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# Optimal Irradiation Conditions for Radiopacity Tests of Dental Materials Using General-purpose X-ray Imaging Devices

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**This study verifies the feasibility and optimal conditions for using a general-purpose x-ray imaging device with a relatively large detector and excellent image quality compared to dental x-ray imaging devices according to international standards. The dental material test specimens were produced in the form of disks from four companies with different radiopacity, and aluminum step wedges was manufactured according to ISO 13116. In order to find the optimal irradiation conditions for general X-ray imaging devices, the distance between the target and the tube was fixed at 700 mm, and the exposure time was fixed at 100 ms. And the tube voltage was 50, 60, 70 kV and the tube current was changed to 40, 80, and 160 mA. As a result, it was sufficient to use general-purpose X-ray imaging devices, and the best results were obtained under the optimal conditions of 60 kV and 40 mA.**

**Keywords :** electromagnetic radiation, radiopacity, optimal irradiation condition, international organization for standardization, X-ray imaging devices

## 1. Introduction

Radiopacity is an important characteristics of dental materials required to either distinguish them from teeth and other surrounding tissues, or to assess and confirm their existence [1]. Therefore, manufacturer claims on the radiopacities of materials, such as that for direct dental restoration, dental adhesive, root-canal filling, and cavity-filling materials, must be submitted at the licensing stage; these radiopacities constitute performance evaluation parameters [2-6].

The testing and confirmation that dental materials have adequate radiopacities is standardized by the International Organization for Standardization (ISO). Particularly, ISO 4049 standardizes polymer-based restorative materials (Dentistry–Polymer-based restorative materials) [2], ISO 6876 (Dentistry–Root-canal sealing materials) [3] standardizes root-canal sealing materials, ISO 9917-1 (Dentistry–Water-based cements-Part 1: Powder liquid acid–base cements) [4] standardizes water-based cement-based materials, and ISO 9917-2 (Dentistry–Water-based cements-Part 2: Resin-modified cements) [5] guides the requirements and test methods for radiopacity according to the type of material. However, after ISO 13116 (Dentistry-Test method for determining radio-opacity of materials) [6] was enacted in 2014 as a radiopacity test standard for dental materials, the number of materials adopting this standard has been increasing gradually.

ISO 13116 requires the use of aluminum step wedges with thicknesses in the range 0.5 to 5.0 mm as reference standards, given that aluminum has an equivalent radiopacity at the same thickness as that of dentin in teeth. For imaging, radiation is generated and transmitted using a dental X-ray imaging device, including conventional or digital sensors, at the following conditions: tube voltage = 60 ± 10 kV, tube current = 10 mA, and exposure times = 100-400 ms. In addition, the image of the specimen and aluminum step wedge are acquired as luminance/grayscale values at each step, and a method of measuring the radiopacity is presented.

However, analog sensing is among the dental radiography techniques recommended by ISO 13116. This is conducted using occlusal films; however, it is cumbersome to prepare a photometer, developer, and fixative separately [6]. In addition, it has the disadvantage that the image quality is not consistent, depending on the degree of film


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development; thus, it has rarely been used recently [7]. Conversely, digital sensing is extensively used in clinical and laboratory settings because it is easy to use, has a lower radiation dose than analog sensing, and ensures reconstruction of images at a constant quality achieved by the ability to facilely correct the captured image with software [8]. Despite these advantages, digital sensing used for intraoral imaging comprises detectors of very small sizes, and imaging and analyzing the specimen and aluminum step wedge simultaneously for radiopacity performance evaluation material tests is difficult.

Conversely, general-purpose X-ray imaging devices are radiation devices that acquire images outside the mouth. The size of the detector is large; thus, the specimen and the step wedge can be fixed at once, and setting various imaging conditions according to the target specimen is easy. Accordingly, excellent quality images can be obtained. However, recent publications [9, 10] that studied the radiopacity of dental materials conducted tests using dental digital radiation devices guided by the standard. To our knowledge, to date, there are no publications on the study of radiopacity of dental materials using general-purpose radiographic imaging devices.

