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Evaluation of the Radiopacities of Bulk-fill Restoratives Using Two Digital Radiography Systems

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Clinical Relevance

Bulk-fill restoratives had higher radiopacity values than dentin and enamel at varying thicknesses, which makes these restoratives suitable for radiographic visualization of caries.

SUMMARY

This study investigated the radiopacity values of bulk-fill restoratives by using two digital radiography systems. Nine bulk-fill restoratives and a conventional composite were used in the study. Six disc-shaped specimens were prepared from each of these materials, three each at thicknesses of 1 mm and 2 mm, and tooth slices with these same thicknesses were obtained. As a control, an aluminum step wedge varying in thickness from 0.5 to 10 mm in was used. Three specimens of each of the materials, together with the tooth slice and the aluminum step wedge, were placed over a complementary metal oxide semiconductor (CMOS) sensor and a storage photostimulable phosphor (PPS) plate system and exposed using a dental x-ray unit. The images were analyzed using a software program to measure the mean gray values (MGVs). Five measurements were obtained from each of the restorative materials, the enamel, the dentin, and the stepwedge. The MGVs were converted to the equivalent aluminum thicknesses. Three-way analysis of variance (ANOVA) was used to determine the significance of the differences among the groups. A Tukey test was applied for pairwise comparisons ($p<0.05$). All composite-based restoratives were found to have greater radiopacities than enamel or dentin. Equia Fil had the lowest radiopacity value. Radiopacity increased as the thicknesses of the restorative material increased. The CMOS system showed significantly higher radiopacity values than the

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PSP system. In conclusion, all investigated bulk-fill restoratives passed the International Organization for Standardization and American National Standard Institute/American Dental Association requirements for radiopacity values when evaluated with the two digital radiography systems.

INTRODUCTION

Radiopacity is an essential property for all restorative materials[1] and one of the revised five requirements that a dental material must meet according to the American Dental Association (ADA), Council on Dental Materials, Instruments and Equipment.[2] A material with adequate radiopacity allows detection of secondary caries and distinguishes the caries from the restorative material and surrounding tooth structure. In addition, the proximity of the pulp, marginal defects, overhangs, and open margins can be easily seen.[3,4] Both the International Organization for Standardization (ISO) and American National Standard Institute (ANSI)/ADA have recommended standardized procedures for quantifying material radiopacity using aluminum as a reference.[5] According to the last declaration in IS0 4049:2009, if the manufacturer claims that a material is radiopaque, the radiopacity should be equal to or greater than that of the same thickness of aluminum and no less than 0.5 mm below any value claimed by the manufacturer.[6]

Several factors may affect the radiopacity of dental materials, including the type of restoration, the processing system (digital or conventional), the type of digital sensors, the device setup parameters (exposure time, voltage, and target distance), and material thickness and composition.[7]

Since 1989, digital systems have been used in dental practice and provide numerous advantages over conventional radiographic systems. These benefits include shorter radiation exposure for operator and patient, faster and easier operation, a convenient method to store image and exchange data for referrals, and elimination of the need for film development chemicals.[8] Although traditional film development may produce significant variations in the final radiograph, digital systems provide more consistent results.[5,9,10] However, depending on the radiographic system used, image-modifying procedures, and location on the dental arch, dental materials can show significant differences in radiopacity when measured using digital versus conventional systems.[11,12] In laboratory research, digital systems also offer advantages in evaluating the radiopacity of dental materials. By using the image software programs of these systems, the mean gray values (MGVs) of each material or structure on the radiograph can be calculated within a scale ranging between 0 (black) and 255 (white).[3]

Several types of sensors are used in digital radiographic systems: charge-coupled devices (CCDs); complementary metal oxide semiconductor (CMOS), also referred to as wired sensors or direct systems; and photostimulable phosphor (PSP) plates, also referred to as wireless sensor or indirect systems. Both direct and indirect digital radiograph systems allow quantitative measurements, enlargement to focus on areas of interest, color correction, and adjustment of contrast and density to sharpen and improve image quality. However, the exposure times required by direct systems are lower than those for indirect systems, and the image quality is higher.[11] Although CCD and CMOS use basically the same approach, it has been reported that CMOS sensor values were comparable to those of the CCD sensors but require higher exposure times.[13]

