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Evaluation of the radiopacity of restorative materials with different structures and thicknesses using a digital radiography system

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ABSTRACT

Purpose: The aim of this study was to evaluate the radiopacities of various types of restorative materials with different thicknesses compared with enamel, dentin, and aluminum.

Materials and Methods: Four bulk-fill resins, 2 hybrid ceramics, 2 micro-hybrid resin composites, 6 glass ionomer-based materials, 2 zinc phosphate cements, and an amalgam were used in the study. Twelve disk-shaped specimens were prepared from each of 17 restorative materials with thicknesses of 1 mm, 2 mm, and 4 mm ($n=4$). All the restorative material specimens with the same thickness, an aluminum (Al) step wedge, and enamel and dentin specimens were positioned on a phosphor storage plate and exposed using a dental X-ray unit. The mean gray values were measured on digital images and converted to equivalent Al thicknesses. Statistical analyses were performed using 2-way analysis of variance and the Bonferroni *post hoc* test ($P<0.05$).

Results: Radiopacity was significantly affected by both the thickness and the material type ($P<0.05$). GCP Glass Fill had the lowest radiopacity value for samples of 1 mm thickness, while Vita Enamic had the lowest radiopacity value for 2-mm-thick and 4-mm-thick samples. The materials with the highest radiopacity values after the amalgam were zinc phosphate cements.

Conclusion: Significant differences were observed in the radiopacities of restorative materials with different thicknesses. Radiopacity was affected by both the material type and thickness. ***(Imaging Sci Dent 2021; 51: 261-9)***

KEY WORDS: Dental Materials; Radiography, Dental, Digital

Introduction

The radiopacity of restorative materials is particularly important for radiographic diagnoses[1] because adequate radiopacity enables clinicians to assess restoration integrity, to observe the restoration margins to diagnose secondary caries, and to distinguish restorative material from carious and sound tooth structures.[2] Additionally, restoration failures and problems related to the operator's skill can be detected on radiographs.[3] Therefore, the radiopacities of dental materials have been studied in detail, and radiographs are one of the main diagnostic tools used in dentistry for patient examinations.

Clinical examinations can detect approximately 15% of restoration failures, while radiography can reveal most of the remaining failures.[4] One of the common reasons for failure in posterior resin composite restorations is secondary caries located under the proximal gingival walls,[5] which are difficult to diagnose clinically. The restorative material used in posterior restorations should have sufficient radiopacity to permit the diagnosis of secondary caries.[6] In addition, with sufficient radiopacity, clinicians can assess the adaptation of the restoration, its contact with neighboring teeth, voids, and interfacial gaps of the restoration.[7]

Resin composites are frequently preferred in dental applications due to their favorable aesthetic properties and ease

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of use. The radiographic evaluation of these materials allows the dentist to distinguish the restorative material from carious lesions and to assess the lack of adaptation along the cervical margins.[8] For the restoration of posterior teeth, the use of resin composite materials that are more radiopaque than enamel and dentin is suggested for accurate detection of the restoration-tooth interface.[6] Various types of composite resins with different compositions, fillers, and matrix types are currently available on the market. The flowable resin composites have more cavity adaptation and flexibility, as they are less viscous as a result of their low filler content.[9] Since the recently developed resin-based bulk-fill composite materials can be polymerized up to a thickness of 4 mm, they do not require time-consuming layering. The use of bulk-fill composite resins of different thicknesses affects the radiopacity of the material.[10]

The radiopacity of glass ionomer-based restorative materials is highly variable.[11] These materials should have adequate radiopacity for use as a base, lining, and restorative material. If materials that are less radiopaque than dentin are used as a base, they could be mistaken for carious or decalcified dentin on radiographs.[12] Glass ionomer-based bulk fill materials continue to be used in dentistry with the latest developments in their composition. High-viscosity glass ionomers are used as an alternative to amalgam, especially in the atraumatic restorative treatment technique. The phased discontinuation of amalgam use has been discussed in recent years because of the ecotoxic features of mercury;[13] however, the radiographic diagnosis of failed amalgam restorations is a routine clinical procedure.