Therefore, the first goal of this study is to verify the scientific validity of an alternative test, and ascertain the possibility of executing this test with a general-purpose X-ray imaging device based on which it is relatively easy to set various test conditions and achieve superior quality compared with dedicated, dental X-ray imaging devices guided by ISO 13116. The second goal is to identify the optimal radiographic conditions for radiopacity tests of dental materials using a general X-ray imaging device.

## 2. Materials and Methods

### 2.1. Fabrication of radiopacity specimens

In this study, Rely X-U200 (3M ESPE, Irvine, Califorclia, USA), Metacem (Meta Biomed, Cheongju-si, Korea), Vioseal (Spident, Incheon, Korea), and Adseal (Meta Biomed, Cheongju-si, Korea) were selected as four products with different radiopacities. Their radiopacity values were as follows: 1.79 mm, 2.3 mm, ≥8 mm, and 4.25 mm (Table 1). The specimens were prepared in the forms of disks (diameter: 15 mm × thickness: 1 mm) using a suitable mold according to ISO 13116 [6]. The material was allowed to cure for a specific period (manufacturer's instructions) after mixing. The thickness of the fabricated specimen was controlled with a micrometer for standardization, and excess material was stored in a humid condition at 37 °C until the radiopacity test was performed after polishing. Three specimens are produced for each manufacturer.

### 2.2. Fabrication of aluminum step wedge

Aluminum step wedges were made of aluminum with a minimum purity of 98 % (mass fraction) with < 0.1 %

**Table 1.** Radiopacity values of the dental materials used in the present study.

| Name | Specimen code | Use | Radiopacity (mm Al) | Manufacturer |
|---|---|---|---|---|
| Rely X U200 | A | Dental cement | 1.79 | 3M ESPE, USA |
| Metacem | B | Dental cement | 2.3 | Meta Biomed, Korea |
| Vioseal | C | Root-canal sealing materials | ≥8 | Spident, Korea |
| Adseal | D | Root-canal sealing materials | 4.25 | Meta Biomed, Korea |

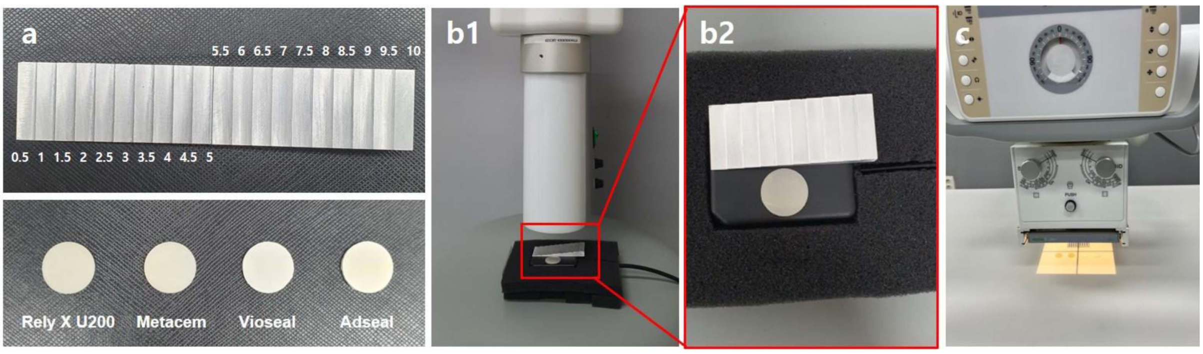


**Fig 1.** (Color online) (a) Aluminum step wedge (0.5-10 mm). (b1, b2) Specimens and step wedge on digital sensor and dental X-ray imaging devices, (c) General-purpose X-ray imaging device.

(mass fraction) copper, and < 1.0 % (mass fraction) iron, with thicknesses in the range 0.5-10.0 mm, according to ISO 13116. These consisted of equally spaced steps. As shown in Fig. 1a, the thickness deviation of each step was <0.05 mm (i.e., 20 steps in total).

