



Image quality assessment and medical physics evaluation of different portable dental X-ray units

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ABSTRACT

Introduction: Recently developed portable dental X-ray units increase the mobility of the forensic odontologists and allow more efficient X-ray work in a disaster field, especially when used in combination with digital sensors. This type of machines might also have potential for application in remote areas, military and humanitarian missions, dental care of patients with mobility limitation, as well as imaging in operating rooms.

Objective: To evaluate radiographic image quality acquired by three portable X-ray devices in combination with four image receptors and to evaluate their medical physics parameters.

Materials and methods: Images of five samples consisting of four teeth and one formalin-fixed mandible were acquired by one conventional wall-mounted X-ray unit, MinRay[®] 60/70 kVp, used as a clinical standard, and three portable dental X-ray devices: AnyRay[®] 60 kVp, Nomad[®] 60 kVp and Rextar[®] 70 kVp, in combination with a phosphor image plate (PSP), a CCD, or a CMOS sensor. Three observers evaluated images for standard image quality besides forensic diagnostic quality on a 4-point rating scale.

Furthermore, all machines underwent tests for occupational as well as patient dosimetry.

Results: Statistical analysis showed good quality imaging for all system, with the combination of Nomad[®] and PSP yielding the best score. A significant difference in image quality between the combination of the four X-ray devices and four sensors was established ($p < 0.05$).

For patient safety, the exposure rate was determined and exit dose rates for MinRay[®] at 60 kVp, MinRay[®] at 70 kVp, AnyRay[®], Nomad[®] and Rextar[®] were 3.4 mGy/s, 4.5 mGy/s, 13.5 mGy/s, 3.8 mGy/s and 2.6 mGy/s respectively. The kVp of the AnyRay[®] system was the most stable, with a ripple of 3.7%. Short-term variations in the tube output of all the devices were less than 10%. AnyRay[®] presented higher estimated effective dose than other machines.

Occupational dosimetry showed doses at the operator's hand being lowest with protective shielding (Nomad[®]: 0.1 μ Gy). It was also low while using remote control (distance > 1 m: Rextar[®] <0.2 μ Gy, MinRay[®] <0.1 μ Gy).

Conclusions: The present study demonstrated the feasibility of three portable X-ray systems to be used for specific indications, based on acceptable image quality and sufficient accuracy of the machines and following the standard guidelines for radiation hygiene.

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1. Introduction

Different portable hand-held with battery powered dental X-ray units have become recently available in the market. Especially for forensic odontological purposes these offer various advantages.

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The small camera-like design and light weight make them easy to be carried into disaster fields. Moreover they simplify the identification process because dental radiographs are one of the crucial evidences in post mortem profiling and age estimation work [1–8]. The integrated battery supplies the electrical power for convenient cordless operation. Together with digital image sensors, this type of machines helps the forensic odontologists to ensure quick and fully digitized data collection.

In addition to forensic purposes (such as DVI operations), the portable X-ray machines may also have potential for application in

dent care in remote areas, such as military medical bases and humanitarian missions, and in home care for geriatric patients and those with limited mobility. The portable device may also be used in operation rooms for sedated patients.

In a previous study [9], two portable X-ray units: AnyRay[®] (VATECH Co., Ltd., Gyeonggi-do, Republic of Korea) and NOMAD[®] (Aribex, Utah, USA) were evaluated and compared with a standard wall mounted radiographic unit: MinRay[®] (Soredex, Tuusula, Finland), on their performances with Vistascan[®] phosphor image plates (Dürr Dental, Bietigheim-Bissingen, Germany) and SIGMA[®] M CMOS Active Pixel technology sensor (Instrumentarium Dental, Tuusula, Finland) CMOS image receptors. The ideal parameter set up for obtaining excellent image quality disregarding the object-to-image-receptor-distance (OID) was the phosphor plate system combined with the MinRay[®] unit and if a portable device is needed, the NOMAD[®] unit is recommended. Furthermore, it was found that the radiological image quality was significantly higher for phosphor image plates compared to the CMOS system ($p < 0.0001$). A significantly superior image quality was obtained for OID set at 0.8 cm compared to 2.5 cm ($p = 0.039$). The ideal parameter set up

for obtaining excellent image quality disregarding the OID was the phosphor plate system combined with the MinRay[®] unit.

