

Original

Comparative study of radiopacity of resin-based and glass ionomer-based bulk-fill restoratives using digital radiography

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Abstract: This study investigated the radiopacity values of glass ionomer- and resin-based bulk-fill restoratives of different thicknesses using digital radiography. Two glass ionomer-based and three resin-based bulk-fill restoratives, and a conventional composite were studied. Five disc-shaped specimens were prepared from each of these materials at three different thicknesses; specimens of enamel and dentin with the same thicknesses were also prepared. Materials were placed over a complementary metal oxide-semiconductor sensor together with the tooth specimen and an aluminum step-wedge, and then exposed using a dental X-ray unit. The images were analyzed using a software program to measure the mean gray values (MGVs), which were converted to equivalent aluminum thicknesses. Two-way ANOVA was used to investigate the significance of differences among the groups. The GCP Glass Fill specimens showed the lowest radiopacity values, and the Quixfil specimens had the highest values. All materials had higher radiopacity values than enamel and dentin, except for GCP Glass Fill, which had a radiopacity similar to that of enamel. The resin-based bulk-fill restoratives had significantly higher radiopacity values than glass ionomer-based restoratives. All of the tested materials showed radiopacity values higher

than that of dentin, as recommended by the ISO. (J Oral Sci 57, 79-85, 2015)

Keywords: dental materials; bulk-fill restoratives; radiopacity; digital radiography.

Introduction

The radiopacity of dental materials used for restorations is very important for radiographic diagnosis, particularly because radiopaque materials allow for better radiographic detection of secondary caries in posterior teeth (1,2). A material with adequate radiopacity makes it possible to detect secondary caries and distinguish them from the restorative material, assisting in the recognition of faulty proximal contours, voids, inadequate marginal adaptation, and interfacial gaps (3,4). For this reason, the radiopacity of dental materials has been studied extensively.

Several authors have discussed the question of how a radiopaque restorative material should function for optimal diagnosis. Studies of radiopacity normally compare a material with enamel, dentin, or aluminum (2,5). The International Standard Organization (ISO) 4049 (6) and ISO 9917 (7) have published a radiopacity protocol and guidelines for resin composite and glass ionomer cements. According to the ISO (6,7), if a manufacturer claims their product to be radiopaque, the radiopacity of a 1.0-mm-thick specimen should be equal to or greater than the same thickness of aluminum. Aluminum is the reference of choice because its reported radiopacity is similar to that of dentin and it can be

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Table 1 Materials used in this study

Material		Radiopaque filler content - Filler % (wt/vol)	Manufacturer	Batch No
Quixfil	composite resin-based	Zirconiumoxide, Silicon dioxide - 86/66	Dentsply DeTrey, Konstanz, Germany	121000
SDR Bulk Fill	composite resin-based	Barium alumino fluoro borosilicate glass, Strontium alumino fluoro silicate glass - 68/44	Dentsply DeTrey, Konstanz, Germany	1001086
Filtek Bulk Fill	composite resin-based	Zirconia/silica, ytterbium trifluoride - 64/42	3M ESPE, St Paul, MN, USA	N435626
Equia Fil	glass-ionomer-based	Fluoro-alumino silicate glass - NA	GC Corp., Tokyo, Japan	1203121
GCP Glass Fill	glass-ionomer-based	Fluoro-alumino silicate glass - NA	GCP Dental, Vianen, Netherlands	7211953
Filtek Z550	conventional composite resin	Silane treated ceramic, Silane treated silica 85/70	3M ESPE, St Paul, MN, USA	N334740

machined easily and accurately (1,8). For the same thickness, the radiopacities of Al and dentin are approximately equivalent, and enamel has approximately twice the radiopacity of Al (9). Most studies suggest that a material with a radiopacity equal to or slightly greater than that of enamel would be ideal for detection of secondary caries in radiographs (10-15).