### 2.3. Conditions of X-ray imaging devices

The dental X-ray imaging device (STAR-X, HDX, Korea) used in the experiment had the following settings: tube voltage: 65 kV, tube current: 3 or 6 mA, and exposure time: 10-320 ms [Fig. 1b], General-purpose X-ray imaging devices (DRGEM, DIAMOND, Korea) used the following settings: tube voltage: 40-150 kV, tube current: 10-640 mA, and tube current seconds: 0.1-500 mAs (Fig. 1c).

### 2.4. Radiopacity test procedure

We measured the thickness of the specimen (stored in a humid condition at 37 °C) according to ISO 13116, and each step of an aluminum step wedge using a micrometer at an accuracy of 0.01 mm before radiopacity measurements.

In the first experiment, the specimen and the step wedge were positioned with respect to the center of the detector of the dental X-ray imaging device, and the distance between the object and the tube was adjusted to 350 mm. Radiation was performed under the following conditions: tube voltage = 65 kV, tube current = 6 mA (manufacturer's fixed value), and exposure time = 160 ms. In the general-purpose X-ray imaging apparatus, the specimen and the step wedge were positioned in the center of the detector, and the distance between the object and the tube was set to 350 mm. Subsequently, the irradiation conditions were as follows: tube voltage = 65 kV, tube current = 10 mA, and an exposure time = 100 ms. Each acquired image file was analyzed by using a measurement tool in the grayscale analysis software.

The second experiment was used to identify the optimal radiation conditions during the evaluation of the radiopacity of dental materials using a general-purpose X-ray imaging device. All four specimens were placed together alongside a step wedge in the center of the detector of the general-purpose X-ray imaging device. The distance between the specimens and the tube was 350 mm (tube voltage = 65 kV, tube current = 10 mA, exposure time = 100 ms) and 700 mm (tube voltage = 65 kV, tube current = 40 mA, exposure time = 100 ms), respectively. The distance between the subject and the tube was then fixed at 700 mm, the exposure time was set to 100 ms, and the tube voltage and current were changed to 50, 60, 70 kV, and 40, 80, 160 mA, respectively.

Three specimens prepared for each manufacturer are irradiated with radiation under the same condition, and then exposed to radiation under different conditions.

### 2.5. Grayscale analysis

Digital image files taken under each condition are measured with Adobe Photoshop CS3 Extended, a software capable of gray scale analysis. Define a square area in the specimen image and measure the average gray value by randomly measuring three areas in one image file. Repeat this procedure for each step of the step wedge. The gray scale value of each aluminum step for the thickness of each step is displayed on the graph, respectively. And determine the value of the aluminum thickness corresponding to the gray value for each specimen.

## 3. Results

Table 2 lists the range of aluminum step wedges when specimens were imaged by a dental X-ray imaging apparatus and a general-purposed X-ray imaging apparatus subject to the conditions of ISO 13116. For specimens acquired by the dental X-ray imaging device, the grayscale values ranged from 1.5 to 2.0 for Rely X U200, from 2.0 to 2.5 for Metacem, from 5.0 to 5.5 for Vioseal, and from 5.0 to 5.5 for Adseal. Conversely, the gray scale of the general-purpose X-ray imaging equipment at the same conditions did not fall within the range of aluminum step wedges except for Vioseal.

To solve this problem, the distance was doubled, and the irradiation conditions were quadrupled according to the law of the inverse square of the distance (distance = 700 mm, tube voltage = 65 kV, tube current = 40 mA, exposure time = 100 ms) was performed. By increasing the distance and changing the irradiation conditions, the

