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RESEARCH ARTICLE

Assessment of image quality and exposure parameters of an intraoral portable X-rays device

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Objective: To evaluate the exposure parameters, radiation protection, absorbed dose and radiographic image quality of the DIOX® intraoral portable radiography device.
Methods: The exposure parameters were measured using the Xi UNFORS detector. Operator exposure to secondary radiation was measured using the 1800cc ionization chamber coupled to the electrometer. The absorbed dose (D) in the patient was calculated using TLD-100H positioned in the Alderson RANDO anthropomorphic simulator. The quality of the radiographic digital image was assessed by comparing radiographic images obtained from two conventional devices (CS 2200- Carestream Health®; Heliodent plus- Sirona Dental Systems GMbH®) with the radiological simulator of the upper molar region RMI (Radiation Measurements Instruments), using three acquisition sensors: Kodak RVG 5000® and Kodak PSP®, Eastman Kodak Company, Rochester, NY; EVO Micro Image®, Brazil.
Results: The DIOX intraoral portable radiographic device demonstrated reliability in relation to the performance of the standard evaluated parameters, except for the diameter of the radiation field (5.8 mm) less or greater. No evidence of device head radiation was detected. The Pb lead protection of the apparatus attenuates the secondary radiation, thus protecting the operator. However, it was observed that the region of the operator's gonads was the most exposed during the measurements. In the Alderson RANDO anthropomorphic simulator, the highest value of D was in the region corresponding to the submandibular and lingual glands of the left side (0.568 mGy). The image quality of the DIOX portable radiographic apparatus presented quality standards equivalent to those produced by the two conventional radiographic devices.
Conclusion: The DIOX intraoral portable radiography device demonstrated reliability in relation to the quality control and radioprotection criteria, according to international standards. Results obtained demonstrated the safe use of the DIOX intraoral portable radiography device and indicated the need for debate and change in international sanitary oversight standards regarding the use of portable XR devices in dentistry.
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Introduction

Portable X-ray devices are increasingly available for use in the dental clinic market.[1–5] These devices were first designed for military missions, and later deployed to the forensic area and dental care of patients with limited mobility.[2–8]

The DIOX® (Micro Imaging, Brazil) intraoral portable X-ray device is appropriate for intraoral radiography with conventional film or digital sensors for adult and pediatric applications. It can be handled by professionals in the health field, trained dentists and dental technicians. According to the manufacturer, this device is in compliance with the ABNT NBR IEC 60601 standards and it is certified by ANVISA (National Agency of Sanitary Surveillance). This kind of device is particularly useful in the many countries and remote areas, where its use is mandatory around the world, to permit XR examinations.

The European Academy of Dentomaxillofacial Radiology[5] has determined that portable X-ray devices should be used in specific cases, where it is impossible or impractical to move the patient to a conventional fixed X-ray, forensic examination, military operation and rural or isolated areas.[2–4] Issues related to radiographic image quality, the use of digital sensors and inherent exposure parameters are also in the literature.[3,5,6]

The American Dental Association-ADA[9] and the Public Health Department of England (PHE),[4] in their guidelines for the best use of diagnostic imaging for each patient, established that portable devices do not present a greater risk of radiation than conventional dental radiographic units for the patient or the operator. No additional radiation protection procedures are required when the device is used according to manufacturer's instructions and safety standards established for conventional X-ray devices regarding operator, patient and public exposure control.

Therefore, this study evaluated the parameters of exposure, radiological protection and radiographic image quality of the DIOX intraoral portable radiography device, and discussed the results obtained in relation to international radiation protection standards.[10–13]

Methods and materials

The DIOX handheld radiographic device is a high frequency, dental X-ray machine utilizing a rechargeable 24-volt lithium polymer battery, 1.8 kg weight, internal shielding and an external, acrylic, lead-equivalent shield. This device operates at 60KV (fixed), 2.0 mA current and has a focal point of 0.8 mm with the distance of 20 cm from the source to the patient's skin.