Although the radiopacity of dental materials may be affected by several factors, composition of the materials seems to be the most important. With improvements in the chemical compositions of resin-based composites and the variety of filler reinforcements in the material compositions, many categories of dental materials are now available. As long as new materials are released to the market, ongoing studies to evaluate the radiopacity of dental materials are important to avoid misinterpretation during image diagnosis.[14] Bulk-fill restoratives were introduced as a new category of low- and high-viscosity composites for Class I and Class II restorations. Instead of using the current incremental placement technique, this new material can be placed in a 4-mm thickness because of its particular qualities compared with restoratives with similar properties.[15] It is assumed that the composition of bulk-fill restoratives does not differ markedly from that of current incrementally filled conventional resin composites. 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 radiologic characteristics, as did the depth of cure and mechanical properties in the study by Finan and others.[16] However, there are no comparative data regarding the radiopacity of bulk-fill restoratives. Therefore, the aim of the present study was to evaluate the radiopacities of nine recently produced bulk-fill restoratives at different

Table 1: *Materials used in the study*

Material	Radiopaque Filler Content and Filler % (wt/vol)	Manufacturer	Batch No
X-tra base	Not applicable (75/58)	Voco GmbH, Cuxhaven, Germany	1147278
Tetric N-Ceram Bulk Fill	Barium glass, ytterbium trifluoride, mixed oxide; (77/55)	Ivoclar Vivadent AG, Schaan, Liechtenstein	R72543
Tetric EvoCeram Bulk Fill	Barium aluminium silicate glass, prepolymer filler, ytterbium fluoride, and spherical mixed oxide (80/61)	Ivoclar Vivadent AG, Schaan, Liechtenstein	R82389
SonicFill	Glass, oxide, chemicals, silicon dioxide (not applicable/83)	Kerr Corporation, Orange, CA, USA	3851730
X-tra fill	Barium aluminium silicate glass (86/70)	Voco GmbH, Cuxhaven, Germany	1245232
SDR Bulk Fill	Barium alumino fluoro borosilicate glass, strontium alumino fluoro silicate glass (68/44)	Dentsply DeTrey, Konstanz, Germany	1001086
Quixfil	Zirconium oxide, silicon dioxide (86/66)	Dentsply DeTrey, Konstanz, Germany	121000
Equia Fil	Fluoro alumino silicate glass (not applicable)	GC Corp, Tokyo, Japan	1203121
Filtek Bulk Fill	Zirconia/silica, ytterbium trifluoride (64/42)	3M ESPE, St Paul, MN, USA	N435626
Clearfil Majesty Posterior	Silanated glass ceramics, Surface-treated alumina microfiller, silanated silica filler (92/82)	Kuraray, Medical Co., Tokyo, Japan	00152

Abbreviations: CMOS, complementary metal oxide semiconductor; PSP, photostimulable phosphor.

thicknesses using two different digital radiography systems. The null hypothesis was that there was no statistically significant difference in the radiopacities of bulk-fill restoratives at different thicknesses.

METHODS AND MATERIALS

Specimen Preparation

Nine bulk-fill restoratives and a conventional composite were used in this study. Table 1 lists the materials, chemical compositions, manufacturers, and batch numbers.

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 and others.[3] Although according to the data from that study, 12 specimens are sufficient for analysis, a worst-case scenario was proposed with a 0.99 effect size for the current study. According to the worst-case scenario, a total sample size of 27 (n=3) was calculated considering 87% power at a significance level of 0.05. Plastic ring molds with an internal diameter measuring 6 mm and depths of 1 mm and 2 mm were used to prepare standardized specimens. Three specimens were prepared from each of the materials at each height in accordance with the manufacturers' instructions. The mold was placed on a glass microscope slide, and the materials were inserted into the mold until it was overfilled. A Mylar matrix strip was then placed on the top. A second glass slide was positioned over the strip to flatten the surfaces before curing using a light-activating source (Valo, Ultradent Products Inc, South Jordan, UT, USA). The specimens of each material were cured through the Mylar strip and glass slide. After the specimens were removed from the mold, the thicknesses were verified with a digital caliper to ensure standardization. The specimens were placed in 37°C distilled water for one day to complete the polymerization process, then maintained in moist conditions pending the radiographic procedures.