The radiopacity of dental restorative materials has been standardized by the International Standards Organization (ISO). According to ISO 4049 and ISO 9917, for the manufacturer to claim their product as radiopaque, the restorative material must have a radiopacity of equal to or greater than the radiopacity of the same thickness of aluminum (Al).[14,15] Van Dijken et al.[16] reported that at the same thickness, the radiopacity of dentin was almost equal to that of Al, and the radiopacity of enamel was almost twice that of Al. It has also been reported that an ideal restorative material should have a radiopacity equal to or slightly higher than that of enamel in order to detect secondary caries on radiography.[17]

Densitometers or digital radiography systems with Al step wedges are commonly used to assess the radiopacity of dental restorative materials.[18] The main advantages of digital imaging systems that are routinely used in dentistry are the shorter X-ray exposure time, improved speed and ease of use, and accurate evaluation of radiopacity, when compared with traditional radiographic systems.[19]

Although the radiopacity of resin composites has been evaluated in many studies, no published article has yet compared different permanent restorative materials and base materials with different thicknesses. The aim of this study was to evaluate the radiopacities of restorative materials with different thicknesses that are routinely used in clinics, including zinc phosphate cement, glass ionomer-based materials, amalgam, resin composites, bulk-fill composites, and hybrid ceramics, using a digital radiography system.

The null hypotheses of the study were that the type of materials tested in the study would not significantly affect the radiopacity and that the thicknesses of the materials tested in the study would not significantly affect the radiopacity.

Materials and Methods

Four bulk-fill restoratives, 2 hybrid ceramics, 2 microhybrid resin composites, 6 glass ionomer-based materials, 2 zinc phosphate cements, and 1 amalgam were evaluated in this study. The types of restorative materials, compositions, and manufacturers are listed in Table 1. The sample size was calculated considering 80% power and a significance level of 0.05 (effect size = 0.50).

Metal molds with depths of 1 mm, 2 mm, and 4 mm and an internal diameter of 5 mm were used to prepare the standardized specimens. Four specimens were prepared in accordance with the manufacturers' instructions for each material at each depth. The mold was placed on a glass microscope slab, and restorative materials were overfilled. A mylar matrix strip was then placed and a glass slab was placed over the strip to flatten the surface of each specimen. The light-activated resin composite materials were polymerized with a light curing unit (1000 mW/cm^2; Woodpecker LED D unit, Guilin Woodpecker, Guangzhou, China). In the GCP Glass Fill group, a light curing unit (1400 mW/cm^2, CarboLED, GCP Dental, Ridderkerk, Netherlands) was applied to the specimens for 60 s. Chemically cured materials were allowed to set for the time period according to manufacturers' instructions. The thickness of each specimen was controlled with a digital caliper to ensure standardization. The specimens were stored under moist conditions at 37°C until the radiographic experiments were carried out.

Enamel and dentin specimens with thicknesses of 1 mm, 2 mm, and 4 mm were obtained from freshly extracted human molars that were free of caries, cracks, or fractures with a

Table 1. Materials used in the study

Material	Type	Radiopaque filler content-filler (wt%/vol%)	Manufacturer	Batch No.
Beautifil Bulk Restorative	Bulk-fill	Fluoro-silicate glass - (72.5%/51%)	Shofu, Kyoto, Japan	031832
Filtek One Bulk Fill	Bulk-fill	Ytterbium trifluoride, zirconia/silica - (76.5%/58.5%)	3M Dental Products, St. Paul, MN, USA	NA44194
Filtek Bulk Fill Flowable	Flowable bulk-fill	Ytterbium trifluoride, zirconia/silica - (64.5%/42.5%)	3M Dental Products, St. Paul, MN, USA	NA38730
Estelite Bulk Fill Flowable	Flowable bulk-fill	Spherical silica-zirconia - (70%/56%)	Tokuyama, Tokyo, Japan	060E29
Cerasmart	Composite resin nanoceramic	Silica (20 nm), barium glass (300 nm) - (71%/NA)	GC Corparation, Tokyo, Japan	1809193
Vita Enamic	Polymer infiltrated ceramic network (PICN)	Feldspar ceramic enriched with aluminum oxide - (86%/75%)	Vita Zahnfabrik, Bad Säckingen, Germany	78540
Filtek Z250	Micro-hybrid resin composite	Zirconia/silica - (NA/60%)	3M/ESPE, St Paul, MN, USA	NA49030
G-aenial Posterior	Micro-hybrid resin composite	Fluoroaluminosilicate, fumed silica, pre-polymerized fillers (16-17 μm), silica, strontium and lanthanoid fluoride - (77%/65%)	GC Corparation, Tokyo, Japan	81011A
Photac-Fil Quick Aplicap	Resin-modified glass ionomer (RMGI)	Fluoro-aluminasilicate glass - (76%/NA)	3M/ESPE, St Paul, MN, USA	5015644
Fuji II LC	Resin-modified glass ionomer (RMGI)	Fluoro-aluminosilicate glass - (58%/NA)	GC Corporation, Tokyo, Japan	190204A
EQUIA Forte	High-viscosity glass ionomer (Hv-GIC)	Fluoro-aluminosilicate glass, iron oxide	GC Corporation, Tokyo, Japan	1903161
Fuji IX	High-viscosity glass ionomer (Hv-GIC)	Aluminosilicate glass	GC Corporation, Tokyo, Japan	181127A
Ketac Cem	Glass ionomer cement (GIC)	Fluoro-aluminosilicate glass	3M, Seefeld, Germany	4898088
GCP Glass Fill	Glass carbomer	Fluoro-aluminosilicate glass, Hydroxyapatite, and Fluorapatite	GCP Dental, Vianen, Netherlands	71704318
Master Dent	Zinc phosphate cement	NA	Dentonics, North Caroline, USA	3080045
Adhesor	Zinc phosphate cement	Metal oxide (Mg, Al, Zn, B)	Spofa Dental, Praha, Czech Republic	6768123
Nogama	High copper amalgam alloy	Ag 69.5%, Sn 19.5%, Cu 10.5%, Zn 0.5% (by weight)	Silmet Ltd, Or Yehuda, Israel	310007068

