Radiopacity Measurement of Restorative Resins Using Film and Three Digital Systems for Comparison with ISO 4049: International Standard

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Abstract

This study compared Ultra Speed Occlusal Film (USOF) and 3 digital systems in determining the radiopacity of 5 different restorative resins in terms of equivalents of aluminum thickness. Whether those digital systems could be used to determine whether radiopacity was in line with International Organization for Standardization (ISO) recommendations was also investigated. Disks of each of 5 restorative resins and an aluminum step wedge were exposed at 65 kVp and 10 mA on USOF and imaged with each digital system. Optical density on the film was measured with a transmission densitometer and the gray values on the digital images using Image J software. Graphs showing gray value/optical density to step wedge thickness were constructed. The aluminum equivalent was then calculated for all the resins using a regression equation. All the resins were more radiopaque than 1 mm of aluminum, and therefore met the ISO 4049 recommendations for restorative resins. Some resins showed statistically higher aluminum equivalents with digital imaging. The use of traditional X-ray films is declining, and digital systems offer many advantages, including an easy, fast, and reliable means of determining the radiopacity of dental materials.

Key words: Radiopacity—Restorative resins—Digital system

Introduction

Radiopacity is a prerequisite of dental materials, including restorative composite resins. A standardized method for measuring the radiopacity of dental materials was established³.

It is important to evaluate restorations accurately and in detail, which means the dentist must be able to ascertain whether secondary caries or marginal defects are present, what the contours of the restorations are, whether there is contact with adjacent teeth, and whether there are any cement
overhangs or interfacial gaps, for example. Therefore, the materials used in such restorations need to be sufficiently radiopaque to allow them to be distinguished from background enamel and dentin. Radiopaque materials offer a number of advantages over those that are radiolucent: for example, they make detection of recurrent dental caries and visualisation of the radiographic interface between the materials and the tooth substrates easier. Several factors may affect the radiopacity of dental materials, but composition seems to be most important. Additional factors include material thickness, type of X-ray film used, and alteration of powder/liquid ratio of luting materials. It has been demonstrated that the radiopacity of dentin is approximately equivalent to that of aluminum of the same thickness, and that enamel has approximately twice the radiopacity of aluminum of the same thickness. According to the International Organization for Standardization (ISO), the radiopacity of a material should be equal to or greater than the same thickness of aluminum, and should not be less than 0.5 mm of any value claimed by the manufacturer.

One of the most highly recommended methods of measuring radiopacity involves using an aluminum step wedge as a reference standard. The ISO and American National Standards Institute/American Dental Association have published standardized procedures for quantifying the radiopacity of several types of dental material which use a ≥98% pure aluminum step wedge as a reference.

Radiographic image density is commonly evaluated by means of conventional X-ray films and densitometers or spectrophotometers. A digital system for dentistry was first introduced in 1989, since which time digital radiography has found its way into dental practice. Several types of sensor are available for imaging: a charge-coupled device (CCD), a complementary metal oxide semiconductor (CMOS), and photo-stimulable phosphor plates. The most important advantages of digital radiographic systems are that they are more sensitive than silver halide film and allow exposure to radiation to be reduced. In digital imaging, the gray scale has an inverse relationship with optical density, with white being allotted a value of 255 (for an 8-bit image) and black 0. Unless performed with great care, traditional film development can produce significant variations in the final radiograph. The results of digital imaging, on the other hand, are more consistent.

The aim of the present study was to determine the radiopacity of 5 different restorative resins in terms of equivalent aluminum thickness by using an ultra-speed film and 3 different digital systems. Whether those digital systems could be used to determine whether radiopacity was in line with ISO recommendations was also investigated.

