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Forensic oral imaging quality of hand-held dental X-ray devices: Comparison of two image receptors and two devices

P. Pittayapat [a,b], P. Thevissen [a], S. Fieuws [c], R. Jacobs [d], G. Willems [a,*]

[a] Biomedical Sciences Group, Department of Dentistry, Oral Pathology and Maxillofacial Surgery, Section Forensic Odontology, Katholieke Universiteit Leuven, Kapucijnenvoer 7, B-3000 Leuven, Belgium
[b] Radiology Department, Faculty of Dentistry, Chulalongkorn University, Henri-Dunant Road, Bangkok 10330, Thailand
[c] Biomedical Sciences Group, Department of Public Health, Leuven Biostatistics and Statistical Bioinformatics Centre (L-BioStat), Katholieke Universiteit Leuven, Kapucijnenvoer 35, 3000 Leuven, Belgium
[d] Biomedical Sciences Group, Department of Dentistry, Oral Pathology and Maxillofacial Surgery, Oral Imaging Center, Katholieke Universiteit Leuven, Kapucijnenvoer 7, 3000 Leuven, Belgium

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ABSTRACT

Recently, different portable hand-held and battery-powered dental X-ray units have become available. Especially for forensic odontological purposes, they offer diverse advantages such as for use in disaster areas and crime-scene locations as also in autopsy rooms and mortuaries. For any application, the most important feature of these hand-held devices is the delivered image quality. The aim of this study is to evaluate the radiographic image quality acquired by two portable X-ray devices in combination with two types of image receptors and to compare the findings with the image quality of a standard intra-oral X-ray device.

Eleven samples consisting of eight teeth, two dry skeletal specimens and one formalin-fixed mandible part were mounted on blocks for standardised (re)positioning. Radiological images were acquired with two hand-held (AnyRay® 60 kVp, 0.02–4.00 mAs and NOMAD® 60 kVp, 0.023–2.277 mAs) and one wall-mounted (MinRay® 60/70 kVp 0.14–22.4 mAs) X-ray device combined with two image receptor systems (VistaScan® phosphor storage plate (PSP) and SIGMA® M CMOS Active Pixel technology sensor). The effect of X-ray source-to-object distance (SOD) was checked at 20 cm in conjunction with object to image receptor distances (OIDs) of 0.8 and 2.5 cm. For each parameter setup, the exposure times were run from low till high. An expert consent statement was achieved by agreement of four expert observers selecting the optimal images based on a developed four point quality rating system. Next, a selection of the images was assembled in a set of 198 observation screens and scored by seven observers. The observation screens were designed to compare observer scores, relations between devices, receptors and OIDs and images obtained from the different devices at equal exposure levels (mAs). All results were statistically analysed.

Radiological image quality was significantly higher for phosphor plate compared with the CMOS digital receptor system ($p < 0.0001$). Furthermore, a significantly superior image quality was obtained for OID = 0.8 than for OID = 2.5 ($p = 0.039$). A significant difference in image quality between the three devices was also established ($p = 0.02$). The present study demonstrated the feasibility of portable X-ray systems for forensic odontological applications based on rendering optimal image quality, provided an *in vitro* guideline of optimal parameter settings and offered a radiological image database usable in further research.

Dental radiographs constitute crucial information that plays an important role in the registration, detection, collection and preservation of forensic evidence [1–3]. These records are of major significance during comparative dental identification [2,4], postmortem profiling [5,6] and certain age estimations [7–12].

* Corresponding author. Tel.: +32 16332459; fax: +32 16337578.
E-mail address: guy.willems@med.kuleuven.be (G. Willems).

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Portable X-ray units are developed to ease radiological imaging in welding, industrial, veterinary and military applications. In particular, for forensic odontological purposes, different portable hand-held and battery-powered dental X-ray units became available. These light-weight, small and autonomic working devices can easily be brought in the proximity of recovered body remains and simply positioned in the radiologically required geometric setups [13]. This avoids transportation as well as unnecessary movement of the remnants and allows, on occasions, a complete and immediate forensic odontology examination before the start of the rigor mortis period, excluding body-mutilating interventions [14,15]. The integrated battery furnishes the unit power for continuous and multiple image collection. Furthermore, this wireless power supply makes the devices more independent of fixed electric current sources [16]. Although all units can expose classical film, phosphor storage plate (PSP), charged-couple device (CCD) as well as complementary metal–oxide–semiconductor (CMOS) image sensors, most efficient *ad hoc* X-ray images can be obtained using the hand-held device(s) in combination with digital imaging and management systems [17].

Evaluation of the general image quality of dental radiographs is based on their brightness, contrast and intensity and on the appearance of noise [13,18]. Especially for forensic odontological investigations, clear distinction of the cemento-enamel junction, the pulpal outline and the root apex contour, together with the ability to discriminate different restoration types, are essential quality requirements.

No studies have been accomplished on the radiological image quality offered by the portable and hand-held X-ray device(s). In a pilot setup performed previous to this research, exposure parameters obtaining excellent radiological images depending on the source-to-object (SOD) and object to image receptor (OID) distances were detected. Based on these parameters, the portable AnyRay® (VATECH Co., Ltd., Gyeonggi-do, Republic of Korea) and NOMAD® (Aribex, Utah, USA) X-ray devices were evaluated in combination with Vistascan® PSP (Dürr Dental, Bietigheim-Bissingen, Germany) and SIGMA® M CMOS Active Pixel technology sensor size 1 (Instrumentarium Dental, Tuusula, Finland) CMOS image receptors and their obtained image quality was compared with that of images obtained in similar experimental conditions with a standard wall-mounted MinRay® (Soredex, Tuusula, Finland) radiographic unit.

