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Comparison of the diagnostic accuracy of cone beam computed tomography and three intraoral radiographic systems in the diagnosis of carious lesions *in vitro*.

Comparación de la precisión diagnóstica de la tomografía computarizada de haz cónico y tres sistemas radiográficos intraorales en la detección de lesiones de caries *in vitro*.

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Abstract: Objective: The objective of the study was to compare the diagnostic accuracy of cone beam computed tomography and three intraoral radiographic systems in the detection of in vitro caries lesions. **Material and Methods:** One hundred teeth (46 molars and 54 premolars) were evaluated, including 176 proximal surfaces and 90 occlusal surfaces, with or without dental caries lesions. Digital images of all teeth were obtained using specific intraoral radiographs, VistaScan DürrDental®phosphor-plate radiography, XIOS XG Sirona® digital sensor radiography, and CBCT I-CAT™. Observers evaluated the images for the detection of caries lesions. The teeth were clinically sectioned and stereomicroscopy served as a validation tool. The relationship of sensitivity and specificity between all systems was determined through the ROC curve using Az values. **Results:** The values of the area under the curve (Az) selected for the CBCT I-CAT™ system were 0.89 (0.84-0.93), for conventional radiography 0.71 (0.66-0.76), digital sensor radiography 0.74 (0.70-0.78) and digital radiography with phosphor-plates 0.73 (0.69-0.77). Statistically significant differences were found between the CBCT I-CAT™ system and intraoral radiographic systems ($p<0.01$). The sensitivity and specificity values for the CBCT I-CAT™ were 0.84 and 0.93 respectively. **Conclusion:** CBCT has a high sensitivity and specificity compared to intraoral radiographic systems for the diagnosis of dental caries lesions *in vitro*.

Keywords: Dental caries; cone-beam computed tomography; dental caries; diagnosis; radiography, dental, digital; sensitivity and specificity; roc curve.

Resumen: Objetivo: El objetivo del estudio fue comparar la precisión diagnóstica de la tomografía computarizada de haz cónico y tres sistemas radiográficos intraorales en la detección de lesiones de caries *in vitro*. **Material y Métodos:** Se evaluaron 100 dientes, 46 molares y 54 premolares; 176 superficies proximales y 90 superficies oclusales, con o sin lesión de caries dental. Se obtuvieron imágenes digitales de todos los dientes utilizando radiografías intraorales convencionales, radiografía con placas de fósforo VistaScan DürrDental®, radiografía con sensor digital XIOS XG Sirona® y CBCT I-CAT™. Tres observadores evaluaron las imágenes para la detección de lesiones

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de caries. Los dientes se seccionaron clínicamente y la estereomicroscopía sirvió como herramienta de validación. Se determinó relación de sensibilidad y especificidad entre todos los sistemas a través de la curva ROC utilizando valores Az. **Resultados:** Los valores de área debajo de la curva (Az) obtenidos para el sistema CBCT I-CAT™ fueron de 0.89 (0.84-0.93), para radiografía convencional 0.71 (0.66-0.76), radiografía con sensor digital 0.74 (0.70-0.78) y radiografía digital con placas de fósforo 0.73 (0.69-0.77). Se encontró diferencias estadísticamente significativas entre el sistema CBCT I-CAT™ y todos los sistemas radiográficos convencionales y digitales (p<0.01). Los valores de sensibilidad y especificidad para el CBCT I-CAT™ fueron 0.84 y 0.93 respectivamente. **Conclusión:** La CBCT tiene una alta sensibilidad y especificidad en comparación a los sistemas radiográficos intraorales en el diagnóstico de lesiones de caries dental *in vitro*.

Palabra Clave: *Caries dental; tomografía computarizada de haz cónico; radiografía dental digital; diagnóstico; sensibilidad y especificidad; curva roc.*

INTRODUCTION.

Dental caries is the main disease of the oral cavity. Its origin, prevalence and treatment have been studied for a long time, but there are still difficulties in the clinical and radiographic diagnosis of carious lesions.[1] There are several methods (clinical diagnosis, conventional radiography, digital radiography, transillumination, etc.) to detect dental caries in early stages before they affect pulp tissue. Intraoral radiography is a common conventional method for the diagnosis of dental caries, especially for proximal caries that are difficult to identify by direct examination.[2] Conventional radiography is an alternative, but there are other auxiliary methods such as digital radiography, and even cone beam computed tomography.