### Materials and Methods

#### 1. Preparation of specimens

The 5 restorative resins used in the study are summarized in Table 1. All were obtained directly from the maker and were manufactured in accordance with ISO standards. The test specimens were prepared by using

<table>
<thead>
<tr>
<th>Material</th>
<th>Manufacturer</th>
</tr>
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<tbody>
<tr>
<td>Sorare® P</td>
<td>GC Dental (Tokyo, Japan)</td>
</tr>
<tr>
<td>Gradia® DirectX</td>
<td>GC Dental (Tokyo, Japan)</td>
</tr>
<tr>
<td>Estelite® Sigma Quick</td>
<td>Tokuyama Dental Corp. (Tokyo, Japan)</td>
</tr>
<tr>
<td>Clearfil® AP-X</td>
<td>Kuraray Medical Inc. (Tokyo, Japan)</td>
</tr>
<tr>
<td>Beautiful® II</td>
<td>Shofu Inc. (Kyoto, Japan)</td>
</tr>
</tbody>
</table>
Disk-shaped specimens 10 mm in diameter and 1.0 mm in thickness were made from each of the 5 resins. The thickness of each specimen was measured to an accuracy of ±0.01 mm using a micrometer. An aluminum step wedge was also fabricated according to ISO recommendations with an aluminum purity exceeding 98%. The aluminum step wedge had steps of 1.0, 1.5, 2.0, 3.0, 4.0, 6.0, 8.0 and 10.0 mm in thickness.

2. Film and digital systems

Kodak Ultra Speed Occlusal Film (USOF: DF-50, Carestream Health, Rochester, NY, USA) was used. Table 2 shows the 3 digital imaging systems employed: Arcana, RVG, and Digora.

3. Exposure conditions

In ISO 4049:2009, it is recommended that dental X-rays be taken with a single-phase unit with a total filtration of 1.5 mm aluminum and capable of operating at 65 ± 5 kVp. Currently, single phase X-ray units are being replaced by constant-potential machines, which yield a longer contrast scale and reduce patient exposure to radiation. In the present study, X-rays were produced by an inverter-type constant-potential dental X-ray unit, the Max-DC70 (J. Morita, Kyoto, Japan), with spot sizes of 0.8 and 2.5 mm aluminum filtration for each exposure.

All 5 disk shaped specimens were placed on the USOF along with the aluminum step wedge. All 5 disk shaped specimens were also subsequently placed on the imaging plate of the Arcana. Only one resin disk shaped specimen at a time was used for Digora and RVG owing to the small size of the imaging plate and sensor, respectively. To reduce variation in the intensity of radiation in the central X-ray beam due to the anode heel effect, the film and specimen were placed perpendicular to the cathode-anode axis. Exposure was set at 65 kVp and 10 mA, with a 30-cm focus to film distance. The X-ray unit was kept in the same position throughout the experiment. Exposure time was 0.05 and 0.25 sec for RVG, Digora, and Arcana, and 0.25 sec for USOF. These exposure parameters were selected so that the individual steps of the aluminum step wedge would be clearly visible on the images produced. Three exposures were made for each of the settings for the USOF and 3 digital systems.

The images produced on USOF were processed immediately in an automatic processor (Dent-X, AFP Imaging, Elmsford, NY, USA) operating at 28°C with a Dent-X developer and fixer (Dent-X, AFP Imaging). The imaging plates produced with Digora and Arcana were scanned immediately, whereas direct digital images were displayed with RVG (Fig. 1).

4. Image analysis

Optical density on the USOF images was measured by using a transmission densitometer (Konica Densitometer PDA-15; Konica Minolta Holdings, Tokyo, Japan) with an
aperture of 1 mm in diameter. The optical densities were measured for all 1 mm thick disk resin specimens and each step of aluminium step wedge on each film. Each film was measured three times.

All digital images were generated without using automatic gain control and were exported as 24-bit Tag Image File Format (TIFF) files with 8-bit gray value data. Only images with no voids and in which all the steps of the aluminium step wedge were clearly distinct were used. Gray values were measured for each of the digital images using Image J software (ver. 1.46; National Institute of Health, Bethesda, MD, USA). Figure 2 shows a sample screen capture during mean gray value measurement: a 50×50-pixel region of interest was set up in each of the steps and in the resin disks.

5. Aluminum equivalence in millimeters

Graphs were constructed (one each for the USOF and 3 digital systems) to obtain aluminium equivalence in millimeters. Each graph was constructed using an Excel spreadsheet (ver. 2007), with the Y axis equalling the step wedge thickness in millimeters and X axis the corresponding gray value/optical density of the step wedge. A regression equation was obtained from each graph using the polynomial method to the third degree up to 10 decimal places. The regression curve and reliability of each plot exceeded 0.99, indicating that there was no deviation from linearity for the different thicknesses of the aluminium step wedge. According to ISO recommendations, the slope of the graph may be used only when the correlation coefficient, R, of the plot, is more than 0.97. This equation was used to calculate the equivalent aluminium thickness of the resins in millimeters.

