Abstract:

Purpose: This study evaluated the contrast-to-noise ratio (CNR), spatial resolution, and subjective quality of dual imaging plates (DIP) intraoral radiography.

Methods: The DIP and conventional single IP (CSIP) methods both used YCR DT-1 imaging plates (Yoshida Co.). The DIP, comprising a front IP (FIP) and back IP (BIP), was constructed. DIP images were synthesized from the FIP and BIP images. An aluminum step phantom was used to measure the CNR. A line pair gauge was used to measure the spatial imaging resolution. A phantom comprising a porcine mandible embedded in acrylic resin was used for subjective evaluation.

Results: The CNR of the DIP image was 32% higher than that of the FIP image. The spatial resolution achieved using the FIP, DIP, and CSIP was high, as it was comparable except above 4 line pairs/mm, where that of the CSIP was highest. In subjective evaluation, the noise in the DIP images was significantly lower than in those obtained using the FIP and CSIP.

Conclusion: The CNR of the DIP was higher than that of the FIP. The decrease in spatial resolution of the DIP was limited. The subjective image quality of the DIP was higher than that of the FIP.

Keywords: contrast-to-noise ratio, dual imaging plate, intraoral radiography, spatial resolution

Introduction

Digital intraoral radiography uses either semiconductor-based imaging sensors [1] or imaging plates (IPs) as a photostimulable phosphor (PSP). The IP was developed for the Fuji Computed Radiography system in the 1980s (Takano M, Image technology & Information display 14: 409-413, 1982). It was first applied to digital dental panoramic radiography in 1985 by Kashima et al. [2] and Noikura et al. [3] and came into routine use for intraoral radiography in the early 1990s [4-6]. Compared with semiconductor-based detection methods, the IP is thinner and thus causes less discomfort in the oral cavity during insertion. Its sensitivity is the same as radiographic film and thus permits lower radiation exposure [7-9]. However, the “as low as reasonably achievable” (ALARA) principle (European Commission. Radiation protection no 136: European guidelines on radiation protection in dental radiology: The safe use of radiographs in dental practice 2004. http://ec.europa.eu/energy/sites/energy/files/en/docs/136.pdf Accessed 17 October 2021.) has driven demand for even higher sensitivity.

To increase the sensitivity, it is necessary to reduce noise and increase the contrast-to-noise ratio (CNR) [10]. Furthermore, it is desirable to increase the spatial resolution [8]. To address these aims, the dual IP (DIP) method using an outer cassette was developed and shown to increase the CNR [11,12]. However, to the authors’ knowledge, no studies have reported the spatial resolution of the DIP in intraoral radiography. Therefore, this study evaluated the CNR, spatial resolution, and subjective quality of DIP intraoral radiographic images.

Materials and Methods

Imaging plates

The DIP and conventional single IP (CSIP) methods both used YCR DT-1 IPs (Yoshida Co., Tokyo, Japan). The DIP, comprising a front IP (FIP) and back IP (BIP), was constructed as shown in Fig. 1. A thin iron plate (TIP) was adhered to the base of the PSP of each IP. The TIP was peeled from the base of the FIP, then both IPs were packed in a protective bag (disposable cover for DIGORA Optime imaging plate, size 2, Tanaka-ya Co., Tokyo, Japan). For the CSIP method, a single IP was also packed in a protective bag.

Image acquisition and measurement of patient entrance dose

Table 1 shows the equipment used in this experiment. An Xspot-TS (Asahi Roentgen, Kyoto, Japan) dental X-ray generator was used as a radiation source. The distance between the X-ray focal spot and the IP was 40 cm. The X-ray tube was operated at 60 kV and 6 mA and exposure times of 0.1 s and 0.2 s were used for the DIP and CSIP, respectively. Radiation dose was measured as incident air kerma (IAK) using “X-ray Output Meter MSM-3” (provided by Izumi Ogura, Tokyo Metropolitan University [Ogura I et al., Jpn J of Radiol Technol 70: 1403-1412, 2014]).

Image plate scanning

A Digora Optime DXR-60 (Zoredex, PaloDEx Group, Tuusula, Finland) digital imaging plate system was used in a darkroom to read the IPs. Images (1,333 × 1,020 pixels) were captured with a 30 µm × 30 µm resolution and output in bitmap format (8-bit, gray-scale). Before FIP readout, the TIP was re-adhered to its base. The BIP and the CSIP were read out conventionally.

Synthesis of the DIP image

DIP images were synthesized from the FIP and BIP images using an in-house least squares method implemented in C# version 2019 (Microsoft Co., Redmond, WA, USA).

