RESEARCH ARTICLE

Precision of aiming with a portable X-ray device (Nomad Pro 2) compared to a wall-mounted device in intraoral radiography

Reinier C. Hoogeveen, Bram R. Meertens and W. Erwin R. Berkhout

Department of Oral and Maxillofacial Radiology, Academic Center for Dentistry Amsterdam (ACTA) University of Amsterdam and Vrije Universiteit Amsterdam, Gustav Mahlerlaan, Amsterdam, The Netherlands

Background:

Hand-held (HH) X-ray devices are currently introduced for routine dentistry in some global areas. Safety issues are resolved but imaging quality aspects remain to be explored. Aim: To compare the aiming accuracy of two intraoral radiography devices: the portable Nomad Pro2 and the wall-mounted (WM) Planmeca Intra. Setting and design: *In vitro* experimentation involving radiologic mannequins and unbiased student operators.

Methods and materials: 20 operators obtained intraoral radiographs of four regions (bite-wing, upper molar, lower molar and upper anterior) in five mannequins, using HH and WM devices. Beam-aiming devices were fitted with metal cross-wires to project on image sensors. Deviation from ideal perpendicular incidence of beam was calculated, based on positions of cross-wires relative to gold-standard positions (*i.e.* average of 10-fold precise aiming by authors via WM system). Analytic models relied on Wilcoxon signed-rank test and mixed model analyses.

Results: Mean deviations from perfect aim were $2.88^\circ (\pm 1.80^\circ)$ for WM and $3.06^\circ (\pm 1.90^\circ)$ for HH methods. The difference among all operators (HH vs WM) was $0.17^\circ (\pm 2.48^\circ)$, which was not significant. Seven operators showed better aim by HH device (13 by WM system); and in one instance, this difference was significant.

Conclusions: Aiming precision proved similar for HH and WM methods of intraoral radiography, although individual operators may perform better using one of these modalities. Aim is not an expected limiting factor for image quality in HH (vs WM) diagnostics.

Dentomaxillofacial Radiology (2019) 48, 20180221. doi: [10.1259/dmfr.20180221](https://doi.org/10.1259/dmfr.20180221)

Cite this article as: Hoogeveen RC, Meertens BR, Berkhout WER. Precision of aiming with a portable X-ray device (Nomad Pro 2) compared to a wall-mounted device in intraoral radiography. *Dentomaxillofac Radiol* 2019; 48: 20180221.

Keywords: dental radiography; dental equipment; diagnostic equipment; diagnostic imaging

Introduction

Portable hand-held (HH) X-ray devices were first used in forensic dentistry and in veterinary and military settings.¹⁻⁴ However, they have now been introduced in some global regions to replace fixed or wall-mounted (WM) X-ray systems used in dental offices for intraoral radiography.^{5,6} A single HH device may serve multiple office suites, conferring an economic advantage, and may benefit patients for whom dental office visits are prohibitive.

When using such devices, the operator remains in close proximity to patients, thus facilitating the radiographic process but also threatening to increase operator exposures beyond recommended dose limits.^{7,8} Subsequently, manufacturers have devised protective features, including proper shielding around tubes to curtail radiation leakage and shields for stray radiation. Both the United States Food and Drug Administration (USFDA) and the Conformité Européenne (CE) have already approved a number of HH devices. The Nomad Pro 2 (Aribex [KaVo Kerr], Charlotte, NC) (Figure 1) has earned the approval of both agencies; and according

Correspondence to: Dr Reinier C. Hoogeveen, E-mail: r.hoogeveen@acta.nl

Received 06 June 2018; revised 13 February 2019; accepted 13 March 2019

Figure 1 A Nomad Pro two HH X-ray device (Aribex Inc., Charlotte, NC). HH, hand-held.

to recent data, its judicious use poses no undue operator risk.^{9–11}

To ensure that shielding against stray radiation works as intended, patient positioning during intraoral radiography must be adjusted so that central beam emissions are directed parallel to the floor. Public Health England has issued guidelines on safe HH X-ray equipment usage to include measures for general public and environmental protection.⁶