**Table 2.** Radiopacity of all specimens evaluated according to ISO 13116 conditions.

| Device | Irradiation conditions | A | B | C | D |
|---|---|---|---|---|---|
| Dental X-ray imaging device | 350 mm, 65 kV, 6 mA, 160 ms | 1.5-2.0 | 2.0-2.5 | 5.0-5.5 | 5.0-5.5 |
| General-purpose X-ray imaging device | 350 mm, 65 kV, 10 mA, 100 ms | <0.5 | <0.5 | 1.5-2.0 | <0.5 |
| | 700 mm, 65 kV, 40 mA, 100 ms | 1.5-2.0 | 2.5- | 9.0-9.5 | 4.0-4.5 |

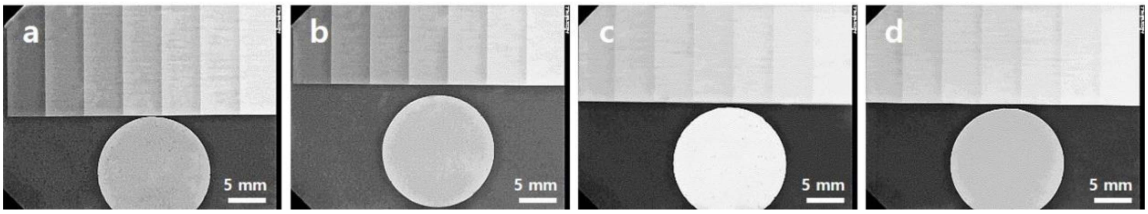


**Fig. 2.** Radiopacity images of all tested specimens and step wedge measured with the use of dental X-ray devices (a: Rely X U200, b: Metacem, c: Vioseal, d: Adseal).

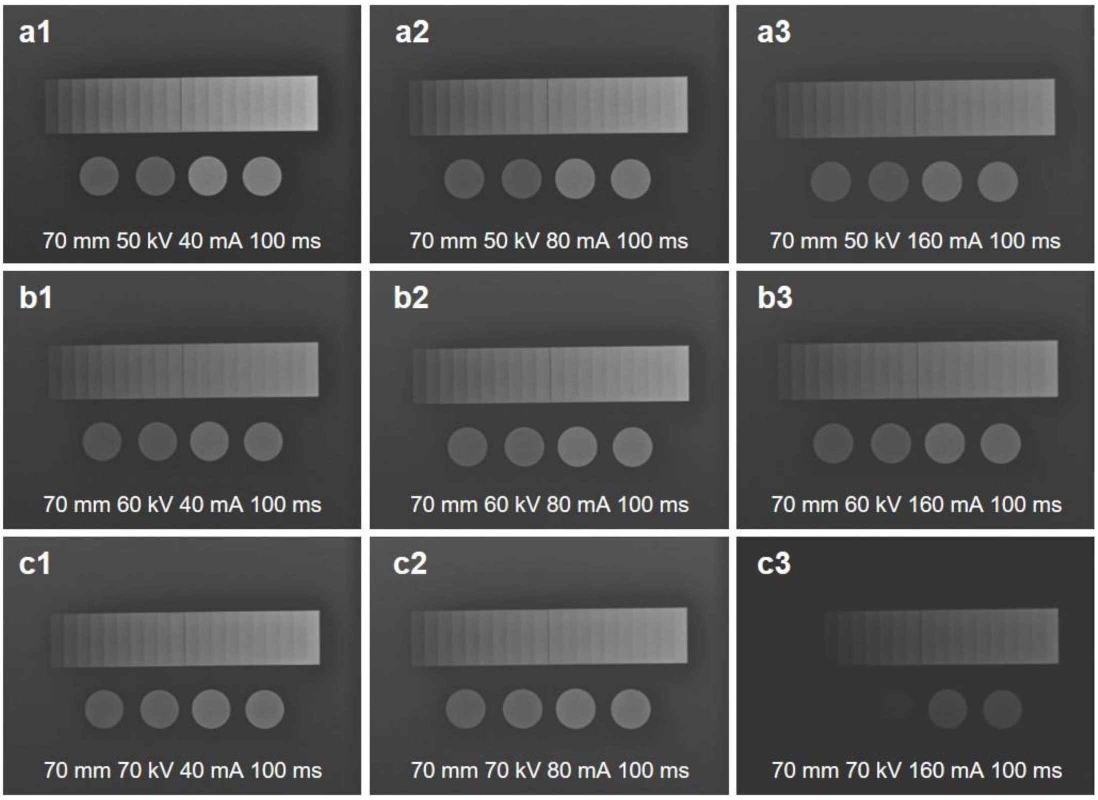


**Fig. 3.** Radiopacity image of aluminum step wedges measured according to the variables of a general-purpose X-ray imaging device.