Each radiograph was taken with an Al step wedge. A regression curve and regression equation were created for each radiographic image. The equivalent aluminium thickness of the resins was calculated by using the regression equation which was obtained from the same radiographic image measurements. A sample equation graph is shown in Fig. 3.

6. Statistical analysis

Statistical calculations were performed using the Statistical Package for the Social Sciences (SPSS, ver. 17). Data were analysed using an analysis of variance (ANOVA). The Dunnett test was then used to make multiple comparisons. The level of significance was set at p<0.05.
Results

The mean aluminum equivalents obtained for all 5 resins in millimeters by all methods used are shown in Table 3.

The images obtained with Digora at 0.25 sec exposure could not be used due to overexposure of the resins and aluminum step wedge, which produced darker, non-diagnostic images.

All the resins were more radiopaque than 1 mm of aluminum, and thus met ISO 4049 recommendations for restorative resins. Sorare was the least radiopaque (Al eq = 1.0–1.63 mm) and Clearfil the most (Al eq = 2.59–3.93 mm).

The Dunnett test was used for a multiple comparison of the aluminum equivalent obtained with the USOF and 3 digital systems. With some of the resins, a statistically significant difference was observed between the mean aluminum equivalent obtained with the digital systems and that achieved with the USOF (p<0.05) (Table 3).

Only Sorare showed no statistically significant difference in mean aluminum equivalent between with USOF and the digital systems (p>0.05).

The other 4 restorative resins (Gradia, Estelite, Clearfil and Beautiful), however, showed a statistically significant difference in the mean aluminum equivalent obtained with USOF and the digital systems (p<0.05).

A higher mean aluminum equivalent (p<0.05) was seen with RVG at 0.05 sec exposure with Gradia. Estelite showed a higher mean aluminum equivalent with RVG at 0.05 and 0.25 sec exposure, but a lower mean aluminum equivalent with Digora at 0.05 sec exposure (p<0.05). Beautiful showed the higher mean aluminum equivalent (p<0.05) with all digital systems except Digora (at 0.05 sec), where it showed similar values to with USOF. Clearfil showed a higher mean aluminum equivalent with all the digital systems than with the USOF (p<0.05) (Table 3).

Discussion

Radiology plays a significant role in the diagnoses of various lesions associated with the head and neck region. For a restorative material to be clearly visualized, there needs to be a considerable difference in the radiopacity of that material and the surrounding structures. According to previous ISO recommendations (4049:2009), the radiopacity of a 1.0-mm thick specimen should be evaluated based on its optical density on an X-ray image; and this may be evaluated in terms of the equivalent thickness of aluminum in reference to an image of an aluminum step wedge. In this method, the aluminum equivalent is calculated from the linear regression of the logarithm of optical density and aluminum thickness for the step wedge, which allows a precise result to be obtained. The accuracy
of this procedure depends, however, on the purity of the aluminum step wedge used. In one study, it was shown that the purity of the aluminum step wedge was very important, as only 4% copper in an aluminum alloy would result in radiopacity measurements a full 50% lower than those of 99.5% aluminum, creating a systematic error of 1.25%\(^4\). Hence, an aluminum step wedge of more than 98% purity was used in the present study.

The composition of a material appears to be the most important factor in determining its degree of radiopacity. Manufacturers include chemical elements such as barium, zinc, aluminum, strontium, silicon, yttrium, ytterbium, and lanthanum in products to increase their radiopacity. The higher the atomic number of the element added, the higher the radiopacity of the material, as the absorption capacity of X-rays is increased. Therefore, ytterbium, which has the atomic number 70, provides the highest radiopacity, followed by barium (Z = 56), yttrium (Z = 39), strontium (Z = 38), zinc (Z = 30), silicon (Z = 14), and aluminum (Z = 13). The percentage in which these elements is included also affects radiopacity\(^2,9,12\). Obtaining accurate information on the detailed composition of dental composites is difficult, however, as this is considered confidential by most manufacturers\(^4\).