low-speed diamond saw (Microcut 201, Metkon, Bursa, Turkey). The tooth slices were stored in distilled water until the radiographic experiments were carried out.

All the restorative material specimens with the same thickness, as well as the enamel and dentin specimens and an Al step wedge, were positioned on a phosphor storage plate (PSP) (size 4; 5.7×7.5 cm, VistaScan, Dürr Dental, Bietigheim-Bissingen, Germany). The Al step wedge was made of 99.5% Al alloy with a thickness ranging from 1 mm to 10 mm in uniform steps of 1 mm. Digital radiographic images were obtained with a dental X-ray unit for 0.20 s (Kodak 2100; 60 kVp/7 mA, Eastman Kodak Co, Rochester, NY, USA). The distance between the head of the X-ray unit and the specimens was 30 cm, and the central X-ray beam was directed at a 90° angle. The PSPs were scanned immediately after exposure (Vistascan Mini Easy,

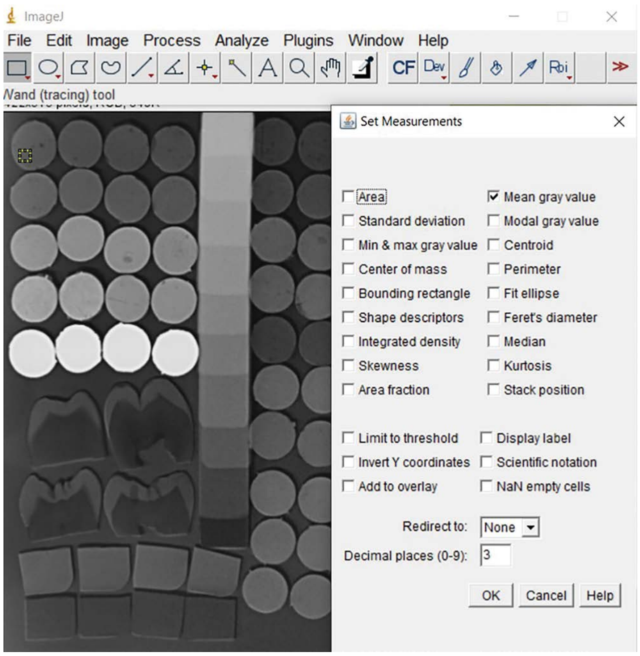

Fig. 1. Screenshot reveals the measurement of mean gray values on digital images using software (ImageJ).

Dürr Dental, Bietigheim-Bissingen, Germany).

Radiographic images were exported in TIFF format with a contrast resolution of 8-bits and spatial resolution of 25 line-pairs per mm. The mean gray values (MGV) of the Al step wedge, enamel, dentin, and materials were measured on digital images using a software (ImageJ, National Institute of Health, Bethesda, MD, USA). Measurements were made on 3 different regions of the samples with a size of 1 mm^2 (square, 10×10 pixels) that were free of bubbles, and the means of these readings were calculated (Fig. 1). The MGVs of each sample, as well as the enamel and dentin specimens, were converted into millimeters of aluminum (mmAl) using the equation described by Lachowski and others[1]:

$$A \times T/B + \text{mmAl below the material's MGV},$$

where A is the MGV of the material - the MGV of the Al step wedge increment immediately below the material's MGV, B is the MGV of the Al step wedge increment immediately above the material's MGV - MGV of the Al step wedge increment immediately below the material's MGV, and T is the thickness of the Al step wedge increment.

Statistical analyses were performed using 2-way analysis of variance (ANOVA) considering 2 factors (type of restorative material and specimen thickness) at a significance level of 0.05. The Bonferroni *post hoc* test was used for multiple comparisons.