The tests of accuracy, reproducibility of tube tension and exposure time, reproducibility and linearity of Kerma rate in the air, X-ray tube yield, semi-reducing layer (CSR) and airkerma were performed using Xi Unfors® detector positioned at the collimator output of the DIOX portable X-ray device. Exposure times ranged from 0.05 to 1.6 s. The kerma value in the air was obtained using equation 1.

$$Ki\,(mGy) = \frac{\mathrm{T}\,(\mathrm{s}) - 0.002}{0.972} \qquad (1)$$

Where Ki is the Kerma in the incoming air in mGy and the T is the exposure time in seconds.

The extraoral radiographic sensor (Kodak PanV2 15 × 30 cm) was used to measure the diameter of the radiation field.

To measure the leakage radiation of the head of the DIOX X-ray apparatus, the 10 × 6–180 ionization chamber coupled to the 9015 RadcalAccu-Dose model electrometers with exposure times of 1.6 s.

Secondary radiation was measured with an 1800cc ionization chamber, coupled to a 9015 RadcalAccu-Dose model electrometer, with operator distance of 44 cm from the X-ray tube. The operator's body regions evaluated were the skull, abdomen and gonads.

Thermoluminescent dosimeters- LiF: Mg, Cu, P (TLD-100H, Harshaw-Bricon), were selected and calibrated according to ISO 12794.[14] The reliability of the Thermoluminescent dosimetry system was achieved after several performance tests were carried out at the Calibration and TL Dosimetry Laboratories of the Nuclear Technology Development Center (*Centro de Desenvolvimento Tecnológico Nuclear -CDTN*). The Thermoluminescent dosimeters were submitted to 10 cycles of radiation exposure with a ^{60}Co γ beam, under electroni c equilibrium conditions, with an air kerma of 10 mGy.[15] The selected dosimeters were used to measure the absorbed dose (D) in regions corresponding to organs and tissues[16] on a RANDO Alderson anthropomorphic simulator (Alderson Research Laboratories, Stanford, CT).

The simulation of the upper left molar periapical XR examination, using the RANDO Alderson simulator prepared with the select dosimeters, was performed with and without the acrylic protector. (Figure 1)

Absorbed doses of organs and tissues were calculated using equation 2[17]: where D is the mean value of the dosemeter readings in mGy, and μen/ρ tissue/air is the ratio between mass energy absorption coefficients of the tissues and air for the mean energy of the qualities of the radiographic examinations obtained using the Online Program WinXCOM (National Institute of Standards and Technology - NIST).[18]