Cone Beam Computed Tomography (CBCT) was developed in the 1990's with the aim of capturing three-dimensional images of the maxillofacial anatomy, irradiating lower doses than medical computed tomography (CT). In fact, CBCT revolutionized maxillofacial radiology because it offered an alternative to conventional intraoral and panoramic images.[3]

There are an increasing number of brands and models of CBCT equipment available today. However, scientific evidence produced in recent years about these new machines is quite scant and cannot be applied to all systems in general.[4] Therefore, it is sensible to make comparisons between CBCT equipment of the same brand and model. When reviewing the literature, no data have been found about the diagnostic capacity for detecting carious lesions *in vitro* using the I-CAT™ system, so the present study would be the first of its kind in the world.

This study aimed to determine the effectiveness and validity of CBCT as an alternative method in the diagnosis of carious lesions *in vitro*.

MATERIALS AND METHODS.

The sample consisted of 100 teeth that met the selection criteria. They were obtained from the Tooth Bank of the Academic Department of Oral-Maxillofacial Medicine and Surgery (DAMCIBUM, for its acronym in Spanish) of the School of Stomatology at Universidad Peruana Cayetano Heredia (FAEST-UPCH). The study was approved by the Institutional Ethics Committee of the Universidad Peruana Cayetano Herediay (No. 62542).

The in vitro study sample was determined following the minimum sample size parameters proposed by Haiter-Neto *et al*.,[5] who used 100 teeth. Healthy molar and premolar teeth with occlusal or proximal carious lesions were selected. The exclusion criteria consisted of premolars and molars with dental destruction caused by trauma. Premolars and molars with some type of restorative or rehabilitation treatment, premolars and molars with some type of root canal treatment.

Prior to their storage, the teeth were sterilized in an autoclave for 40 minutes at 240°F (115.6°C) and 20 psi (1.36 atm) to prevent bacterial growth.[6,7] The samples were kept immersed in saline solution to maintain them hydrated, with the the saline being replaced every week. To select specimens for examination, the teeth were air-dried with a triple syringe for 5 seconds. The selected teeth were coded and placed in the study model of 8 pieces each, according to the standards of previous studies.[8] A rectangular acrylic base (30x30x70 cm) was built. Two rows were made separated by a 0.5x0.5 cm groove, to randomly place 4 teeth in each one (2 premolars and 2 molars). The purpose of this groove was the placement of the radiographic image receptor. Images of all blocks were obtained using three intraoral systems (conventional film and two digital systems), and a CBCT system as follows (Figure 1):

1. Conventional radiographs were obtained using Kodak Ultraspeed film (Eastman Kodak Company, Rochester, NY) with an image exposure time of 0.25 s. A single X-ray unit was used for all three intraoral systems (Intra ProX, Planmeca, Helsinki, Finland). These intraoral radiographs were exposed using standardized conditions: 70 kVp, 8 mA, 20 cm focus-tooth distance. The films were developed in an A/T 2000 XR automatic processor (Air Techniques®, New York, USA).

2. Digital radiographs were obtained using the VistaScan phosphor-plate system (DürrDental®, Bietigheim-Bissingen, Germany), and the XIOS XG direct digital sensor system (Sirona®, Bensheim, Germany).

3. The study unit was immersed in water on a pre-designed platform (12x12 cm) in the CBCT I-CAT™ (Kavo dental®, California, USA). Then, the tomographic images were captured with a resolution of 0.125mm voxel size and a capture field (FOV) of 8x6 cm. Subsequently, they were transferred to the tomography software, I-CAT Vision®. Finally, all the images were stored in .JPG format and saved with a code.

Then, three examiners were calibrated in the different diagnostic imaging techniques. Each examiner had more than 10 years of experience in the area of Oral and Maxillofacial Radiology with proven experience in the use of CBCT equipment and the I-CAT™ system. A number of three examiners was used to reduce individual variation, increase reliability and maintain repeatability, assuring the reliability and validity of the research. These radiologists evaluated the surfaces and completed the registration table in Excel v.10.0 (Microsoft Corporation, Redmond, WA, USA), based on the following radiographic classification:

R0: healthy,

R1: carious lesion in the outer half of the enamel,

R2: carious lesion in the inner half of the enamel,

R3: carious lesion in the external half of the dentin, and

R4: carious lesion in the internal half of the dentin.[9]

An inter and intra-examiner calibration process was performed using the specimens to determine the agreement of the proposed values for dental caries, achieving a high intraclass correlation coefficient of 0.90.