Apart from related safety issues, image quality must be ensured before dentistry accepts HH systems as alternative for WM systems. Brooks *et al* have conducted a clinical trial ($N = 12$), comparing full-mouth series with a split mouth design.¹² They found the image quality of HH and WM units to be similar, and motion artifacts were not problematic during Nomad HH device usage. However, Mah and McDavid studied the effects of motion on image quality *in vitro*,¹³ observing poorer quality by HH device if high-resolution sensors are engaged. Recently, Zhang and coworkers investigated HH and WM devices in terms of operator safety and image quality.¹⁴ In this effort, junior dental students obtained intraoral images using a radiologic mannequin. They found no safety issues, and the HH device seemed more user friendly; but image quality of the WM unit was still superior. In a review of the existing literature, studies evaluating the image quality of HH units have been few, involving low numbers of patients and reporting mixed outcomes.

Curiously, the challenge of correctly aiming a HH device is seldom mentioned in available publications. A

beam-aiming device is an ideal adjunct to improve the quality and reproducibility of intraoral radiographs, regardless of method.¹⁵ One may step away from a WM unit to broadly assess tube and beam-aiming device alignment, but a HH device does not afford this advantage. If the beam of a HH device and the aiming device are incorrectly aligned, the diagnostic value of the image may be compromised, owing to distortion and overlap or cone cutting.^{16–18} Imprecise aim tends to deepen the appearance of carious lesions on bitewing radiographs, potentially resulting in clinical overtreatment.^{17,18} As reported by Van der Stelt *et al*, the range acceptable for caries detection allows a deviation from perpendicular of $\pm 7^\circ$.¹⁷

If proven substantially inferior in aim, the dental profession would be dissuaded to switch from WM to HH. A study comparing HH aiming precision to that of customary WM units is therefore essential. The operators we selected were inexperienced in both systems to prevent bias; and for ethical reasons, *in vivo* experimentation was not entertained. Instead, we used radiologic mannequins to test precision of aim during intraoral X-ray studies, comparing outcomes of the Nomad HH X-ray device with a conventional WM radiography system.

Methods and Materials

Using a NOMAD Pro 2 (Aribex [KaVo Kerr], Charlotte, NC) HH unit and five Planmeca Intra (Planmeca, Helsinki, Finland) WM systems, X-rays were taken of five radiologic mannequins used in undergraduate training. Each system was equipped with a rectangular collimator. Focus-to-sensor distances were 31 and 43 cm for HH and WM devices, respectively. Exposure parameters used were those suggested by manufacturers, as shown in Table 1.

The rings of three aiming devices (anterior, bitewing, and molar) (Rinn RVG6100; Dentsply Sirona, York, PA) were equipped with cross-wires precisely marking ring centers (Figure 2). The distance from ring to sensor was fixed at 70 mm. The aiming devices were modified for HH use, shortening their metal rods to limit interference with stray radiation shields.

Three Planmeca ProSensor digital sensors were mounted on the beam-aiming devices, reinforced with silicone putty (Silagum; DMG, Hamburg, Germany) to ensure rigidity and stabilization (preventing relative movement of sensors). Each beam aiming device with sensor was then positioned in a mannequin, with the intent of establishing a gold standard for correct aim.

Table 1 Exposure parameters

Modality	Tube voltage	Tube current	Exposure time
Hand held	60 kV	2.3 mA	0.16 s
Wall mounted	63 kV	8 mA	0.12 s

Figure 2 The Rinn aiming device for (pre)molar periapical exposures equipped with the metal cross.

30 WM exposures of mannequins were performed (10 per beam-aiming device) by two authors (RH and BM). Each exposure involved meticulous aim, jointly acknowledged by both authors. Average x and y cross-wire co-ordinates were assessed in resultant images using proprietary software (Emago v6.1; Oral Diagnostic Systems, Amsterdam, Netherlands), generating gold-standard positions (GSP) for each of the three sensor-beam-aiming device combinations. These GSP's served as references for experimental exposures subsequently undertaken.