The aim of this study was first, to establish a database of radiographic images acquired in forensic settings of two kinds of portable dental X-ray devices combined with two different image receptors and, second, to evaluate the obtained image quality.

1. Materials and methods

1.1. Parameters

To assemble radiological images containing details of all oral tissue combinations a forensic odontologist encounters during his judicial investigations, the following human body parts were collected as test objects: eight extracted teeth comprising, out of each jaw, an incisor, a canine, a premolar and a molar, a dry maxillary and mandibular skeletal part including teeth and a tooth containing formalin-fixed mandible part. The teeth out of this test sample were intact, decayed, restored or showed a combination of the last two features. All were mounted on LEGO® bricks (the LEGO Group, Billund, Denmark) with radiolucent polyurethane spraying foam (Den Braven, Oosterhout, the Netherlands) allowing repeated standardised and parallel sample positioning. At the base, all bricks had a corner cut-off to smoothen their removal from the bottom plate with use of a lever (Fig. 1). The samples were stored in a water solution of 3% chloramine at room temperature.

The radiological exposures were performed with two hand-held portable X-ray devices: AnyRay® 60 kVp, 2 mA, 0.02–4.00 mAs and NOMAD® 60 kVp, 0.023–2.277 mAs and one referenced wall-mounted X-ray unit: the MinRay® 60/70 kVp 0.14–22.4 mAs (Table 1). The images were activated on Vistascan® PSP size 3 and captured by a SIGMA® M CMOS Active Pixel technology sensor size 1. The exposed PSPs were scanned with the VistaScan® machine, processed with DBSWIN® (Dürr Dental, Bietigheim-Bissingen, Germany) software and exported as 16-bit tagged image file format (TIFF). The images collected on the CMOS device were visualised with CliniView® (Instrumentarium Dental, Tuusula, Finland) software and exported as 8-bit TIFF files.

Often, radiological examinations during a forensic odontological investigation have to be performed in make-shift circumstances constraining the position of the X-ray unit or the image receptor in inconvenient setups. To cover all these positions in a pilot study, the short coned AnyRay® unit combined with Vistascan® PSP was used to check the effect of X-ray SOD at 10, 15, 20 and 30 cm in relation with OID set at 0.8, 2.5 and 5 cm. The obtained results (Table 1) indicated that the exposure times necessary to obtain excellent image quality at SOD 30 cm are too high ($\geq$1.10 s) for practical applications because of the extreme occupational radiation doses and the high risks for operator movement during the exposure. Furthermore, the overall excellent image quality was not reached in all combinations with OID 5 cm mainly because of the lack of contrast and sharpness. Moreover, a comparable SOD for long-coned unit applications was only possible starting at 20 cm. Therefore, in this study, SOD was set at 20 cm and combined with an OID of 0.8 and 2.5 cm.

Running exposure times from the lowest image giving at first-step a too-bright object image to the highest one providing a too-dark image resulted in all possible parameter combinations in a 132-image series (11 objects × 3 devices × 2 image receptors × 1 SOD × 2 OIDs) (Fig. 2).

To assure optimal radioprotection, a box covered with 1-mm-thick lead was constructed to enclose all research devices during the radiological exposures.

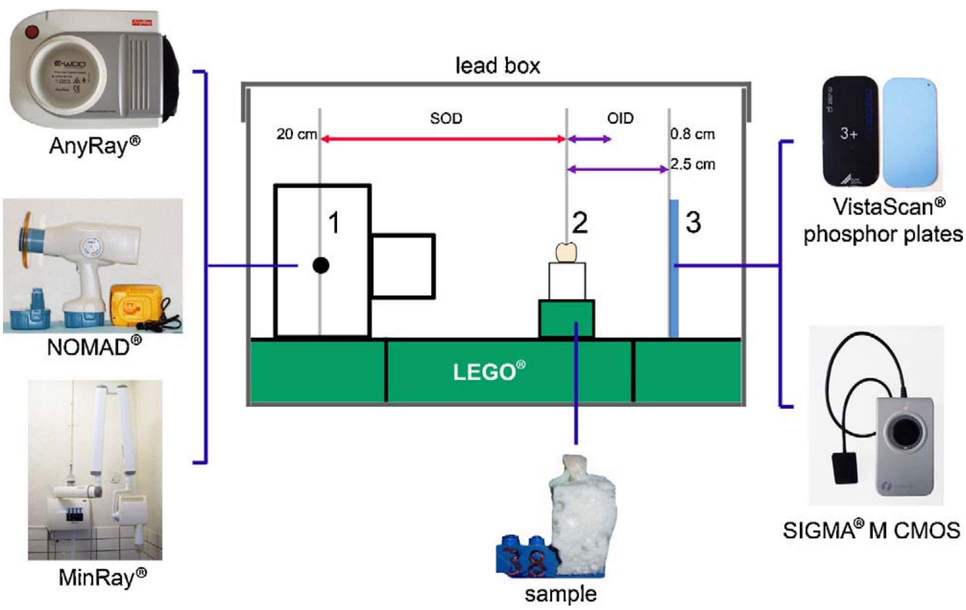

Fig. 1. Procedure diagram. During radiological image collection, the tubes of 3 different x-ray devices. (1) AnyRay, NOMAD and MinRay, were fixed at a reference point, allowing for parallel (re)positioning of 11 separately on LEGO bricks foamed samples, (2) at source-to-object distance (SOD) of 20 cm combined with two types of image receptors, and (3) Vistascan® PSP and Sigma® M CMOS, at object to image receptor distances (OID) 0.8 and 2.5 cm. For all 132 setup combinations an image series was obtained by running the exposure times from the lowest to the highest image providing level. For radio protective reason all setups were surrounded by a 1 mm-thick lead box.

