement of the images was not allowed since the aim of the study was to evaluate the tube setting potential as an isolated criterion. To avoid fatigue, a minimum of 24 h interval between each evaluation was established. The presence of proximal caries lesions was scored in a 5-point confidence scale: (1) definitely not present, (2) probably not present, (3) unsure, (4) probably present, and (5) definitely present.

Gold Standard

Histologic sections (700 µm) were used as validating criteria for the presence and depth of the caries lesions. Prior to section, the teeth were individually embedded in acrylic (Vipi, São Paulo, Brazil) and then sectioned in the mesiodistal direction, using a 200 mm diamond band (AcuThin™ Abrasive Cut-off Wheels, Buehler ITW Company, Illinois, USA). The sections were cleaned and glued to microscope slides using transparent varnish. Histological validation was performed, independently, by two previously trained observers under incident light (10–20X magnification) using a binocular stereomicroscope (Ample Scientific CM503 Nexcope Professional Binocular Microscope, Ample Scientific, Norcross, GA, USA). If the observer's ratings varied, they were asked to perform a joint assessment to establish agreement.

Caries lesions were defined as present when an opaque-white demineralization or brown discolored spot was observed on the surface. For the histological surface the following scale was applied: (0) no enamel demineralization or narrow surface zone of opacity; (1) demineralization limited to the enamel; (2) demineralization involving the dentine.

From the 40 evaluated proximal surfaces, 18 proximal surfaces had caries – 2 dentine caries and 16 enamel caries – against 22 sound surfaces.

STATISTICAL ANALYSIS

To measure the accuracy of the images acquired in different tube potential settings, the area under the Receiver Operating Characteristic (ROC) curves (Az) were calculated. An Az value of 0.5 represents chance performance and 1.0 perfect accuracy. Two-way ANOVA was applied to compare the Az values using an appropriate model for block experiments so the tube potential setting was the main factor to be evaluated. Pair-wise multiple comparisons of Az values of the different image types at the different exposure settings were performed using the Tukey's t-test. Data analyses were performed using Sigma Stat for Windows (version 3.5; Systat Software Inc, Erkrath, Germany). The level of significance was set at $p < 0.05$.

RESULTS

Data from each observation of three observers were pooled together. Inter observer *k* coefficients reliability ranged between 0.25 and 0.49.

The mean values for the area under the ROC curve, standard deviation, confidence intervals and the differences among tube potential setting for the PSP digital system are shown in [Table/Fig-2]. Mean ROC curve areas for tube potential setting varied from 0.446 to 0.628 for digital images. Based on the observed means, the tube setting of 70 kV presented the best result followed by 75 and 65 kV and was significantly higher than the other tube settings ($p = 0.084$).

Tube Potential Settings (Kv)	Mean (Az)	Standard Deviation	Confidence Intervals (95%)		Tukey's Groups (α=0.05)
			superior	inferior	
70	0.628	0.062	0.690	0.566	a
75	0.619	0.059	0.678	0.560	a
65	0.598	0.059	0.657	0.539	a
60	0.507	0.059	0.566	0.448	b
50	0.488	0.062	0.550	0.426	b
55	0.451	0.060	0.511	0.391	b c
80	0.446	0.060	0.506	0.386	c

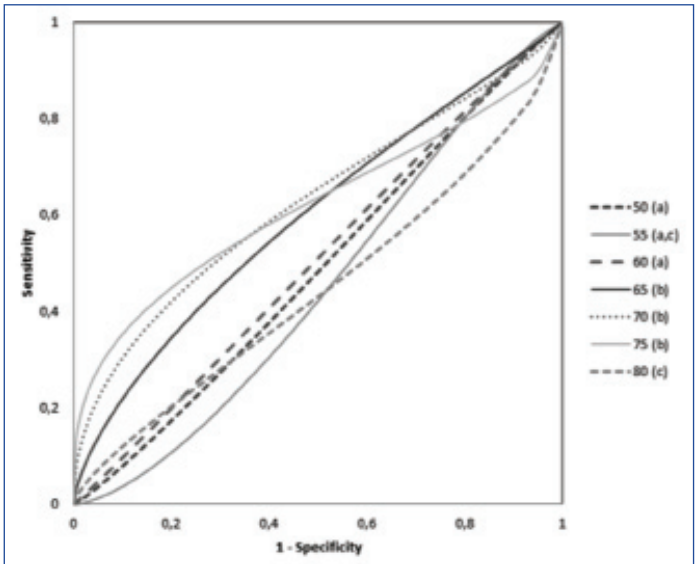
[Table/Fig-2]: PSP kV accuracy means (Az), standard deviations, confidence intervals (95%) and Tukey's test (α=0.05)