Currently, bulk-fill restoratives are clinically preferred because they are easy to handle. Instead of using the conventional incremental placement technique, bulk-fill restoratives allow for homogeneous increment thicknesses up to 4 mm, eliminating the need for the time-consuming layering processes (16). Resin-based composites and glass ionomer-based materials can be used as bulk-fill restoratives (17). Resin-based composites that differ in terms of particle size, distribution, volume fraction, viscosity, and application methods, are already available commercially. Similarly, glass ionomer-based bulk-fill restoratives have been introduced for clinical applications following recent refinements to their composition. In fact, glass ionomer-based materials have been widely used in restorative dentistry since 1972 (18). One of the disadvantages of the early glass ionomers was that they lacked suitable radiopacity, which made it difficult to radiographically differentiate any recurrent caries from the restoration (19). Because of this insufficiency, manufacturers improved glass ionomer-based materials by incorporating fillers or by using radiopaque compounds to enhance the degree of radiopacity.

Pedrosa et al. (20) have suggested that the radiopacity of materials is an important aspect of studies aimed at the evaluation of new commercial materials, and for prevention of imaging misdiagnosis. It is assumed that the composition of bulk-fill restoratives does not differ markedly from that of currently used, incrementally filled conventional resin composites and glass ionomer-based materials. However, the differing chemistry of the monomeric resin formulations and filler characteristics (type, volume fraction, density, and particle size and distribution) of bulk-fill restoratives may affect radiological characteristics such as the depth of cure and mechanical

properties, which Finan et al. (21) have shown to be significantly impacted. To our knowledge, no published papers have yet compared glass-ionomer and resin-based bulk-fill restoratives. Therefore, the aim of the present study was to evaluate the radiopacities of resin- and glass ionomer-based bulk-fill restoratives using digital radiography, and to compare them with enamel, dentin, and a conventional composite at different thicknesses. Our working hypothesis was that there would be a significant difference in the radiopacity of resin-based and glass ionomer-based bulk-fill restoratives at different thicknesses.

Materials and Methods

Specimen preparation

The present study was approved by the Research Ethics Committee of the Izmir Katip Celebi University, under report number 2014-70. Three resin-based bulk-fill restoratives, two new commercial glass ionomer-based bulk-fill restoratives, and a conventional composite material were selected for this study. The selected materials, manufacturers, and chemical compositions are listed in Table 1.

The sample size was calculated considering 80% power and a significance level of 0.05 using data (effect size = 4.08) obtained from the study by Lachowski et al. (2). Although the data in this study suggested that a total of nine specimens would be sufficient for the analysis, a worst-case scenario was proposed with a 0.93 effect size. According to this worst-case scenario, the total sample size was calculated to be 30 ($n = 5$) considering 95% power at a significance level of 0.05.

Plastic ring molds with an internal diameter of 5 mm and depths of 1 mm, 2 mm, and 4 mm were used to prepare standardized specimens. Five specimens of each material at each depth were prepared in accordance with the manufacturers' instructions. The mold was placed on a microscope glass slab, and the materials were inserted into the mold until it was overfilled. Then a mylar matrix strip was placed on the top and a second glass slab was positioned over the strip to flatten the surface. Chemi-