Apart from image quality, occupational and patient dosimetry also were considered. The radiation dose is expressed as effective dose (microSievert, μSv) which is calculated for any X-ray technique by measuring the energy absorption in a number of 'key' organs in the body, so that the final figure is a representation of 'whole body' [10,11].

In this study, a newly developed portable X-ray machine with integrated computer, Rextar[®] (Sungwon Econet, Seoul, Korea) was also evaluated (Fig. 1). The primary aim of the study was to determine which combination of portable X-ray device and image receptor provided the best images. A secondary aim of this study was to evaluate the occupational and patient exposures and operating medical physics parameters of these devices. A tertiary aim was to convey the readers, the varying clinical features of these portable machines. Additionally, technical features concerning the portability of some portable machines are presented.

2. Materials and methods

The following parameters settings and image quality evaluation were integrated in the research set up in detail described in a previous study [9].

2.1. Parameter settings

Images of five samples consisting of four teeth (one upper incisor, one lower incisor, one upper canine, and one premolar) and one formalin-fixed mandible, were taken by three hand-held portable X-ray devices: AnyRay[®], NOMAD[®], Rextar[®] and one standard wall-mounted X-ray unit: MinRay[®]. Detailed technical information of each device was reported in Table 1.

Images were captured on four receptors, namely: Vistascan[®] phosphor image plates (PSP) (Dürr Dental, Bietigheim-Bissingen, Germany), SIGMA[®] M CMOS Active Pixel technology sensor (Instrumentarium Dental, Tuusula, Finland), VistaRay[®] CCD sensor (Dürr Dental, Bietigheim-Bissingen, Germany) and Sopix²[®] fiber-optic based CMOS sensor (SOPRO-Acteon Imaging, La Ciotat cedex, France). The source-to-object-distance (SOD) was fixed at 20 cm in combination with an object to image receptor distances (OID) of 0.8 cm.

Technical data and features impacting on the portability of the machines tested, as well as two other commercially available machines, were gathered from brochures and information on the manufacturers' websites.

The most optimal images of each combination of X-ray device and receptor were exported from their viewing software at their maximum quality in Tagged Image File Format (TIFF).

2.2. Image quality evaluation

The observations were done individually by one undergraduate dental student, one oral radiologist and one post-doctoral academic staff member in low ambient lighting on 20-inch Clinical Review LCD Display MDRC (Barco, Kortrijk, Belgium) (Fig. 2). A calibration session was done before the observation and all observers received a score sheet as a guideline during performing each observation. The 4-point scoring system (3-Excellent, 2-Good, 1-Poor, 0-very poor) was described in Pittayapat et al. study [9]. The observations were repeated after a period of 1 month for the intra-observer agreement evaluation.

2.3. Medical physics test and patient dose estimation

All devices were tested by a medical physicist according to the requirements of the Belgian Federal Agency for Nuclear Control. Tested parameters consisted of exposure rate, time to reach full exposure rate, beam filtration, kVp ripple, short term reproducibility of tube output and the accuracy of indicated exposure time. Protocol and limiting values used in these tests are published in the Belgian Official Journal [12]. Potential patient dose was estimated for exposure parameters that give a similar image quality according to the different observers. Conversion factors were derived from studies by Kaeppler and Cederberg [13,14].

2.4. Occupational dose measurements

All machines were tested for the occupational dosimetry. Scattered radiation was measured by the radiation protection service, University Hospitals Leuven, using a portable gamma and X-ray dosimeter (Babyline, Canberra, USA) and a water phantom. Cumulated dose per exposure taken was measured at fixed distances from a water phantom: at 5 cm, 30 cm, at 1 m or if available at the end of the exposure switch cable (>1 m), and at the operator's hand that pushed a start button. Radiation in the primary beam was measured to estimate the exposure in case of incident (e.g. exposure to the primary beam, especially if the unit fails to terminate correctly).