Results

The results of two-way ANOVA revealed that the radiopacity values were significantly affected by the type and thickness of the restorative material ($P < 0.05$). The interaction between material type and material thickness was also significant ($P < 0.05$). The mean radiopacity and standard deviations of equivalent Al values of the materials, enamel, and dentin for different thicknesses are presented in Figures 2-4 and Table 2.

Large variance was found in the radiopacity values of the tested materials. The radiopacities of the bulk-fill restorative materials ranged from 1.93 to 3.96 mmAl for samples of 1 mm thickness, from 3.41 to 7.04 mmAl for samples of 2 mm thickness, and from 6.18 to 10.54 mmAl for samples of 4 mm thickness. The highest radiopacity was observed for the Beautifil Bulk Restorative samples, and the Estelite Bulk Fill Flowable samples had the lowest radiopacity of the bulk-fill restoratives at all thicknesses.

The radiopacity values of the Vita Enamic were 2.01, 2.31, and 3.56 mmAl, and the corresponding values of the Cerasmart were 3.23, 5.83, and 10.21 mmAl for 1 mm, 2 mm, and 4 mm, respectively. The Cerasmart showed significantly higher radiopacities at all thicknesses ($P < 0.05$).

Regarding micro-hybrid composite resins, the radiopacity values of the Filtek Z 250 were 3.72, 6.90, and 10.43 mmAl, and those of the G-eanial Posterior were 3.80, 6.47, and 10.16 mmAl for thicknesses of 1 mm, 2 mm, and 4 mm, respectively. The radiopacities of these 2 micro-hybrid composites were similar at all thicknesses ($P > 0.05$).

The radiopacity values of the glass ionomer-based restorative materials ranged from 1.66 to 3.48 mmAl at 1 mm thickness, from 3.27 to 6.84 mmAl at 2 mm thickness, and from 6.62 to 10.66 mmAl at 4 mm thickness. The GCP Glass Fill samples had the lowest radiopacity values, and the highest radiopacity values were observed for the Photac Fil Quick Aplicap at all thicknesses of the glass ionomer-based restorative materials. The Adhesor showed significantly higher radiopacity than the Master Dent at 1 mm ($P < 0.05$), while differences between the zinc phosphate cements were not significant at 2 mm and 4 mm ($P > 0.05$). The highest radiopacity values were observed in the amalgam alloy group at all thicknesses ($P < 0.05$).

Each of the tested materials, except for the GCP Glass Fill at 1 mm, 2 mm, and 4 mm, and the Vita Enamic at 1 mm and 2 mm, showed higher radiopacities than the corresponding dentin samples ($P < 0.05$). The enamel samples showed higher radiopacities than the Estelite Bulk Fill, Vita Enamic, GCP Glass Fill, Ketac Cem, and Equia Forte Fil at 1 mm

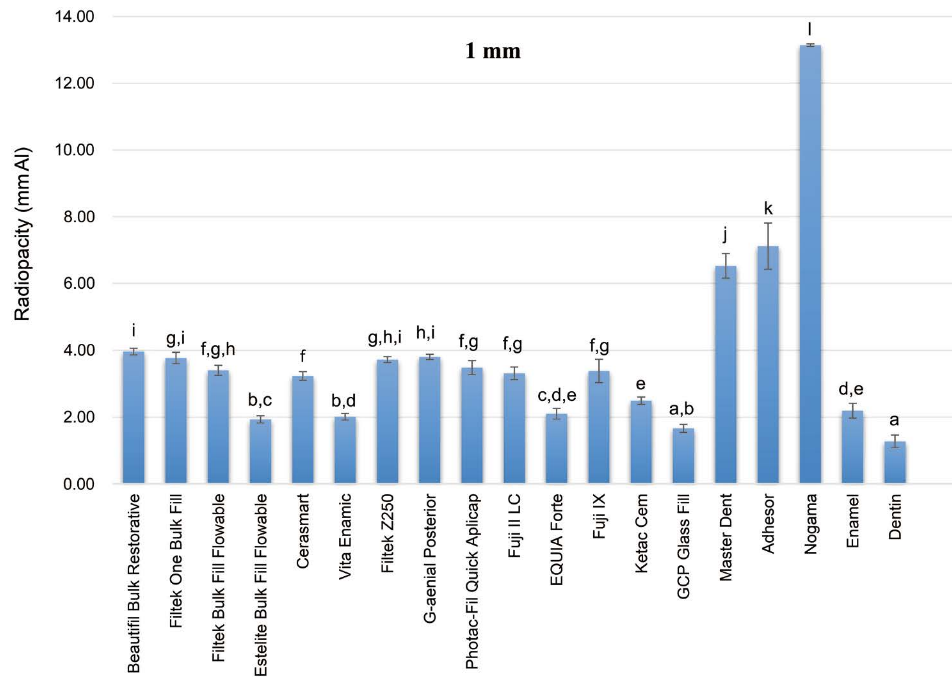

Fig. 2. Mean radiopacity values (in millimeters of aluminum) of restorative materials, enamel, and dentin for samples of 1 mm thickness.

