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Original Research

In-vitro Diagnosis of Approximal Caries in Teeth Periapical Radiography with Different Exposure Parameters

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ABSTRACT

Objective: The aim of this study was to evaluate periapical radiographs of enamel caries, dentin caries, and deep caries with exposed pulp and intact teeth obtained in vitro using photo-stimulated phosphor plates (PSP) under different exposure parameters.

Methods: 3 non-carious extracted molars were selected. The obtained molars were embedded in the wax created from pink wax by ensuring approximal contact and a base was created. 14 different imaging protocols were used with 60 kVp, 4 mA 0.02-0.1 second and 70 kVp 7 mA, 0.25-1.25 second exposure parameters. Intact teeth were imaged with these various imaging protocols. Artificial cavities were then created for enamel caries, dentin caries and deep caries with exposed pulp and imaged according to the same protocols. The images were evaluated by 3 clinicians who were blind to the exposure protocol and caries status. Inter-observer agreement with actual situations was examined with Kappa statistics.

Results: In the low-dose group, the kappa values of observer 1, observer 2, and observer 3 were 0.905, 0.952, 0.952, respectively. The kappa values of observer 1, observer 2, and observer 3 in the ultralow-dose group were 0.833, 1, 1, and the kappa values of observer 1, observer 2, and observer 3 in the high-dose group were 1, 1, 0.833, respectively. The results obtained in all groups showed a statistically significant-excellent agreement ($p<0.001$).

Conclusion: Approximal caries can be diagnosed with intraoral radiography obtained with low radiation doses with PSP in dentistry. Thus, patients could be exposed to less ionizing radiation.

Keywords: Approximal Caries, Periapical Radiography, Photo-stimulated Phosphor Plate

INTRODUCTION

One of the most frequently encountered problems in clinical dentistry is dental caries [1]. In today's standard clinical practice, visual examination, probing, and radiography are the most commonly employed methods for the diagnosis of caries [2]. Radiographic examination should be used in conjunction with clinical examination, especially as proximal caries lesions can be difficult to detect [2]. In dental clinics, panoramic radiographs are commonly used. Panoramic radiography, which is achieved by simultaneously rotating the X-ray source and image receiver around the patient in a fixed position, is a simple technique for image acquisition. The distances between the radiation source, the object, and the image receiver add to the magnification factor associated with image formation, and the projection geometry results in image distortion and a noticeable overlap of teeth [3]. Panoramic radiographs from patients do not completely eliminate the necessity of intraoral imaging for the definitive diagnosis of dental disease. Therefore, it is essential to supplement information obtained from panoramic radiography with intraoral radiographs to allow a comprehensive examination of the teeth and surrounding bone with a low radiation dose and without loss of diagnostic information [4].

Demineralization of hard tissues in teeth is a result of the caries process. Because the X-ray absorption of the demineralized region of teeth is less than that of the unaffected area, the lesion appears as a radiolucent area on radiographic images as a result of the caries process [5]. Significant advances in computer technology have enabled the rapid advancement of digital radiologic systems and different digital radiologic methods have been developed [6]. These systems allow for measurements and improvements that are not possible using conventional films. Images can be electronically transmitted to different healthcare providers without any change in the original image quality, and digital intraoral sensors require fewer rays than film, thus lowering the radiation dose to the patient [6-8].

Dental practices use a variety of sizes and shapes of digital image receptors that support various technologies. These are divided into two categories: solid-state detectors and photo-stimulated phosphor plates (PSP) [9]. Although solid-state detectors are subdivided into charge-coupled devices (CCD) and complementary metal oxide semiconductors (CMOS), they share certain common features and the ability to create digital images on a computer without the need for other devices [9]. PSP systems do not have a cable connection between the sensor and the computer, and the size and flexibility of the plates used are very similar to periapical films, thus ensuring ease of use [10-12]. Additionally, the main advantages of these systems are decreased radiation and a larger dynamic range [12].