following values of aluminum step wedges were obtained: Rely X U200: 1.5-2.0, Metacem: 2.5-3.0, Vioseal: 9.0-9.5, and Adseal: 4.0-4.5.

Figure 3 shows the radiopacity image acquired by fixing the distance to the target at 700 mm, and by changing the conditions of tube voltage and tube current. Analyzing each image file, the images were observed to become darker as the values of tube voltage and tube current increased. In particular, subject to the conditions of a tube voltage of 70 kV and a tube current of 160 mA, analyzing the specimen and the grayscale image of the aluminum step wedge was not possible.

Table 3 lists the analyzed results at all the imaging

**Table 3.** Measured values of aluminum step wedges according to the variables of the general-purpose X-ray imaging device.

| Irradiation condition | A | B | C | D |
|---|---|---|---|---|
| 50 kV, 40 mA, 100 ms | 1.5-2.0 | 1.5-2.0 | 6.0-6.5 | 4.5-5.0 |
| 50 kV, 80 mA, 100 ms | 1.5-2.0 | 1.5-2.0 | 6.0-6.5 | 4.5-5.0 |
| 50 kV, 160 mA, 100 ms | 1.5-2.0 | 1.5-2.0 | 6.0-6.5 | 4.5-5.0 |
| 60 kV, 40 mA 100 ms | 1.5-2.0 | 2.0-2.5 | 9.0-9.5 | 4.5-5.0 |
| 60 kV, 80 mA 100 ms | 1.5-2.0 | 2.0-2.5 | 9.5-1.0 | 4.5-5.0 |
| 60 kV, 160 mA 100 ms | 1.5-2.0 | 2.0-2.5 | 9.5-1.0 | 4.5-5.0 |
| 70 kV, 40 mA 100 ms | 1.5-2.0 | 2.5-3.0 | 9.5-1.0 | 4.0-4.5 |
| 70 kV, 80 mA 100 ms | 1.5-2.0 | 2.5-3.0 | 9.5-1.0 | 4.0-4.5 |
| 70 kV, 160 mA 100 ms | - | - | - | 4.0-4.5 |

