Odontology
https://doi.org/10.1007/s10266-023-00854-5

ORIGINAL ARTICLE

The radiographic evaluation of 11 different resin composites

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Received: 11 May 2023 / Accepted: 6 September 2023

Abstract

Radiopacities of dental materials used in restorations are very important in making the radiographic diagnosis. Therefore, the aim of our study was to evaluate the radiopacity of five single-shade and six simplishade resin composites with digital technique. Five different single-shade (Charisma Topaz One, Omnichroma, Clearfil Majesty ES-2 Universal, Vittra APS Unique, ZenChroma) and six different simplishade resin composites (G-aenial A'CHORD, Essentia Universal, OptiShade, Estelite Asteria, Filtek Universal, Filtek Z250) were used. For each group, five disk-shaped resin composites of 1 mm and 2 mm thicknesses were prepared. As a control, tooth slices with 1 mm and 2 mm thicknesses and a 99.5% pure aluminum step-wedge were used. The samples, tooth slices, and a step-wedge were placed on a photostimulable phosphor plate. Digital radiographs were taken from 30 and 40 cm distances (70 kVp, 7 mA 0.28 ms). The images were analyzed using ImageJ software to measure the mean gray values. Data were analyzed using SPSS 22 package program and Kruskal–Wallis H Test ($p < 0.05$). The highest radiopacity was seen in Filtek Universal at both distances and thicknesses. Omnichroma had the lowest radiopacity in all parameters. All specimens showed higher radiopacity than dentin. Except for Omnichroma 1 and 2 mm thick, Clearfil Majesty ES-2 Universal 2 mm thick, samples showed higher radiopacities than enamel ($p < 0.05$). The restorative materials tested were found to be more radiopaque than dentin. The samples passed the International Organization for Standardization for radiopacity values. The radiopacity values were affected by thickness and type of materials.

Keywords Radiopacity · Single-shade resin composite · Simplishade resin composite · Dental digital radiography · Aluminum step-wedge

Introduction

A suitable radiopacity is an important requirement for restorative materials [1]. Appropriate radiopacity of the dental materials makes the correct and easy diagnosis of secondary caries between the restorative material and enamel/dentin, incorrect proximal contours and contacts, excessive dental cement, marginal gaps, and mismatch marginal adaptation [2, 3].

One of the main reasons for replacing restoration is recurrent dental caries. Therefore, the restoration materials should have the optimum radiopacity, which makes it easy to distinguish the restoration–tooth interface from the tooth structure [4].

Radiographic examinations are necessary for determining the success of dental restorations and for long-term follow-ups. The radiopacity of materials can help dentists to choose the right restorative material during treatment [5].

The required radiopacity of any dental material depends on its clinical application. Materials indicated for posterior regions or deep cavities require higher radiopacities than easily accessible anterior regions for radiographic evaluation. Materials exhibit different radiopacities depending on their chemical properties and microstructures. Radiopacity is mainly obtained by incorporating heavy elements (atomic number > 20) into the inorganic structure without compromising optical and physical properties. In particular, the addition of radiopaque elements can adversely affect translucency and color stability. These elements need to be carefully added to the material [6]. In dental conditions, materials may be accidentally aspirated or swallowed, and the radiopacity of the material is an important factor for locating the material [7].

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Published online: 27 September 2023

The materials with low radiopacity could lead to misdiagnosis, and too much radiopacity would prevent both the material and the decay under restoration from being monitored on radiography; so, moderate radiopacity was preferred in the evaluation of the radiograph.

The International Standards Organization (ISO) has determined the radiopacity standards that dental materials should have. According to ISO 4049:2019, restorative materials used on coronal dental tissue should have a radiopacity similar to or higher than pure aluminum of the same thickness. It is also stated in ISO 4049:2019 that restorative materials should have the lowest radiopacity value similar to dentin of the same thickness [8, 9].

Recently, several studies have investigated the radiopacity of commercially available resin composites [10].

This study aims to evaluate the radiopacity of five single-shade and six simplishade resin composite materials using digital techniques.

The null hypotheses were as follows: 1. There will be no difference in the radiopacity of the materials to be used. 2. The thickness of the materials will significantly affect the radiopacity. 3. There will be no difference in the radiopacity of the materials when the film cone distance is changed.

Materials and methods

Preparation of samples

In the study, the tested resin composites are shown in Table 1. In the study, five different single-shade resin composites: Charisma Topaz One (Kulzer, Hanau, Germany), Omnichroma (Tokuyama Dental Corporation, Tokyo, Japan), Clearfil Majesty ES-2 Universal (Kuraray Noritake Dental, Osaka, Japan), Vittra APS Unique (FGM Dental, Joinville, SC, Brasil), and ZenChroma (President Dental GmbH, Allershausen, Germany); and six different simplishade composites G-aenial A'CHORD (GC Europe, Leuven, Belgium), Essentia Universal (GC Europe, Leuven, Belgium), OptiShade (Kerr Dental, California USA), Estelite Asteria (Tokuyama Dental Corporation, Tokyo, Japan), 3 M Filtek Universal (3 M ESPE, St. Paul, USA), and 3 M Filtek Z250 (3 M ESPE, St. Paul, USA) were used.