20 operators (undergraduate dental students) inexperienced at HH or WM radiography performed the exposures, once instructed on correct beam-aiming principles. The characteristics of the observers are shown in Table 2. One researcher placed a beam-aiming device at one of four regions (bitewing, upper molar, lower molar, or upper anterior) in the five mannequins. The operators applied two modalities (HH and WM) in random order, without changing positions of the beam-aiming devices in relation to the mannequin. For the HH device, the mannequin's head was tilted ensure that the central beam of exposure parallel to the floor (Figures 3 and 4). This was done to mimic clinical settings, thus ensuring proper function of the stray radiation shield. The procedure was repeated in sequence for the other three regions, consecutively imaging the four other mannequins in identical fashion. (Table 3) The entire process produced a total of 800 radiographs with cross-wire lines superimposed (Figure 5), all digitally warehoused (Emago).

Table 2 Operator characteristics

<i>Gender</i>	<i>Preferred hand</i>
♀ 14	Right 17
♂ 6	Left 3

Figure 3 Aiming with the WM device in the right upper quadrant of one of the mannequins. WM, wall-mounted.

The x and y co-ordinates of the depicted wire cross were registered to be compared to those of the GSP. Based on these coordinates and using Pythagorean theorem, we calculated the distance (d) from GSP. This distance in conjunction with the known distance (70 mm) from sensor to ring served to calculate the deviation of incident beam angle from perpendicular (dev) in radials as a trigonometric function (Figure 6).

$$\text{Formula (1): } \text{dev} = \tan^{-1} \left(\frac{d}{70} \right)$$

The radial values derived were subsequently converted to degrees. All calculations were performed in Excel (Microsoft Office 2016; Microsoft Corp, Redmond, WA).

Descriptive statistics were used to calculate mean deviation from ideal aim for both modalities and percentage of aiming errors $>7^\circ$. The Wilcoxon

Figure 4 Aiming with the HH device in the right upper quadrant of one of the mannequins. The head of the mannequin is tilted in such a way that the central ray of the beam is parallel to the floor in order to ensure the proper functioning of the stray radiation shield. HH, hand-held.

Table 3 Exposure protocol

Operators 1–20	Mannequin 1	Bitewing	HH
		Upper molar	WM
			HH
		Lower molar	WM
			HH
		Upper anterior	WM
			HH
			WM
	Mannequin 2–5	Four regions	Two modalities

HH, hand-held; WM, wall-mounted.
Exposure protocol generated 800 exposures overall (20 operators x 5 mannequins x 4 regions x two modalities)

signed-rank test was invoked to explore differences in angles of HH and WM units per operator. To otherwise analyze such differences, a mixed model was applied, using region, mannequin, gender, and left/right handedness as fixed factors and operator as random effect. A separate mixed-model analysis was also performed, using angle as dependent variable, method (HH, WM) and region as fixed effects, and operator as random effect.

All participating undergraduate students were informed of their personal radiation exposures and granted informed consent. The Ethical review board of the Academic Centre for Dentistry Amsterdam (ACTA) approved this experiment (number 2018046).

Figure 6 (a) The distance (d) from the GSP to the depiction of the cross-is calculated by using the difference between the x - and y -co-ordinates (x' and y'). The pixels size is applied to transpose x' and y' to mm. The Pythagorean theorem is used to calculate the distance d . (b) The distance d in combination with the known distance of 70 mm between the metal cross and the image sensor are used to calculate the angle α using trigonometry. The red line represents the ideal perpendicular incident beam. GSP, gold-standard positions.

Figure 5 Representative image of the upper (pre)molar periapical exposure with the superimposed cross from the aiming device.

Figure 7 Boxplots representing the difference of aiming with the two modalities (HH and WM) for all exposures by the operators 1–20. A negative value signifies that aiming with HH for the exposure was more precise than WM. HH, hand-held; WM, wall-mounted.

Results

The mean deviation from perfect aim was $2.88^\circ (\pm 1.80^\circ)$ for the WM system and $3.06^\circ (\pm 1.90^\circ)$ for the HH device (Figure 7). Mean difference in aim by device (HH vs WM) among all operators was $0.17^\circ (\pm 2.48^\circ)$. Of all images by HH method, 3.75% showed aiming errors $> 7^\circ$. For WM exposure, this percentage was 4%.