Evaluation

Contrast-to-noise ratio

An aluminum step phantom with 12 steps in 1 mm increments was used to measure the CNR [11]. An acrylic resin block was positioned in front of the aluminum step to simulate soft tissue. The mean brightness and standard deviation (SD) of a 50 × 50-pixel area of the 1 mm and 5 mm steps were measured using ImageJ version 1.53e (NIH, Bethesda, MD, USA). The CNR of the FIP, DIP, and CSIP images was calculated using the following formula:

\[
CNR = \frac{\text{Mean}_{(Al5\text{mm})} - \text{Mean}_{(Al1\text{mm})}}{\sqrt{\text{SD}_{(Al5\text{mm})}^2 + \text{SD}_{(Al1\text{mm})}^2}}
\]

Spatial resolution

A line pair gauge was used to measure the spatial imaging resolution (micro chart R-1W100, Huettner Roentgenteste, Bayern, Germany). An acrylic resin block was positioned in front of the gauge to simulate soft tissue. The gauge was made from a tungsten plate (0.1 mm thick) and contained 1.0,
It was positioned in front of each IP, then the spatial resolution of the obtained images was measured using the square wave response function (SWRF) \([4, 8, 9]\) and the line profile of the square wave was measured using ImageJ.

**Subjective evaluation**

A phantom (10 cm width, 4 cm height and 3 cm depth) comprising a porcine mandible embedded in acrylic resin was used for subjective evaluation (Fig. 2a, b). The FIP, DIP, and CSIP images were displayed on a high-resolution LCD monitor (1,920 × 1,200 pixels, FMV VL-24WM1D, Fujitsu Co., Tokyo, Japan). Subjective pairwise image comparisons were made (i.e., FIP versus DIP, FIP versus CSIP, DIP versus CSIP), with the position of the images on the screen being randomized. Image pairs with high and low subjective similarity were scored 1 and 0, respectively. Seven radiologists with more than 5 years of experience and 2 radiographers with more than 4 years of experience participated in the evaluation. Images with lower noise were evaluated as 1 point. Sharper images were also evaluated as 1 point. The average of points was calculated.

**Table 1** Instrumentation and experimental parameters

| X-ray generator | Xspot-TS (Asahi Roentgen Co., Kyoto, Japan) |
|-----------------|--------------------------------------------|
| tube voltage    | 60 kV                                       |
| tube current    | 6 mA                                        |
| exposure time   | 0.1 or 0.2 s                                |
| focus-imaging plate distance | 40 cm             |
| Imaging plate   | YCR DT-1 (Standard type, Cross Field Co., Tokyo, Japan), single or dual |
| Scanner         | Digora optime DXR-60 (SOREDEX, PaloDEx Group Oy, Tuusula, Finland) |
| Object          | rectangular wave chart (micro chart R-1W100, Huettner Roentgenteste, Bayern, Germany), JIS Z4916-1997 |
|                  | phantom (porcine mandible embedded in acrylic resin) |
| Dose meter      | X-ray Output Meter MSM-3* |

*Provided by Izumi Ogura, Tokyo Metropolitan University

**Fig. 1** Structure of the dual imaging plate (DIP), comprising a front imaging plate (FIP) and back imaging plate (BIP). The FIP was peeled off the thin iron plate (TIP) prior to X-ray exposure. After exposure, the TIP was replaced, then the image was read out.

**Fig. 2** Block diagram (a) and overview (b) of X-ray generator, subject, and DIP. The distance between the DIP and X-ray focal spot was 40 cm. A porcine mandible was used for the subjective evaluation of image noise and sharpness.
The CNR was analyzed using an F-test with the reciprocal of the CNR as the normalized SD and the number of pixels as the sample size. Total number of samples per an image was 2,500 pixels. The subjective evaluations were analyzed using the Friedman test. When significant differences were identified, a Bonferroni-corrected Wilcoxon signed rank test was used for intergroup comparisons. Interobserver reliability between 9 observers in the subjective evaluation was assessed by Fleiss’s kappa coefficient. All statistical analyses were performed using SPSS 25 (IBM Corp., Armonk, NY, USA) and its extension plug-in. In each case, the significance level was $P < 0.05$.

**Results**

The patient entrance doses were 0.33 mGy and 0.66 mGy for exposure times of 0.1 s and 0.2 s, respectively (Table 2). Images of the aluminum steps are shown in Fig. 3 and the results of the sensitometry analysis are provided in Fig. 4, which shows that the CNR of the DIP image was 32% higher than that of the FIP image ($P < 0.05$) but not significantly different from that of the CSIP image.

Figure 5 shows images of the line pair gauge, and the resulting SWRF values are presented in Fig. 6, which shows that the spatial resolution achieved using the FIP, DIP, and CSIP was highly comparable except above 4.0 line pairs/mm, where that of the CSIP was highest.

The FIP, DIP, and CSIP images used for the subjective evaluation of the porcine phantom are shown in Fig. 7. As shown in Fig. 8, the noise in the DIP images was significantly lower ($P < 0.05$) than in those obtained using the FIP and CSIP. However, no statistically significant differences in image sharpness were observed. Fleiss’ kappa coefficient was 0.48 and 0.00 in the evaluation of noise and sharpness, respectively.

**Discussion**

The IP was developed in the 1980s and achieved widespread use in Fuji Computed Radiography systems [2,3]. Digital intraoral radiography began around the same time. Semiconductor methods came into practical use in the 1990s and employed either charge-coupled devices or complementary metal-oxide semiconductor sensors [1,4]. These alternatives to the IP [5,7] offer the advantage of immediate image acquisition, but the relative thickness of these sensors causes some discomfort when inserted into the oral cavity. In comparison, the IP is as thin as conventional film and therefore less uncomfortable, but image acquisition is slower because of the need for laser scanning [3,5,14].