One freshly extracted human molar was used to obtain enamel and dentin specimens. The tooth was prepared by longitudinal sectioning using a slow-speed diamond saw (Isomet1000, Buehler, Lake Bluff, IL, USA), and slices measuring 1 mm and 2 mm in thickness were obtained. The tooth specimens were stored in distilled water pending evaluation.

Digital Radiography

A 99% pure aluminum step wedge with 20 incremental steps measuring 0.5 mm was used. Three specimens of each material, together with the aluminum stepwedge and a tooth specimen, were positioned over the CMOS sensor (Digora Toto, Soredex, Milwaukee, WI, USA), and the storage phosphor plate system (VistaScan, Dürr Dental, Bietigheim-Bissingen, Germany) on each of the radiographs. All specimens were placed at a distance

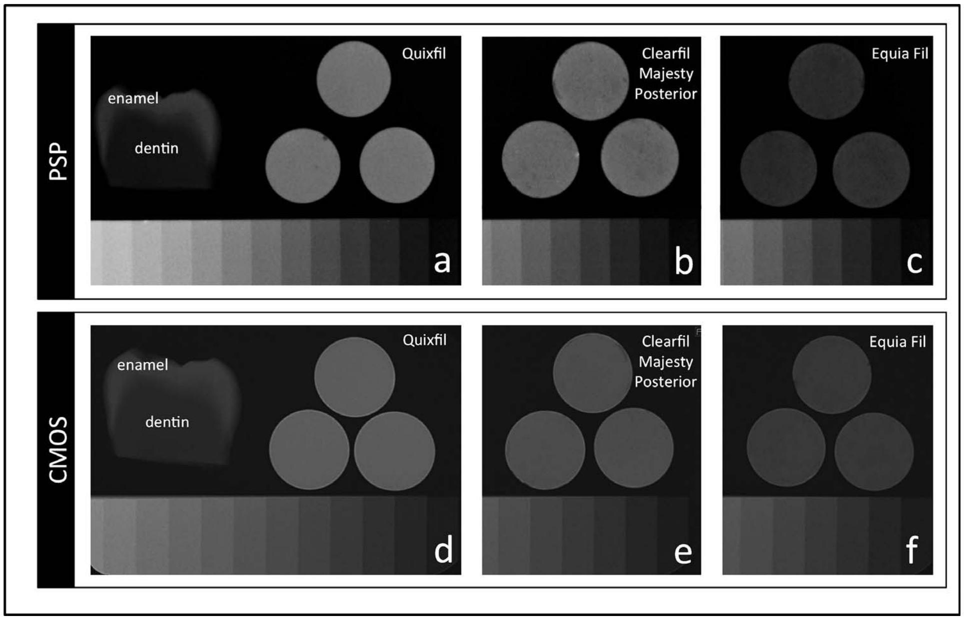

Figure 1. *Radiographic images of the enamel, dentin, aluminum step wedge in which the highest and the lowest radiopacity bulk-fill restoratives were tested in comparison to the conventional composite at thicknesses of 1 mm over the storage phosphor plate (upper) and the complementary metal oxide semiconductor sensor (lower). (a and d): Quixfil; (b and e): Clearfil Majesty Posterior; (c and f): Equia Fil.*

of 30 cm for 0.32 seconds in a dental x-ray unit (65 kVp/7 mA, Myray, Cefla Dental Group, Imola, Italy). Figures 1 and 2 show radiographic images of the enamel, dentin, aluminum step wedge, and a material at different thicknesses over the CMOS sensor and the storage phosphor plate.

The MGVs of each of the materials and tooth slices were measured on the digital radiographs using the Adobe Photoshop CS3 Extended computer program, version 10.0 (Adobe Systems, San Jose, CA, USA), in five different regions each with a 10 × 10 pixel area to reduce measurement bias. Selected regions avoided areas containing air bubbles or other anomalies, and measurements were taken by one evaluator, who was blinded to the identities of the materials. After the MGVs of visible steps of the aluminum step wedge on the image were calculated, a regression curve equation ($y = 10.209x + 13.265$; R^2=0.99876) was defined for the MGVs of further steps that could not be seen on the image because of limited dimensions of CMOS and PSP. The MGVs of each of the materials and tooth slices were then converted