$$\mathrm{D_T} = D.\left(\frac{\mu en}{\rho}\right)_{tecido/ar} \qquad (2)$$

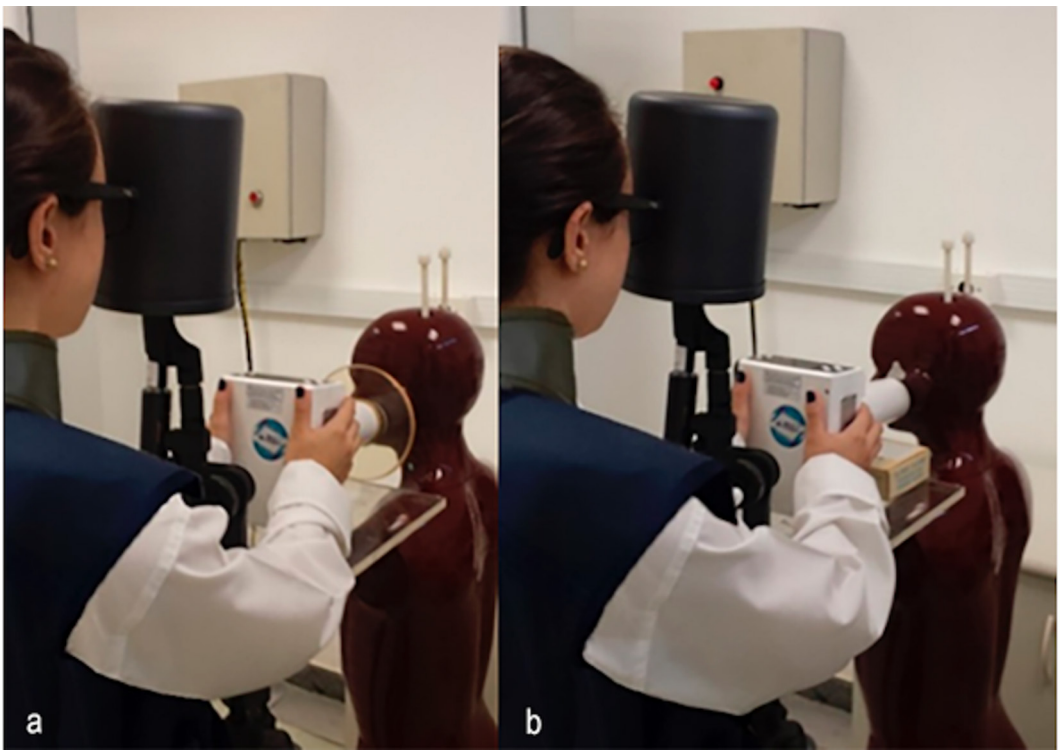

Figure 1 Simulation of the upper left molar periapical examination using the RANDO Alderson simulator: (a) With acrylic protector (b) without acrylic protector

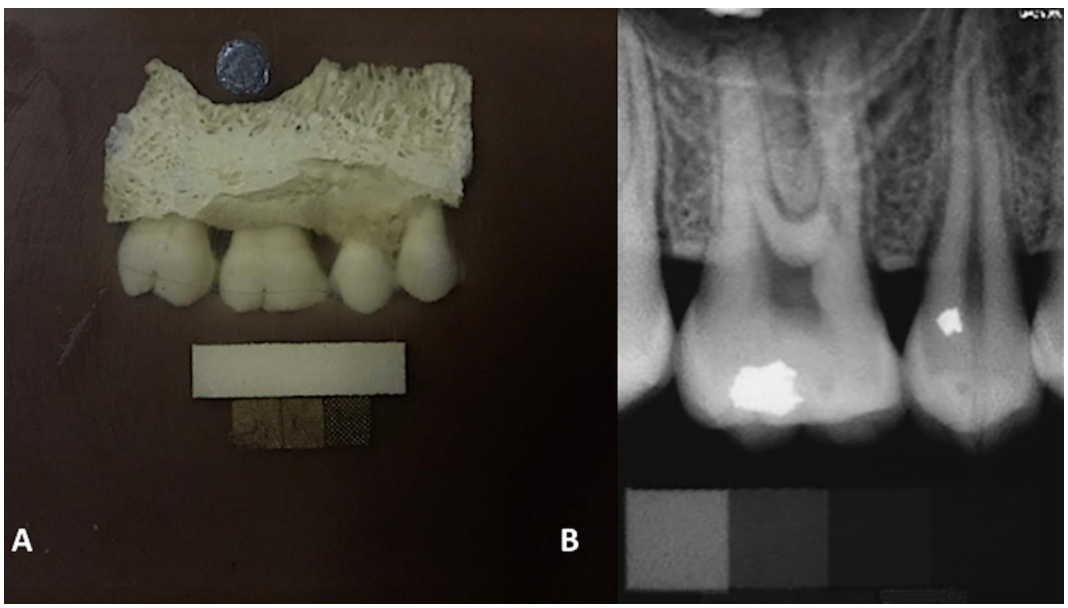

Figure 2 (A) Dental radiographic simulator of the upper molar region - RMI (Radiation Measurements Instruments) - (B) Radiographic image obtained using DIOX® - Portable Radiographic Dentistry Device and the Kodak RVG 5000® sensor.

