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ORIGINAL ARTICLE

Accuracy in positioning of dental X-ray images – A comparative study of a portable X-ray device and a wall-mounted device

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KEYWORD

Dental;
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Abstract *Introduction:* The benefits of portable dental X-ray devices remain controversially debated. This study aimed to compare the accuracy in positioning dental X-ray images using handheld (Nomad Pro 2) and wall-mounted (Heliodent Plus) X-ray devices.

Materials and methods: Radiographical imaging was exercised on a maxillofacial phantom using the handheld dental X-ray device Nomad Pro 2 (Kavo Kerr, Biberach, Germany) and the wall-mounted dental X-ray device Heliodent Plus (Sirona Dental Systems, Bensheim, Germany). Accuracy of device positioning (i.e., centeredness and perpendicularity) was measured as horizontal and vertical deviation (pixels and millimeters) from a centrally positioned crosshair. The reproducibility of the results was tested for 80 images per device and operator. IBM SPSS (SPSS Inc., Chicago, IL) was used for statistical analyses.

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Results: Centeredness of produced dental X-rays was significantly better for the wall-mounted device than for the handheld device in both deviation from the x-axis ($p = 0.042$) and y-axis ($p = 0.020$). The perpendicularity of the produced dental X-rays was significantly better for the handheld device than for the wall-mounted device for both horizontal ($p < 0.001$) and vertical ($p < 0.001$) plains.

Conclusions: Handheld dental X-ray devices appear to provide a high degree of accuracy in image positioning, especially in regard to proper perpendicular image angulation.

1. Introduction

Radiological examinations are an integral part of daily clinical dentistry. The number of annually performed dental X-rays in the United States is estimated to be up to 1.4 billion, demonstrating significant relevance for patient health (Muzzin et al., 2019). Historically, dental X-ray machines have been stationary wall-mounted (WM) devices deployed in a special examination room within practice and clinics due to the complex procedure of high voltage generation (Inscoe et al., 2018). The nonportable nature of such X-ray machines excludes a huge collective of immobile, disabled, and severely ill patients from radiological examination, rendering proper treatment difficult and at worst impossible.

With new technical possibilities arising, the need for bulky X-ray machines diminishes, giving way to a new era of portable, handheld (HH) X-ray devices, such as Nomad Pro 2 (Kavo Kerr, Biberach, Germany) (Rottke et al., 2018). Ideally, HH X-ray devices offer a compact size, can be easily operated, and allow bedside dental X-ray imaging in hospitals and nursing homes while abiding by radiation protection regulations (Gray et al., 2012). Hence, there is a heated scientific debate about the radiological safety, image quality, and accuracy of HH X-ray devices. Pending results of some clinical trials currently limit the use of HH X-ray devices in some Western European countries (Pittayapat et al., 2010). Since HH devices are not common practice in Germany, the incentive of the present study was to provide data on the positioning accuracy of an HH device at a German university hospital.

A crucial point of discussion is the impact on the radiation exposure of HH X-ray devices for the operator and the risk of malignant diseases (Han et al., 2013). For example, Smith et al. (2019) found the annual exposure of stray radiation to the operator of five HH X-ray devices to be higher compared to a WM X-ray device, resulting in the recommendation to only use HH X-ray devices when the use of WM devices is not feasible (Smith et al., 2019). However, Rottke et al. (2018) proposed that there is no increased risk of radiation exposure to the operator by the use of HH X-ray devices (Rottke et al., 2018). Nitschke et al. (2020) showed that the image quality (according to the guidelines of the German Federal Medical Association) of an HH X-ray device is at least comparable to that of a WM X-ray device (Nitschke et al., 2020). Hoogeveen et al. (2019) analyzed the precision of aiming with HH X-ray devices (compared to WM) for 20 different operators by measuring the deviation from the ideal perpendicular incidence of the radiation beam onto the sensor plane (Hoogeveen et al., 2019). They found similar precision for HH and WM X-ray devices but could show a high degree of operator dependability.

Therefore, the aim of this study was to analyze 1) reproducible image centeredness and 2) perpendicular imaging accuracy of the HH X-ray device Nomad Pro 2 compared to the WM dental X-ray device Heliodent Plus for one skilled operator using a real tooth maxillofacial phantom.