The difference between HH and WM did not differ significantly from zero, as shown by the constant of the mixed model ($p = 0.157$). Ignoring all insignificant fixed factors, neither the random effect of operator and nor the difference between methods (HH vs WM) proved significant ($p = 0.080$ and $p = 0.355$, respectively). In this model, there were no significant differences in any fixed or random effects: region ($p = 0.529$), mannequin ($p = 0.441$), left/right handedness ($p = 0.586$), gender ($p = 0.152$), and operator ($p = 0.107$).

Seven operators performed better using a HH (vs WM) device. One operator showed a significant difference, performing better by WM method ($p = 0.003$).

In a mixed model, wherein angle itself was viewed as dependent, method (HH vs WM) again proved insignificant ($p = 0.165$), although aim differed significantly by region. This was primarily due to significantly better performance at lower (pre)molar (vs bitewing) region (p

$= 0.005$). Here, the random effect of operator showed significance ($p = 0.016$) as well, indicating that aim for both modalities (WM and HH separately) differed significantly per region between operators. Graphic representation of aiming precision for both modalities at the four regions tested is provided in scatter plots depicting projections of cross-wires fixed to rings of aiming devices (Figure 8).

Discussion

On average, operator aim was quite accurate, and differences between modalities were small. The average aim was 0.17° less precise by HH device, which was not statistically significant. In examining individual operator performance, there were observable differences. 7 operators performed better on average using a HH device, whereas 13 showed better performance via WM system. For one operator the difference proved significant, in favor of the WM. The tested variables of gender and left or right handedness were not significant factors, nor was mannequin or region.

Van der Stelt *et al* have reported a tolerance of $\pm 7^\circ$ for caries diagnostics using bitewings.¹⁷ If using 7° as a cutpoint for acceptable aim, we see that 4% (WM) and

Figure 8 (a) Scatterplot of the position where the cross was depicted during the bitewing exposures. Blue circles represent the WM device, orange crosses for HH (b) scatterplot of the position where the cross was depicted during the lower (pre)molar exposures. Blue circles represent the WM device, orange crosses for HH. HH, hand-held; WM, wall-mounted.

3.75% (HH) of exposures qualify as unacceptable, due to erroneous aiming. Quality control standards for dental radiography allow a maximum of 10% retakes due to technical errors.¹⁵ Our data were generated by undergraduate students inexperienced in use of HH and WM equipment to prevent bias in this current trial. Deviations of similar magnitude would yield diagnostically

useful images in a clinical setting, and subsequent training would likely improve the aiming accuracy for either method.

Oddly, our second mixed-model analysis showed that aim was better for mandibular (pre)molar exposures, regardless of method. We can only speculate on the basis of this outcome. It is possible that in this particular

region, the operator has better command of over X-ray device positioning relative to beam-aiming device. Although the outcome was statistically significant, the magnitude of difference was not clinically relevant.

Our findings are not readily comparable to those of other studies pertaining to HH technique because aim was not scored by design. Brooks *et al* examined overall image quality, which of course is influenced by correct aim.¹² The fact that image quality of HH and WM methods did not differ for them supports our data indirectly. Zhang *et al* similarly used inexperienced junior students as operators and mannequins as objects, scoring images for contrast and sharpness.¹⁴ Unfortunately, aiming inadequacies do not influence these aspects of image quality, rendering any comparison with our results futile.

A study by van Straaten and van Aken¹⁹ conducted during the period of transition from short cones to tubes took aim into consideration but involved only WM devices and a different method of documentation.¹⁹ The middle of exposed fields was marked to assess ideal size of circular collimation and prevent cone cutting. Scatter plots from this historic study resemble the ones presented in this paper.