Main Points;

- Periapical radiographs are complementary radiologic examination methods in the diagnosis of approximal caries.
- In dental routine, photo-stimulated phosphor plates are frequently used as an intraoral imaging tool.
- While intraoral imaging is provided with photo-stimulated phosphor plates for caries detection, imaging can be performed with lower radiation doses by changing the exposure parameters.

Despite the reduction in radiation dose with the transition from conventional to digital radiography, exposure to X-rays has serious consequences. The effects of X-rays on living organisms are the result of direct and indirect interactions at atomic levels [5]. Patients are likely to be exposed to dental X-rays numerous times. Although the radiation dose related to dental radiography is low, it has been acknowledged that there is no safe level of ionizing radiation exposure [13]. Given this lifetime prevalence and high frequency of exposure, additional efforts should be made to minimize the risks from exposure to X-rays.

This study's objective is to evaluate radiographic images of artificial approximal caries created in extracted teeth using PSP with different irradiation values.

MATERIALS AND METHODS

This study was conducted in vitro in the Department of Oral and Dentomaxillofacial Radiology at Inonu University between 2021 and 2022. The Inonu University Scientific Research and Publication Ethics Committee gave its approval for the study (2021/2454).

Three extracted caries-free molars were selected from the Department of Oral and Maxillofacial Surgery of the Faculty. Blood and soft tissues on the extracted teeth were cleaned on the same day and stored in 0.1% thymol solution at room temperature for one day. Then, the molars obtained were templated by providing approximal contact and embedding them in a wax wall formed from pink wax used in the construction of prosthetic bases up to the enamel-cementum borders of the teeth. To mimic soft tissue, the transparent cup was filled with water to the level determined during exposure.

Exposure Protocols

When radiographs were taken, the PSP (Digora Optime, Soredex, Finland) was placed on a flat surface under a transparent container. The distance between the focal spot and the template was set to 40 cm. To ensure standardization, film holders (Kerr X-ray sensor holders, USA) were used while taking periapical radiographs.

To obtain periapical radiographs, 14 different exposure protocols were used on a dental X-ray machine (Belmont Takara. Phot X, Osaka Japan). These are;

Ultralow-dose
1.60 kVp, 4 mA, 0.02 s
2.60 kVp, 4 mA, 0.03 s

Low dose
1. 60 kVp, 4 mA, 0.04 s
2. 60 kVp, 4 mA, 0.05 s
3. 60 kVp, 4 mA, 0.06 s
4. 60 kVp, 4 mA, 0.08 s
5. 60 kVp, 4 mA, 0.1 s

High Dose
1. 70 kVp, 7 mA, 0.25 s
2. 70 kVp, 7 mA, 0.4 s
3. 70 kVp, 7 mA, 0.5 s
4. 70 kVp, 7 mA, 0.6 s
5. 70 kVp, 7 mA, 0.8 s
6. 70 kVp, 7 mA, 1 s
7. 70 kVp, 7 mA, 1.25 s

Periapical radiographs were obtained to obtain images for the intact tooth group in all the above exposure protocols before obtaining artificial caries.

In the second stage, artificial caries was obtained for the enamel caries group by abrading the enamel tissue and ¼th of the dentin adjacent to the enamel with a round tipped diamond bur (Dimei Royal, China). The radiographs obtained by visualizing enamel caries in all exposure protocols were recorded.

In the third stage, controlled artificial caries was obtained for cases belonging to the dentin caries group by abrading between the ¼th of the dentin adjacent to the enamel and the ¼th of the dentin close to the pulp. In all exposure protocols, dentin caries was visualized, and the radiographs obtained were recorded.

In the fourth stage, ¼ of the dentin adjacent to the pulp was abraded using a round-tipped diamond bur (Dimei Royal, China) to obtain controlled artificial caries in cases deep caries with pulp exposed. Radiographs obtained by visualizing the deep caries with exposed pulp in all exposure protocols were recorded.