2. Materials and methods

2.1. Ethics approval and trial registration

This study was approved by the university's Ethics Committee. A trial registration for prospective trials was conducted. Additionally, this study was approved by the district government for its use of ionizing radiation.

2.2. Radiation devices

A portable handheld dental X-ray device, Nomad Pro 2 (Kavo Kerr, Biberach, Germany), was compared to an approved conventional wall-mounted X-ray device, Heliodent Plus (Sirona Dental Systems, Bensheim, Germany). Images were generated using an approved digital dental radiation sensor, the GXS 700 size 2 (Gendex, Kavo Kerr, Biberach, Germany). For image acquisition, a real tooth maxillofacial phantom (DXTTR mannequin, Densply, Ontario, USA) was used. This phantom has been used for approximately 20 years in numerous scientific international studies and validated to physiologically represent the dentoalveolar anatomy (Wenzel, 1994; Attaelmanan et al., 1999). Calibration of tube voltage, exposure time, and tube current of the Nomad Pro 2 (60 kV, 0,12 s, 2,5 mA) and Heliodent Plus (60 kV, 0,06 s, 7 mA) was conducted with a dosimeter (Thermo Eberline ESM, ThermoFisher Scientific, Waltham, Ma, USA) to obtain equivalent radiation doses at the sensor. The setting for image acquisition was the radiology department adjacent to the outpatient clinic of the clinic of Oral and Maxillofacial Surgery at Dusseldorf University Hospital.

2.3. Parameter analysis

Analyzed dental X-ray parameters (according to the current statutes of the German Dental Association) for both the Nomad Pro 2 and the Heliodent Plus were: 1) centeredness of the image (i.e., of the respective tooth) and 2) perpendicularity of the emitted radiation to the sensor plane. These parameters were analyzed on 80 X-ray images per device ($n = 80$) as required from statistical power analysis using G*Power open source software (Faul et al., 2007). After every X-ray image, Nomad Pro 2 and Heliodent Plus were newly repositioned from the starting position (right upper first molar; tooth 16 (*Fédération Dentaire Internationale* (FDI)) by the same operator. The operator was a trained oral and maxillofacial surgeon with 10 years of experience. Operator experience was two years for the HH device and 10 years for the WM device. Analyses were conducted on two consecutive days. All images were first taken with Nomad Pro 2 (Fig. 1) and then with Heliodent Plus (Fig. 2). Accuracy of device positioning (i.e., centeredness and perpendicularity) was measured as horizontal and vertical deviation (pixels and millimeters) from a centrally positioned crosshair installed to an adjustment aid (Rinn RVG6100, Sirona Dental Systems, Bensheim, Germany) (Fig. 3). Proper positioning of the HH and WM devices was secured by rigid fixation of the radiation sensor to the rectangular adjustment aid using silicone. Hereby, the distance between the sensor plane and the installed crosshair was set to exactly 70 mm (Fig. 3). A gold standard image was then calibrated per device (Nomad Pro 2 and Heliodent Plus) using the adjustment aid by assessing x- and y-coordinates with Sidexis v.4 (Dentsply Sirona, Bensheim, Germany). The successive image analyses were calibrated to this gold standard.

2.4. Diagnostic monitor and image analysis

For image viewing, an approved monitor according to German standards (DIN standard 6868–157) was used for both Nomad Pro 2 and Heliodent Plus. The freeware image processing software ImageJ (National Institutes of Health, Bethesda, Maryland, USA) was used to analyze horizontal and vertical deviation in millimeters (mm), pixels (px) and angular degree (°) from initially calibrated 1) centeredness and 2) perpendicularity by means of an installed crosshair to the adjustment aid, which is visible in all images (Fig. 4). Scattering from centeredness (mm and px) of the 80 Nomad Pro 2 and Heliodent Plus images was graded as the extent to which the devices generate reproducible images. Angular deviation from perpendicularity was graded as the extent to which the devices generated accu-

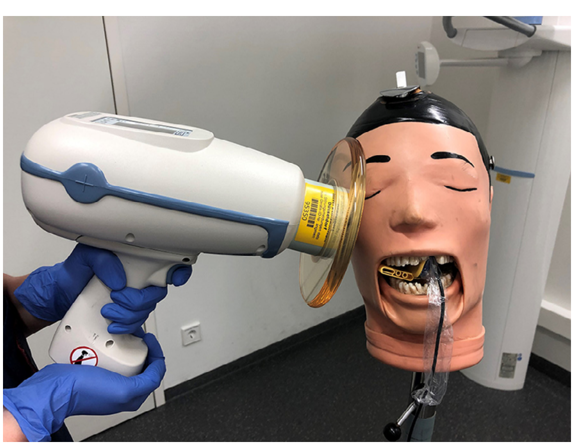

Fig. 1 Handheld dental X-ray image acquisition of the upper right first molar using Nomad Pro 2 (Kavo Kerr, Biberach, Germany).