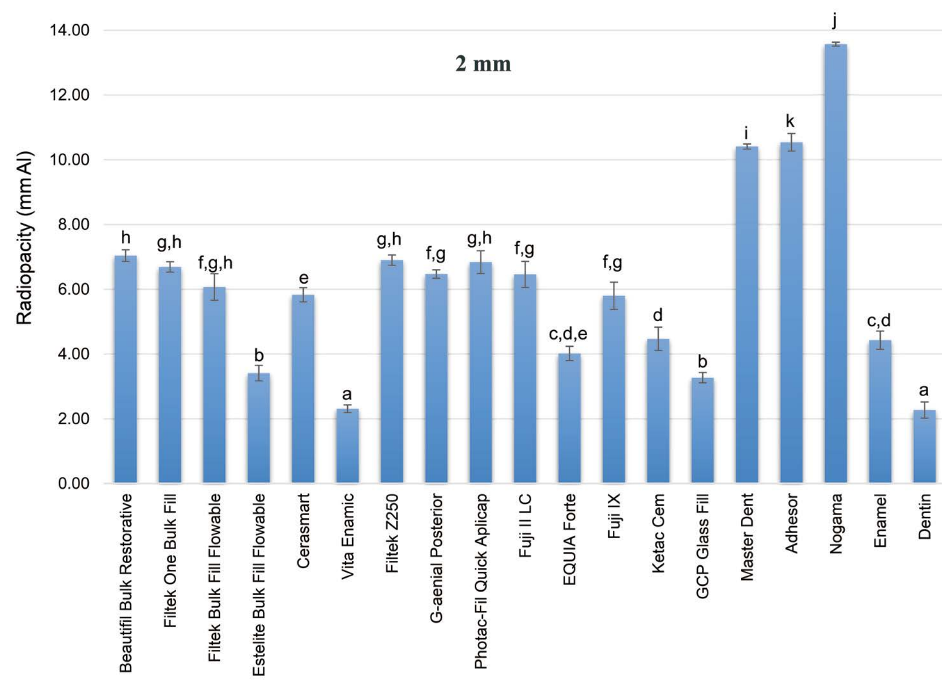

Fig. 3. Mean radiopacity values (in millimeters of aluminum) of restorative materials, enamel, and dentin for samples of 2 mm thickness.

and 2 mm and the Estelite Bulk Fill, Vita Enamic, and GCP Glass Fill at 4 mm. All of the tested materials, except the Vita Enamic at 4 mm, met the minimum ISO standard for radiopacity, which is equal to or greater than that of the same thickness of Al.

Discussion

This study investigated the radiopacities of different thicknesses of restorative materials, such as zinc phosphate cement, glass ionomer-based materials, amalgam, resin com-