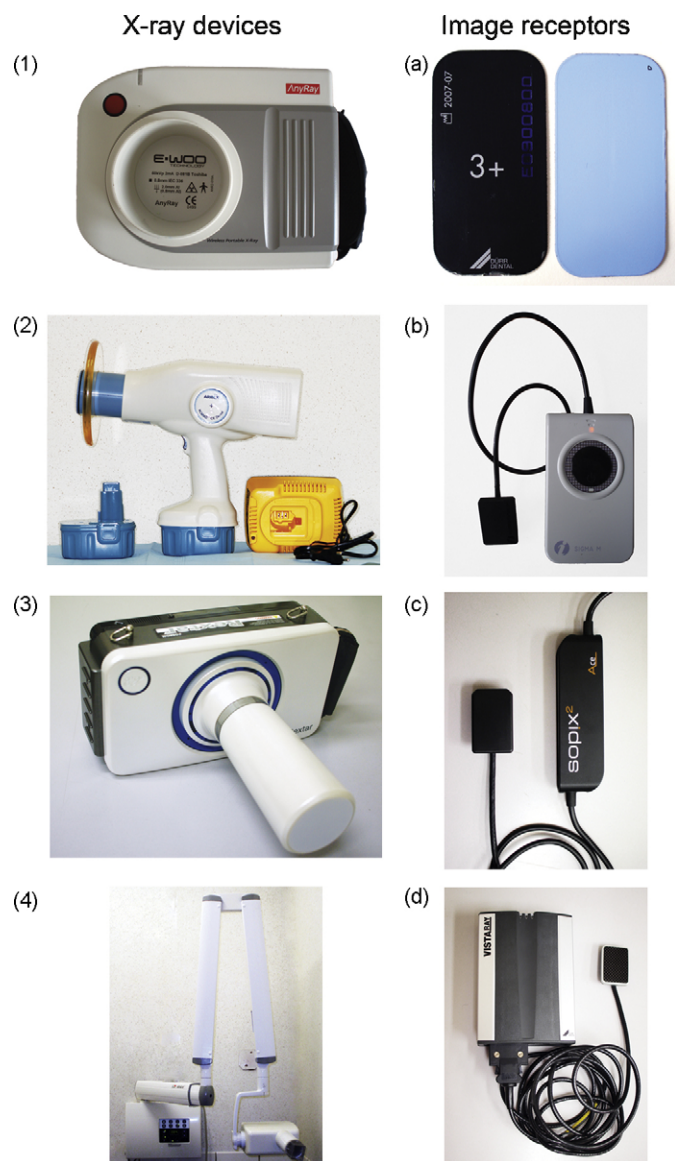


Fig. 1. In the present study, four X-ray devices: AnyRay[®] (1), Nomad[®] (2), Rextar[®] (3) and MinRay[®] (4) were evaluated together with four image receptors: Dürr PSP[®] (a), Sigma[®] M CMOS (b), Sopix²[®] CMOS (c) and VistaRay[®] CCD (d).

Table 1

Technical specification of each device according to the manufacturers.

	AnyRay	Nomad	Nomad Pro	Rextar	Genoray PORT-X II	ADX4000 wireless	MinRay
Computer/viewer integrated	No	No	No	Computer	No	Viewer	No
PC/viewer compatible with other sensors	–	–	–	Yes	–	No	–
Battery autonomy ^a	>100 exposures	>100 exposures	Hundreds of exposures	Hundreds of exposures	>100 exposures	>300 exposures	–
Extra set battery	NS ^a	Yes	Yes	Optional	NS	Yes	–
Power input	110/220 V	110/220 V	110/220 V	110/220 V	110/220 V	110/220 V	Line voltage 115/230 V ± 10%, 50/60 Hz
kVp	60	60	60	70	60	60	60/70
mA	2	2.3	2.5	2	2	1	7
Total filtration Al (mm)	2	>1.5	>1.5	1.5	1.8	NS	2
Anode angle	NS	NS	NS	12	20	20	–
Focal spot (mm)	0.8	0.4	0.4	0.4	0.8	0.8	0.7
Exposure time range (s)	0.03–2	0.01–0.99	0.01–1	0.01–1.30	0.01–2	0.05–1.35	0.02–3.2 s
Size (mm)–WLH	197 × 151 × 77	140 × 270 × 250	160 × 270 × 250	250 × 171 × 136	197 × 147 × 145	NS	–
Weight (kg)	2.6	< 4.0	2.5	2.7	2.35	2.2	30 kg wall mount
Tripod/stand	NS	Optional	Optional	Optional	Yes	Optional	–
Remote shutter	NS	Optional	Optional	Yes	Yes	Yes	Yes
External radiation shield	NS	Circular shield	Circular shield	NS	NS	Circular shield	–

^a NS, not specified by the manufacturer (brochures/website).