Table 1
Exposure times and distance parameter settings providing excellent image quality (valid for all kind of samples).

	SOD			
	10	15	20	30
OID				
0.8	0.20	0.35	0.55	1.10[a]
2.5	[b]	40	0.60	1.20[a]
5.0	[b]	[b]	[b]	[b]

Exposure times in s, SOD source-to-object distance in cm, OID object to image distance in cm.
[a] Too long exposure time.
[b] No excellent image obtained.

1.2. Gold standard

As a gold standard and reference, an expert consensus statement was developed based on agreement for the rating of optimal image quality out of each image series. Observations were carried out by four expert observers (two oral radiologists and two forensic odontologists) in a dimly lit room on a 19-inch SyncMaster 971p LCD diagnostic screen (Samsung, Seoul, Republic of Korea). All images were scored using a 4-point rating scale [19] developed by the four expert observers (Fig. 3) and consensus was reached regarding the selection of the optimal image within an image series if a minimum of two observers (and preferably three or even four) rated the same image as superior to others in that series.

1.3. Observation screens

The observation screens (Fig. 4) comprised, in a blind setup, three parts of the present study. First, for observer comparison, 132 observation screens were composed of eight images chosen out of the corresponding image series including its gold standard optimal image. Second, for device/receptor/OID comparison, 22 observation screens were developed that consisted of six gold standard selected optimal images based on 11 objects and two OIDs from each combination of devices ($n = 3$) and receptors ($n = 2$). Third, for equal mAs comparison, 44 observation screens were constructed comprising three images based on each object, two OID and two receptors taken with the different devices at equal exposure level (mAs).

1.4. Observers

Seven experienced clinical doctors in dental surgery observed the randomly presented set of 198 (132 + 22 + 44) observation screens and scored independently from each other and in the same conditions as the four expert observers.

1.5. Validation

In addition, four new types of teeth were chosen (incisor, canine, premolar and molar) to acquire a new image series in the same condition as the original objects. From these 48 image series (four samples, three devices, two image receptors, one SOD and two OID) the optimal image was selected according to the procedure discussed above. Furthermore, images with a 2 steps lower and 2 steps higher exposure time were retained, enabling to check the exposure time with the results of this study and to validate the findings.

1.6. Statistical analysis

1.6.1. Observer comparison

First, to study the agreement of the scores of the seven observers with the choices of the four expert observers as the gold standard, the mean image quality score over the observers was compared between the optimal exposure level and the non-optimal exposure levels. These non-optimal exposure levels were grouped according to their ranked distance from the optimal level (e.g., consider a screen with images of the following eight exposure times: 0.08, 0.09, 0.10, 0.15, 0.20, 0.25, 0.30 and 0.35 s). When the expert observers had selected 0.20 as the optimal exposure level, 0.25 is considered in the group +1, 0.30 in the group +2, 0.15 in the group (−1, 0.10 in the group −2, . . .). Mann–Whitney *U*-tests were used to compare the image quality scores between each of these groups and the scores given at the optimal level. This was done for all conditions together and separately in specific conditions. Second, the agreement amongst the seven observers was explored in two different ways. First, a weighted kappa was calculated for each pair of observers and a mean weighted kappa was obtained for these 21 pairs of observers. Second, for each observer, the exposure level that received the highest quality score was verified per observation screen. The agreement between the chosen exposure levels obtained within a screen was quantified using the standard error of measurement (SEM).

1.6.2. Device/receptor/OID comparison

The mean image quality score over the seven observers was compared between three X-ray devices, two image receptor types and two OIDs, using a general linear model. Each of the samples contributed to 12 measurements. A constant correlation between these measurements was assumed, and the variance of the scores is allowed to be specific for each of the 12 combinations. The procedure PROC MIXED in the statistical package SAS, version 9.1(SAS Institute Inc., Cary, NC, USA) was used to fit the model. By including interactions in the model, it was verified if the effect of one factor is different at the various levels of another factor.

1.6.3. Equal mAs comparison

A similar general linear model was used as in the previous section to compare the mean image quality score over the seven observers between the three X-ray devices set at the same exposure level (mAs).