Histological technique

Each tooth was sectioned using a high-speed DEMCO E-96 motor (Dental Maintenance Co. Inc, Bonsall, CA, United States of America) with a Giflex-TR two-sided diamond cutting disc (BrendentGmbH & Co.KG, Senden, Germany) of 30mm in diameter, and 0.3mm thick. It was sectioned mesio-distally in the area in which the carious lesion was observed, obtaining specimens of 500µm each. A final finish was performed using sandpaper No. 7. Then the sections were placed in a container with physiological saline to maintain their hydration until they were observed with the Leica DFC425 stereomicroscope with an EC3 camera (Leica, Wetzlar, Germany), at a magnification of 3x.

An oral pathology specialist, blinded to the X-ray capturing method and to the results of that stage, observed the surfaces one time. This specialist filled in the registration table in Excel version 10.0 (Microsoft Corporation, Redmond, WA, USA) according to the radiographic classification described above.

Figure 1. Images of dental caries lesions obtained by radiographic and histological methods.

A. CBCT I-Cat™. **B.** X-ray with phosphor-plate. **C.** Histological section by stereomicroscopy. **D.** Conventional X-ray. ***E.*** X-ray with digital Sensor.

Figure 2. ROC curve for evaluation of the diagnostic capacity of dental carious lesions using I-Cat system cone beam computed tomography, conventional film radiographs, phosphor-plate radiographs, and radiographs with digital sensor *versus in vitro* histological diagnosis (gold standard).

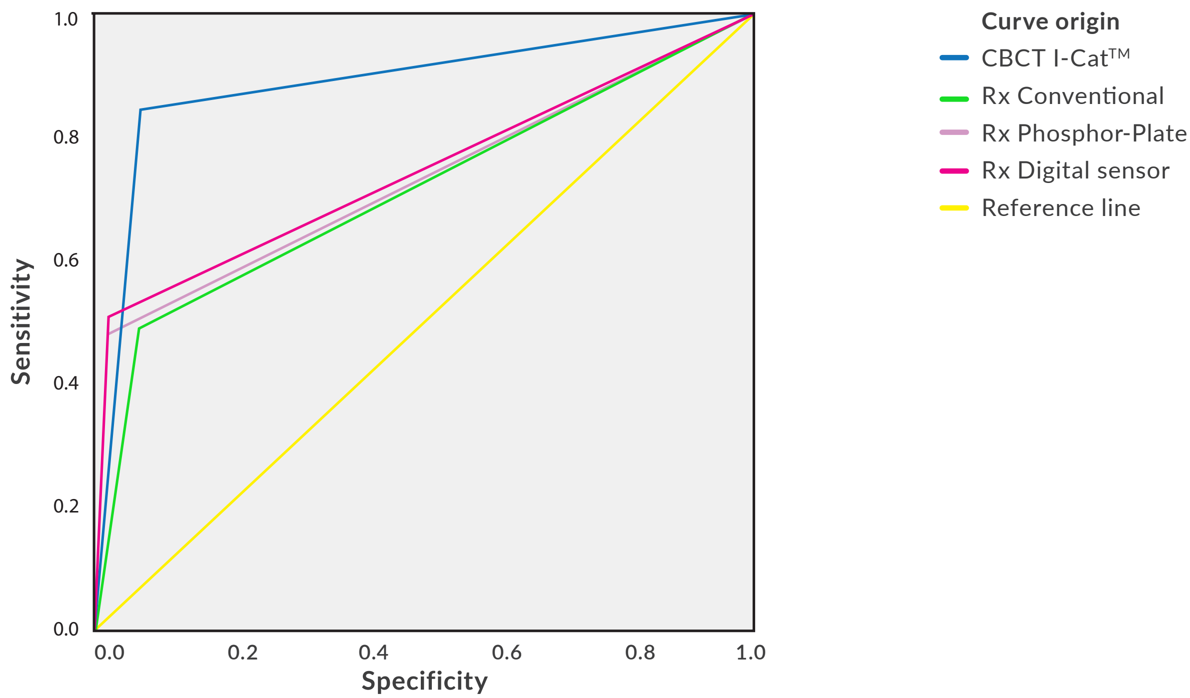

Table 2. Diagnostic test evaluation of dental carious lesions using cone beam computed tomography (CBCT), conventional radiography, phosphor-plate radiography, and digital sensor radiography *versus in vitro* histological diagnosis.