Cylindrical Teflon molds of 1 mm and 2 mm height and 7 mm inner diameter were used to place resin composites. Five samples of each resin composite were produced according to the manufacturer's instructions. Materials were placed into the molds and covered with mylar strips (Hawe Transparent Strip, Kerr Hawe, Switzerland) on both sides to prevent the formation of an oxygen inhibition layer and then polymerized with a LED curing device (Bluephase, Ivoclar Vivadent, Ltd. São Paulo, Brazil). After removal from the mold, both surfaces of the composite disks were polymerized for 20 s. Then, the samples were kept in distilled water in the incubator at 37 °C for 24 h.

Enamel and dentin samples were obtained by cutting (Isomet Low-Speed Saw 1000, Buehler, Lake Bluff, IL, USA) 1 mm and 2 mm thick slices from caries-free human third molar extracted for orthodontic purposes. Tooth samples were kept in distilled water until radiographic evaluation. The thickness of all samples, enamel, and tooth slices was measured using a digital caliper (Dasqua, Cornegliano Laudense, Italy).

In radiopacity comparisons, a pure aluminum step-wedge with increasing thickness is used as a reference. Therefore, a step-wedge of 40 mm in length, 20 mm in width, and 99.5% pure aluminum, with equal spacing of 2.0 mm, starting from 0.5 mm thickness and increasing by 0.5 mm, was used by the standards in ISO 4049:2019. The purpose of the aluminum step is to provide the standard radiographically and to calculate the Al thickness equivalent to the radiopacity of the samples. Vistascan (Dürr Dental, Bietigheim-Bissingen, Germany) was used to scan the radiographs.

Radiographic procedure

Radiographs were taken using with photostimulable phosphor plate (PSP) (Dürr Dental, Bietigheim-Bissingen, Germany): with different distances 1. 1 mm thickness of composite cylinders, 1mm tooth slice, 99,5% pure aluminum step-wedge, film-cone distance 30 cm with 70 kVp, 7mA 0.28 ms 2. 1 mm thickness of composite cylinders, 1mm tooth slice, 99,5% pure aluminum step-wedge, film-cone distance 40 cm with 70 kVp, 7mA 0.28 ms 3. 2 mm thickness of composite cylinders, 1mm tooth slice, 99,5% pure aluminum step-wedge, film-cone distance 30 cm with 70 kVp, 7mA 0.28 ms 4. 2 mm thickness of composite cylinders, 1mm tooth slice, 99,5% pure aluminum step-wedge, film-cone distance 40 cm with 70 kVp, 7mA 0.28 ms.

Measurement of radiopacity procedure

The mean gray values (MGV) of each aluminum step-wedge, disk-shape resin composites, enamel, and dentin were measured on the digital radiographs using a software program (ImageJ, National Institutes of Health, Maryland, USA) (Fig. 1). For each sample, radiopacity measurements of 10 × 10 pixels were made from three different regions. MGV values between 0 and 255 were measured with the Density Measurement tool in the program. Measurements were done by the same operator.

The radiopacity values for all tested materials were converted into MGV values to millimeter aluminum equivalent (mm Al). For this purpose, the radiopacity value was also measured at each step of the aluminum step-wedge on the