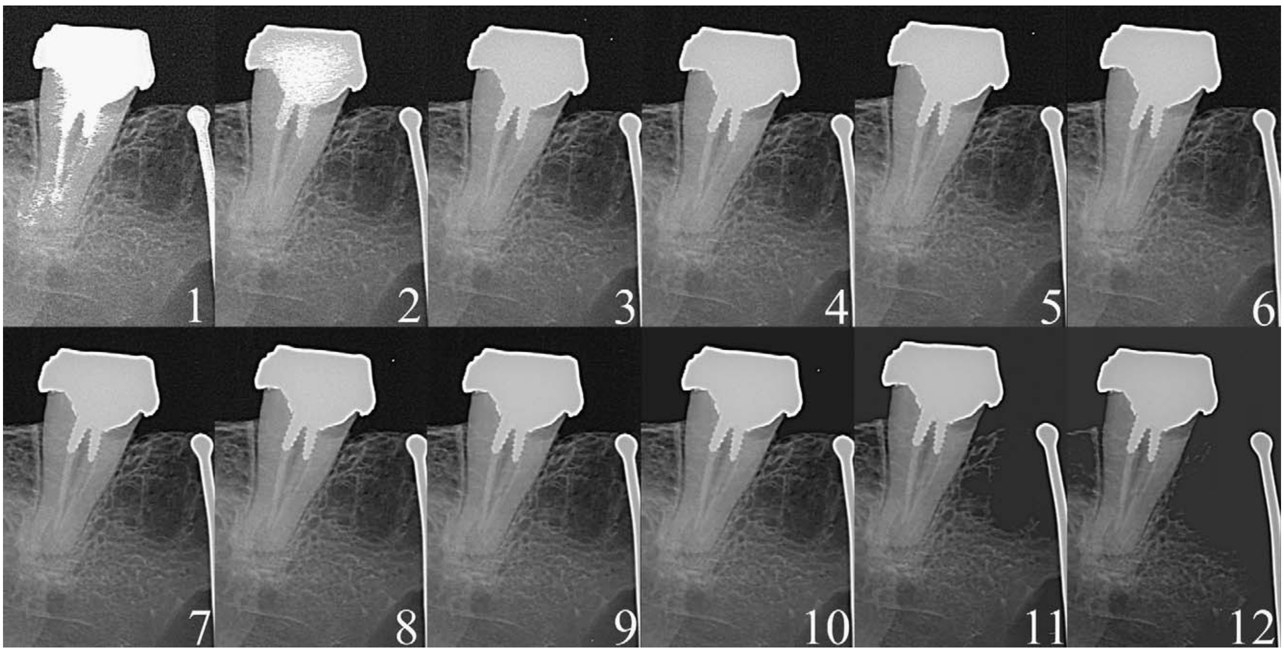

Fig. 2. Image series. Three consecutive features related to the obtained radiological image quality emerged in each image series while running the exposure times step-by-step from low (1) to high (12). At first the quality of the images improved stepwise getting better (1–9). Secondly optimal image quality was reached for one or maximally two images (10). At last a smooth and fast decrease of the image quality features was remarked (11–12).