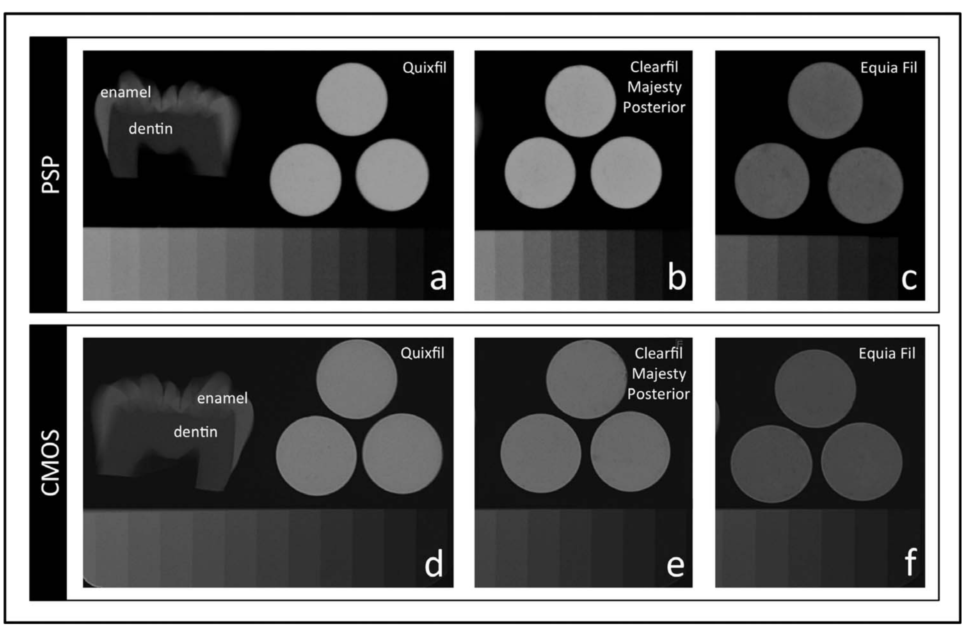

Figure 2. *Radiographic images of the enamel, dentin, aluminum step-wedge, and tested bulk-fill restoratives in comparison to the conventional composite at thicknesses of 2 mm over the storage phosphor plate (upper) and the complementary metal oxide semiconductor sensor (lower). (a and d): Quixfil. (b and e): Clearfil Majesty Posterior; (c and f): Equia Fil.*

Table 2: *Mean radiopacity values and standard deviation of the materials, enamel, and dentin at 1-mm, and 2-mm*

Material	Radiography Method	1 mm	2 mm
X-tra base	CMOS	3.38±0.09	7.06±0.04
	PSP plate	2.61±0.10	6.02±0.05
Tetric N-Ceram Bulk Fill	CMOS	3.68±0.05	7.68±0.13
	PSP plate	3.25±0.10	7.02±0.01
Tetric EvoCeram Bulk Fill	CMOS	3.67±0.07	7.73±0.02
	PSP plate	3.19±0.05	6.36±0.01
SonicFill	CMOS	3.07±0.01	6.59±0.04
	PSP plate	2.51±0.01	5.27±0.03
X-tra fill	CMOS	3.83±0.02	8.15±0.03
	PSP plate	2.93±0.07	6.59±0.01
SDR Bulk Fill	CMOS	2.92±0.09	6.27±0.08
	PSP plate	2.34±0.03	5.85±0.03
Quixfil	CMOS	3.98±0.04	7.69±0.04
	PSP plate	3.55±0.03	6.85±0.02
Clearfil Majesty Posterior	CMOS	2.98±0.08	6.44±0.05
	PSP plate	2.47±0.03	5.52±0.08
Equia Fil	CMOS	2.03±0.03	3.97±0.08
	PSP plate	1.60±0.01	3.63±0.01
Filtek Bulk Fill	CMOS	2.48±0.01	5.08±0.03
	PSP plate	2.20±0.01	4.87±0.05
Enamel	CMOS	1.99±0.04	3.63±0.03
	PSP plate	1.94±0.09	3.43±0.05
Dentin	CMOS	1.04±0.01	1.92±0.01
	PSP plate	0.94±0.23	1.83±0.05

into millimeters of aluminum (mm Al) using the following equation described by Lachkowski and others:[3]

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

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 stepwedge increment immediately below the material's MGV.