	HISTOLOGICAL DIAGNOSIS										
DIAGNOSTIC TECHNIQUES	With caries		Without caries		Total						
	N	%	N	%	N	%	Sensitivity	Specificity	PPV	NVP	Accuracy
CBCT											
With caries	189	71.1	3	1.1	192	72.2	0.84	0.93	0.98	0.53	0.86
Without caries	35	13.2	39	14.7	74	27.8					
Total	**224**	**84.2**	**42**	**15.8**	**266**	**100.0**					
CONVENTIONAL RADIOGRAPHY											
With caries	110	41.4	3	1.1	113	42.5	0.49	0.93	0.97	0.25	0.56
Without caries	114	42.9	39	14.7	153	57.5					
Total	**224**	**84.2**	**42**	**15.8**	**266**	**100.0**					
PHOSPHOR-PLATE RADIOGRAPHY											
With caries	107	40.2	1	0.4	108	40.6	0.48	0.98	0.99	0.26	0.56
Without caries	117	44.0	41	15.4	158	59.4					
Total	**224**	**84.2**	**42**	**15.8**	**266**	**100.0**					
DIGITAL SENSOR RADIOGRAPHY											
With caries	114	42.9	1	0.4	115	43.2	0.51	0.98	0.99	0.27	0.58
Without caries	110	41.4	41	15.4	151	56.8					
Total	**224**	**84.2**	**42**	**15.8**	**266**	**100.0**					

** 100 teeth, 46 molars and 54 premolars, 176 proximal and 90 occlusal surfaces.
PPV: Positive predictive value. **NPV:** Negative predictive value.

Table 2. Area under the curve in the diagnosis of dental carious lesions using cone beam computed tomography (CBCT), conventional radiography, phosphor-plate radiography, and digital sensor radiography *versus in vitro* histological diagnosis.

DIAGNOSTIC TECHNIQUES	Az	CI 95%	SE	p**
CBCT	0.89	0.84 - 0.93	0.02	0.89[a]
Conventional Radiography	0.71	0.66 - 0.76	0.03	0.71[b]
Phosphor-plate radiography	0.73	0.69 - 0.77	0.02	0.73[b]
Digital sensor radiography	0.74	0.70 - 0.78	0.02	0.74[b]

Az: Area under the curve. **CI 95%:** 95% confidence interval. **SE:** Standard error. ***p:*** Statistical significance. ** DeLong Test ($p<0.01$).
[a]: statistically significant differences (DeLong's Test; ($p<0.01$),
[b]: statistically non-significant difference (DeLong's Test; $p>0.05$).
* 100 teeth, 46 molars and 54 premolars, 176 proximal and 90 occlusal surfaces

Analysis of data

Data analysis was carried out using the statistical program SPSS v. 22.0 (IBM Corp., New York, NY; formerly SPSS INC., Chicago, IL) for Windows. Sensitivity and specificity tests were performed. The area under the ROC curve (Az value) was used to compare the diagnostic accuracy of the different diagnostic imaging systems.[10] The comparison between these areas was performed using the DeLong test in the EPIDAT *v*.3.1 statistical program. (Pan American Health Organization-PAHO). The level of significance was set at $p<0.05$.

RESULTS.

One hundred teeth were evaluated in the present study: 46 molars and 54 premolars, representing 176 proximal surfaces and 90 occlusal surfaces, which account for a total of 266 surfaces. The frequency of distribution in the detection of carious lesions with three intraoral radiology systems, a CBCT system and the histological diagnosis is shown in Table 1.

Likewise, sensitivity and specificity values are shown in the same Table. Figure 2 shows the sensitivity and specificity relationship between all systems through the ROC curve. The Az-values of the systems are shown in Table 2. Statistically significant differences were found between the Az-values obtained by the CBCT I-CAT™ and the other systems evaluated ($p<0.01$). No statistically significant differences were found between conventional radiography, phosphor-plate and digital sensor ($p>0.05$).

DISCUSSION.

The results of the present study indicate clearly that the CBCT I-CAT™ is a valid technique for the diagnosis of carious lesions *in vitro* compared to conventional or digital radiographic methods. In the study of diagnostic tests, the selection of a gold standard is always a must. This standard is compared with the new diagnostic techniques. Histological diagnosis was considered as the gold standard for this research.