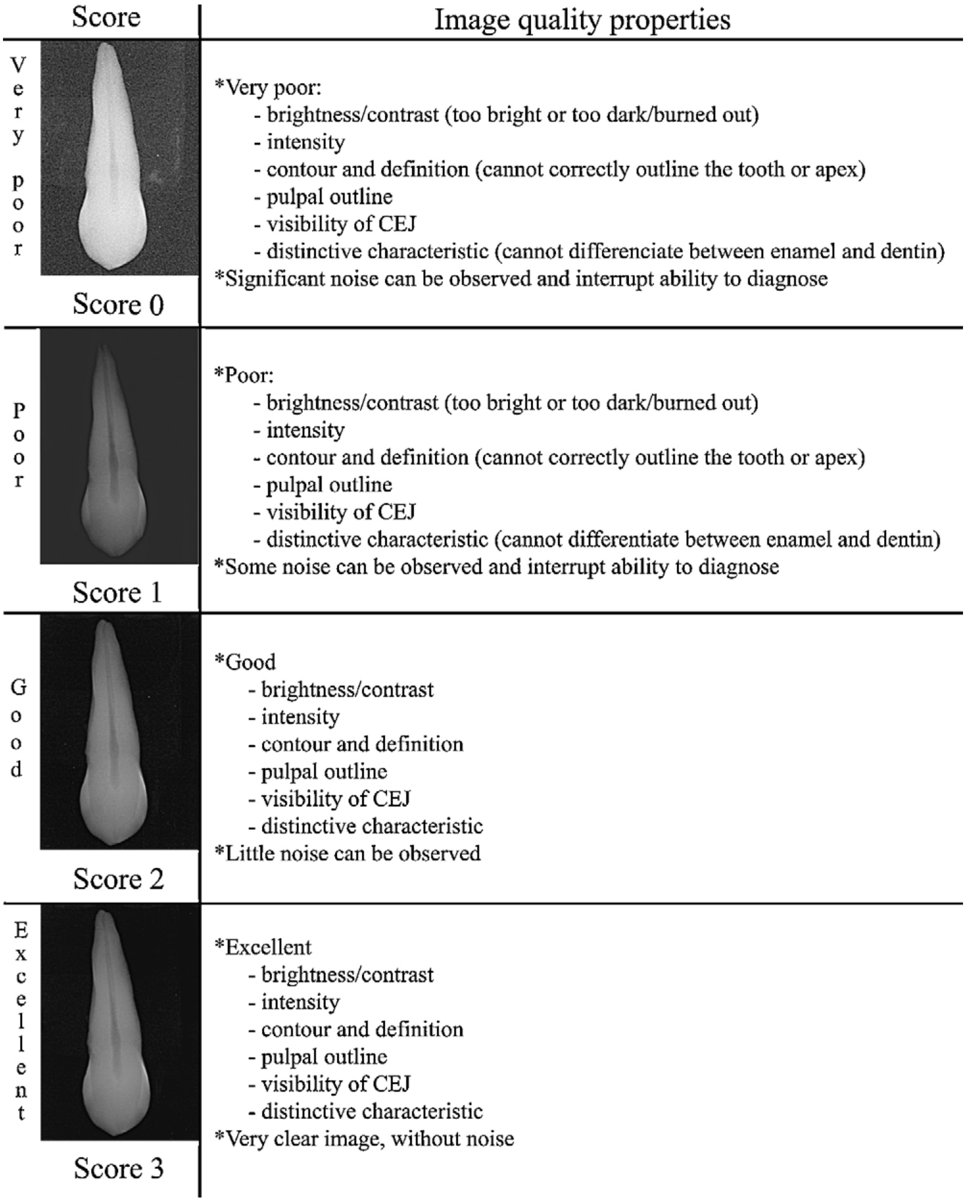

Fig. 3. Four point image quality rating scale. For each scoring level (0–3) a corresponding image is shown and a description of the related standard image and forensic diagnostic quality properties is listed. CEJ, cemento-enamel junction.

2. Results

During the preceding pilot study, the present research and its validation, a database of approximately 6000 *in vitro* radiographs taken from 15 samples with three different X-ray devices in combination with two image receptors at possibly three OID and four SOD was collected.

2.1. Observer comparison

The observed mean image quality score for the seven observers was in line with the gold standard optimal image chosen by the four expert observers (Fig. 5). The inter-observer agreement was relatively low as quantified by the mean weighted kappa for overall pairs of observers, namely kappa = 0.24 with a within-screen standard deviation of 0.09 s and a mean exposure receiving the highest scores of 0.32 s.

2.2. Device/receptor/OID comparison

The result of the statistical analysis of the device/receptor/OID comparison reveals that none of the 12 included combinations of the analysed parameters gave a significant outstanding image quality (Fig. 6). Yet, within each parameter, there was one significant difference in image quality between the three devices ($p = 0.02$): image quality was significantly lower for AnyRay® than for NOMAD® ($p = 0.007$), while significantly higher for the PSP than for the CMOS ($p < 0.0001$) as well as for OID = 0.8 compared with OID = 2.5 ($p = 0.039$).

The image quality strongly depends on the corresponding interactions of the used parameters (i.e., devices and receptors, OID and receptors and devices and OID). Concerning the interaction between device and receptor, it was found that the difference between the devices was not the same for the PSPs and the CMOS ($p = 0.0005$). With the CMOS, there was no significant difference