The spectra of the DIOX and conventional Kodak and Sirona portable X-ray devices were simulated using the Siemens Healthcare GmbH program.

The quality of the radiographic digital image was assessed by comparing the periapical radiographic images (parallelism technique) obtained with the DIOX portable X-ray device and two conventional (fixed) dental X-ray devices (CS 2200®, Carestream Health; Heliodent plus®, Sirona Dental Systems, GMbH).

Image acquisition parameters are in the frames. The images were obtained using the radiological simulator of the upper molar region (RMI) and using three digital

Table 1 Acquisition parameters of radiographic images

Technical specifications	*DIOX®*	*Heliodent plus®*	*CS 2200®*
Tube tension	60 kV	60 kV	60 kV
Tube current	2 mA	7 mA	4 mA
Mean energy (keV)	36.59	36.44	37.74
Focal point	0.8 mm	0.4 mm	0.7 mm
Target angle	20°	12°	19°
Total Filtration	1.6 mm Al	>1.5 mm Al	2.5 mm Al
Focus film/distance	20 cm	20 cm	20 cm

Table 2 Indicated and measured time, tension and Kerma in the air measured using the DIOX - Portable Radiographic Dentistry Device

Indicated time (s)	*Measured time (s)*	*Measured kV*	*Kerma in the air (μGy)*
0.05	0.05	58.20	0.05
0.10	0.10	57.70	0.10
0.30	0.30	57.80	0.30
0.50	0.50	57.86	0.49
0.80	0.80	58.05	0.78
1.00	1.00	58.30	0.98
1.30	1.30	58.35	1.26
1.60	1.61	58.35	1.56

image acquisition sensors: Kodak RVG 5000®, Eastman Kodak Company, Rochester, NY; Micro Image EVO®, Brazil (CMOS - Complementary Metal Oxide Semiconductors) and Kodak PSP® sensor (photoactivated phosphor plate). (Figure 2)

Image acquisition parameters are shown in Table 1. The DIOX X-ray device was attached to a tripod at a source-object distance (patient skin) of 20 cm. Exposure times for image acquisition ranged from 0.2 to 0.7 s with the three X-ray devices. Each image combination of X-ray device and digital image acquisition sensor was exported from their respective software with the highest quality Joint Photographers Expert Group (JPEG).

Three professional dental radiologists analyzed the images individually in an adequately lighted environment. The analysis training of the professionals was conducted before the measurements and all received the scoring table (0- bad, 1-good, 2-excellent) adapted from Pittayapat et al.[3,6]

Analyses were repeated over a 2 day period to assess inter- and intra observer agreement, using a total of 54 images. It was determined that the gold standard would be when two observers chose the same image, acquired in the least time. The power of - and intra observer agreements was calculated using the κ test.

Results and discussion

The results of the analyzed parameters were compared with the reference parameter levels used in Brazil (ANVISA),[13] the European Commission guidelines,[10,11] Department of Public Health of England (PHE)[4] and recommendations of the American Dental Association (ADA).[9]

In relation to the exposure time, kV value and Kerma in the air, calculations were performed to determine the parameters using the Xi UNFORS detector (Table 2).

The values of the voltage accuracy and reproducibility deviations measured in the present study (3.2 and