It is important to note that use of mannequins in the present study perhaps skewed aiming quality. Unlike actual patients in clinical situations, mannequins do not move during the aiming of beams. However, once the operator of a WM system leaves to initiate exposure, the patient or the beam-aiming device may shift imperceptibly. This is perhaps less apt to occur during HH imaging, because the operator remains by the patient throughout the procedure, continuously controlling the correctness of aim. Ultimately, clinical studies will determine if this is a genuine benefit of HH devices.

In intraoral radiography, aiming as such does not constitute the most decisive index of image quality. Placement of the beam-aiming device in the course of paralleling technique is a key factor. If done incorrectly, resultant images will be compromised, despite accurate aim; and this is no different for either method. On the other hand, imprecise aim will nullify the effect of a correctly placed beam-aiming device, so aim cannot be discounted.

Certain factors other than aiming differences may also impart disparate image quality, depending on method. The stability of human arms in HH imaging is presumably inferior to the stability of mechanical arm

in WM systems and may impose some motion blur, as demonstrated by Mah *et al*.¹³ The shorter focus-to-image receptor distance of HH devices is also of potential detriment to image quality. However, some WM systems have equally short focus-to-image receptor distances, so this issue is not restricted to portable units. Still another factor is the battery dependency of HH devices. In 2012, Kim demonstrated that battery depletion reduces tube current, which in turn may impact image quality.²⁰ Regular recharging and adopting newer generations of batteries may help overcome this.

Clinical trials that encompass all factors above are needed to comprehensively gauge the image quality of HH and WM devices. However, this would entail patient exposures to ionizing radiation for experimental purposes and require Medical Ethics Committee approval.²¹ Such a request must be supported by evidence from non-clinical studies (*e.g.* the present study for example) that demonstrate the comparable diagnostic capacities of HH and conventional WM imaging systems. According to our data, accuracy of HH device aim is not a disqualifying factor. Abilities of operators, however, may bear a distinctive influence. Training and testing of operator aim in a clinical trial is thus deserving of attention.

In conclusion, the aiming precision of HH and WM imaging methods appears similar, although individual operators may perform better at one of these modalities. The inaccuracy of our inexperienced operators was limited but varied and differed with respect to best-performing modality. Aim is therefore not an expected limiting factor for image quality in HH (*vs* WM) intra-oral radiography. In this setting, clinical trials are needed to address other aspects of image quality and the diagnostic merits of HH devices.

No human or animal subjects were used for experimentation by any of the authors during the course of this study.

The present study was financially supported by the KaVo Kerr Group

Acknowledgment

The authors wish to thank the students who participated in this project, especially Jitse Huisinga BDS and Griffin Reep BDS. We also thank Noor Toxopeus DDS for her assistance with the illustrations and Edwin Martens PhD for assistance with the statistical analyses..

References

1. Pittayapat P, Oliveira-Santos C, Thevissen P, Michielsen K, Bergans N, Willems G, *et al*. Image quality assessment and medical physics evaluation of different portable dental X-ray units. *Forensic Sci Int* 2010; **201**(1-3): 112–7. doi: <https://doi.org/10.1016/j.forsciint.2010.04.041>
2. Pittayapat P, Thevissen P, Fieuws S, Jacobs R, Willems G. Forensic oral imaging quality of hand-held dental X-ray devices: comparison of two image receptors and two devices. *Forensic Sci Int* 2010; **194**(1-3): 20–7. doi: <https://doi.org/10.1016/j.forsciint.2009.09.024>
3. Tyson R, Smiley DC, Pleasant RS, DANIEL GB. Estimated operator exposure for hand holding portable X-ray units during

