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A pilot study of half-value layer measurements using a semiconductor dosimeter for intraoral radiography

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ABSTRACT

Purpose: This pilot study was conducted to evaluate half-value layer (HVL) measurements obtained using a semiconductor dosimeter for intraoral radiography.

Materials and Methods: This study included 8 aluminum plates, 4 of which were low-purity (less than 99.9%) and 4 high-purity (greater than 99.9%). Intraoral radiography was performed using an intraoral X-ray unit in accordance with the dental protocol at the authors' affiliated hospital: tube voltage, 60 kVp and 70 kVp; tube current, 7 mA; and exposure time, 0.10 s. The accuracy of HVL measurements for intraoral radiography was assessed using a semiconductor dosimeter. A simple regression analysis was performed to compare the aluminum plate thickness and HVL in relation to the tube voltage (60 kVp and 70 kVp) and aluminum purity (low and high).

Results: For the low-purity aluminum plates, the HVL at 60 kVp (Y) and 70 kVp (Y) was significantly correlated with the thickness of the aluminum plate (X), with $Y = 1.708 + 0.415X$ ($r = 0.999$, $P < 0.05$) and $Y = 1.980 + 0.484X$ ($r = 0.999$, $P < 0.05$), respectively. Similarly, for the high-purity aluminum plates, the HVL at 60 kVp (Y) and 70 kVp (Y) was significantly correlated with the plate thickness (X), with $Y = 1.696 + 0.454X$ ($r = 0.999$, $P < 0.05$) and $Y = 1.968 + 0.515X$ ($r = 0.998$, $P < 0.05$), respectively.

Conclusion: This pilot study examined the relationship between aluminum plate thickness and HVL measurements using a semiconductor dosimeter for intraoral radiography. Semiconductor dosimeters may prove useful in HVL measurement for purposes such as quality assurance in dental X-ray imaging. ***(Imaging Sci Dent 2023; 53: 217-20)***

KEY WORDS: Radiography, Dental; Quality Assurance, Health Care; Radiation Exposure; Radiation Dosimeters

Introduction

The half-value layer (HVL) refers to the thickness of a material that reduces the intensity of X-rays passing through it to half of their original air kerma value. This measurement is used to determine the characteristics of X-ray beams.[1] As a required radiation safety parameter under regulatory guidelines, HVL must be measured annually. The introduction of semiconductor dosimeters has made HVL measurement a relatively simple process.[2]

Dental radiographic imaging is an integral component in the assessment of dental health. Dentists often base diagnoses and treatment decisions on information obtained from radiographic examinations, and optimizing radiographic exposures improves image quality and accuracy in clinical decision-making.[3] Additionally, in a previous study, quality assurance audits of intraoral radiography were recommended as an improvement measure for the radiology department at an undergraduate dental school.[4]

Methods for measuring entrance surface dose in intraoral radiography include K-shell absorption edge filters[5] and radiophotoluminescent dosimeters.[6] Several reports

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have been published on HVL measurement in computed tomography (CT),[1] dental cone-beam CT,[7,8] fluoroscopic X-ray systems,[2,9] and dual-energy CT.[10] However, to the authors' knowledge, no reports have been published on HVL measurement using semiconductor dosimeters for dental radiography. This pilot study was performed to evaluate the HVL measurements obtained using a semiconductor dosimeter for that purpose.

Materials and Methods

Aluminum plate

Eight aluminum plates (AcroBio, Tokyo, Japan) were analyzed using intraoral radiography and a semiconductor dosimeter designed for intraoral radiography. The aluminum plates used in this study included 4 low-purity (less than 99.9%) and 4 high-purity (greater than 99.9%) plates. The thicknesses of the low-purity aluminum plates were 0.50 mm, 1.00 mm, 2.00 mm and 3.00 mm, while the high-purity aluminum plates had thicknesses of 0.25 mm, 0.50 mm, 1.00 mm, and 2.00 mm.

Image acquisition and analysis

Intraoral radiography was performed using an intraoral X-ray unit (Heliodent Plus; Sirona Dental Systems, Tokyo, Japan) in accordance with the dental protocol at the authors' affiliated hospital: tube voltage, 60 kVp and 70 kVp; tube current, 7 mA; and exposure time, 0.10 s. The accuracy of HVL measurements for intraoral radiography was assessed using a semiconductor dosimeter (RaySafe X2 Solo DENT; RaySafe, Billdal, Sweden). The RaySafe X2 Solo DENT is a device designed for the quality assurance and servicing of dental X-ray machines. The specifications of the semiconductor dosimeter adhere to the X-ray meter standard (IEC 61674), with a dose range of 1 nGy to 9999 Gy, a dose rate range of 1 µGy/s to 500 mGy/s, and a kVp range of 40-130 kVp. The sensor consists of a multilayered structure of semiconductors with varying filtration rates, allowing for the measurement of HVL.

Figure 1 illustrates the display of a semiconductor dosimeter. The source-to-detector distance used in this study measured 42.0 mm, while the source-to-aluminum distance was 21.0 mm. To determine the mean HVL of an aluminum plate, 3 measurements were taken using the same plate. Figures 2 and 3 depict the actual experimental setup and the schematic representation, respectively.