Evaluation of Periapical Radiographs

The resulting images were scrambled and coded by a clinician (7 years of experience DCO) based on the exposure protocols and caries status. Images were evaluated individually on a monitor (HP Compaq LA2205wg) by three clinicians (23 years of experience (OA), 15 years of experience (ND) and 10 years of experience (SBD)), each with a minimum of 15 years of experience. They were blinded to the exposure protocol and caries status and instructed to select a suitable option from the list below. All three clinicians evaluated the images on the same day. Since the clinicians had more than 10 years of experience, they responded as soon as they looked at the image. Therefore, it took an average of 10 minutes for the three clinicians to evaluate the images.

A1. Dental tissues can be identified radiographically.
A2. Dental tissues cannot be identified radiographically.
If the answer A1 is given,
B1. Intact: No carious lesions are present on the tooth.
B2. Enamel caries: There is a carious lesion in the enamel extending up to ¼th of the dentin.
B3. Dentin caries: There is a carious lesion in the enamel and dentin extending to about ¼th of the pulp.
B4. Deep caries with exposed pulp**:** There is a carious lesion extending from the enamel and dentin to the pulp.

In addition, if the answer B1 was given, it was classified as intact, and if any of the answers B2, B3, and B4 were given, it was classified as carious and a carious-intact comparison was also made.

In the first grouping, periapical radiographs obtained with 70 kVp, 7 mA were grouped as high doses, while those obtained with 60 kVp, 4 mA were grouped as low doses.

In the second grouping, images obtained with 60 kVp, 4 mA, 0.02 s and 60 kVp, 4 mA, 0.03 s were compared by grouping them as ultralow-dose and others.

Statistical Analysis

Data was analyzed using IBM SPSS V23 (Chicago, USA). Inter-observer agreement with actual situations was analyzed with the Kappa statistic. The results of the analysis were presented as frequency (percentage). The level of significance was set at $p<0.050$.

RESULTS

A total of 56 periapical radiographs were evaluated by 3 observers. In 12 (21.4%) of these radiographs, dental tissues could not be observed and therefore were not evaluated. Of the exposure factors used in periapical radiographs without dental tissues, 4 were 70 kVp, 7 mA, 0.8 s, 4 were 70 kVp, 7 mA, 1 s, and the other 4 were 70 kVp, 7 mA, 1.25 s.

Inter-observer Agreement with the Actual Situation without Group Distinction

The kappa value between the actual situation and observer 1 was 0.939; the kappa value between the actual situation and observer 2 was 0.970; the kappa value between the actual situation and observer 3 was 0.909. A statistically significant and a very good level of agreement was obtained between the actual situation and all three observers (p<0.001) (Table 1).

Inter-observer Agreement with the Actual Situation within Dose Groups

In the low-dose group, the kappa value between the actual situation and observer 1 was 0.905; in the high-dose group, the kappa value between the actual situation and observer 1 was 1. In both cases, a statistically significant and a very good level of agreement was obtained between the actual situation and observer 1 (p<0.001). In the low-dose group, the kappa value between the actual situation and observer 2 was 0.952 and in the high-dose group, the kappa value between the actual situation and observer 2 was 1. A statistically significant and a very good level of agreement was obtained between the actual situation and observer 2 (p<0.001). The kappa value between the actual situation and observer 3 in the low-dose group was 0.952, and the kappa value between the actual situation and observer 3 in the high-dose group was 0.833. A statistically significant and excellent agreement was obtained between the actual situation and observer 3 (p<0.001) (Table 2).

Inter-observer Agreement with the Actual Situation at Ultralow-dose and Others (High and Low Dose)

The kappa value between the actual situation and observer 1 in the ultralow-dose group was 0.833, and the kappa value between the actual situation and observer 1 in the "others" group was 0.963. A statistically significant and excellent agreement was obtained between the actual situation and observer 1 (p<0.001). The kappa value between the actual situation and observer 2 in the ultralow-dose group was 1, and the kappa value between the actual situation and observer 2 in the "others (high and low dose)" group was 0.963. A statistically significant and a very good level of agreement was obtained between the actual situation and observer 2 (p<0.001). The kappa value between the actual situation and observer 3 in the ultralow-dose group was 1, and the kappa value between the actual situation and observer 3 in the "others" group was 0.889. A statistically significant and a very good level of agreement was obtained between the actual situation and observer 3 (p<0.001) (Table 3).