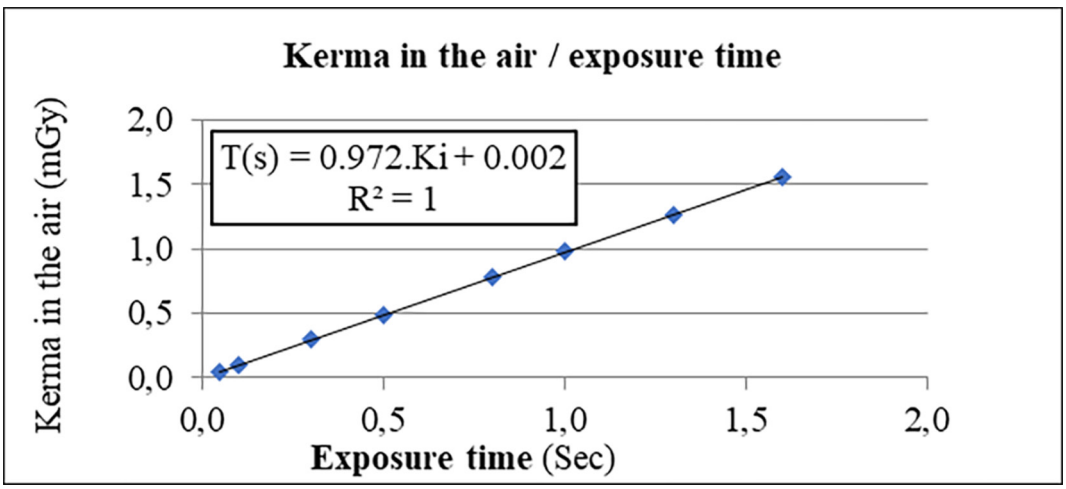

Figure 3 Kerma in the air Linearity as a function of exposure time.

Table 3 Measurements of secondary radiation in the cranial, abdominal and gonadal regions of the operator, with or without lead acrylic protector

		Reading (nGy s^{-1})		*Equivalent dose (mSv/weekly)*	
		Acrylic protector		*Acrylic protector*	
Position	***Region***	*With*	*Without*	*With*	*Without*
A	Cranial	6.76	73.66	0.004	0.040
B	Abdominal	13.96	37.86	0.008	0.021
C	Gonadal	22.32	104.14	0.012	0.057

Table 4 Absorbed dose values in the patient during upper molar periapical examination

Anatomic points	***Absorbed dose (mGy)***
Thyroid (right)	0.01 (±0.002)
Thyroid (left)	0.01 (±0.001)
Cervical Lymph node (right)	0.01 (±0.006)
Cervical Lymph node (left)	0.02 (±0.001)
Oral Mucosa (right)	0.24 (±0.108)
Oral Mucosa (left)	0.39 (±0.182)
Submandibular and Sublingual Glands (right)	0.14 (±0.216)
Submandibular and Sublingual Glands (left)	0.57 (±0.216)
Parotid gland (right)	0.05 (±0.013)
Parotid gland (left)	0.09 (±0.015)
Cristaline (right)	0.02 (±0.005)
Cristaline (left)	0.05 (±0.012)
Cortical bone (right)	0.03 (±0.002)
Cortical bone (left)	0.04 (±0.004)
Brain, esophagus, bone marrow, para-sternum region	

1.1%) were within the tolerance levels, *i.e.* less than 10% according to the 453SVS/MS[12] directive.

The reproducibility of the exposure time presented no variation. The accuracy assessment was 0.6%.

The result of the reproducibility and linearity of the Kerma rate in the air, performed with exposure time of 1.0 s, was 0.8 and 100%, respectively.

The analysis of the behavior of the X-ray beam in relation to the Kerma value in the air when the exposure time varied, had a coefficient of variation (R^2) equal to 1 (Figure 3), which shows a perfect linearity between Kerma and exposure time.

In the present study, the maximum measured value of Kerma in the air was 1.6mGy obtained with the maximum exposure time (1.6 s) and tube current of 2mA.

The handheld device had an appropriate focus-film distance relation (20 cm). The diameter of the radiation field, 5.8 cm, is according to the Ordinance No. 453 SVS/MS[12] requirement; but, it is greater than the value established by the European Commission[10,11] *i.e.* less than 5 cm.