2.5. Statistical analysis

A Kruskal–Wallis test was performed to find the differences between all parameters. The comparison of paired groups was carried out with the Wilcoxon test. Inter- and intra-observer agreement were calculated by weighted kappa for each pair of observers and the two sets of scores respectively.

3. Results

3.1. Image quality evaluation

Concerning MinRay[®] and Rextar[®], the mean image quality score for the three observers are shown in Fig. 3. It was found that

there were significant differences amongst the parameters ($p < 0.001$). The combination of MinRay[®] with PSP and Sopix² sensor was superior to that of MinRay[®] with Sigma[®] and MinRay[®] with Vistaray[®] and also better than Rextar[®] with Sigma[®] and Rextar[®] with Vistaray[®]. Image quality obtained when using Rextar[®] with PSP was significantly better than when using MinRay[®] with Sigma[®]. Furthermore, Rextar[®] with a Sopix² sensor was significantly better than MinRay[®] with Sigma or with Vistaray[®], and also superior to the combination Rextar[®]–Vistaray[®] ($p < 0.05$).

When considering four X-ray devices with two sensors (PSP and Sigma[®] CMOS sensor), Nomad[®] with PSP yielded the highest

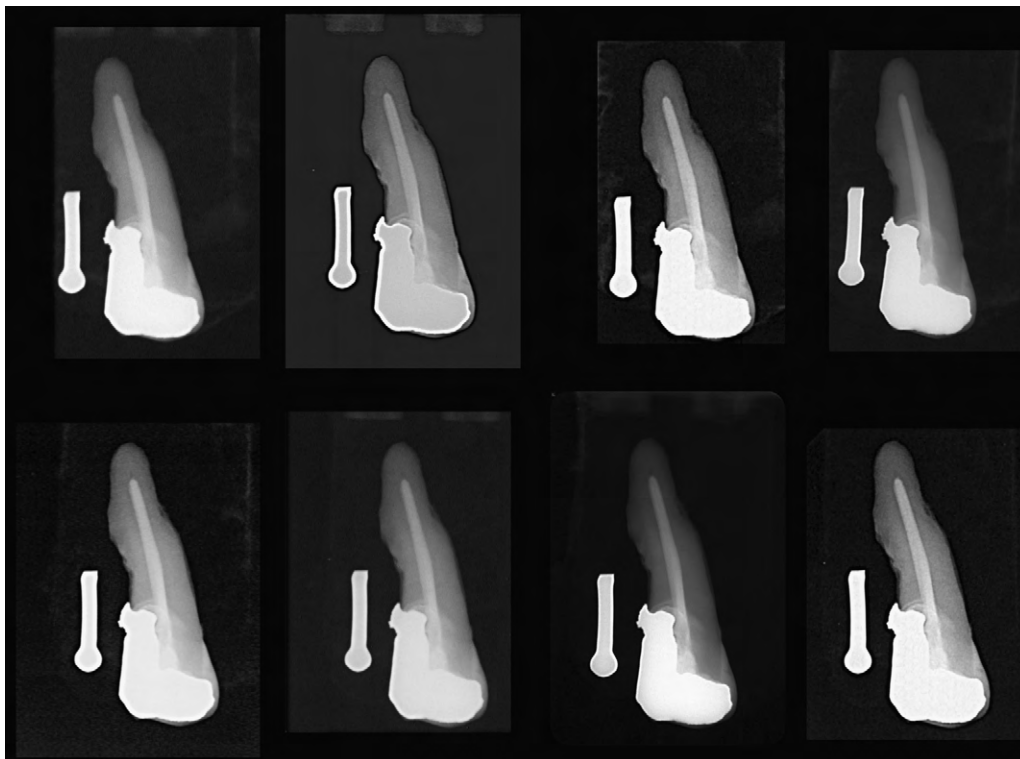


Fig. 2. The observation screen of a premolar sample, comparing images taken by four X-ray devices (AnyRay[®], Nomad[®], Rextar[®], and MinRay[®]) with two image receptors (Dürr PSP[®] and Sigma[®] M CMOS). All images were scored using the 4-point rating scale (3–excellent, 2–good, 1–poor, and 0–very poor).