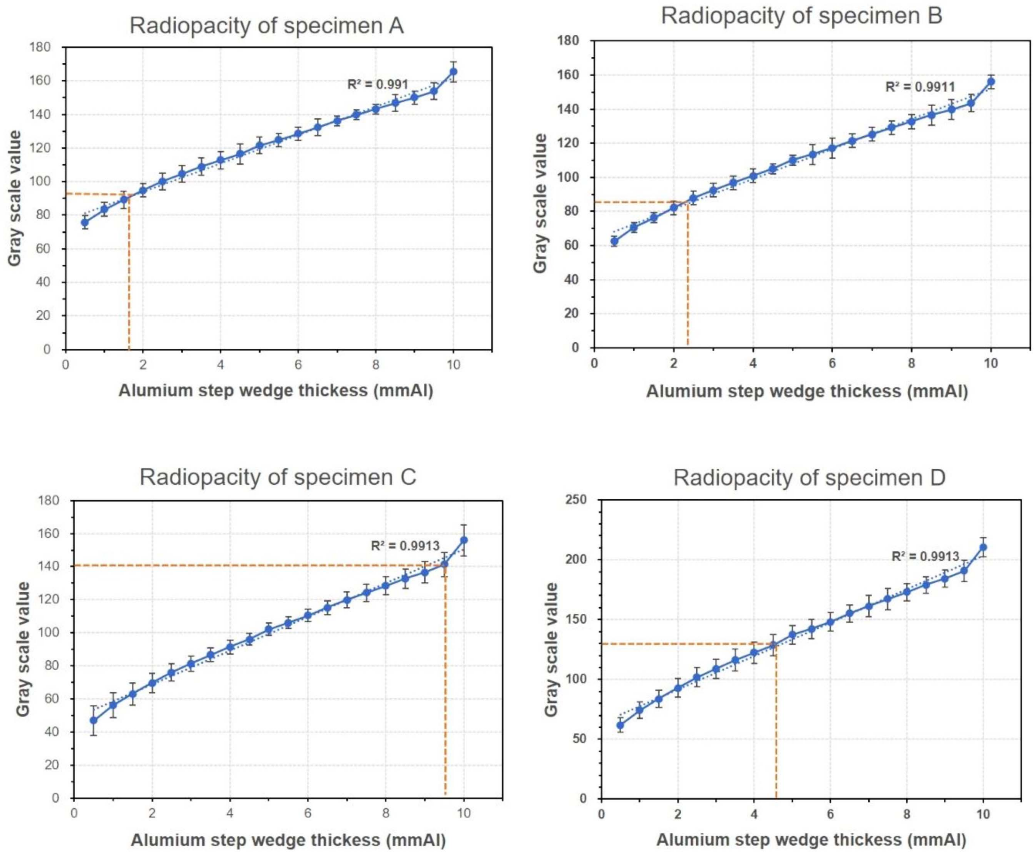


**Fig. 4.** (Color online) Radiopacity plots of all measured specimens at the optimal conditions (700 mm, 60 kV, 40 mA, 100 ms) based on the use of a general-purpose X-ray imaging device.

conditions except for the following condition: tube voltage = 70 kV and tube current = 160 mA. As indicated, the listed readings of the specimens according to each imaging condition are consistent with the trend of specimen opacities provided by the manufacturer. Among them, when the general X-ray imaging conditions were 60 kV, 40 mA, and 100 ms, readings were obtained that were similar to the radiopacities suggested by the manufacturer.

Figure 4 shows that when the irradiation conditions are 60 kV, 40 mA, and 100 ms, the corresponding aluminum value is determined after displaying the luminous intensity/gray value of the aluminum step wedge for the thickness of each specimen on the chart. In the case of specimen A (Rely X U200), the radiopacity suggested by the manufacturer was 1.79, and the readings shown when acquired with normal radiographs varied from 1.5 to 2.0, and from 2.0 to 2.5 for Specimen B (Metacem). As a result, specimen A value close to 2.3 was obtained. Specimen C (Vioseal) showed increased reading values that varied from 9.0 to 9.5, but the manufacturer also suggested radiopacity values ≥8. Specimen D (Adseal) also had a radiopacity equal to 4.25, and yielded readings that varied from 4.5 to 5.0, even in normal radiographic conditions.

## 4. Discussion

The radiopacity of a dental material depends on the dental material used and its intended purpose [11]. Root-canal obturators must have high opacity values to determine whether the root canal is completely filled [12, 13]. Direct dental restorations are more radioactive than enamel; in this way, the cervical margins and proximal contours can be identified when used for posterior teeth. Hence, the material used for restoration should be highly opaque [1, 14]. However, if the radiopacity is too high, it may obstruct the diagnosis by masking the defect, and if the radiopacity is too low, distinguishing it from the surrounding tissue is difficult [15, 16]. Hence, it should be manufactured so that its value is measured accurately.

The specifications for radiopacity for these dental materials initially guided the requirements, such as the shape and size of the specimen, the specimen preparation process, and the imaging conditions of the radiation device for each standard; however, there were some differences depending on the material. ISO 13116, established in 2014, provides comprehensive guidance on the requirements for dental material specimens, imaging conditions, and test methods, and provides references to other revised dental material standards and to the radiopacity test. In addition, ISO 13116 introduces all three methods of conventional, digital, and image grating for radiographic imaging devices for imaging dental materials.