Tube Potential Settings (Kv)	Mean (Az)	Standard Deviation	Confidence Intervals (95%)		Tukey's Groups (α=0.05)
			superior	inferior	
70	0.559	0.058	0.617	0.501	a
80	0.543	0.057	0.600	0.486	a b
60	0.511	0.059	0.570	0.452	b c
55	0.504	0.061	0.565	0.443	b c
75	0.500	0.061	0.561	0.439	c
65	0.495	0.060	0.555	0.435	c
50	0.494	0.062	0.556	0.432	c

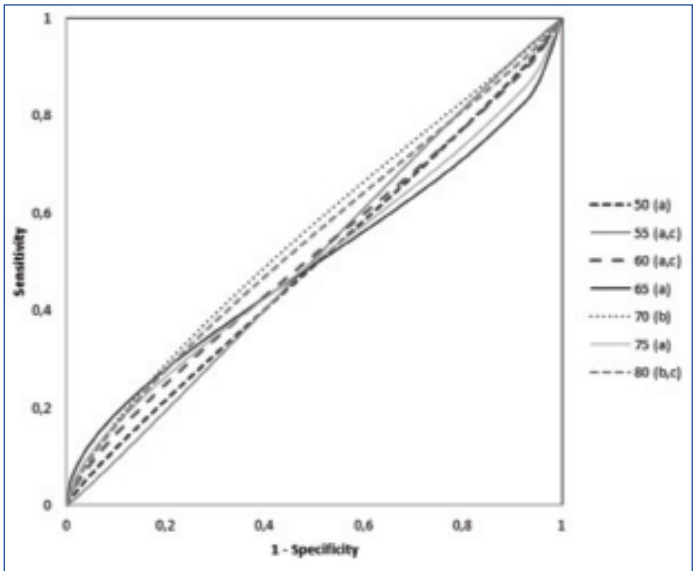
[Table/Fig-3]: Digitized film Kv accuracy means (Az), standard deviations, confidence intervals (95%) and Tukey's test (α=0.05)

The mean values for the area under the ROC curve, standard deviation, confidence intervals and the differences among tube potential setting for digitized film modality are shown in [Table/Fig-3]. Mean ROC curve areas for tube potential setting varied from 0.494 to 0.559. Based on the observed means, even though 70 kV presented the best result it did not differ significantly from 80 kV, which did not present statistical difference from 60 and 55 kV, which did not significantly differ from 75, 65 and 50 kV (p =0.53).

ROC curve comparisons were illustrated for the mean ROC curves of the observers in each condition on [Table/Fig-4,5].



[Table/Fig-4]: Overall receiver operating characteristic curves for conventional image in each tube potential setting. The same letter means non-significant differences, whereas different letters mean significant differences (p < 0.05)



[Table/Fig-5]: Overall receiver operating characteristic curves for digital image in each tube potential setting. The same letter means non-significant differences, whereas different letters mean significant differences (p < 0.05)

DISCUSSION

The correct selection of the exposure parameters is essential to obtain an image with diagnostic quality. The energy used influences the absorbed radiation dose as well as the radiographic contrast in an inverse way: the higher the energy, the lower the contrast [11]. Among all exposure parameters, tube potential setting is highly important for caries detection. It was established that caries lesions are more easily detected in images with high contrast [12], thus low tube potential settings are usually recommended for this purpose [2,13].

According to Xavier et al., [14] digitalized images from the Genius Color Page scanner and the four digital cameras used in their study generated good quality images, in both file formats (JPEG and TIFF) and their use is appropriate for the radiographic digitalization for caries diagnosis in the daily clinical routine. According to Peretz et al., [15], Storing existing radiographs in a digital medium for space saving purposes using a digital camera does not loose critical information. Based on those studies conventional images from this study were scanned, so the observers would evaluate the images under the same light, size and display conditions.

Sogur et al. [2] evaluated tube potential settings for the detection of proximal caries in primary teeth using PSP digital system, CCD system and conventional film. They found that 50 kV when used combined with the PSP digital system presented the best accuracy results for caries detection. In our study, on the other hand, higher tube potential settings, such as 70 and 75 kV, presented the best results and significantly differed from the other settings. The difference could be explained by the fact that (1) the PSP digital system used was not the same in both studies, (2) the previous authors did not use histological sections as gold standard, and (3) their sample consisted of non-extracted primary teeth, what could result in false negative and false positive results, not corresponding to the real surface condition.