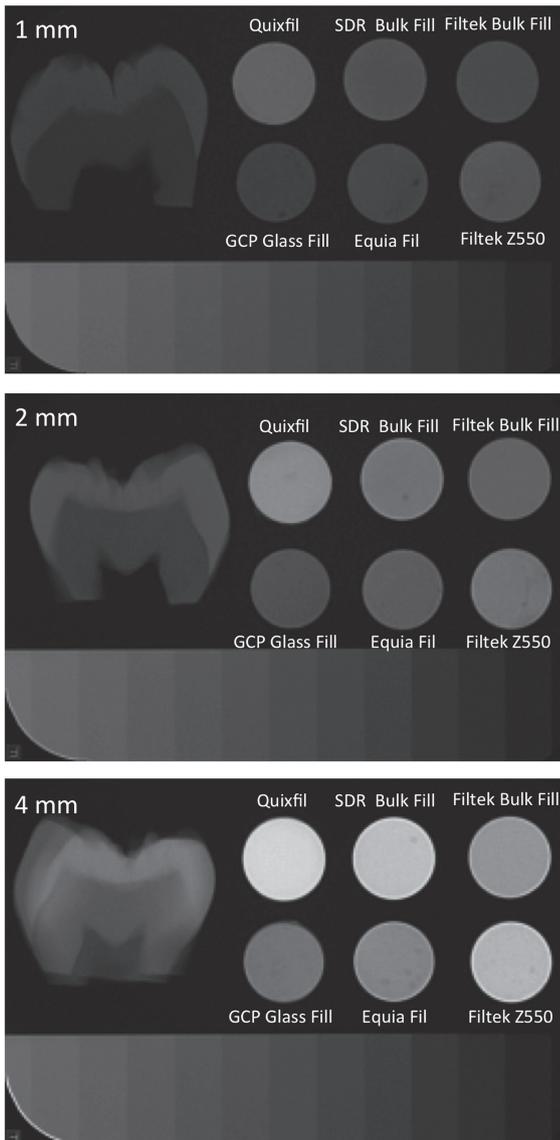


Fig. 1 Radiographic images of tested restorative materials, enamel, dentin, and aluminum for thicknesses of 1 mm, 2 mm, and 4 mm. Notice that increased thicknesses of the materials was correlated with significant increases in their radiopacity.

cally activated materials were allowed to set for the period of time recommended by each manufacturer. The light-activated materials were cured with a light source as recommended by the manufacturer (Valo, Ultradent Products, South Jordan, UT, USA). After the samples had been removed from the mold, the thicknesses were checked with a digital caliper in order to ensure standardization. After preparation, the specimens were stored under moist conditions at $37 \pm 1^\circ\text{C}$ until they were used for radiographic experiments.

One freshly extracted human molar was used in this study to obtain enamel and dentin specimens. It was prepared by longitudinal sectioning using a low-speed

diamond saw (Isomet 1001, Buehler Ltd., Lake Bluff, IL, USA), and slices measuring 1 mm, 2 mm, and 4 mm in thickness were obtained. The slices were kept in distilled water until used for radiographic experiments.

Digital radiography

One specimen of each material together with the aluminum stepwedge and a tooth specimen were positioned over the CMOS (complementary metal-oxide-semiconductor) sensor (DIGORA Toto, SOREDEX, Milwaukee, WI, USA). The aluminum step-wedge was made of 99.5% pure aluminum alloy, with the thickness varying from 0.5 to 10 mm in uniform steps of 0.5 mm. Radiographic images were obtained at 65 kVp and 7 mA. The exposure time was set at 0.32 s with a focus to target distance of 30 cm (Myray, Cefla Dental Group, Imola, Italy).

Figure 1 shows radiographic images of the enamel, dentin, aluminum step-wedge, and bulk-fill restoratives at different thicknesses on the CMOS sensor.

The mean gray values (MGVs) of each of the materials and tooth slices were measured on the digital radiographs using a software program (Adobe Photoshop CS3 Extended, ver. 10.0, Adobe Systems, San Jose, CA, USA) in five different regions, each with a 10×10 pixel area, to reduce the measurement bias. Care was taken to avoid areas containing air bubbles or other anomalies, and measurements were taken by an evaluator who was blinded to the identities of the materials. After the MGVs of the observed steps of the aluminum step-wedge on each image had been calculated, a regression curve equation for each image was defined for the MGVs of further steps that could not be observed on the image because of the limited dimensions of the CMOS. Thus, MGVs for each of the steps of the aluminum step-wedge, varying from 0.5 to 15 mm in uniform steps of 0.5 mm, were obtained. (Fig. 2). The MGVs for each of the materials and tooth slices were then converted into millimeters of aluminum (mm Al) using the following equation, as reported by Lachkowski et al. (2):

$$\frac{A \times 0.5}{B} + \text{mm Al below material's MGV}$$

where:

A: MGV of the material - the MGV of the aluminum step-wedge increment immediately below the material's MGV.

B: MGV of the aluminum step-wedge increment immediately above the material's MGV - MGV of the aluminum step-wedge increment immediately below the material's MGV.

0.5: 0.5-mm increments of the aluminum step-wedge.