The value of the area under the ROC curve (Az-Value) is directly related to the sensitivity and specificity of the tests. There is no Az-value in the literature to be used as a standpoint from which it can be considered that a diagnostic test is capable of discriminating healthy *versus* sick patients.[10] However, it is indeed considered that an Az value of 0.75 is halfway between the non-ability to discriminate (Az:0.50) and perfection (Az:1.00).[11]

In the present study, the highest Az values were obtained for the CBCT I-CAT™ system Az=0.89 (0.84-0.93). The differences between the Az values for the CBCT I-CAT™ system and the other intraoral modalities were significant. Similar Az values were documented by Senel *et al.*,[12] who reported Az=0.783+-0.035 with the Illuma 3D system.

Furthermore, the research of Kayipmaz *et al.*,[13] reported an Az value=0.705+-0.062 for the Kodak 9500 equipment. However, different authors have documented lower Az values. Zhang *et al.*,[14] reported an Az value=0.528+-0.049 for the ProMax 3D system, and 0.525+-0.023 for the Kodak 9000 system, or

Qu *et al.*,[15] with Az value=0.541+-0.033 for the NewTom 9000 system, and Az=0.555+-0.044 for the 3Dx Accuitomo. In another study conducted by Krzyzostaniak *et al.*,[16] an Az=0.629 (0.58-0.679) was reported for the NewTom 3G system.

All these studies were carried out on *in vitro* teeth, using a histological gold standard, just like the present research. The high values found in the present study could be due to the fact that the examiners were more qualified for the evaluation of dental caries with CBCT I-CAT™ (IEC=0.92), and to the high imaging quality of the system, which shows details that facilitate the diagnosis of carious lesions.

Other authors have reported lower sensitivity and specificity values. Haiter-Neto *et al.*,[5] obtained a sensitivity value of 0.18 and a specificity of 0.85 for the NewTom 3G system, and a sensitivity of 0.21 with a specificity of 0.89 for the 3Dx Accuitomo system. Young *et al.*,[8] reported a sensitivity of 0.61 and a specificity of 0.95 for the Accuitomo Plus system. In the present study, similar sensitivity and specificity values were obtained, which suggests that all these systems are very good at identifying healthy teeth. However, there is a significant difference in sensitivity between the CBCT I-CAT™ system and the other systems, suggesting that this system has a better ability to diagnose teeth with carious lesions *in vitro*.

Regarding the evaluations of the diagnostic capacity of intraoral radiographic systems in the detection of carious lesions *in vitro*, the results agree with previous studies such as that of Haiter-Neto *et al.*,[5] who studied different intraoral systems. This showed a sensitivity of 0.16 and a specificity of 0.92 in the detection of dental caries lesions. On the other hand, Pontual *et al.*,[17] compared the sensitivity and specificity of three phosphor-plate systems against a conventional plaque in the detection of carious lesions, finding low sensitivity values (0.14 - 0.16), and high values of specificity (0.89 - 0.94).

These results demonstrate the low capacity of digital and conventional radiographic systems to detect dental carious lesions *in vitro* compared to CBCT I-CAT™, which is logical because radiographs in any of their methods evaluate only two spatial dimensions, whereas tomography allows the examination of teeth in three dimensions. Despite this significant difference, the specificity values of the radiographic and tomographic systems are quite similar, suggesting that all diagnostic imaging systems that use X-rays are capable of detecting healthy teeth appropriately.

In the present study, Az values of intraoral systems were also found. Taking into account the study by Swets,[10] the three devices show low accuracy in detecting carious lesions *in vitro*. Similar results have been found in the studies by Krzyżostaniak *et al.*,[16] and Li *et al.*,[18B] in which posterior teeth were evaluated with the Digora Optime system and a conventional film, finding Az values of 0.65 and 0.66, respectively. However, when evaluating three phosphor-plate systems at different resolutions, they found an Az value of 0.60 for VistaScan with a resolution of 10 pl/mm, and 0.72 for the same sensor with a resolution of 20 pl/mm.

On the other hand, Şenel *et al.*,[12] when studying posterior teeth with conventional film, Progeny Vision DX, Digora Optime, found Az values of 0.73, 0.76 and 0.72, respectively. These results are similar to those of the present study for digital sensor and phosphor plates. However, they are lower than those obtained with CBCT I-CAT™, demonstrating its lower diagnostic capacity for detecting dental carious lesions *in vitro*.