0.5: increment thickness of the aluminum stepwedge.

Statistical Analysis

All statistical analyses were performed using SPSS Statistics, version 20.0 (SPSS Inc, Chicago, IL, USA) at a significance level of 0.05 and a confidence interval of 95%. The resulting data were statistically analyzed using a three-way analysis of variance (ANOVA), considering three factors (restorative material type, thickness of material, and radiographic system). A Tukey post hoc test was used for multiple comparisons.

RESULTS

The three-way ANOVA of the radiopacity data revealed that radiopacity was significantly affected by the restorative material type, thickness of the material, and type of radiographic system used ($p<0.001$). All interactions between the evaluated factors were significant ($p<0.001$).

The mean radiopacity values and standard deviations of the enamel, dentin, and materials are shown in Table 2 and Figure 3. There was a large variation between the radiopacities of the bulk-fill restoratives. Using the CMOS system, values ranged from 2.03 to 3.98 mm Al at 1 mm and from 3.97 to 8.15 mm Al at 2 mm, Using the PSP system, values ranged from 1.60 to 3.55 mm Al at 1 mm and from 3.63 to 7.02 mm Al at 2 mm. The highest radiopacity was observed in Quixfil using both radiographic systems at 1-mm thickness (Figures 1a and 1d), X-tra Fil using CMOS at 2 mm thickness, and Tetric N-Ceram Bulk Fill using PSP at 2-mm thickness. Equia Fil had the lowest radiopacity at all parameters (Figures 1c, 1f, and 2c, 2f).

Each of the bulk-fill restoratives, except for Equia Fil and the conventional composite, showed higher radiopacities than did the dentin and enamel at all thicknesses and using both radiographic systems ($p<0.001$). Although Equia Fil had a higher radiopacity than dentin parameters ($p<0.001$), its radiopacity was similar to that of enamel (Figure 3).

When the radiopacities of the bulk-fill restoratives were compared with that of conventional composite using the CMOS, there was a significant difference between the materials, except for Sonic Fill and SDR Bulk Fill at both thicknesses ($p<0.001$) (Figures 3a and 3c). Using the PSP system, the radiopacity of the conventional composite was not significantly different from that of X-tra base, Sonic Fill, SDR Bulk Fill, or Filtek Bulk Fill at 1 mm ($p=0.086$) (Figure 3b), whereas it was significantly different at 2 mm ($p<0.001$) (Figure 3d).

The results showed that increased thicknesses in the materials that were studied correlated with significant increases in their radiopacity ($p<0.001$) (Figures 1 and 2). The CMOS system showed

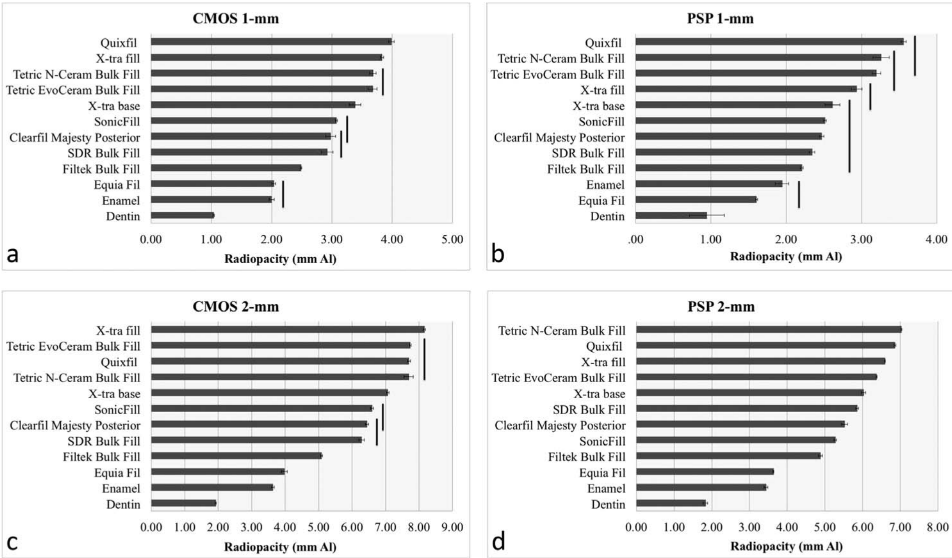

Figure 3. *The mean values of radiopacity (millimeters of aluminum) and standard deviations of nine bulk-fill restoratives and the conventional composite in comparison to enamel and dentin. (a): 1-mm thickness on complementary metal oxide semiconductor (CMOS); (b): 1-mm thickness on the photostimulable phosphor (PSP) plate system; (c): 2 mm thickness on CMOS; (d): 2 mm thickness on PSP. Vertical black lines indicate that the mean values have no statistically significant differences from each other when analyzed using a Tukey test ($p>0.05$.)*