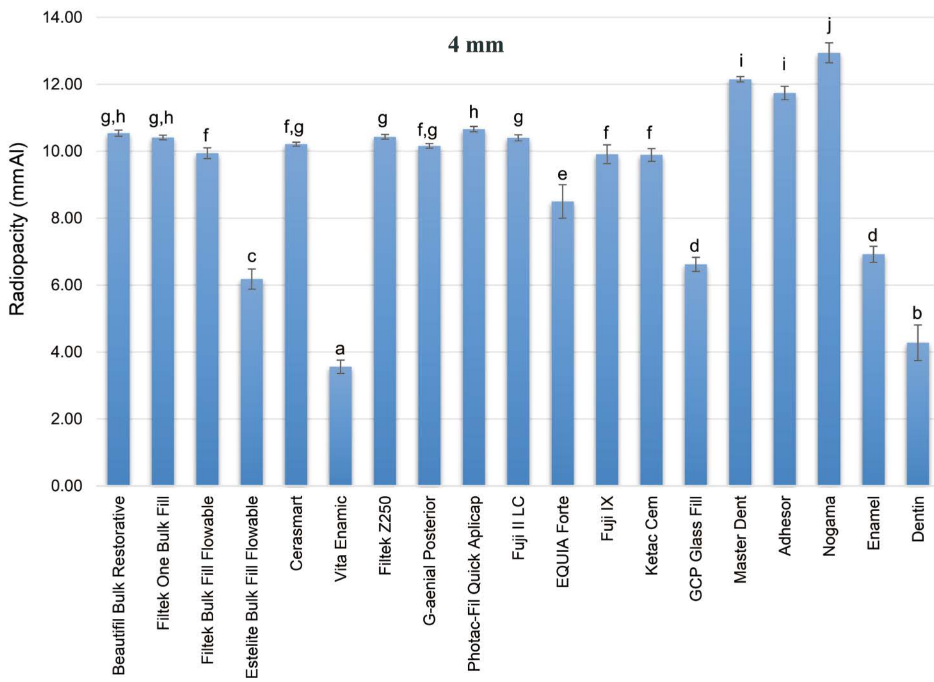

Fig. 4. Mean radiopacity values (in millimeters of aluminum) of restorative materials, enamel, and dentin for samples of 4 mm thickness.

Table 2. Mean radiopacity values and standard deviations of the tested materials, enamel, and dentin at 1 mm, 2 mm, and 4 mm thicknesses

Materials	1 mm	2 mm	4 mm
Beautifil Bulk Restorative	$3.96 \pm 0.10^{i,A}$	$7.04 \pm 0.18^{h,B}$	$10.54 \pm 0.09^{gh,C}$
Filtek One Bulk Fill	$3.77 \pm 0.17^{gi,A}$	$6.69 \pm 0.16^{gh,B}$	$10.41 \pm 0.07^{gh,C}$
Filtek Bulk Fill Flowable	$3.40 \pm 0.15^{fgh,A}$	$6.07 \pm 0.41^{efg,B}$	$9.94 \pm 0.16^{f,C}$
Estelite Bulk Fill Flowable	$1.93 \pm 0.11^{bc,A}$	$3.41 \pm 0.24^{b,B}$	$6.18 \pm 0.30^{c,C}$
Cerasmart	$3.23 \pm 0.13^{f,A}$	$5.83 \pm 0.22^{e,B}$	$10.21 \pm 0.06^{fg,C}$
Vita Enamic	$2.01 \pm 0.10^{bd,A}$	$2.31 \pm 0.12^{a,B}$	$3.56 \pm 0.20^{a,C}$
Filtek Z250	$3.72 \pm 0.09^{ghi,A}$	$6.90 \pm 0.16^{gh,B}$	$10.43 \pm 0.07^{g,C}$
G-aenial Posterior	$3.80 \pm 0.08^{hi,A}$	$6.47 \pm 0.13^{fg,B}$	$10.16 \pm 0.07^{fg,C}$
Photac-Fil Quick Aplicap	$3.48 \pm 0.21^{fg,A}$	$6.84 \pm 0.35^{gh,B}$	$10.66 \pm 0.08^{h,C}$
Fuji II LC	$3.31 \pm 0.19^{fg,A}$	$6.46 \pm 0.40^{fg,B}$	$10.40 \pm 0.09^{g,C}$
EQUIA Forte	$2.10 \pm 0.16^{cde,A}$	$4.02 \pm 0.22^{c,B}$	$8.50 \pm 0.50^{e,C}$
Fuji IX	$3.38 \pm 0.35^{fg,A}$	$5.80 \pm 0.42^{e,B}$	$9.91 \pm 0.28^{f,C}$
Ketac Cem	$2.49 \pm 0.11^{e,A}$	$4.47 \pm 0.36^{d,B}$	$9.89 \pm 0.19^{f,C}$
GCP Glass Fill	$1.66 \pm 0.12^{ab,A}$	$3.27 \pm 0.16^{b,B}$	$6.62 \pm 0.21^{d,C}$
Master Dent	$6.53 \pm 0.37^{j,A}$	$10.41 \pm 0.08^{i,B}$	$12.15 \pm 0.08^{i,C}$
Adhesor	$7.12 \pm 0.69^{k,A}$	$10.54 \pm 0.27^{i,B}$	$11.74 \pm 0.20^{i,C}$
Nogama	$13.14 \pm 0.04^{l,A,A}$	$13.57 \pm 0.06^{j,B}$	$12.94 \pm 0.30^{j,A}$
Enamel	$2.19 \pm 0.22^{de,A}$	$4.43 \pm 0.28^{cd,B}$	$6.92 \pm 0.24^{d,C}$
Dentin	$1.27 \pm 0.19^{a,A}$	$2.27 \pm 0.25^{a,B}$	$4.28 \pm 0.53^{b,C}$

*Different uppercase letters in each row indicate significant differences within a material at different thicknesses, different lowercase letters in each column indicate significant differences between different materials ($P < 0.05$; Bonferroni test).

posites, bulk-fill composites, and hybrid ceramics, using a digital radiography system. Radiopacity values were significantly affected by the type and thickness of the restorative material; therefore, the findings of this study did not support the null hypotheses.