- imaging of the equine distal extremity. *Vet Radiol Ultrasound* 2011; **52**: 121–4. doi: <https://doi.org/10.1111/j.1740-8261.2010.01754.x>
4. Coy J, Vandre RH, Davidson WR. Use of the hand-held dental X-ray machine during joint operation, NATO exercise display Determination-92. *Mil Med* 1997; **162**: 575–7. doi: <https://doi.org/10.1093/milmed/162.8.575>
 5. Drage N. Hand-held dental X-ray equipment—an update. *Dental Update* 2017; **2017**: 146–50.
 6. Public Health England Guidance on the safe use of hand-held dental x-ray equipment. 2016. 2018;.
 7. Berkhout WER, Suomalainen A, Brüllmann D, Jacobs R, Horner K, Stamatakis HC. Justification and good practice in using handheld portable dental x-ray equipment: a position paper prepared by the European Academy of DentoMaxilloFacial radiology (EADMFR). *Dentomaxillofac Radiol* 2015; **44**: 20140343. doi: <https://doi.org/10.1259/dmfr.20140343>
 8. Kim EK. Leakage and scattered radiation from hand-held dental X-ray unit. *Korean J Oral MFRadiol* 2007; **37**: 65–8.
 9. Gray JE, Bailey ED, Ludlow JB. Dental staff doses with handheld dental intraoral X-ray units. *Health Phys* 2012; **102**: 137–42. doi: <https://doi.org/10.1097/HP.0b013e318230778a>
 10. McGiff TJ, Danforth RA, Herschaft EE. Maintaining radiation exposures as low as reasonably achievable (ALARA) for dental personnel operating portable hand-held x-ray equipment. *Health Phys* 2012; **103**(Suppl 2): S179–S185PMID. doi: <https://doi.org/10.1097/HP.0b013e318259fa29>
 11. Rottke D, Gohlke L, Schrödel R, Hassfeld S, Schulze D. Operator safety during the acquisition of intraoral images with a handheld and portable X-ray device. *Dentomaxillofac Radiology* 2018; **20160410**: 20160410. doi: <https://doi.org/10.1259/dmfr.20160410>
 12. Brooks SL, McMinn WE, Benavides E. A clinical trial of the Nomad portable X-ray unit. *J Mich Dent Assoc* 2009; **91**: 54–8.
 13. Mah P, McDavid WD. Portable hand-held X-ray unit: effects of motion. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology* 2008; **105**: e55–6. doi: <https://doi.org/10.1016/j.tripleo.2007.12.068>
 14. Zhang W, Warner B, Miller M, Sutton J, Gutiérrez J. Imaging quality and radiation safety evaluation of different handheld intraoral X-ray units. *Oral Surgery, Oral Medicine, Oral Pathology and Oral Radiology* 2017; **124**: e35–6. doi: <https://doi.org/10.1016/j.oooo.2017.03.046>
 15. European Commission. *European Guidelines on radiation protection in dental radiology: The safe use of radiographs in dental radiology. Radiation protection 136*. Luxembourg: Office for Official Publications of the European Communities; 2004.
 16. Sewerin I. Influence of x-ray beam angulation upon the radiographic image of proximal carious lesions. *Commun Dent Oral Epidemiol* 1981; **9**: 74–8. doi: <https://doi.org/10.1111/j.1600-0528.1981.tb01032.x>
 17. van der Stelt PF, Ruttiman UE, Webber RL, Heemstra P. In vitro study into the influence of x-ray beam angulation on the detection of artificial caries defects on bitewing radiographs. *Caries Res* 1989; **23**: 334–41. doi: <https://doi.org/10.1159/000261202>
 18. Chadwick BL, Dummer PM, van der Stelt PF. The effect of alterations in horizontal X-ray beam angulation and bucco-lingual cavity width on the radiographic depth of approximal cavities. *J Oral Rehabil* 1999; **26**: 292–301. doi: <https://doi.org/10.1046/j.1365-2842.1999.00370.x>
 19. van Straaten FJ, van Aken J. The optimum circular field size for dental radiography with intraoral films. *Oral Surgery, Oral Medicine, Oral Pathology* 1982; **54**: 347–59. doi: [https://doi.org/10.1016/0030-4220\(82\)90108-6](https://doi.org/10.1016/0030-4220(82)90108-6)
 20. Kim E-K. Effect of the amount of battery charge on tube voltage in different hand-held dental X-ray systems. *Imaging Sci Dent* 2012; **42**: 1–4. doi: <https://doi.org/10.5624/isd.2012.42.1.1>
 21. .World Medical Association. World Medical association Declaration of Helsinki. ethical principles for medical research involving human subjects. *Bull World Health Organ* 2001; **79**: 373.