Fig. 2 Wall-mounted dental X-ray image acquisition of the upper right first molar using Heliodent Plus (Sirona Dental Systems, Bensheim, Germany).

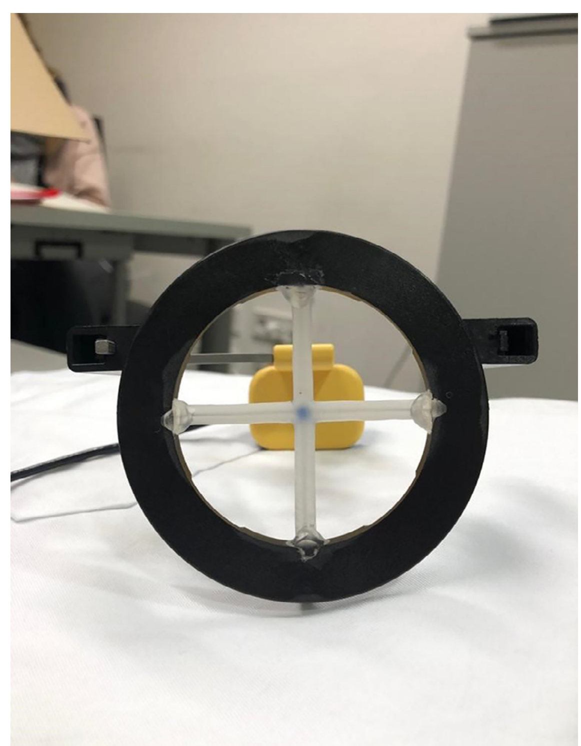

Fig. 3 Radiation aiming device (Rinn RVG6100, Sirona Dental Systems, Bensheim, Germany) with a centrally positioned crosshair.

Fig. 4 Centered and perpendicularly taken dental X-ray image of the upper right first molar as displayed on the analysis monitor. The crosshair becomes clearly visible.

rate images. Two investigators blinded to the device used analyzed image centredness and perpendicularity independently.

2.5. Radiation dose

For safety, shared film-based radiation dosemeters were worn by all investigating personnel at chest height on an X-ray apron approved for dental radiology throughout this study to measure ionizing radiation dose uptake.

2.6. Statistical methods

Data analysis was performed using IBM SPSS statistics for Mac version 26 (SPSS Inc., Chicago, IL USA) and Microsoft Excel for Mac version 16.16.3 (Microsoft, Redmond, WA, USA). Independent unpaired sample t-tests were conducted for significance testing. Homogeneity of variance was tested with Levene's test. Inhomogeneous variances were corrected using Welch's test. The level of significance was set to $p \leq 0.05$. Values of $p \leq 0.01$ were considered highly significant.

3. Results

3.1. Centeredness of Nomad Pro 2 and Heliodent plus images

The defined gold standard pixel center of an initially generated image was 662 px for the x-axis and 921 px for the y-axis. The mean values of pixel centers achieved by Nomad Pro 2 images were 711.94 px (SD = 130.66 px) for the x-axis and 891.04 px (SD = 99.98 px) for the y-axis. Heliodent Plus achieved mean pixel center values of 671.15 px (SD = 121.07 px) for the x-axis and 951.85 px (SD = 206.90 px) for the y-axis. Positioning to image centeredness was significantly more reproducible with Heliodent Plus for both the x-axis ($p = 0.042$) and the y-axis ($p = 0.020$) compared to Nomad Pro 2 (Fig. 5A and B).