In addition to X-ray-based diagnostic systems, when it comes to diagnosing dental carious lesions, a variety of other methods are available. Among them, clinical visual inspection, validated visual inspection such as the ICDASII system (International Caries Detection and Assessment System), the fluorescent laser system, fluorescence camera, and light-induced fluorescence such as QLF-D. All of these carious lesion diagnosis methods have been evaluated for their sensitivity, specificity and Az-value. Thus, for clinical visual inspection, Gimenez *et al.*,[19] reported a sensitivity of 0.814, specificity of 0.732, and Az=0.86.

For the ICDASII system, Dulanto *et al.*,[20] found a sensitivity of 0.67, specificity of 0.76, and Az=0.71; while Jallad *et al.*,[21] for the same method, reported a sensitivity of 0.82, specificity of 0.86, and Az=0.87. Regarding the fluorescent laser system, Diniz *et al.*,[22] reported a sensitivity of 0.89, specificity of 0.80, and Az=0.94. Another advanced method for the diagnosis of dental carious lesions is the fluorescence camera, for which Diniz *et al.*,[22] found a sensitivity of 0.74, specificity of 0.80, and Az=0.79.

It is worth mentioning that Jallad *et al.*,[21] reported evaluations for the diagnosis of dental carious lesions with a QLF-D light-induced fluorescence system, whose sensitivity, specificity and Az values were 0.84, 0.89, and 0.94, respectively. When observing the results obtained by different systems for the diagnosis of carious lesions, it is found that the CBCT I-CAT™

system has a similar diagnostic capacity as those other systems, even superior to those of visual inspection.

Evidence related to the use of CBCT and caries diagnosis is based primarily on *ex vivo* research, and most studies have shown little difference in the accuracy of diagnosis when using CBCT images compared to intraoral radiography.[23] *Ex vivo/in vitro* images can result in better quality images than those obtained clinically, since artifacts from adjacent restorations are absent. An *ex vivo* study reported that carious lesions could be identified with greater precision using CBCT compared to bitewing radiographs.[24] These same authors carried out studies of clinical diagnostic accuracy, confirming the ex vivo findings and concluding that the presence of caries should be reported in CBCTs taken for other diagnostic purposes.[25] To date, there has been no evidence of research at the highest levels of diagnostic efficacy.

Existing guidelines provided a unanimous view against the use of CBCT as a standard tool for caries diagnosis.[4] However, the high resolution of CBCT makes it clear that dentists do not need to supplement a study with conventional radiographs to diagnose dental carious lesions.

To conclude, there are some points to consider. First, there is ample evidence that the technical efficacy of different CBCT systems varies between equipment. Most of the evidence is based on studies using expensive "high-end" equipment that generally provides high-quality images. Some CBCT equipment provides lower image quality; therefore, the evidence of diagnostic efficacy for one research team may not apply to another. Second, post-capturing adjustment makes a difference in diagnostic value, but it is generally a subjective conclusion. Specialists may or may not adjust the brightness and contrast of CT scans when evaluating them.

However, software allows multiple image processing actions that can change the diagnostic value. On the other hand, it is undeniable that CBCT produces lower radiation doses and higher resolution in the axial direction than medical CT scanners. According to Ludlow *et al.*,[26] in a study that compared the radiation dose of three different equipment, they reported a dose of approximately 45 µSv, 135 µSv, and 477 µSv, for NewTom (FOV 12 inches), i-CAT and CBCT Mercuray, respectively. Thus, CBCT scanners produce lower doses compared to medical CT scanners, whose dose values are in the range of 364–1200 µSv for a mandibular scan, and 100–3324 µSv for a maxillary scan, according to the European guidelines on radiation protection in dental radiology.[4] Despite the potential benefits in the diagnostic outcome of CBCT, it should be noted that it still results in higher radiation doses than conventional imaging alternatives and intraoral examinations. Effective doses for conventional imaging are in the range of 1–8.3 µSv for an intraoral exam, 4–30 µSv for panoramic machines, and 2–3 µSv for a lateral cephalometric exam.[4]

Ultimately, each patient is unique. Justifying the use of CBCT equipment should not be reduced to a simple "... it is indicated" or "... it is contraindicated" in a particular clinical context; instead, an individual approach is needed in order to be able to choose in which cases a CBCT exam would actually be justified.

CONCLUSION.

CBCT had greater diagnostic efficacy than digital sensor radiography, phosphor-plate radiography and conventional radiography, in the diagnosis of carious lesions in molars and premolars *in vitro*.

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