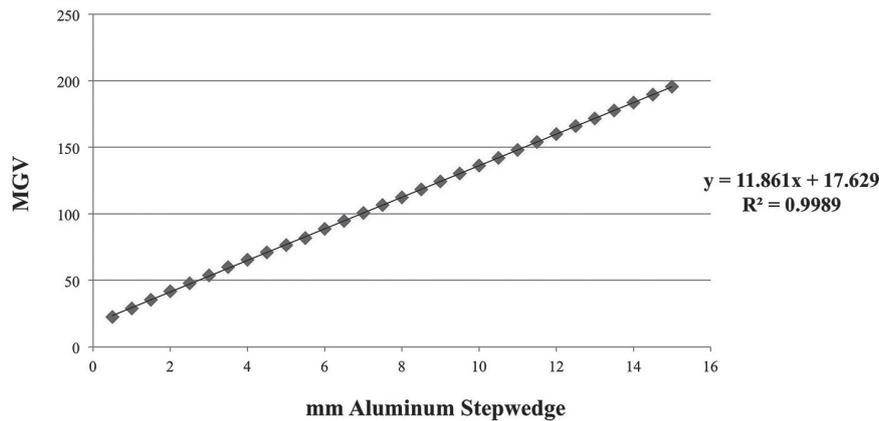


Fig. 2 Example of the calculation of the MGVs for each step of the aluminum step-wedge using a regression curve equation on one of the images of a 4-mm sample.

The following example illustrates the application of this equation to calculate the radiopacity one 4-mm-thick Quixfil sample:

MGV of the sample = 193.68

MGV of the aluminum step-wedge increment (14.5 mm) immediately below that of the sample = 189.61

MGV of the aluminum stepwedge increment (15 mm) immediately above that of the sample = 195.54

Using the equation:

A $(193.68 - 189.61) = 4.07$

B $(195.54 - 189.61) = 5.93$

$(4.07 \times 0.5 / 5.93) + 14.5 \text{ mm Al} = 14.84 \text{ mm Al}$

Statistical analysis

Data were analyzed statistically using two-way analysis of variance (ANOVA, IBM SPSS statistics ver. 20.0, IBM Corp., Armonk, NY, USA) and Tukey's test with the level of significance set at 0.05, to determine the presence of statistically significant differences between the mean values of the tested materials.

Results

Two-way ANOVA of the radiopacity testing data revealed that the radiopacity was significantly affected by the restorative material type and the thickness of the material ($P < 0.05$), and the interaction effect between the evaluated factors was significant ($P < 0.05$) (Table 2). The mean radiopacity values and the standard deviations of the materials, enamel, and dentin are shown in Fig. 3.

There was a statistically significant difference in radiopacity values between the resin-based and glass ionomer-based groups ($P < 0.05$). The radiopacity values increased significantly with the specimen thicknesses ($P < 0.05$).

There was a large variation among the radiopacities of resin-based and glass ionomer-based bulk-fill restoratives, ranging from 1.95 to 5.04 at 1 mm, to 3.44 to 8.51 at 2 mm, and 6.53 to 14.73 at 4 mm. Quixfil had the highest radiopacity value at all thicknesses, while GCP Glass Fill showed the lowest value at all thicknesses.

All of the radiopacities of the resin-based bulk-fill restoratives showed a significant difference in comparison with enamel and dentin ($P < 0.001$). For the glass ionomer-based bulk-fill restoratives, the radiopacity values of Equia Fil were significantly higher than those of enamel and dentin, while the radiopacity values of GCP Glass Fill were significantly higher than only dentin ($P < 0.05$). The radiopacity values of GCP Glass Fill were not significantly different from those of enamel at thicknesses of 1 mm ($P = 1.000$) and 2 mm ($P = 0.211$). At a thickness of 4 mm, the radiopacity of enamel was significantly higher than that of GCP Glass Fill ($P < 0.001$). For the resin-based bulk-fill restoratives, the radiopacity values were significantly higher than those of enamel and dentin ($P < 0.05$).

When the radiopacities of bulk-fill restoratives were comparable to that of the conventional composite, the glass ionomer-based bulk-fill restoratives showed a significant difference ($P < 0.05$), but the resin-based restoratives did not ($P > 0.05$).