3.2. Perpendicularity of Nomad Pro 2 and Heliodent plus images

Horizontal and vertical angular deviations were measured as discrepancies from the rectangular 90° gold standard. The mean angular degree values achieved by Nomad Pro 2 images were 90.75° (SD = 1.32°) to the horizontal plane and 88.64° (SD = 3.83°) to the vertical plane. Heliodent Plus images showed mean angular degree values of 93.31° (SD = 2.19°) to the horizontal plane and 86.29° (SD = 2.33°) to the vertical plane. The accuracy of rectangularly produced images was significantly higher for Nomad Pro 2 for both the horizontal ($p < 0.001$) and vertical ($p < 0.001$) planes than for Heliodent Plus (Fig. 5C and D).

3.3. Operator's radiation dose

The radiation dose measured by the dosemeter after 80 images was 0.0205 mGy for Nomad Pro 2 and 0.0105 mGy for Heliodent Plus.

4. Discussion

The presented results show high accuracy in image positioning for both the HH Nomad Pro 2 and the WM Heliodent Plus. However, scattering from the image center was significantly less using the WM device compared to HH. Here, the WM device displayed higher accuracy in the 80 repeatedly taken radiographs by the same operator. Hoogeveen et al. (2019), who also analyzed the precision of aiming of an HH versus a WM device, showed that aiming performance was operator-dependent for both the HH and WM devices (Hoogeveen et al., 2019). Nevertheless, in their study, radiographs were taken by undergraduate students, whereas in our study, a highly trained oral and maxillofacial surgeon conducted radiographical imaging. The present study aimed to display standard hospital settings with only one professional operator being on call. Hence, this study uniquely connects daily clinical practice to experimental methods at a department for oral and maxillofacial surgery. Since immobile ICU patients often profit from accessible oral X-ray imaging during night shifts, the rule out dental inflammation foci is highly relevant if operators on the same level of experience are capable of producing well-positioned images. Hoogeveen et al. (2019) did not find significant differences in terms of gender, right or left handedness, or the region in which the radiographs were taken (Hoogeveen et al., 2019). However, in their study, they only analyzed angulation of aiming and not scattering from the image center. Since the design of the present study only included one operator and one radiographical region of interest, it is unclear whether multiple operators or radiographed regions would produce the same results. Neither were gender or handedness analyzed. As HH devices are scarce in Western Europe, it is possible that operator training would significantly improve the precision of the aim. This is in conformity with other studies (Gray et al., 2012; Nitschke et al., 2020). The studies of Ulusu et al. (2010) and Nitschke et al. (2020) described comparable image quality of HH and WM devices on digital radiographs (Ulusu et al., 2010; Nitschke et al., 2020). The present results show that the accuracy of HH and WM devices seem comparable.

With radiation guidelines for caries diagnostics mandating a maximum tolerance of ± 7° in image angulation to the sensor plane, the results of our study conform with these guidelines (van der Stelt et al., 1989). This could also be demonstrated by Hoogeveen et al. (2019), even though they described angulation of HH being slightly less precise than WM (Hoogeveen