The development of both detection methods has increased the sensitivity compared with radiographic film and contributed to the reduction of IAK. According to the ALARA principle, a sensor with higher sensitivity
permits the use of a shorter radiation time and thus lowers the radiation dose. However, in practice, sensitivity enhancements were limited by concomitant increases in noise, resulting in a reduced CNR deterioration of the image quality. Therefore, preliminary tests of the DIP were undertaken by Workman in 1994 [11], who reported improvements in the CNR compared with the CSIP. The DIP was applied to the quantification of bone minerals using a dual energy method in which a copper plate was sandwiched between a pair of IPs [15-17]. However, there have been no reports on the basic application of the DIP to intraoral radiography.

In this study, attempts were made to increase the sensitivity of intraoral radiography by using a DIP to reduce the noise and increase the CNR. The DIP was composed of an FIP and BIP so that half of the X-rays were absorbed by each. Images were obtained from the FIP and BIP and combined into one DIP image using the least-squares method. In order to improve the convergence of the method, it is required that the two images are not distorted and have a high correlation. For that reason, normally, the focus-detector distance (FDD) is 20 cm, however, this experiment employed the FDD of 40 cm to reduce the geometric distortion of images. In this experiment, the SWRF value for the DIP was the same as that achieved using the FIP and CSIP at 4.0 LP/mm. The causes were scattering of X-rays from the FIP, leading to blurring on the BIP, and errors in the least-squares method for synthesis of the DIP.

The subjective evaluation yielded no significant difference in the sharpness of images produced using the DIP, FIP, and CSIP, and these findings were supported by the measured SWRF values. The noise in the images produced by the FIP and CSIP was significantly lower than that in the DIP image. From the CNR analysis, the CSIP produced the highest score. In contrast, the subjective evaluation concluded that the DIP produced the lowest image noise. The use of two IPs in the DIP may be responsible for these findings, although the precise cause could not be determined from the data available from this study. From these results, it was concluded that the DIP resulted in decreased noise and an increased CNR. The decrease in spatial resolution due to blurring was limited, and the subjective evaluation of the performance of the DIP was higher than that of the FIP and CSIP.

This study used an exposure time of 0.1 s and a 40 cm distance between the X-ray focus and the IP. A distance of 20 cm is normally used in clinical practice, which is equivalent to an exposure time of 0.025 s. If such a short time could be used by a DIP in clinical applications, image blurring caused by body movement could be reduced [18]. This would have obvious advantages in pediatric radiography, where blurring due to body movement is a common cause of poor image quality.

The IAK in the present study was 0.33 mGy at 0.1 s (Table 2), which is less than half the current diagnostic reference level (DRL) [19,20] for pediatric imaging of mandibular incisors in Japan (National diagnostic reference levels in Japan - Japan DRLs 2020. Japan Network for Research and Information on Medical Exposure [J-RIME], http://www.radher.jp/J-RIME/report/DRL2020_Engver.pdf Accessed 28 August 2021.). This indicates that DRLs could be improved using a DIP.

Because the DIP contains two IPs, it is thicker than a CSIP. However, the overall thickness remains less than 1 mm, and therefore any increase in discomfort during insertion into the oral cavity may be minor.

In this examination, the DIP was exposed to normally incident X-rays. However, in clinical practice, X-rays are incident at an oblique angle. Moreover, if the IP is curved, the images produced by the FIP and BIP will be distorted so that a simple least-squares method may require improvements to synthesize the final image. In addition, the necessity to read out the FIP and BIP extends the reading time by a factor of two or more, which may limit operability.

It was necessary to peel the TIP from the FIP before X-ray exposure and replace it before reading the image. The purpose of this was to prevent the attenuation of X-rays during their traversal to the BIP. During reading, the TIP was fixed to a magnetic conveyor belt within the instrumentation used to read the IP. To apply this method clinically, it will be necessary to omit each of these steps. In addition, repeated experiments using various IPs are required for clinical application.

Subjective evaluation of the DIP showed that its noise performance was improved in comparison with a CSIP. However, it remains to be shown whether the DIP can improve the accuracy of diagnosis [21,22]. Interobserver agreements in the evaluation of noise and sharpness were moderate and poor, respectively. These results are correlated with the results of CNR and spatial resolution. This will require analysis of the receiver operating characteristic curve [23]. In addition, evaluation of various anatomical structures such as periodontal ligament space and pulp cavity are required.

In conclusion, a DIP image was synthesized from FIP and BIP images for intraoral radiography. The following conclusions were reached: the CNR of the DIP was 32% higher than that of the FIP; the decrease in spatial resolution of the DIP was limited; and the subjective image quality of the DIP was higher than that of the FIP. From the above, the relative sensitivity was deemed to be increased. This may permit the use of shorter exposure times, which will be advantageous for pediatric radiography.

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Conflict of interest
The authors have no conflict of interest to declare.

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