Radiological examinations are of great importance in evaluating the success of dental restorations in long-term follow-up. A material that has sufficient radiopacity allows the identification of secondary caries, insufficient marginal adaptation, faulty proximal contours, and interfacial openings.[20] Radiopacity also plays an important role in determining the location of ingested restorations.[17] In traumatic accidents, radiopacity has a life-saving role by making it possible to track the localization and movement of dental materials in soft tissues.[21]

In the literature, it has been proposed that the radiopacity of restorative materials should be compared with the radiopacities of enamel and dentin of the same thicknesses using an Al step wedge as a reference.[12] An Al step wedge is the preferred reference because it can be easily and accurately used, and its radiopacity is similar to that of dentin.[10,22] According to the relevant ISO standards (ISO 4049 and ISO 9917), at least 99.5% pure Al should be used for the comparison.[14] For this reason, in the current study, we used a 10-step Al wedge of 99.5% purity. In this study, MGV was converted to mmAl using the equation proposed by Lachowski et al.[1] In order to minimize the number of radiographs, we only took 1 radiograph for each thickness studied and placed all samples on an occlusal phosphor plate with an Al step wedge. The image quality of phosphor plates is also affected by the exposure of the plates to ambient light before scanning and the time between exposure and scanning. Akdeniz et al. reported that the plates should be scanned within 10 minutes following irradiation.[23] It has been reported that longer time intervals lead to poorer image quality and contrast.[23] For these reasons, new phosphor plates were used and phosphor plates were scanned immediately after irradiation in this study.

In a study by Yaşa et al., the average radiopacity values of dentin samples were found to be 1.10, 2.01, and 4.33 mmAl and those of enamel samples were found to be equivalent to 1.96, 3.65, and 7.16 mmAl at thicknesses of 1 mm, 2 mm, and 4 mm, respectively.[10] The average enamel radiopacity values observed in our study were 2.19, 4.43, and 6.92 mmAl and the dentin radiopacity values were 1.27, 2.27, and 4.28 mmAl for thicknesses of 1 mm, 2 mm, and 4 mm, respectively. Although these values are within the range reported in the literature, the differences between the values may be caused by many factors, such as the teeth used in the study, the storage conditions, the X-ray voltage, the type of image receptor, the purity of the Al used, and the thickness of the test materials. In our study, we observed that a 1-mm dentin radiopacity approximated the radiopacity of a 1-mmAl sample, and this value satisfies the previously mentioned ISO standards. Consistent with the literature, the radiopacity of dentin was shown to be approximately equivalent to the same thickness of Al, while enamel had almost twice the radiopacity.

It has been reported that in order to achieve the highest accuracy in the radiographic diagnosis of secondary caries, the radiopacity of the restorative material should be slightly higher than that of enamel.[24] The first layer of the restorative material must be sufficiently radiopaque in order to distinctly diagnose the margin of the restoration on the radiograph. However, dental materials with very high radiopacity values, such as amalgam, can make it difficult to detect radiolucent areas adjacent to the restoration. Highly radiopaque materials may mask carious lesions due to superposition and can cause the Mach band effect.[25]

The radiopacity of composite resins is important for the diagnosis of secondary caries, marginal defects, restoration contours, contact with neighboring teeth, cementum protrusions, and interface spaces.[17] The radiopacity of a resin material can be influenced by its content, chemical composition, and thickness.[25] The higher the atomic number of the element added to the composite, the higher the restorative material's radiopacity. Additionally, the angle of the X-ray beam,[17] the methodology used for evaluation, and the type of X-ray film can affect the radiopacity of dental materials.[26] More consistent results can be obtained with digital methods.[27] In this study, a digital radiographic system was used because it reduces the radiation exposure of the operator and the patient, offers higher resolution and a wider dynamic range than X-ray film, facilitates image analysis, and most importantly, provides consistent radiographs.[28,29] As in the study by Yıldırım et al.,[30] the present study used an X-ray device operating at 60 kV and 7 mA, and the object-focus distance was adjusted to 30 cm.