Discussion

Secondary caries are generally located on the proximal gingival margin in 80-90% of cases, and radiopaque dental restorative materials allow better radiographic detection of secondary caries (1). In order to allow for a correct diagnosis, restorative materials must have an optimal radiopacity to contrast with secondary caries (2).

Table 2 Two-way ANOVA for the material type, thickness and interaction term according to the radiopacity data ($P < 0.05$)

	Sum of Squares	df	Mean Square	F	P
Corrected model	922.797	23	40.122	6285.897	<0.0001
Intercept	2346.381	1	2346.381	367610.224	<0.0001
Thickness of material	540.717	2	270.358	42357.353	<0.0001
Material type	322.284	7	46.041	7213.240	<0.0001
Material type \times thickness of material	59.796	14	4.271	669.160	<0.0001
Error	0.306	48	0.006		
Total	3269.484	72			
Corrected total	923.103	71			

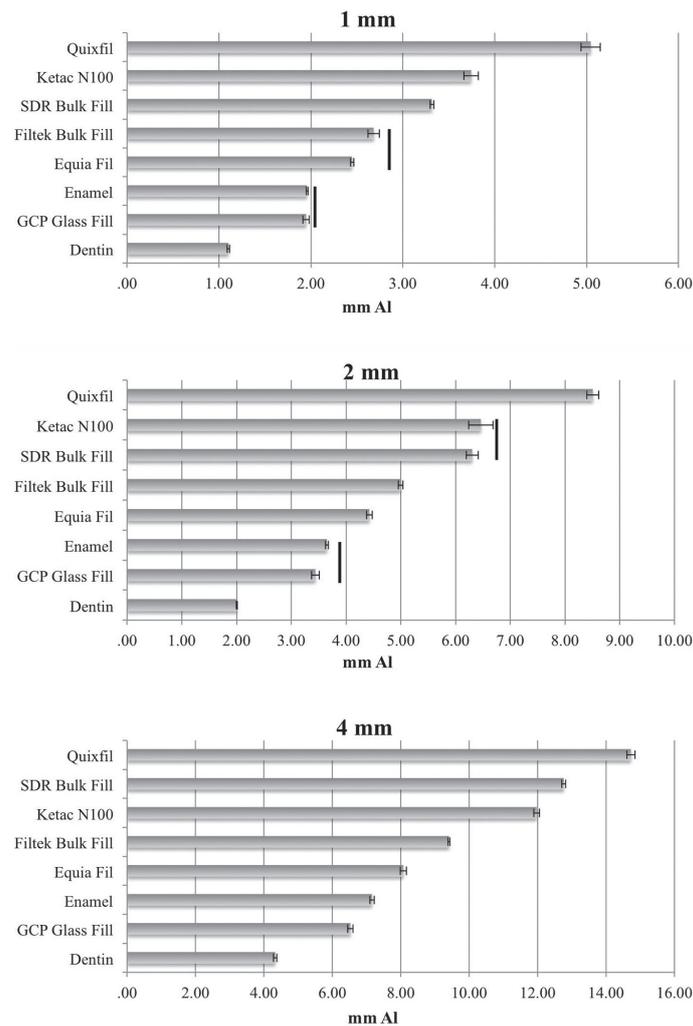


Fig. 3 Mean mm Al radiopacity values of bulk-fill restoratives in comparison to enamel and dentin. (Vertical black lines indicate that the mean values have no statistically significant differences from each other when analyzed using Tukey's test, $P > 0.05$.)

Therefore, materials with a radiopacity lower than that of enamel are not suitable for use as an initial increment. The first increment has to be adequately radiopaque to make the tooth restoration margin clearly visible (22). Otherwise, highly radiopaque materials may mask caries

lesions because of superimposition (23). Moreover, high radiopacity near a less radiopaque area can cause the Mach Band effect, which produces a visual illusion that enhances the contrast between a light and a darker area, making the dark borderline area darker. This effect might

be misinterpreted as caries (1,20). Some authors have suggested that a material with a moderate radiopacity is more appropriate, and that an optimal radiopacity would be slightly greater than enamel (i.e., 2 mm eq. Al) (10-15). In the present study, the radiopacity of the Quixfil and SDR Bulk Fill far exceeded the radiopacity of enamel, making them more likely to obscure the presence of a caries lesion, and therefore less suitable. On the other hand, the radiopacities of Equia Fil and Filtek Bulk Fill seemed to be more appropriate. Additionally, because it has radiopacity values that are similar to or lower than that of enamel, GCP Glass Fill, when used as the first increment in the gingival part of posterior restoration, may result in areas that are misinterpreted as secondary caries on a radiograph. Therefore, GCP Glass Fill should not be used as the first increment in the gingival part of restorations.