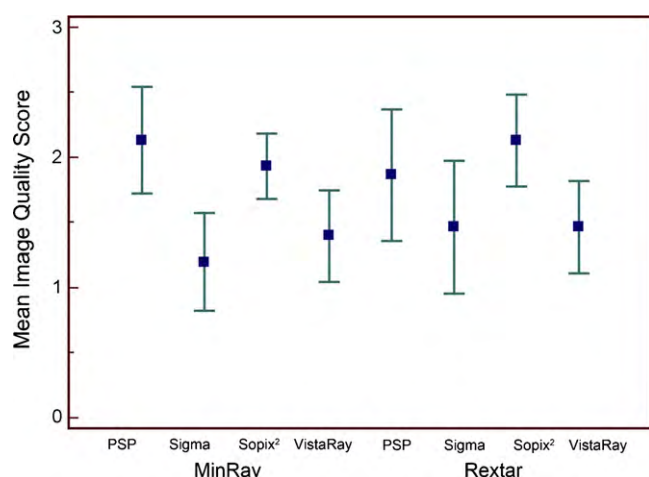


Fig. 3. The mean image quality score compared between MinRay[®] and Rextar[®] with four image receptors. Vertical lines refer to the 95% confidence interval for the mean. The image quality is significantly higher for the Dürr phosphor image plate system (PSP) and for the Sopix²[®] sensor for both X-ray devices.

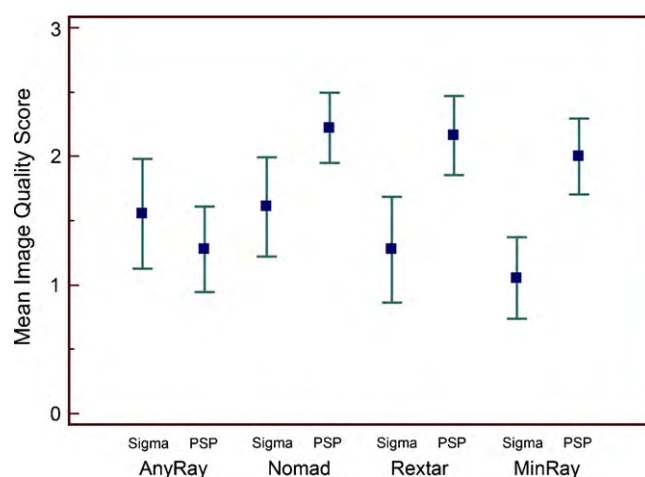


Fig. 4. The mean image quality score compared between four X-ray devices with two image receptors. The image quality is significantly higher for the Dürr phosphor image plate system (PSP) combined with Nomad[®], Rextar[®] and MinRay[®]. The vertical lines refer to the 95% confidence interval for the mean.

image quality score (Fig. 4). The image quality of the combination of Rextar[®] or Nomad[®] with PSP was higher than all four devices with Sigma[®] sensor and AnyRay[®] with PSP while MinRay[®] with PSP is higher than MinRay[®] and Rextar[®] with Sigma[®] and AnyRay[®] with PSP.

The inter-observer agreement was relatively low as quantified by the mean weighted kappa for overall pairs of observers, namely kappa = 0.19 with a standard error of 0.06. The intra-observer agreement is fair with the mean weighted kappa = 0.30 with standard error of 0.07.

3.2. Medical physics test and patient dose estimation

An overview of the results of medical physics tests performed and patient dose estimation are reported in Tables 2 and 3. AnyRay[®] presented at least three times higher exposure rate at the exit of the cone and thus there was a threefold increased in the estimated effective dose as compared to other devices. The kVp of the AnyRay[®] system was the most stable, with a ripple of 3.7%. Short-term variations in tube output of all devices were less than 10%. Deviation between nominal and measured exposure times remains below 20% for all systems.