significantly higher radiopacity values than the PSP system, independent of the material thickness ($p=0.036$).

DISCUSSION

The radiopacity of a restorative material is a valuable diagnostic tool for evaluating the quality and long-term success of restorations. The radiographic diagnosis of recurrent caries, inadequate proximal contours, and marginal adaptation can be accurately interpreted because of the proper contrast between the enamel/dentin and the restorative material. Marginal defects and secondary caries are usually positioned on the gingival third of Class II restorations.[17] The first increment of the restorative material must be adequately radiopaque to be able to clearly evaluate the tooth-restoration interface.[4] It is desirable for resin composites to have a radiopacity equal to or greater than that of the enamel.[17] Materials with a radiopacity that is less than that of the enamel are not recommended for clinical usage in areas that are prone to secondary caries, especially as an initial increment material in cavities.[4]

Based on our results, the null hypothesis must be rejected because the radiopacities of the bulk-fill restoratives were significantly different. All of the composite-based bulk-fill restoratives showed higher radiopacity values than the enamel and dentin. Only Equia Fil, a glass ionomer–based material, showed similar radiopacity values to enamel; the radiopacity values of Equia Fil were higher than those of dentin. There are no previous studies in the dental literature that compared bulk-fill restorative radiopacities, although two of the bulk-fill restoratives in our study, Quixfil and SDR Bulk Fill, were compared with conventional composites in studies by Dukic and others[18] and Lachowski and others.[3] They reported radiopacities of 4.26 and 3.11 mm Al at 1-mm thickness on CCD for Quixfil and SDR Bulk Fill, respectively, whereas the present study showed 3.98 mm and 2.92 mm Al, respectively using CMOS and 3.55 mm and 2.34 mm Al, respectively, using PSP. The purity of the aluminum, methods used for evaluation, and thicknesses of the specimens are among the important factors causing variability in radiopacity.[19]

The composition of the material seems to be the most important factor that influences radiopacity.[20] The radiopacity of a material increases with a higher percentage of filler and larger amounts of elements with high atomic numbers in the filler particles.[21,22] Therefore, the manufacturers include chemical elements, such as barium, zinc, aluminum, strontium, silicon, yttrium, ytterbium, and lanthanum, in their products to increase radiopacity.[8] The higher the atomic number of the element added to the radiopaque filler, the higher the radiopacity of the material, because the absorption capacity of x-rays is increased.[3] The radiopacity of a dental composite material will exceed that of human enamel[22] if the filler volume is increased to 70% or beyond, and the amount of radiopaque oxide in filler particles is >20%.[21]

According to our results, Filtek Bulk Fill and SDR Bulk Fill, which have lower weight and volume percentages, showed lower radiopacity values compared with other materials. Tetric N-Ceram Bulk

Fill, Tetric EvoCeram Bulk Fill, Quixfil, and X-tra fill composite materials have high filler percentages; they also include radiopaque fillers that are composed of elements with higher atomic numbers in the filler composition, which leads to significantly higher radiopacity values compared with the other bulk-fill restoratives and enamel. The compound fluoro alumino silicate glass, which is a radiopaque filler used in the glass ionomer–based Equia Fil, did not provide an adequate amount of radiopacity, although the other fillers did. The ISO has stated that a resinous dental material should be at least as radiopaque as the same thicknesses of pure aluminum,[6] and the ADA recommends that these materials have a radiopacity equivalent to 1 mm Al, which is approximately equal to that of natural tooth dentin.[23] Some authors have suggested that a radiopacity equal to or slightly greater than enamel is more appropriate to detect secondary caries in posterior teeth.[24] It has been reported that highly radiopaque materials may mask caries because of superimposition. Moreover, a high radiopacity near a less radiopaque area can cause the Mach band effect, which produces a visual illusion that enhances the contrast between a lighter and a darker area, making the dark borderline area appear darker. This effect might be misinterpreted as caries.[25] In the current study, the radiopacities of Quixfil, X-tra fill, Tetric N-Ceram Bulk Fill, Tetric Evoceram Bulk Fill, and X-tra Base far exceeded the radiopacity of enamel, making them less suitable because excessive radiopacity may obscure the presence of a caries lesion.