Table 1. Evaluation of the inter-observer agreement with the actual situation without making a group distinction

	Actual Situation				Kappa	p
	Intact	Enamel caries	Dentin caries	D.c.e.p*		
Observer1						
Intact	11 (100)	0 (0)	0 (0)	0 (0)	0.939	**0.000**
Enamel caries	0 (0)	11 (100)	1 (9.1)	0 (0)		
Dentin caries	0 (0)	0 (0)	10 (90.9)	1 (9.1)		
D.c.e.p*	0 (0)	0 (0)	0 (0)	10 (90.9)		
Observer2						
Intact	11 (100)	0 (0)	0 (0)	0 (0)	0.970	**0.000**
Enamel caries	0 (0)	10 (90.9)	0 (0)	0 (0)		
Dentin caries	0 (0)	1 (9.1)	11 (100)	0 (0)		
D.c.e.p*	0 (0)	0 (0)	0 (0)	11 (100)		
Observer3						
Intact	10 (90.9)	0 (0)	0 (0)	0 (0)	0.909	**0.000**
Enamel caries	1 (9.1)	9 (81.8)	0 (0)	0 (0)		
Dentin caries	0 (0)	2 (18.2)	11 (100)	0 (0)		
D.c.e.p*	0 (0)	0 (0)	0 (0)	11 (100)		

***:** Deep caries with exposed pulp

Table 2. Evaluation of inter-observer agreement with actual situation within dose groups

Observation	Dose groups		Actual Stuation				Kappa	p
			Intact	Enamel caries	Dentin car-ies	D.c.e.p*		
Observer1	Low dose	Intact	7 (100)	0 (0)	0 (0)	0 (0)	0.905	**0.000**
		Enamel caries	0 (0)	7 (100)	1 (14.3)	0 (0)		
		Dentin caries	0 (0)	0 (0)	6 (85.7)	1 (14.3)		
		D.c.e.p*	0 (0)	0 (0)	0 (0)	6 (85.7)		
	High dose	Intact	4 (100)	0 (0)	0 (0)	0 (0)	1.000	**0.000**
		Enamel caries	0 (0)	4 (100)	0 (0)	0 (0)		
		Dentin caries	0 (0)	0 (0)	4 (100)	0 (0)		
		D.c.e.p*	0 (0)	0 (0)	0 (0)	4 (100)		
Observer2	Low dose	Intact	7 (100)	0 (0)	0 (0)	0 (0)	0.952	**0.000**
		Enamel caries	0 (0)	6 (85.7)	0 (0)	0 (0)		
		Dentin caries	0 (0)	1 (14.3)	7 (100)	0 (0)		
		D.c.e.p*	0 (0)	0 (0)	0 (0)	7 (100)		
	High dose	Intact	4 (100)	0 (0)	0 (0)	0 (0)	1.000	**0.000**
		Enamel caries	0 (0)	4 (100)	0 (0)	0 (0)		
		Dentin caries	0 (0)	0 (0)	4 (100)	0 (0)		
		D.c.e.p*	0 (0)	0 (0)	0 (0)	4 (100)		
Observer3	Low dose	Intact	7 (100)	0 (0)	0 (0)	0 (0)	0.952	**0.000**
		Enamel caries	0 (0)	6 (85.7)	0 (0)	0 (0)		
		Dentin caries	0 (0)	1 (14.3)	7 (100)	0 (0)		
		D.c.e.p*	0 (0)	0 (0)	0 (0)	7 (100)		
	High dose	Intact	3 (75)	0 (0)	0 (0)	0 (0)	0.833	**0.000**
		Enamel caries	1 (25)	3 (75)	0 (0)	0 (0)		
		Dentin caries	0 (0)	1 (25)	4 (100)	0 (0)		
		D.c.e.p*	0 (0)	0 (0)	0 (0)	4 (100)		