Table 2
Reports from medical physics test.

	AnyRay (60 kVp)	Nomad (60 kVp)	Rextar (70 kVp)	MinRay (60 kVp)	MinRay (70 kVp)
Exposure rate at cone exit	13.5 mGy/s	3.8 mGy/s	2.6 mGy/s	3.4 mGy/s	4.5 mGy/s
Measured total filtration	1.8 mm Al	2.0 mm Al	2.3 mm Al	2.3 mm Al	
kVp ripple	3.7%	10.6%	7.6%	8.7%	
Time until full exposure rate	50 ms	40 ms	60 ms	10 ms	
Short term reproducibility of tube output	5.4%	4.1%	1.4%	0.5%	
Deviation of nominal and measured exposure time for 60 ms	N/M ^a	3.6%	16.8%	1.7%	
Deviation of nominal and measured exposure time for 200 ms	10.5%	2.0%	3.8%	1.2%	

^a N/M, not measured.

Table 3
Patient dose estimation.

	AnyRay (60 kVp)	Nomad (60 kVp)	Rextar (70 kVp)	MinRay (70 kVp)
Exposure time (s)	0.30	0.25	0.15	0.10
Focus-skin distance (mm)	100	200	200	300
Entrydose (μGy)	3542	938	404	430
Effective dose (μSv)	14.65	4.58	2.13	0.41

3.3. Occupational dose measurements

Occupational exposure was reported in Table 4. At 1 m distance, exposure measured was at the same level as the natural radiation background. Exposure at the operator's hand was lowest when a protection shield was used (Nomad[®]) or with the use of an exposure switch cable (distance > 1 m).

3.4. Technical data and portability features

Table 1 summarized technical data, as well as features concerning the portability of the machines. As stated in this table, some components might be presented by each machine as standard settings or optional features.

4. Discussion

4.1. Image quality comparison

For the first part concerning the image quality between Rextar[®] and MinRay[®] with four image receptors, the same trends were found for both MinRay[®] and Rextar[®] that the image quality of

Table 4

A report concerning the occupational dose of all devices.

	AnyRay	Nomad	Rextar	MinRay
kVp	60	60	70	60
mA	2	2.3	2	7
Time (s)	1	0.99	0.24	0.32
Measured dose/exposure				
Primary beam (μGy)	400	1000	30	200
At 30 cm (μGy)	1	1.6	0.6	1
At 1 m (μGy)	0.1	0.1	–	0.14
At the door (μGy)	–	–	–	<0.1
At end of cable (μGy)	–	–	<0.2	<0.1
At the operator's hand (μGy)	0.6	0.1	<0.2	–
Others				
Radiation exposing signal	Ok	Ok	Not clear	Ok

Vistaray[®] and Sigma[®] sensor was lower than the PSP and Sopix^{2®}. The PSP yielded higher image quality scores as it allows enhancement of details with a detail recognition of 22 LP/mm, wider latitude of exposure and high grey scale range.

While looking at all devices with two sensors, Nomad[®] with PSP had the highest mean score. The image quality of AnyRay[®] was significantly lower than the other devices which could be due to the effect of the short cone that reduced sharpness of images obtained.

Taking into account all these factors, the recommended combination was the Nomad[®] with the phosphor image plate system. Considering the applicability in real disaster situation, Rextar[®] can be very useful as a result of integrated computer system used together with the Sopix^{2®} sensor, which also yielded good image quality, in order to reduce the number of devices need to be taken to the disaster field.

It should be noted that a large inter-observer variation was found. An initial observer calibration, involving an instructional session with group exercises, followed by individual observations with evaluation and discussion, could not prevent that their varying background and experience contributed to a fairly low agreement.