The value of the semi-reduction layer (SRL), measured using the portable device analyzed, was 2.7mmAl, in agreement with the European Commission,[10,11] Ordinance n° 453 SVS/MS,[12] IAEA.[19]

In the present study, no leakage radiation was detected, and the head shield of the portable device was considered adequate and safe.[4,12] Gorem et al[20] evaluated possible leakage radiation, backscattering radiation through the acrylic shield and exposure of the patient to NOMAD® portable X-ray radiographic equipment. The authors showed that NOMAD® portable equipment presented risks to the patient and operator, but they are not greater than traditional dental radiographic equipment. However, the measured radiation doses are lower than the accepted levels.

The acrylic shield that accompanies the DIOX portable dental radiographic device has a diameter of 15.4 cm, in accordance with the guidelines of radiological protection established by the European Commission.[10,11]

In the present study, to ensures operator safety in the work environment, the radiometric survey was performed initially both with and without the plumbifer acrylic shield. Secondary radiation measurements were based on assessing the most critical points. The values of the measured readings in the detector and the weekly equivalent dose rates calculated for the three critical points: skull, abdomen and gonad regions. The calculated weekly dose was almost 20 times lower than the established value[4,9,12,13] without the use of the acrylic protector in the gonads region. Using the acrylic shield

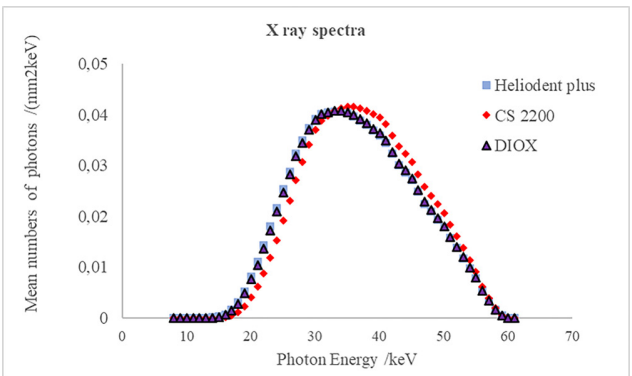

Figure 4 Spectra of DIOX - Portable Radiographic Dentistry Device compared to conventional CS 2200 and Heliodent plus- Sirona.