However, several factors, such as the thickness of the material, type of X-ray film, angle of the X-ray beam, method used for evaluation, and composition of the material can affect the radiopacity of dental materials [17, 18]. To reduce these errors, the radiopacity of materials was evaluated by either comparing analog and digital methods, or by correcting calculated values from radiographs [19, 20]. In addition, according to a study by Wenzel *et al.* [21] on the radiopacity of dental materials that used analog and digital methods, analog methods required a higher dose than digital methods. Gu *et al.* [8] reported that when digital methods were used, they provided consistent radiographs by reducing operator exposure to additional radiation and by eliminating the need for film-developing chemicals. Hence, digital dental radiography equipment is mainly used to evaluate the radiopacity of dental materials in various publications and test institutes [22, 23].

However, the digital dental radiographer is generally used for intraoral imaging; as shown in Fig. 2, the detector has a size equal to width 45 mm × length 30 mm. Performing an accurate analysis is difficult because it is not possible to image including all in-step wedges; accordingly, images of step wedges and specimens are not all available. In addition, the wire connected to the sensor protrudes due to the structure of the detector. Thus, to acquire an image, a fixable accessory is required, but the quality of the captured image may also be affected by the accessories.

Therefore, in this study, a general radiographer was used because it provides a higher resolution and a wider range than a dental X-ray imaging device. This facilitated imaging and image analysis and provided consistent radiographs. The radiopacity was measured based on the imaging conditions guided by ISO 13116.

However, as shown in Table 2, when a general radiographic imaging device was used under the same conditions as those used for dental X-ray imaging devices, the grayscale values did not fall within the range of the aluminum step wedge, and analysis could not be performed.

A general-purpose X-ray imaging device has an inappropriate geometric structure for close-up imaging, and given that the irradiation area is wider than that of a dental X-ray imaging device, semi-shading occurs when the distance between specimen and device is close, thus resulting in image distortion.

Hence, the distance was increased from 350 mm to 700 mm according to the law of the inverse square of distances that states that as the distance increases, the intensity decreases as a function of the square of the distance. It was confirmed that all specimens yielded the same value as that of the aluminum step wedge. Additionally, when the imaging conditions were based on a distance equal to 700 mm, tube voltage equal to 60 kV, tube current equal to 40 mA, and an exposure time equal to 100 ms, the validity of the test, which used a general-purpose radiographer device as an alternative equipment was verified based on the readings.

However, one of the limitations of this study is the inability to simulate the oral environment. The radiopacity of dental materials can be influenced by several factors, such as the presence of oral fluid, soft tissue, and surrounding dental structures in the oral environment, as well as the imaging conditions [10, 24]. Therefore, in future studies, the radiopacity of dental materials should also be investigated using a general radiographic imaging device under conditions that emulate the oral environment.

In summary, to compensate for the large irradiation area of the general-purpose X-ray imaging device, the distance was increased, and the irradiation condition was adjusted based on the inverse square law of distance to measure the radiopacity of the dental material. The required image quality was achieved, the value was equivalent to that of the aluminum step wedge, and the ease and convenience of the shooting method was confirmed.

## 5. Conclusions

In this study, we verified the possibility of evaluating the radiopacity of dental materials using a general-purpose X-ray imaging device, and identified the optimal test conditions. It was confirmed that a general-purpose X-ray imaging device is sufficient for the execution of radiopacity tests, and the optimal conditions for these tests are 60 kV, 40 mA, and 100 ms, yielding the best image quality and aluminum readout outcomes. However, it is difficult to confirm that the results are applicable to all dental materials as only specific samples were used. In addition, international standards recommend that dental materials be evaluated using a dental X-ray device for product licensing. Therefore, the radiopacity tests conducted with an alternative equipment type, as done in this study, should be used as an auxiliary test method. These tests and their outcomes are valuable as they provide valuable basic data for the revision of international standards and the deduction of optimal conditions for test material in future studies.

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