*:Deep caries with exposed pulp

Table 3. Evaluation of inter-observer agreement with actual situation in ultralow-dose and others

Observer	Dose-subgroup		Actual Situation				Kappa	p
			Intact	Enamel caries	Dentin caries	D.c.e.p*		
Observer 1	Ultralow-dose	Intact	2 (100)	0 (0)	0 (0)	0 (0)	0.833	**0.000**
		Enamel caries	0 (0)	2 (100)	1 (50)	0 (0)		
		Dentin caries	0 (0)	0 (0)	1 (50)	0 (0)		
		D.c.e.p*	0 (0)	0 (0)	0 (0)	2 (100)		
	Others	Intact	9 (100)	0 (0)	0 (0)	0 (0)	0.963	**0.000**
		Enamel caries	0 (0)	9 (100)	0 (0)	0 (0)		
		Dentin caries	0 (0)	0 (0)	9 (100)	1 (11.1)		
		D.c.e.p*.	0 (0)	0 (0)	0 (0)	8 (88.9)		

Observer 2	Ultralow-dose	Intact	2 (100)	0 (0)	0 (0)	0 (0)	1.000	**0.000**
		Enamel caries	0 (0)	2 (100)	0 (0)	0 (0)		
		Dentin caries	0 (0)	0 (0)	2 (100)	0 (0)		
		D.c.e.p *	0 (0)	0 (0)	0 (0)	2 (100)		
	Others	Intact	9 (100)	0 (0)	0 (0)	0 (0)	0.963	**0.000**
		Enamel caries	0 (0)	8 (88.9)	0 (0)	0 (0)		
		Dentin caries	0 (0)	1 (11.1)	9 (100)	0 (0)		
		D.c.e.p *	0 (0)	0 (0)	0 (0)	9 (100)		
Observer3	Ultralow-dose	Intact	2 (100)	0 (0)	0 (0)	0 (0)	1.000	**0.000**
		Enamel caries	0 (0)	2 (100)	0 (0)	0 (0)		
		Dentin caries	0 (0)	0 (0)	2 (100)	0 (0)		
		D.c.e.p *	0 (0)	0 (0)	0 (0)	2 (100)		
	Others	Intact	8 (88.9)	0 (0)	0 (0)	0 (0)	0.889	**0.000**
		Enamel caries	1 (11.1)	7 (77.8)	0 (0)	0 (0)		
		Dentin caries	0 (0)	2 (22.2)	9 (100)	0 (0)		
		D.c.e.p *	0 (0)	0 (0)	0 (0)	9 (100)		

***:** Deep caries with exposed pulp

Inter-observer Agreement with Intactness Regardless of Group

The kappa value between real intactness and observer 1 was 1, the kappa value between real intactness and observer 2 was 1, and the kappa value between real intactness and observer 3 was 0.938. A statistically significant and a very good level of agreement was obtained between real robustness and all three observers (p<0.001) (Table 4).

Table 4. Evaluation of robustness and inter-observer agreement without group distinction

	Intactness		Kappa	p
	Intact	Carious		
Intactness O1*				
Intact	11 (100)	0 (0)	1.000	**0.000**
Carious	0 (0)	33 (100)		
Intactness O2#				
Intact	11 (100)	0 (0)	1.000	**0.000**
Carious	0 (0)	33 (100)		
Intactness O3**				
Intact	10 (90.9)	0 (0)	0.938	**0.000**
Carious	1 (9.1)	33 (100)		

* :Observer 1; #:Observer 2; **:Observer 3

Inter-observer Agreement with Intactness within Ultralow-dose and Others(High and Low Dose)

In the ultralow-dose group, the kappa value between real intactness and observer 1 was 1, and a statistically significant and a very good level of agreement was obtained between real intactness and observer 1 (p=0.000). In the "others" group, the kappa value between real intactness and observer 1 was obtained as 1, and a statistically significant and a very good level of agreement was obtained between real intactness and observer 1 (p<0.001). In the ultralow-dose group, the kappa value between real intactness and observer 2 was 1, and a statistically significant and a very good level of agreement was obtained between real intactness and observer 2 (p=0.000). In the "others" group, the kappa value between real intactness and observer 2 was obtained as 1, and a statistically significant and a very good level of agreement was obtained between real intactness and observer 2 (p<0.001). In the ultralow-dose group, the kappa value between real intactness and observer 3 was 1, and a statistically significant and a very good level of agreement was obtained between real intactness and observer 3 (p=0.000). In the "others" group, the kappa value between real intactness and observer 3 was 0.923, and a statistically significant and a very good level of agreement was obtained between real intactness and observer 3 (p<0.001) (Table 5).