Statistical analysis

A comparison of the aluminum plate thickness and HVL was conducted with respect to the tube voltage (60 kVp and 70 kVp) and aluminum purity (low and high) using simple regression analysis. These analyses were performed with IBM SPSS Statistics 26 (IBM Japan, Tokyo, Japan). A P-value of less than 0.05 was considered to indicate statistical significance.

Fig. 1. The RaySafe X2 Solo DENT device is a semiconductor dosimeter used for intraoral radiography. The display of the dosimeter indicates a half-value layer (HVL) of 2.08 mmAl (arrow) for a 0.25-mm high-purity aluminum plate at 70 kVp.

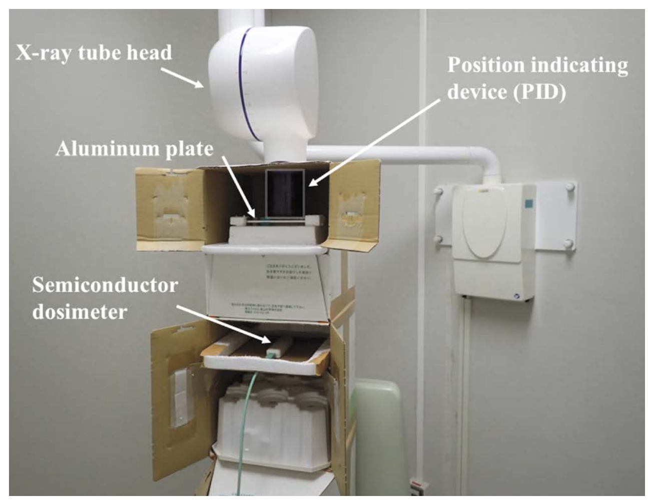

Fig. 2. This real experiment demonstrates the half-value layer measurements of a 3.00-mm low-purity aluminum plate, utilizing a semiconductor dosimeter for intraoral radiography.

Results

Table 1 displays the HVL measurements obtained for each low-purity aluminum plate. The HVLs for 0.00-, 0.50-, 1.00-, 2.00-, and 3.00-mm thicknesses of the low-purity aluminum plates at 60 kVp/70 kVp were 1.68/1.95, 1.92/2.23, 2.15/2.49, 2.56/2.97, and 2.93/3.41 mmAl, re-

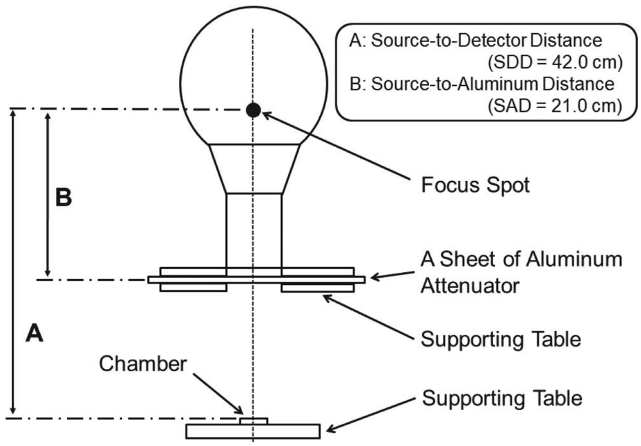

Fig. 3. Schematic illustrating the geometric configuration of half-value layer measurements using a semiconductor dosimeter for intraoral radiography. The source-to-detector distance (SDD) is 42.0 cm (A), while the source-to-aluminum distance (SAD) is 21.0 cm (B).

Table 1. Half-value layer measurements obtained for each low-purity aluminum plate (unit: mm)

Thickness of low-purity aluminum plate	60 kVp	70 kVp
0.00	1.68	1.95
0.50	1.92	2.23
1.00	2.15	2.49
2.00	2.56	2.97
3.00	2.93	3.41

spectively. The HVL at 70 kVp was higher than that at 60 kVp. Furthermore, the HVL at 60 kVp (Y) was significantly correlated with the thickness of the low-purity aluminum plate (X), with $Y = 1.708 + 0.415X$ ($r = 0.999$, $P < 0.05$). Similarly, the HVL at 70 kVp (Y) was significantly correlated with the low-purity aluminum plate thickness (X), with $Y = 1.980 + 0.484X$ ($r = 0.999$, $P < 0.05$).

Table 2 presents the HVL measurements obtained for each high-purity aluminum plate. The HVLs for 0.00-, 0.25-, 0.50-, 1.00-, and 2.00-mm thicknesses of the high-purity aluminum plates at 60 kVp/70 kVp were 1.68/1.95, 1.80/2.08, 1.94/2.25, 2.17/2.51, and 2.59/2.98 mmAl, respectively. The HVL at 70 kVp was higher than that at 60 kVp. Furthermore, the HVL at 60 kVp (Y) was significantly correlated with the thickness of the high-purity aluminum plate (X), with $Y = 1.696 + 0.454X$ ($r = 0.999$, $P < 0.05$). Similarly, the HVL at 70 kVp (Y) was significantly correlated with the high-purity aluminum plate thickness (X), with $Y = 1.968 + 0.515X$ ($r = 0.998$, $P < 0.05$).