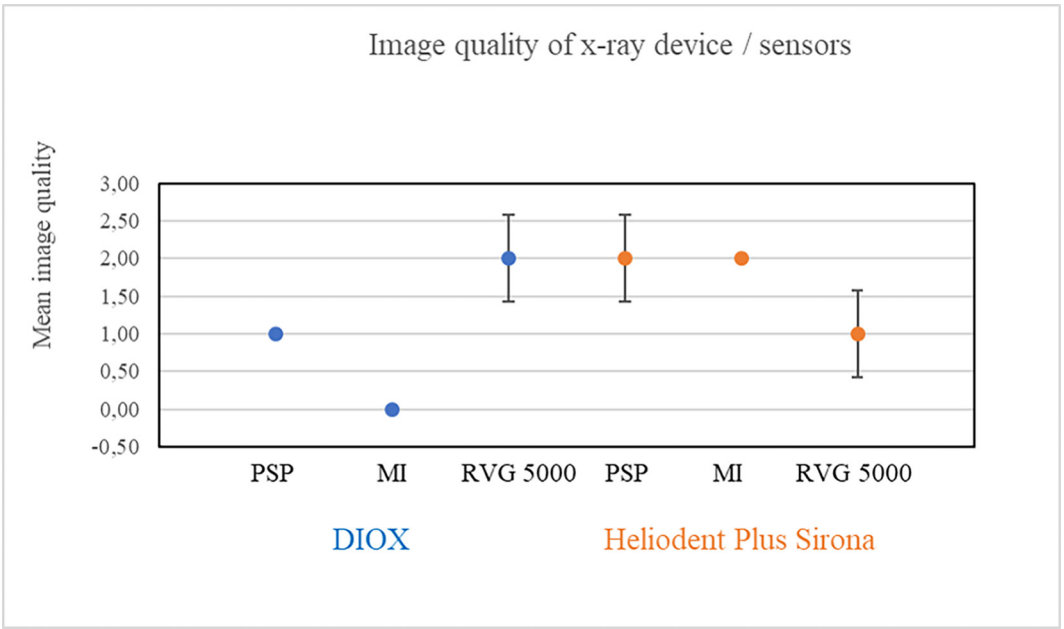

Figure 5 Radiographic image quality using DIOX - Portable Radiographic Dentistry Device compared to conventional Heliodent plus®- Sirona.

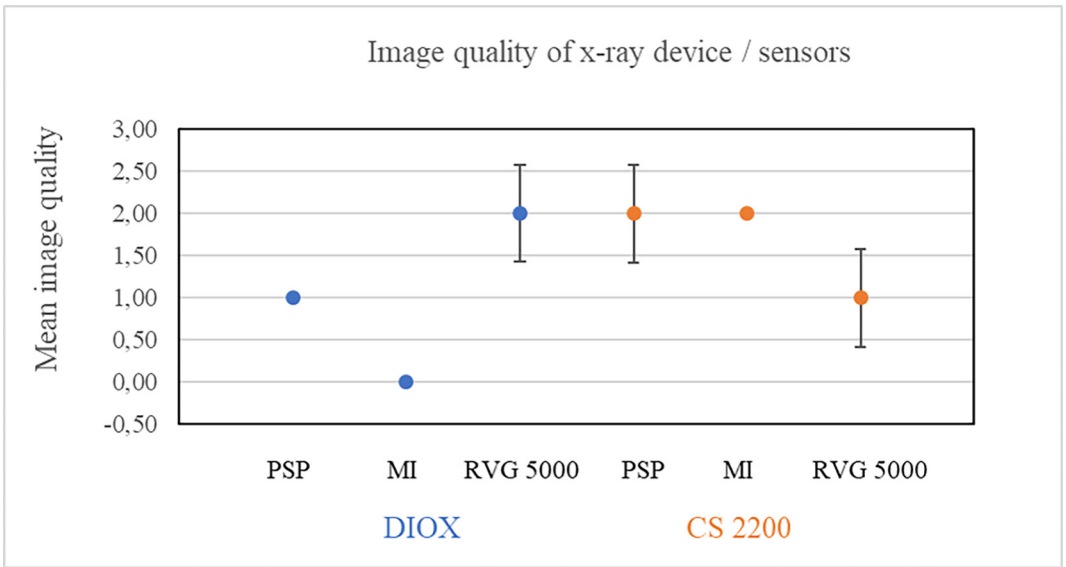

Figure 6 Radiographic image quality using DIOX - Portable Radiographic Dentistry Device compared to conventional CS 2200® - Sirona.

the calculated value was 100 times lower than the acceptable limit of mSv/wt (Table 3).

Results of the study by Danforth et al[7] evaluating the operator's exposure to backscattering radiation of the ARIBEX® and NOMAD®, showed that the reproductive organs received the highest dose and the thyroid the lowest dose, corroborating the results of the present study. Cho et al[8] and ADA[9] concluded that for optimum efficiency when using portable dental X-ray devices, the backscatter protector, long locator and lead gloves should be used.

The highest values of D (Table 4) for the patient were observed in the salivary glands (0.57 mGy) and oral mucosa (0.39 mGy), on the left side, below the radio-diagnosis reference level established by legislation.[10–12] These organs also received the highest absorbed dose during an intraoral examination, in the study of Granlund et al.[21] In the same study, the salivary glands obtained a value of 0.11 mGy and oral mucosa 0.16 mGy and, in the simulation of the whole mouth examination, the values were 0.45 mGy and 0.58 mGy, respectively. In the study by Ludlow et al[22] the doses in the salivary glands were the same and, when performing the whole mouth examination simulation, the salivary glands received a value of 4.11 mGy. Zhang et al[23] when measuring the absorbed doses in organs during

the whole mouth examination simulation, obtained the highest values in the sublingual and submandibular glands, with a value of 1.90 mGy. The doses received in the most distant organs, such as the gonads, were so low that the measurements could not be analyzed.