Tablo 5. Evaluation of intactness and inter-observer agreement in ultralow-dose and others

Observer	Dose-subgroup		Intactness		Kappa	p
			Intact	Carious		
Intactness O1*	Ultralow-dose	Intact	2 (100)	0 (0)	1.000	**0.000**
		Carious	0 (0)	6 (100)		
	Others	Intact	9 (100)	0 (0)	1.000	**0.000**
		Carious	0 (0)	27 (100)		
Intactness O2#	Ultralow-dose	Intact	2 (100)	0 (0)	1.000	**0.000**
		Carious	0 (0)	6 (100)		
	Others	Intact	9 (100)	0 (0)	1.000	**0.000**
		Carious	0 (0)	27 (100)		
Intactness O3"	Ultralow-dose	Intact	2 (100)	0 (0)	1.000	**0.000**
		Carious	0 (0)	6 (100)		
	Others	Intact	8 (88.9)	0 (0)	0.923	**0.000**
		Carious	1 (11.1)	27 (100)		

* :Observer 1; #:Observer 2; ":Observer 3

DISCUSSION

The main goal in radiology is to produce images that have sufficient detail to reveal important diagnostic information while ensuring that patients are exposed to the minimum amount of radiation required due to the potential risks of ionizing radiation. Tissues and organs can be harmed by exposure to radiation even at the low doses that are effective from intraoral radiographs [14]. To protect tissues and organs from ionizing radiation, effective dose estimation and decrease are therefore important.

Several studies have compared different imaging modalities for caries diagnosis [2, 15-17]. Abesi et al. contrasted the diagnostic efficacy of intraoral films, CCD, and PSP in detecting non-cavitated caries. The sensitivity and specificity of film, CCD and PSP for the detection of enamel caries were 38% and 98%, 15% and 96% and 23% and 98%, respectively; while the sensitivity and specificity of dentin and enamel caries were 55% and 100%, 45% and 100%, and 55% and 100%, respectively. These findings show that the diagnostic accuracy of digital images was similar to that of traditional intraoral films in identifying non-cavitated approximal caries [15]. In this study, we only used PSP with high diagnostic efficiency, which is frequently preferred intraorally.

Strong inter-observer agreement was found in a study comparing the diagnostic efficacy of visual inspection, film, PSP, CCD, and cone beam computed tomography (CBCT) in the detection of proximal caries. The detection methods' kappa coefficients ranged from 0.631 to 0.811, and the methods that were chosen demonstrated similar results [2].

In another study, at 50, 65, and 70 kVp, there was no variation in the diagnostic efficacy of PSP, CDD, and film images of proximal caries in deciduous teeth. However, at 50 kVp, a significant difference was noted in favor of PSP images [16].

The current study is the first to compare the detection of intact and carious teeth with 14 different exposure parameters in PSP images. Actual and inter-observer agreement was statistically significant for all three observers in the identification of enamel caries, dentin caries, deep caries with exposed pulp, and intact teeth imaged with high dose parameters (70 kVp; 7 mA; 1.25–0.25 s). However, at high-dose exposure factors, PSPs imaged with application times of 0.8–1.25 s were not visualized, and no interpretation could be made. For PSPs imaged with low-dose (60 kVp; 4 mA; 0.04–0.1 s) and ultra-low-dose (60 kVp; 4 mA; 0.02–0.03) parameters, a statistically significant and good agreement between the three observers and the actual situation was obtained ($p<0.001$).