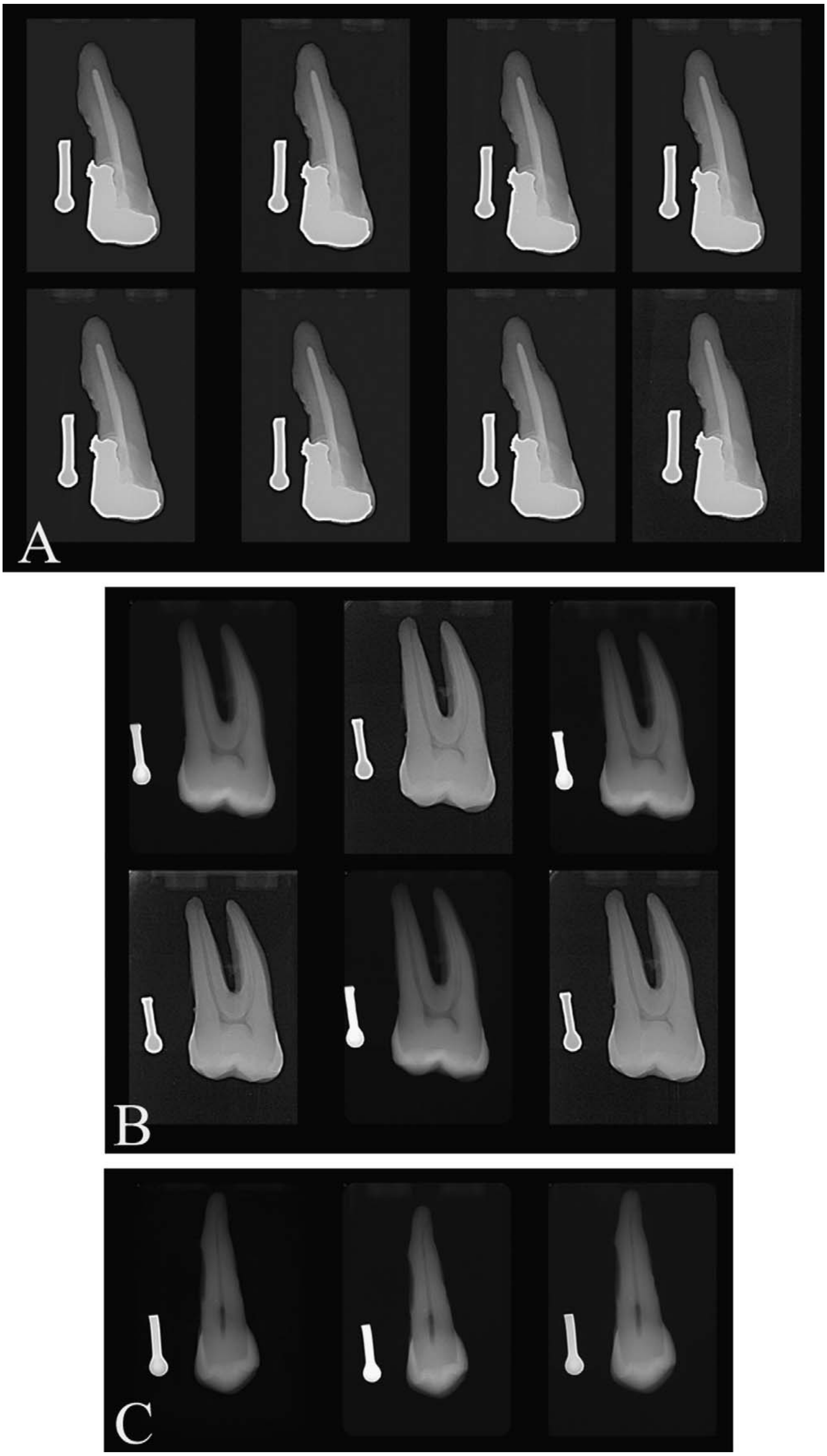

Fig. 4. Observation screens. For observer comparison (A) seven images were randomly chosen out of the corresponding image series and the gold standard optimal image out of the same image series was added. For device/receptor/OID comparison (B) six gold standard optimal images were gathered from the same object at two OID taken by the three devices on two receptors. For equal mAs comparison (C) three images from the same object at two OID on two receptors taken by the three devices at the same exposure level (mAs) were compared.

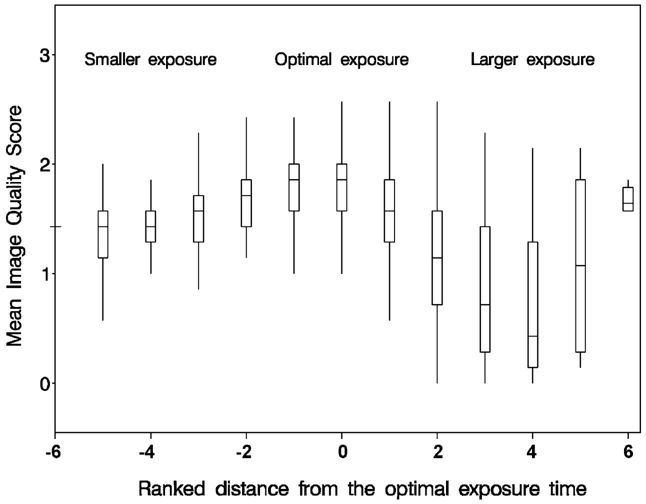

Fig. 5. Box plots of image quality at ranked distances within the observation screens for observer comparison. The observed mean image quality score given by the observers is the highest for the exposure levels selected by the experts as the optimal level (ranked distance 0). The different graft tendency at ranked distances 5 and 6 can be explained by the uncommon amount of observations.

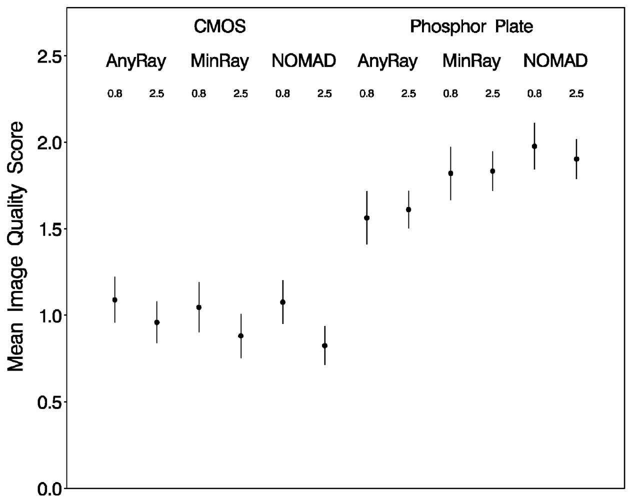

Fig. 6. Mean image quality score compared between the three devices, two receptors and two OID for all exposure settings. There is an overall lower mean quality score for CMOS receptors and for OID = 2.5. There are mean image quality differences between the three devices. Vertical lines refer to the 95% confidence interval for the mean.

between the devices ($p = 0.49$) as compared with the PSPs ($p = 0.0001$). With the PSPs, the image quality was lower for AnyRay® than for MinRay® ($p = 0.002$) and lower for AnyRay® compared with NOMAD® ($p < 0.0001$). There was no significant difference between MinRay® and NOMAD® ($p = 0.11$). Related to the interaction between distance and receptor, the difference between OIDs was not the same for the PSP and the CMOS ($p = 0.046$). There was no significant difference between the distances for the PSP system ($p = 0.94$). However, with CMOS, the image quality was lower for OID 2.5 cm than for 0.8 cm ($p = 0.007$). There was no significant interaction between the devices and OID ($p = 0.42$).