According to recent literature, the radiopacities of resin composites, regardless of viscosity, exhibit huge variations. Independent of the radiographic system and evaluation method, radiopacity values of resin composites for 1-mm thickness are in the range of 1.7-3.5 mm Al,[3] 0.74-4.73 mm Al,[18] 1.29-4.63 mm Al,[25] and 1.50-3.88 mm Al,[25] similar to the values obtained in our study. Considering the results of previous reports and those of the current study, it may seem that the radiopacities of bulk-fill restoratives do not differ from those of incrementally filled conventional resin composites. Additionally, the present study showed that the increased thicknesses of bulk-fill restoratives improved their radiopacity values; this was also found by Lachowski and others[3] and by Pires de Souza and others.[26]

Direct systems have been found to be superior to PSP systems and a conventional system according to study by Wicht and others.[11] Comparison of direct digital sensors considering their advantages and disadvantages is controversial because CMOS receptors have only recently become available for x-ray use.[27] CCDs for x-ray imaging are a very stable and mature industry. They are popular because of their large detector format, high spatial resolution, good quantum efficiency, and nearly Fano-limited energy resolution. However, CCDs have pile-up limitations, problems associated with radiation damage, and high power requirements that become especially serious for long-lived, high-throughput x-ray missions. On the other hand, CMOS receptors are less sensitive to radiation damage, reduce power consumption, offer low costs, and produce a nondestructive and simple readout.[28] Theoretically, CMOS sensors are less efficient at gathering light and x-rays and, thus, have a lower quantum efficiency than CCDs. This means they gather less x-ray or light photon information and thus may not have as much diagnostic information to display. To compensate for reduced x-ray gathering, the CMOS sensors have microlenses and scintillators bonded to them to gather more light.[27]

The results of our study show that the radiopacity values of bulk-fill restoratives were significantly affected by different digital radiography methods, which agrees with the findings of Wicht and others.[11] who demonstrated that a CMOS sensor was the only radiographic system to show the space between the post and the dentin. This result might be an effect of the digital system automatic image processing, which could not be switched off, and of the high spatial resolution of the CMOS sensor. These findings are supported by Shi and others[29] who reported that CMOS sensors had increased perception for low-contrast details and were more sensitive than CCD.

Varying the radiographic exposure time and target distance are factors that affect the radiopacity of restorative materials.[7,30] Nevertheless, Gu and others,[5] using a digital x-ray system, reported that varying exposure times did not significantly affect the radiopacities of three typical dental products measured at a target distance of 30 cm, and varying target distance did not significantly affect the radiopacity as long as the samples were properly exposed. However, different radiography systems may require different exposure times and target distances.[13] From a theoretical standpoint, although an underexposed image has a background fog, overexposed images black out objects of low radiopacity.[5] In the present study, the exposure time was long enough so that not much background fog was produced and 1 mm of the aluminum step wedge was visualized. Further studies on the radiopacities of bulk-fill restoratives are necessary to evaluate the effect of different exposure time and target distance combinations with different x-ray systems.

CONCLUSIONS

All of the bulk-fill restoratives that were tested passed the ISO and ANSI/ADA requirements for radiopacity. There were no differences in radiopacity between conventional composites and the bulk-fill materials. Varying thicknesses of bulk-fill restoratives affected their radiopacities. The radiopacity values of the CMOS system were found to be higher than those of the PSP system.

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Regulatory Statement

This study was conducted in accordance with all the provisions of the local human subjects oversight committee guidelines and policies of the Izmir Katip Celebi Non-Interventional Clinical Studies Institutional Review Board. The approval code for this study is 201404750. This study was conducted by Sifa University, Department of Restorative Dentistry.

Conflict of Interest

The authors of this manuscript certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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