In the current study, the radiopacities of 17 restorative materials that are frequently used in restorative clinical applications, dentin, and enamel samples were evaluated. Filtek Z 250 and G-aenial posterior composite materials in the composite group showed similar radiopacity values at all thicknesses; these values were higher than enamel at all thicknesses. In other studies performed with Filtek Z250 containing zirconia and silica and G-aenial posterior containing silica, strontium, and lanthanoid fluoride, it was reported that the radiopacities of the materials were higher than the radiopacity of enamel.[22,31]

In the bulk fill group, it was determined that the radiopacity of Estelite Bulk Fill was significantly lower than that of the other materials. While the radiopacity of Estelite Bulk Fill was located between enamel and dentin for all thicknesses, the radiopacity values of other bulk fill restoratives were higher than enamel. This may be closely related to the inorganic components of the bulk fill composite materials.

Since conventional glass ionomers do not have sufficient radiopacity, radiopaque secondary filling materials have been added to compensate for this deficiency.[32] In the present study, the radiopacity of Glass Carbomer was close to that of dentin for samples with a thickness of 1 mm (1.66 mmAl) and between dentin and enamel for samples with a thickness of 2 mm (3.27 mmAl), while samples with a thickness of 4 mm (6.62 mmAl) showed the lowest radiopacity values, approximating the radiopacity of enamel. Yaşa et al. compared the radiopacities of resin-based and glass ionomer-based bulk fill materials and reported that GCP Glass Fill had the lowest radiopacity values among the materials tested.[10] In the current study, the radiopacities of Ketac Glass, which is a traditional glass ionomer, and EQUIA Forte, which is a high-viscosity glass ionomer, were similar to those of enamel for samples with thicknesses of 1 mm and 2 mm, and significantly higher than those of enamel for samples with thicknesses of 4 mm. EQUIA Forte contains fluoroaluminosilicate glass and iron oxide, while Ketac Glass contains fluoroaluminosilicate glass. In the present study, the radiopacity of Fuji IX was significantly higher than that of enamel, as observed by Dubois et al.[33] Photac Fil Quick Aplicap had the highest radiopacity values in the glass ionomer group. The radiopacity values of Photac Fil Quick Aplicap and Fuji II LC were similar to each other and higher than enamel for all thicknesses. Despite having the same radiopaque filling contents, significant differences may occur due to differences in filling volume that are not clearly stated by the manufacturers.

The radiopacities of the samples of Vita Enamic, which is a hybrid ceramic, were higher than the radiopacities of the dentin samples with a thickness of 1 mm (2 mmAl); the samples with a thickness of 2 mm were similar to dentin (2.3 mmAl), but the radiopacity values of samples with a thickness of 4 mm were lower than the radiopacity of dentin. In the present study, the radiopacity of Vita Enamic increased less than other materials with increasing thickness. In a study by Varvara et al., significantly lower radiopacity values were observed in the Vita Enamic group when compared with dentin, enamel, and all other CAD-CAM materials.[34] The radiopacity of Cerasmart, which is a hybrid ceramic material, was higher than that of enamel. In a study by Atala et al., while Cerasmart had sufficient radiopacity for inlays, onlays, and crown restorations, Vita Enamic showed low radiopacity values. It has been stated that low-radiopacity blocks such as Vita Enamic should be used with high-radiopacity adhesive cements for the detection of secondary caries.[35]

In the current study, zinc phosphate cements (Adhesor and Master Dent) showed the highest radiopacity values (after amalgam). Similarly, Prevost et al. reported that the radiopacity of zinc phosphate cement was much higher than that of enamel.[12] Zinc polycarboxylate and zinc phosphate cements are more radiopaque than glass ionomer cements because of their magnesium oxide, fluoroaluminosilicate glass, and barium filler particles.[36]

In addition to the atomic composition of a substance, the density of each atom it contains, and the physical structure and thickness of the material can also affect the radiopacity.[37] In this study, the radiopacity of the materials tested increased significantly with increasing thickness, consistent with the results of other studies.[38] Amalgams contain highly radiopaque materials in terms of both weight and volume. For this reason, the highest radiopacity values were observed in the amalgam group in this study.

One of the limitations of this study is that the oral environment could not be simulated. The radiopacity of restorative materials could be affected by many factors, such as the presence of oral fluids, soft tissues, and surrounding tooth structures in the oral environment. In addition, ion leakage from filler particles such as silicon, barium, and strontium into the aqueous environment may decrease the radiopacity. Future studies should investigate restorative materials under conditions that mimic the oral environment and the effect of aging processes.

Within the limitations of this study, the tested restorative materials showed considerable variation in radiopacity. Radiopacity values were affected by both the material thickness and type. All the materials used in this study had radiopacity values that met the requirements of the minimum ISO standards, except for Vita Enamic, which showed lower radiopacity values than dentin at a thickness of 4 mm.

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Conflicts of Interest: None

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