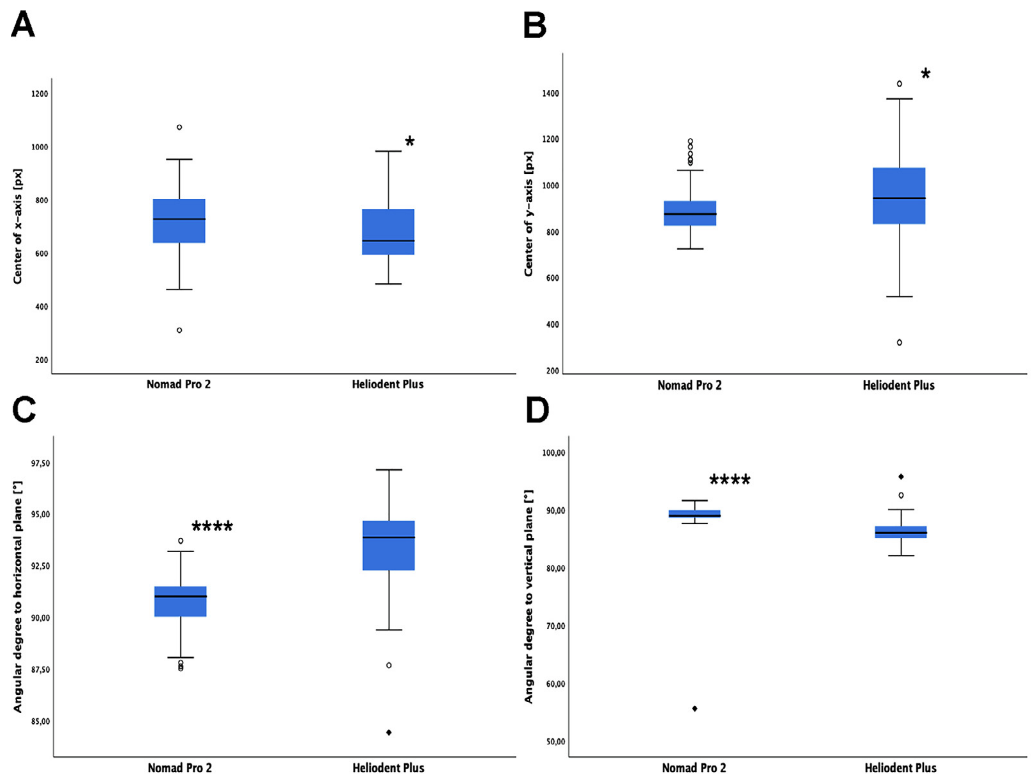

Fig. 5 A) Boxplots of pixel [px] deviation from the absolute center of the x-axis (defined at 662 px) of a series of dental X-ray images (n = 80) for Nomad Pro 2 and Heliodent Plus. B) Boxplots of pixel [px] deviation from the absolute center of the y-axis (defined at 921 px) of a series of dental X-ray images (n = 80) for Nomad Pro 2 and Heliodent Plus. C) Boxplots of angular degree [°] deviation from 90° to the horizontal plane of a series of dental X-ray images (n = 80) for Nomad Pro 2 and Heliodent Plus. D) Boxplots of angular degree [°] deviation from 90° to the vertical plane of a series of dental X-ray images (n = 80) for Nomad Pro 2 and Heliodent Plus; *t*-test, *p $<$ 0.05 (compared to Nomad Pro 2), ****p $<$ 0.0001 (compared to Heliodent Plus).

et al., 2019). In contrast, in this study, Nomad Pro 2 showed superior precision of angulation, with 90.75° (vs. 93.31° WM) for the horizontal plane and 88.64° (vs. 86.29° WM) for the vertical plane. Hoogeveen et al. (2019) found a better aiming precision in the mandible for HH and WM devices (Hoogeveen et al., 2019). Nitschke et al. (2020) describe mandibular image quality of the HH device surpassing the WM device (Nitschke et al., 2020). It seems plausible that precision of aiming in the mandible is facilitated using an HH device over a WM device. This is to be anticipated in particular when clinical radiographs of actual patients and not mannequins are taken since WM devices require the operator to leave the room to initiate radiation. Hence, movement of the patient, especially the tongue, with potential sensor dislocation is likely. It is true that tongue movement occurs with HH and WM devices, but if the operator stands next to the patient as with HH devices, direct prompting of the patient to refrain from any movement improves compliance. The presented data prepares a path for future trials to assess the application of HH radiation devices in emergency dental and oral maxillofacial trauma clinics in Western Europe, which is still rare.

5. Conclusions

We conclude that HH dental X-ray devices such as the Nomad Pro 2 provide high accuracy of radiograph positioning that is comparable to WM devices when used by a skilled professional. However, clinical trials on patients, not mannequins, are indispensable to validate these findings.

Human Rights Statement and Informed consent

Not applicable.

Animal Rights Statement

This article does not contain any studies with human or animal subjects performed by the any of the authors.

Ethics statement

Not applicable. This study was approved by the Ethics Committee of the University of Duesseldorf (Study number: 2018-162-KFogU). Trial registration of prospective trials: Central Study Register of Duesseldorf University Hospital, Registration-ID: 2018064716. Additionally, this study was approved by the district government of North Rhine-Westphalia due to the use of x-ray radiation (approval 772/18).

CRediT authorship contribution statement

Julian Lommen: Data curation, Writing – original draft. **Lara Schorn:** Visualization, Investigation. **Julia Nitschke:** Software, Validation. **Christoph Sproll:** Writing – review & editing. **Uwe**

Zeller: Writing – review & editing. **Norbert R. Kübler:** Supervision. **Jörg Handschel:** Supervision. **Henrik Holtmann:** Conceptualization, Methodology, Software.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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