The radiopacity of a resin material is related to its content (weight and volume percent) and chemical composition, and can be influenced by specimen thickness (20). In the present study, an increase in thickness was generally correlated with an increased radiopacity of all materials, being consistent with the findings of other studies (2,18,24). When added to the radiopaque filler, elements with a higher atomic number (e.g., barium, zinc, aluminum, strontium, zirconium, silicon, yttrium, ytterbium and lanthanum) increase the radiopacity of the materials because they enhance the capacity to absorb X-rays (2,5,20). Quixfil contains radiopaque fillers, such as zirconia and silica, with a high percentage by both weight and volume (86%, 66%), and therefore it showed the highest radiopacity values among the materials in this study.

One of the disadvantages of conventional glass ionomer is its lack of radiopacity. To overcome this deficiency, radiopaque secondary fillers have been added (25-27). In the present study, Equia Fil showed significantly higher radiopacity values than GCP Glass Fill. Although both of these materials have the same radiopaque filler content, differences may be caused by filler volume fractions, which are not clearly reported by the manufacturers.

ISO standards (6,7) require the minimum radiopacity of restorative materials to be equal to or greater than that of an equivalent thickness of Al. Aluminum was chosen as a reference because it has the same radiopacity as dentin (9). The dentin and enamel radiopacity values in our study were 1.10 and 1.96 at 1 mm, 2.01 and 3.65 at 2 mm, 4.33 and 7.16 at 4 mm eq. Al, respectively. The values for enamel and dentin are in agreement with previous studies, where the dentin radiopacity was close to 1 mm eq. Al and the enamel radiopacity was close to 2

mm eq. Al (3,5,22,28).

In the present study, a digital radiographic system was used. The main advantage of this radiographic digital system is that development procedures are not required. Traditional film development, unless performed carefully, can produce significant variations in the final radiograph. In contrast, a digital method provides more consistent results (8). In addition, it provides the MGV, which is calculated directly by the computer software with the same standard for all specimens. The obtained MGV is used to convert the radiopacity values to millimeters of aluminum (2). In this study, a simplified equation reported by Lachowski et al. (2) was used for conversion to MGVs. However, when this equation is used, the MGV for each step of the step-wedge should be calculated. Therefore, using the originally observed data (MGVs for the first eleven steps of the step-wedge) (Fig. 2), the regression equation was defined for each image in order to calculate the MGVs for the steps of the aluminum step-wedge.

Varying the radiographic exposure time and target distance are factors that affect the radiopacity of restorative materials. Nevertheless, Gu et al. (29) using a digital X-ray system in which the exposure time varied found that this did not significantly affect the radiopacity measured at a target distance of 30 cm, and that varying the target distance did not significantly affect the radiopacity as long as the samples were properly exposed (8). In the present study, the target distance was set to 30 cm and was not changed during the experiment. From a theoretical standpoint, while an underexposed image has a background fog, overexposed images 'black out' objects of low radiopacity (29). In the present study, the exposure time was long enough to visualize a 1-mm thickness of aluminum while not producing very much background fog. Further studies on the radiopacity of bulk-fill restoratives will be necessary for evaluating the effect of different combinations of exposure times and target distances using different X-ray systems.

Within the limitations of this study, the radiopacity values of resin-based and glass ionomer-based bulk-fill restoratives appear to differ considerably, and it is important that any restorative material has sufficient radiopacity to allow detection of secondary caries. All of the tested bulk-fill restoratives in this study passed the ISO requirements for radiopacity.

Declaration of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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