Table 2. Half-value layer measurements obtained for each high-purity aluminum plate (unit: mm)

Thickness of high-purity aluminum plate (mm)	60 kVp	70 kVp
0.00	1.68	1.95
0.25	1.80	2.08
0.50	1.94	2.25
1.00	2.17	2.51
2.00	2.59	2.98

Discussion

HVLs assessed with a semiconductor dosimeter for intraoral radiography were found to be associated with the thickness of both low- and high-purity aluminum plates at 60 kVp and 70 kVp. A simple regression analysis revealed a significant correlation between the HVL and the aluminum plate thickness.

Methods for measuring entrance surface dose in intraoral radiography include K-shell absorption edge filters[5] and radiophotoluminescent dosimeters[6]. Shibuya et al.[5] investigated the effects of K-shell absorption edge filters on the image quality of a charge-coupled device-based digital intraoral radiographic system. They found that the highest effective energy was produced with the KEY filter (an X-ray filter for exposure reduction; component elements undisclosed), and this high effective energy tended to increase the sensitivity of the computed dental radiography. Katoh et al.[6] demonstrated a method for evaluating the entrance surface dose from the measurement of exposure and HVL in intraoral radiography using a radiophotoluminescent dosimeter. However, with the advent of semiconductor dosimeters, HVL measurement can now be conducted with relative ease.[2] The present authors evaluated HVL measurements using a semiconductor dosimeter for intraoral radiography and believe that this device can be useful in HVL measurement, such as in quality assurance of dental X-ray, due to its good operability.

Fukuda et al.[1] demonstrated that the HVLs for CT scanners, measured using the single-rotation technique with and without lead apertures at 80, 100, 120, and 135 kVp, were 3.37/3.50, 4.24/4.47, 5.22/5.44, and 5.90/6.17 mm, respectively. Lin et al.[2] highlighted the accuracy of HVL measurements utilizing solid-state detectors for radiography and fluoroscopy X-ray systems, noting that the HVL was particularly accurate at low tube potentials (60 kVp to 80 kVp). In the present study of intraoral radiography, the HVLs for low-purity aluminum plates with thicknesses of 0.00, 0.50, 1.00, 2.00, and 3.00 mm at 60 kVp/70 kVp were 1.68/1.95, 1.92/2.23, 2.15/2.49, 2.56/2.97, and 2.93/3.41 mmAl, respectively. Additionally, the HVLs for high-purity aluminum plates with thicknesses of 0.00, 0.25, 0.50, 1.00, and 2.00 mm at 60 kVp/70 kVp were 1.68/1.95, 1.80/2.08, 1.94/2.25, 2.17/2.51, and 2.59/2.98 mmAl, respectively. Barrineau et al.[3] concluded that optimizing intraoral radiographic exposures improves image quality and accuracy in clinical decision-making. Khan et al.[4] recommended implementing improvement measures in a dental radiology department and conducting a re-audit after 6 months. Given the large number of X-ray exposures generated annually in dental clinics worldwide and the relatively low exposure dose of intraoral radiography, it is essential to regularly check intraoral X-ray units in accordance with the "as low as reasonably achievable" principle.

Katoh et al.[6] demonstrated that the response of a radiophotoluminescent dosimeter was calibrated within the energy range used in intraoral radiography for measuring exposure in air and HVL. In the present study, both high-purity and low-purity aluminum plates were utilized to elucidate the differences between them. For the low-purity aluminum plates, the HVL at 60 kVp (Y) was significantly correlated with the thickness of the plate (X), with $Y = 1.708 + 0.415X$ ($r = 0.999$, $P < 0.05$). Similarly, the HVL at 70 kVp (Y) was significantly correlated with the thickness of the aluminum plate (X), with $Y = 1.980 + 0.484X$ ($r = 0.999$, $P < 0.05$). As for the high-purity aluminum plates, the HVL at 60 kVp (Y) was significantly correlated with the thickness of the plate (X), with $Y = 1.696 + 0.454X$ ($r = 0.999$, $P < 0.05$), and the HVL at 70 kVp (Y) was also significantly correlated with the plate thickness (X), with $Y = 1.968 + 0.515X$ ($r = 0.998$, $P < 0.05$). These authors believe that the HVL measurements taken using the semiconductor dosimeter were accurate, as evidenced by r-values of 0.998-0.999 and *P*-values < 0.05, and no significant differences were found between low- and high-purity aluminum plates.

This study had several limitations. The sample size was relatively small. Moreover, additional research comparing this method with other types of dosimetry is essential.

In conclusion, this pilot study examined the relationship between aluminum plate thickness and HVL measurements using a semiconductor dosimeter for intraoral radiography. The semiconductor dosimeter has potential utility in HVL measurement, which can contribute to quality assurance in dental X-ray procedures.

Conflicts of Interest: None

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