4.2. Medical physics test and patient dose estimation

According to several studies, the dose derived from an intraoral radiography, taken with round (60 mm diameter) collimation in combination with E-speed dental film is 1.0–8.3 μSv . Intraoral digital radiography can offer a potential dose reduction due to shorter exposure time [10,13]. The Vatech AnyRay[®] system did not comply to the standard as the entry dose was 3.5 mGy, higher than the maximum exposure allowed for molar imaging (2.5 mGy) and almost higher than the maximum exposure allowed for a system (4.0 mGy). Changing the cone length to the normal 200 mm might bring this system to within the acceptable limits. Large differences in the effective dose were mostly a consequence of the different geometries between the fixed system (cone of 300 mm, square collimation) and the portable systems with cone length of 100–200 mm and round collimation. This accounted for differences between MinRay[®] and Rextar[®] at 70 kVp. There was an additional doubling of the dose when switching Nomad[®] to 60 kVp on the, and another fourfold increase when halving the focus-skin distance for the AnyRay[®].

4.3. Occupational exposure measurements

As well as dose to patients, occupational dose should be considered. In a dental practice relatively simple measures can be taken to limit staff dose, such as use of the distance. However these measures cannot always be taken in the field of forensic odontology.

An operator working in a dental practice should not normally receive significant radiation doses. The National Commission for Radiation Protection (NCRP) in the United States report that mean dose received by dental workers is 0.2 mSv per year [11]. In normal dental practice, effective dose should never exceed 1 mSv per year, which is the annual dose limit for the public (and would normally be expected to be lower) [10].

When relying on distance to provide protection, it is important to ensure that staff should stand out of the direction of the primary beam and special care should be taken during radiography to direct the primary beam in such a way that only the intended subject is exposed. For intraoral film radiography the radiation dose in the primary beam is typical a few mGy while the scattered radiation at 1 m is at least 1000 times less [10]. National guidelines generally recommend standing at a distance of at least 1 m up to 2 m from the patient. When there is not enough space or with a high workload protective panels can be used as shielding. To limit exposure to the hands, a protective hand shield or the use of an exposure switch cable is advised for portable X-ray machines.

Dosimetry studies performed with the Nomad[®] portable machine, which is provided with circular lead-filled shields attached to the end of the exit tube, have shown that exposure of the operator to leaking or backscatter radiation is below the maximum permissible for occupational dose [15,16]. To the best of our knowledge, dosimetry studies on other portable machines are not available.

Dose measurements carried out with Nomad[®] in normal conditions (i.e. patient seated in dental chair and operator in the “safe zone” provided by the circular lead-shield) as well as in “atypical” situations (i.e. forensic sites, field work, sedated patients) had demonstrated that the whole body exposure was equivalent to less than 1% of the occupational dose limit [16].

However, the use of a tripod and/or an exposure switch cable allowing a proper distance from the radiation may provide further safety for the operator, especially if the shield is not supplied or in cases where the images must be taken in atypical scenarios. Potential operator movement may also be avoided by the use of a tripod.

4.4. Additional considerations

Considering technical data and portability features, currently, there are several portable X-ray machines commercially available. Different features must be considered when selecting the most appropriate equipment for specific tasks. Whilst some machines work only as X-ray generators, others may additionally present with built-in sensors, storage devices, and LCD screens to display instantly the images, similarly to digital cameras. Equipments with computer integrated are also available.

For utilization in special situations, such as forensic disaster sites or dental care in remote areas, some features such as weight, battery autonomy and possibility of extra set of batteries should be taken into consideration. Built-in computers and LCD screens may reduce the number of equipments required to acquire the radiographs. Ideally the battery charger should be able to work between 100 V and 220 V power input, as it may vary from one geographical area to another.

5. Conclusions

The present study demonstrated the feasibility of three portable X-ray systems to be used for specific indications, based on acceptable image quality and sufficient accuracy of the machines and following the standard guidelines for radiation hygiene. Concerning all factors, the recommended combination of devices was the Nomad[®] with the phosphor image plate system or

Rextar[®] together with Sopix²[®] sensor which could enhance the portability. For patient's safety, X-ray machines should be operated with long cone system and rectangular collimation, while a radioprotective shielding on the cone could help reducing back scatter. Yet, additional studies should be carried out dealing with occupational dosimetry, as very simple optional tools and radioprotection supplies might reduce radiation dose drastically.

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