2.3. Equal mAs comparison

There was a significant difference in image quality between the three devices ($p = 0.021$) (Fig. 7). The image quality was lower for NOMAD® than for MinRay® ($p = 0.007$). There was no

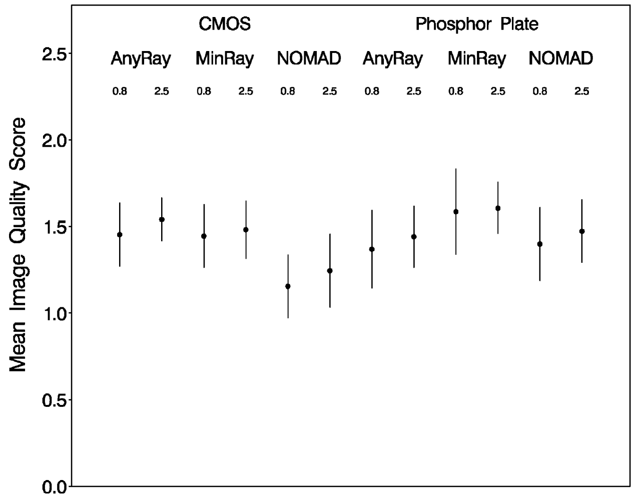

Fig. 7. Mean image quality score compared between the three devices, two receptors and two OID for same mAs exposure settings. Only a significant lower mean image quality score is detected for Nomad® compared to Minray®. Vertical lines refer to the 95% confidence interval for the mean.

evidence of a difference in image quality between the receptors ($p = 0.14$) and between the OIDs ($p = 0.30$). None of the interactions was significant.

2.4. Validation

The result from the validation project performed on four teeth was in agreement with the exposure times selected by the four expert observers and the seven observers on each type of tooth and rendering optimal image quality.

3. Discussion

3.1. Observer comparison

The observers agreed with the experts' choices of optimal images. The image quality became better step-by-step in a series of increasing exposure times until excellent quality was obtained and then dropped steeply with few further increasing exposure times. This finding implicates that the chance of obtaining acceptable image quality is much higher using low exposure times. Agreement amongst observers was relatively low. It is generally known that observer agreement is fair even if there are some preliminary observations [20]. Therefore, in this study, an expert consensus statement was achieved to compare with the scores from observers and to minimise this effect. Diverse reasons can be found for the low inter-observer agreement. First, all observers had a different dental specialisation. All were post-graduated dentists with either a general dentist, a radiology or a surgical background. Second, during the observation screen evaluation some observers might focus on mutually varying, specific parts in the images, resulting in different scorings. Third, at least in some image screens, the difference of exposure time between various images was very small and generated nearly equal radiological quality such that observers might not see the clear difference between consecutive images.

3.2. Device/receptor/OID comparison

The main research question: 'What parameter setting yields the most optimal image quality?', cannot be answered without discussing the interactions between parameters.

For the interaction between devices and receptors, there were significant differences only for the PSPs: the image quality was lower for AnyRay® than for MinRay® and lower for AnyRay® than for NOMAD®. The reason why the significant differences were only detected in the PSP might be related to the inherent higher resolution of its images compared with the CMOS images, which allows enhancement of details.

The interaction between OID and receptors revealed no significant difference for the PSP system; however, with the CMOS, the image quality was lower for OID 2.5 cm than for 0.8 cm. The observation on OID is relevant for the short cone of the AnyRay® hampering image quality and inducing enlargement surely at 2.5 cm OID. The more-divergent beams resulted in greater magnification in the images and possible blurring and low contrast. Therefore, smaller OIDs are recommended for autopsies as long as is practically possible [13,18].

Together with the knowledge that the third interaction between devices and OID was not significant, the only possible answer to the main research question could be that the ideal parameter set up for obtaining excellent image quality disregarding the OID was the phosphor plate system combined with the MinRay® unit and if a hand-held device is needed, the NOMAD® unit is available. Within the scope of the present research, it seems that MinRay®, although impossible to apply in the disaster areas, is still very useful in normal autopsy rooms or in the mortuary.

3.3. Equal mAs comparison

The quality of the images obtained from the different X-ray units at similar mAs was compared to identify the machine with the most optimal image acquisition at the same exposure level. It should be however stated that 'same' was not fully obtained as sometimes equal mAs could not be selected for the various images. For example, the MinRay® had 7 mA while the exposure time could be adjusted grossly as follows: 0.02, 0.03, 0.04, 0.05, 0.06, 0.08, 0.10, 0.12, 0.16, 0.20, 0.25, 0.32, 0.40 and 0.50 s. Comparing the mAs calculated from these values, the images from the NOMAD® usually look darker. This cannot be generally interpreted as if the NOMAD® images were displaying less quality because, for this device, lower exposure time(s) can be installed allowing to take a larger image series that include images of better quality.

3.4. Additional considerations

The working circumstances during specific forensic investigations influence diversely the choice of certain image-gathering devices and their mutual set ups, implementing an effect on the quality of the obtained radiological images. This study implied that the image quality from a PSP system was better than from a CMOS receptor. It should be evaluated whether such plates are feasible to use in disaster areas. The phosphor plates need to be scanned immediately after capturing images to avoid deterioration. Therefore, small and battery-operated phosphor plate scanner should be developed for forensic applications. To maintain a continuous work flow during mass disasters, several phosphor plates should be in use at the same time. The scanning procedures demand diverse manipulations and can include scanning errors, possible mingling of images and loss of time. These disadvantages are of less significance during single or small identification assessments. For these applications and for use in conventional autopsy rooms, mortuaries and dental practices, the phosphor plate receptor should be applied for the acquisition of optimal radiological image quality.

The evaluation of the image quality using the portable hand-held X-ray devices should be studied in future. The influence of the weight of the machine, the convenience of how to hold the unit, aspects influencing operator fatigue and operator movement might be considered as factors affecting the image quality. Incorporating a (wireless) remote control, an easy-to-position tripod or neck braces can solve these hand-held operating problems.