In a previous study CCD, PSP, and intraoral films were compared for caries diagnosis with 60 and 70 kVp parameters. For enamel lesions, the PSP with 70 kVp and an exposure time of 0.03 s was reported to have the highest sensitivity; for the detection of lesions with and without cavitation, the PSP with 60 kVp and an exposure time of 0.07 s was reported to have higher sensitivity and less radiation dose to the patient [17]. Compared to this study, in our study, where we used the same voltage parameters (60 and 70 kVp), observers were able to detect the presence or absence of caries and the level of caries even at shorter exposure times Since the low-dose and even ultralow-dose parameters obtained with 60 kVp do not cause a change in image quality that would prevent accurate diagnosis, the use of 70 kVp in intraoral imaging indicates that the patient will be unnecessarily exposed to a high radiation dose.

De Melo et al. reported that PSPs were sensitive to tube setting changes when the range of use was 50–80 kVp and reported that the best results were obtained using 70 kVp [18]. In this study, the kappa values of the three observers in the identification of intact teeth and caries imaged at 70 kVp, 7 mA, and different application times grouped as high-dose were 1, 1, and 0.833, respectively. The kappa values of the three observers at 60 kVp, 4 mA, and different application times grouped as ultra-low-dose were 0.833, 1, and 1, respectively. Consequently, in our study, decreasing the tube potential (kVp), current, and time did not change the diagnostic accuracy and provided imaging with a lower radiation dose.

Selecting the appropriate exposure parameters is crucial in achieving an image of diagnostic quality. The average photon energy used to create the image is one of the factors affecting contrast, which is determined by the choice of X-ray tube voltage and the amount of X-ray beam filtering. Accordingly, less energy is usually associated with higher contrast [19]. Of all the exposure parameters, tube potential is very important for caries detection, and high contrast is a precondition for the accurate identification of radiographic approximal caries [7]. Studies have found that caries lesions are easier to identify on high-contrast images, so lower tube potential values are generally suggested for this objective [16, 20].

One study showed that reducing the tube voltage from 70 kVp to 60 kVp did not compromise image quality for the evaluation of carious lesions. The same study reported that the patient was exposed to an absorbed dose that was approximately 40–50% higher when a tube voltage of 70 kVp was used [21]. Dehghani et al. suggested the use of PSP with 60 kVp to comply with the As Low As Reasonably Achievable (ALARA) rule, especially when a tooth has clinical signs or discoloration indicative of caries, and they attributed this to the higher sensitivity and lower exposure time of PSP compared to intraoral film [17]. In the present study, one of the three observers incorrectly detected only one enamel caries, and the other two observers incorrectly detected one dentin caries, while all intact teeth and all other caries were correctly detected at low doses. At ultra-low doses, intact teeth and other caries were correctly detected by the three observers, while only one observer incorrectly detected dentin caries. Based on the results of this study, caries diagnosis at ultra-low doses seems possible.

Limitations

A limitation of this study is that it was an in vitro study, and consequently, the accuracy of the imaging modalities tested could not be evaluated in a clinical setting. However, in in vitro radiographic studies, the imaged objects can be repeatedly exposed to X-rays and optimal positioning seems to be possible. By using these advantages of an in vitro environment, effective doses can be calculated based on radiographic studies, and patients' exposure to X-rays can be minimized.

CONCLUSIONS

Even at the lowest dose used in this study (60 kVp 4 ma 0.02 s), images were obtained that enabled accurate diagnosis. Based on this result, it is necessary to revise the routine exposure parameters used in dentistry when obtaining intraoral radiographs with PSP, and it should be recognized that approximal caries diagnosis can be made safely at lower radiation doses. Moreover, it is anticipated that this study will shed light on future clinical studies.

Conflict of interest The authors declare that they have no confict ofinterest.

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Informed consent Informed consent form was not obtained because the study was retrospective.

Ethical Approval Statement This study was carried out with the approval (Protocol no: 2021/2454) from the University Health Sciences Non-Interventional Clinical Research Ethics Committee.

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