A previous study already evaluated DenOptix phosphor plates and intraoral film. They found no significant difference on caries detection neither between the evaluated image modalities nor between the studied tube setting potentials (60 kV and 90 kV) [16]. Intriguingly, the accuracy values were up to 98% for 60 kV. Such a high accuracy value was obtained probably because the sample consisted of simulated caries lesions, done by different size drills that do not represent the real appearance of a natural caries lesion and so are very easily visualized in any radiographic image. These types of simulated lesions are not interesting for the assessment of advanced image modalities, since the purpose of evaluating new systems and establishing exposure parameters protocols is to optimize the visualization of incipient lesions that are not easily detected on any radiographic established image modality or acquisition parameter, nor diagnosed by clinical exam. For this reason natural incipient proximal caries were used in this study.

One of the most important factors that influence the accuracy for caries lesion detection is the size of the lesion, which should be defined as the depth in the enamel in which the lesion extends. Lesions that extend to 1/3 of the enamel depth showed diagnostic accuracy slightly above chance level [13]. The teeth sample used in our study was composed of incipient enamel lesions, and low accuracy results were expected.

Besides the fact that a decrease in tube potential voltage would optimize contrast, and caries diagnosis, there is a controversy about its influence on dose variation. It is not all previous studies that agreed in dose reduction as a result of an increase in the tube potential setting in intraoral radiography [16]. Svenson et al., [13] concluded that the diagnostic accuracy for all lesion depths has about the same value irrespective to tube potential. This factor may basically be disregarded when exposing radiographs for diagnosing proximal carious lesions, and to increase diagnostic accuracy, exposure time should be increased. However, it is important to consider patient exposure to radiation, then all parameters should be analysed individually and the lowest exposure dose that presents an image with diagnostic quality should be chosen.

The continuing introduction of new radiographic film materials had greatly diminished the radiation dose to the patients and was the greatest factor contributing to the reduction of dose through years [11]. Since digital systems became available in the market, the proportion of decrease of patients' radiation dose got even higher. Some studies had shown reduction in radiation dose from 33% up to 80% when comparing digital systems to conventional

X-ray films [17,18]. Berkhout et al., [19] (2004) found that all digital systems analysed in their study – Digora FMX, DenOptix, Sirona and MPDx – can decrease patients radiation dose, although they do not statistically differ in the magnitude of this reduction.

When evaluating two different speed films using four different kilovoltages for caries detection. Svenson et al., [11] observed that the diagnostic accuracy increased with kilovoltage decrement, and a tube voltage of 60 kV offers a proper balance between absorbed radiation dose and diagnostic accuracy. In our study, a voltage of 70 kV showed better diagnostic accuracy for conventional film, what can be related to the use of a higher speed film. Also, higher kilovoltage as 65, 70, and 75 kV showed better results than 60 for the evaluated digital system, demonstrating a different behavior when compared to the conventional modality. It is important to stress that each digital has its own characteristics and that may interfere on contrast setting. It is important to evaluate the behavioral of each setting parameter for each new digital system released on the market to evaluate its influence on brightness, contrast and sharpness.

According to Kaeppler et al., [16] a tube potential setting of 90 kV instead of 60 kV only results in a decrease of the entrance surface dose, not in a decrease of the total absorbed dose. The same authors stated that in intraoral radiography, the 90 kV level did not lead to a marked reduction of the absorbed and effective dose and it was almost the same as at 60 kV. In practice, it is more effective to reduce the milliampere-seconds product combined with the use of more sensitive films or digital systems, while maintaining the low tube potential level (60-70 kV).

According to Jacobs et a.,l [20] most Belgian professionals that filled out their questionnaire (70%) used radiation tubes of 65 to 70 kV, and older dentists generally worked with much lower potential settings than their younger colleagues. The authors also found that only 34% of Belgians dentists used digital receptors (18% storage plates and 16% charged couple device sensors), most of them were still using high speed analogue film (E and F). The chosen tube setting parameters are in accordance with the guidelines and with the results of this study for digital receptor. It can be expected that nowadays probably the Belgian dentist population percentage using digital receptors have increased and if the same settings are kept, a higher quality image for caries detection is being achieved. It is important that all exposure parameters keep up with the advances on digital receptors so the advantages permitted by those can be used to its maximum.

Although DenOptix and conventional images had both presented in this study the best result with tube setting of 70 kV, DenOptix digital images obtained with tube potential of 50, 60 and 80 kV presented lower accuracy results and the same could not be observed in digitalized images (which presented no statistical differences between these tube potentials). Then, it can be conclude that the digital PSP system tested suffers more influence of kV variation than film receptor.

CONCLUSION

Based on the results found in this study, we can conclude that phosphor plate digital images seem to be more susceptible to tube setting potential variations then digitized film images

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