Another important issue to be concerned is the occupational radiation dose. The use of these devices in a hand-holding position for a long period of time, as is the case in disaster circumstances, is still controversial. There were a few studies about radiation dose of dental hand-held X-ray devices [21,22] proving that NOMAD® presents to the patient or operator measured doses well below recommended levels with risks no greater than with standard dental radiographic units. There is still no study available on the occupational and patient radiation dose for the AnyRay® unit. Besides factors related to the operator, the imaging object, the working environment, and the operating time, the design and location of the unit and the position of its on/off button, exposure button and currently not available radiation shield should be thoroughly studied.

4. Conclusions

The present study demonstrated the feasibility of portable X-ray systems for use in forensic odontological applications, based on optimal image quality. It also provided an *in vitro* guideline of optimal parameter settings. Further radiation dose measurement should be carried out to assess the radiation burden and determine if hand-held machine setups are acceptable from an occupational health point of view.

References

[1] J. Gruber, M. Kameyama, Role of radiology in forensic dentistry, Pesqui Odontol. Bras. 15 (2002) 263–268.
[2] C.J. McKenn, Radiography in forensic dental identification—a review, J. Forensic Odontostomatol. 17 (1999) 47–53.
[3] R.E. Wood, Forensic aspects of maxillofacial radiology—a review, Forensic Sci. Int. 159S (2006) S47–S55.
[4] J.A. Kieser, W. Laing, P. Herbison, Lessons learned from large-scale comparative dental analysis following the South Asian tsunami of 2004, J. Forensic Sci. 51 (2006) 109–112.
[5] I.A. Pretty, Forensic dentistry. 1. Identification of human remains, Dent. Update 34 (2007) 621–622, 624-6, 629–30.
[6] I.A. Pretty, D. Sweet, A look at forensic dentistry. Part 1. The role of teeth in the determination of human identity, Br. Dent. J. 190 (2001) 359–366.
[7] K. Haavikko, K. Mattila, The correspondence between the orthopantomographic and the clinical appearance of an erupting permanent tooth replacing a deciduous tooth, Suom Hammaslaak Toim. 66 (1970) 190–195.
[8] S.I. Kvaal, K.M. Kolltveit, I.O. Thomsen, T. Solheim, Age estimation of adults from dental radiographs, Forensic Sci. Int. 74 (1995) 175–185.
[9] N. Bosmans, P. Ann, M. Aly, G. Willems, The application of Kvaal's dental age calculation technique on panoramic dental radiographs, Forensic Sci. Int. 153 (2005) 208–212.
[10] K. Mesotten, K. Gunst, A. Carbonez, G. Willems, Chronological age determination based on the root development of a single third molar: a retrospective study based on 2513 OPGs, J. Forensic Odontostomatol. 21 (2003) 31–35.
[11] F.M. Vandevoort, L. Bergmans, J. Van Cleynenbreugel, D.J. Bielen, P. Lambrechts, M. Wevers, A. Peirs, G. Willems, Age calculation using X-ray microfocus computed tomographical scanning of teeth: a pilot study, J. Forensic Sci. 49 (2004) 787–790.
[12] F. Yang, R. Jacobs, G. Willems, Dental age estimation through volume matching of teeth imaged by cone-beam CT, Forensic Sci. Int. 159S (2006) S78–S83.
[13] S.C. White, M.J. Pharoah, Oral radiology: principles and interpretation, 5th ed., Elsevier, New Delhi, 2004.
[14] M. Kobayashi, H. Ikegaya, I. Takase, K. Hatanaka, K. Sakurada, H. Iwase, Development of rigor mortis is not affected by muscle volume, Forensic Sci. Int. 117 (2001) 213–219.
[15] Y. Nakayama, Y. Aoki, H. Niitsu, K. Saigusa, Forced oral opening for cadavers with rigor mortis: two approaches for the myotomy on the temporal muscles, Forensic Sci. Int. 118 (2001) 37–42.
[16] I. Dawidson, The dental identification of the Swedish Tsunami victims in Thailand, Forensic Sci. Int. 169S (2007) S47–S48.
[17] S. Salo, H. Salo, A. Liisanantti, J. Reponen, Data transmission in dental identification of mass disaster victims, J. Forensic Odontostomatol. 25 (2007) 17–22.
[18] E. Whaites, Essentials of dental radiography and radiology, 4th ed., Elsevier, Spain, 2007.

[19] D. Albarracin, B. Johnson, M. Zanna, The Handbook of Attitudes, Psychology Press, London, 2005.
[20] C. Lindh, A. Petersson, M. Rohlin, Assessment of the trabecular pattern before endosseous implant treatment: diagnostic outcome of periapical radiography in the mandible, Oral Surg. Oral Med. Oral Pathol. Oral Radiol. Endod. 82 (1996) 335–343.
[21] K.P. Hermsen, S.S. Jaeger, M.A. Jaeger, Radiation safety for the NOMAD handheld X-ray system in a temporary morgue setting, J. Forensic Sci. 53 (2008) 917–921.
[22] A.D. Goren, M. Bonvento, J. Biernacki, D.C. Colosi, Radiation exposure with the NOMAD handheld X-ray system, Dentomaxillofac. Radiol. 37 (2008) 109–112.