The comparison of the spectra of the portable DIOX compared to conventional X-ray devices CS 2200, Heliodent plus-Sirona is shown in Figure 4. The portable equipment and Heliodent plus® presented X-ray spectra with similar performance. The CS 2200®-Carestream Health X-ray device presented a higher average energy spectrum, in which the performance is due to the higher filtration that this equipment presents, *i.e.* 2.5 mmAl.

The evaluations of image quality assessed by the three observers, comparing the DIOX portable X-ray and the conventional X-ray devices (CS 2200®- Carestream Health and Heliodent plus®- Sirona Dental Systems GMb), are presented and compared in Figures 5 and 6.

It was observed that the combination of the DIOX portable X-ray device and the Kodak RVG 5000 sensor with the manufacturer's specified exposure time (0.5 s) received (score 2), that was superior to the CS 2200® and Heliodent plus®- Sirona devices using the same sensor, which received the (score 1), with the exposure times of 0.35 and 0.20 s, respectively.

The combination of the DIOX device and the Kodak PSP sensor (0.5 s) allowed the acquisition of radiographic image with score 1 (good). With the MI® (Micro Image EVO) sensor, it presented the worst performance (score 0), making it impossible to use this equipment at the rated exposure times.

The CS 2200® and Heliodent plus®- Sirona X-ray devices showed superior performance with the Kodak PSP and MI® sensors (score 2). Only the combination of the CS 2200® device and the Kodak PSP sensor obtained an image with better quality (score 2) with an exposure time lower than that defined by the manufacturer (0.22 s).

According to the κ test, the intra observer agreement was moderate (0.514) with $p < 0.001$. The inter observer agreement was moderate (0.438) to almost perfect (0.824) with $p < 0.001$.

In the studies of Pittayapat et al[3,6] the combinations between fixed and portable devices, using the CMOS, CCD and PSP sensors, presented variable scores. The combination of the portable Nomad® device with the PSP® sensor presented the highest score in relation to all the devices evaluated.

According to Berkhout et al,[5] portable X-ray devices operate at low current and require longer exposure times than conventional radiographic devices. This was observed in the technical specifications of the manufacturer of the DIOX X-ray device, where the value of the current used by the portable device is lower than that of the rated conventional devices. The value of the current is related to the density of the radiographic image, requiring a longer exposure time when using the portable X-ray device for better image quality.

The DIOX handheld dental radiographic device features a 1.8 kG weight which may increase the risk of tube movement during exposure and misalignment.[3] Berkhout et al[5] observed that exposure times greater than 1 s should never be used in patients, even when using a tripod, because of movement artifacts caused by patient or operator. The risk of unusable images will be increased due to the longer exposure time and movement of the device. The use of a tripod, when available, as well as a risk assessment regarding handling and use, is recommended. This is particularly important in situations where the patient is in the supine position, such as in an operating room, in order to avoid the risk of dropping the unit on the patient's head.[4,5]

Conclusion

The DIOX portable handheld intraoral radiography device demonstrated reliability in relation to the quality control and radioprotection according to international standards. The tests performed showed the reduction of the radiation dose to the operator within the acceptable levels, especially when the acrylic protector was used. The regions of the salivary glands and oral mucosa were the organs with the highest absorbed dose values and entry dose into the patient's skin in a periapical radiographic examination of the upper left molar. The images evaluated met quality standards equivalent to those of standard radiographic devices.

The results of the present study showed the safe use of the DIOX portable dental radiographic device and indicate the need for more studies, debate and change in international sanitary oversight standards regarding the use of portable XR devices in dentistry.

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