The presence of secondary caries is one of the main reasons for restorations to be replaced. However, excessive radiopacity may hinder the diagnosis of caries when it is adjacent to the restoration. The degree of radiopacity directly affects radiographic contrast, and when too high may lessen visual acuity, consequently diminishing the perception of detail, according to Espelid \textit{et al.} These authors also suggested that material with a moderate degree of radiopacity is more appropriate, and that the optimal radiopacity would be slightly greater than that of enamel\(^6\). Moreover, a high level of radiopacity near a less radiopaque area can give rise to the Mach Band effect, where a visual illusion is produced that enhances the contrast between a light and a darker area, making the dark borderline area darker. This effect might be misinterpreted as caries, and its perception can vary between observers\(^6,14,15\). Therefore, according to ISO recommendations, the radiopacity of a material should be equal to or greater than the same thickness of aluminum, and should not be less than 0.5 mm of any value claimed by the manufacturer.

Digital image analysis is believed to offer the same degree of accuracy as transmission densitometry, and can produce measurements equivalent to those obtained with film, but with reduced noise, providing precise and trustworthy numerical values for comparative radiodensity studies. Moreover, digital radiography does not involve film development, a process that introduces variation in the final radiograph. Transmission densitometry measures optical density, a logarithmic measure of the ratio of transmitted to incident light through the film image. In digital image analysis, radiographic density is evaluated directly using the gray scale of the pixels, assigning values on a scale of 0 to 255 using computer software. Furthermore, unlike with conventional X-ray film, no subtraction is required when calculating radiopacity\(^5\).

In the present study, the radiopacity of 1-mm thick specimens made from 5 restorative resins was evaluated using USOF and 3 digital systems, the Arcana, RVG, and Digora. The radiopacity of all the restorative resins was found to be in line with ISO standards, whether evaluated on USOF or by any of the digital methods employed. In a study by Dukic \textit{et al.}, a CCD sensor (DiXi3Bi, Planmeca) was used to measure the radiopacity of Gradia Direct X at an exposure of 60 kVp for 0.06 sec. The equivalent aluminum thickness obtained was 2.31 mm, which was similar to that observed in the present study, in which it was 3.93 \((\pm 0.15)\) mm at an exposure of 0.05 sec.
The aluminum equivalent thickness calculated in the present study was similar to that reported by Watts and McCabe [15] and Dukic et al. [4], who used a 3rd-degree polynomial mathematical equation to best represent the data. The aluminum equivalent obtained on the USOF was compared to that obtained by the digital systems. It was observed that statistically significant higher values were obtained on the digital system for some of the resins. These findings are similar to those found in an earlier study, in which the digital system used yielded higher radiopacity values, regardless of the type of cement, when compared to a conventional system [7]. However, authors such as Sanderink et al. note that it is difficult to compare digital systems with conventional ones, as they have totally different characteristics [13]. In another study, it was shown that the equivalent aluminum thickness method was not suitable for materials of low radiopacity, while the attenuation coefficient method could be used for all without difficulty [10]. On the other hand, it has been shown that imaging plates may be a preferable in determining attenuation coefficients due to the intrinsic noise and more limited dynamic range of film (deviation from linearity) [13]. The differences in the radiopacity values obtained with the 3 digital systems used in the present study may have resulted from the fact that the latitude of RVG and complementary metal oxide semiconductor sensor receptors, similar to conventional films, are limited, covering 0.5–2.5 sec on the scale of optical density. Imaging plates, however, provide a wider range and higher latitude in addition to linear correlation between exposure and the gray scale (0–5 on the scale of optical density) [10]. These differences may also have arisen due to the lack of studies simultaneously comparing all the digital systems with conventional films in assessing the radiopacity of restorative resins. Such studies might improve our understanding of how these devices differ in quantifying the radiopacity of dental materials [10].

**Conclusion**

To the best of our knowledge, this is the first study to simultaneously investigate and compare conventional film with 3 different digital systems with different exposure settings. Moreover, this is the first study to use the Arcana digital system to evaluate radiopacity. The digital systems showed higher radiopacity values for some of the resins. The use of traditional X-ray films is declining, and digital systems offer many advantages, including an easy, fast, and reliable means of determining the radiopacity of dental materials.

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