Table 1 Resin composite materials evaluated in this study

Brand name	Matrix	Filler composition/size	Filler w/v%	Manufacturer	Shades
Charisma Topaz one	UDMA, TCD-DI-HEA, TEGDMA	Barium aluminum fluoride glass filler of 0.02–2 µm, 5 vol% pyrogenic silicon dioxide filler of 0.02–0.07 µm	81/64	Kulzer, Hanau, Germany	Single shade
Omnichroma	UDMA, TEGDMA	Uniform sized supra-nano spherical filler (260 nm spherical SiO_2–ZrO_2)	79/68	Tokuyama Dental Corporation, Tokyo, Japan	Single shade
Clearfil majesty ES-2 universal	Bis-GMA, hydrophobic aromatic DMA, and hydrophobic aliphatic DMA, dl-Camphorquinone	Silanated barium glass (particle size 0.37–1.5 µm), PPF	78/66	Kuraray Noritake Dental, Osaka, Japan	Single shade
Vittra APS unique	UDMA, TEGDMA	Zirconia charge, silica (200 nm)	82/72	FGM Dental, Joinville, SC, Brasil	Single shade
ZenChroma	UDMA, Bis-GMA, TEMDMA	Glass powder, silicon dioxide, inorganic filler (0.005–3.0 µm)	75/53	President Dental GmbH, Allershausen, Germany	Single shade
G-aenial A'CHORD	Bis-MEPP	Glass filler (300 nm barium glass) 16 nm (fumed silica), organic filler (300 nm barium glass; 16 nm fumed silica)	82/na	GC Europe, Leuven, Belgium	Simplishade
Essentia universal	UDMA, Bis-MEPP, Bis-EMA, Bis-GMA, TEGDMA	PPF (17 µm): strontium glass (400 nm), lanthanide flüoride (100 nm), fumed silica (16 nm) FAISi glass (850 nm)	81/na	GC Europe, Leuven, Belgium	Simplishade
OptiShade	Bis-EMA, Bis-GMA, TEGDMA	PPF, BaO–Al_2O_3–SiO_2, silica, F_3Yb	81/64.5	Kerr Dental, California, USA	Simplishade
Estelite asteria	Bis-GMA, Bis-MPEPP, TEGDMA	Uniform supra-nano spherical silica and zirconia fillers (200 nm)	82/71	Tokuyama Dental Corporation, Tokyo, Japan	Simplishade
Filtek universal	AUDMA, AFM	silica, zirconia, F_3Yb nanoparticles	76.5/58.4	3 M Oral Care, St. Paul, Minnesota	Simplishade
Filtek Z250	TEGDMA, Bis-GMA, Bis-EMA, UDMA	Zirconia/silica	82/60	3 M ESPE, St. Paul, USA	Simplishade

UDMA urethane dimethacrylate, *TCD-DI-HEA* bis-(acryloyloxymethyl)tricyclo [5.2.1.0.sup.2,6] decane, *TEGDMA* triethyleneglycol dimethacrylate, SiO_2 silicone oxide, ZrO_2 zirconium oxide, Bis-*GMA* bisphenol-A-diglycidyl methacrylate, *DMA* dimethacrylate, *PPF* prepolymerized fillers, *TEMDMA* tetra-ethylene di methacrylate, *Bis-MEPP* Bisphenol-A ethoxylate di methacrylate, *Bis-EMA* ethoxylated bisphenol-A di methacrylate, *FAISi* fluoroaluminosilicate, BaO-Al_2O_3-SiO_2 barium aluminosilicate glass, *F3Yb* ytterbium trifluoride, *Bis-MPEPP* bisphenol-A polyethoxy methacrylate, *na* not available

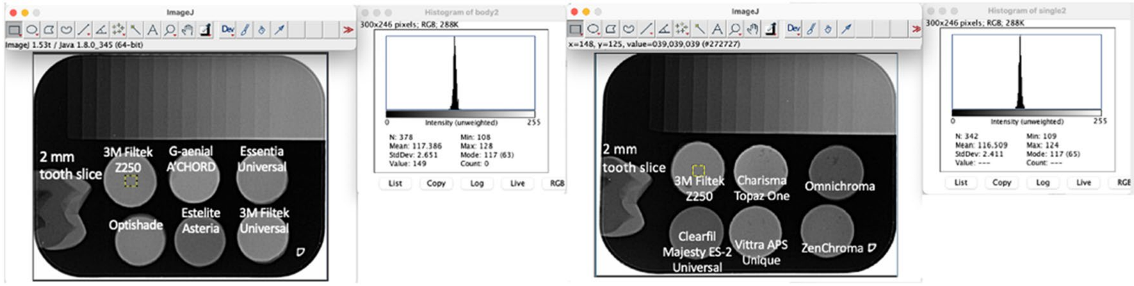

Fig. 1 Radiographic images of 2 mm thicknesses of tooth slice and resin composites and aluminum step-wedge

radiograph, and mm of Al data was obtained using the following formula [11].

$$\frac{X \times 0.5}{Y} + \text{ mm Al below materials}'\text{mean gray value.}$$

X = Mean gray value of the material−mean gray value of the step-wedge increment immediately below the material's mean gray value.

Y = Mean gray value of the step-wedge increment immediately above the material's mean gray value−mean gray value of the step-wedge increment immediately below the material's mean gray value.

0.5 = Increment thickness of the step-wedge.

Statistical analysis

Data were analyzed using SPSS 22 package program (IBM SPSS Statistics for Windows, Armonk, NY: IBM Corp.). Kolmogorov–Smirnov and Levene tests were used for the normality and homogeneity distribution of variances. A non-parametric Kruskal–Wallis analysis of variance assessed significant differences among the groups. Tukey HSD and Tamhane multiple comparisons were applied for post hoc comparisons. The statistically significant level was established at $p < 0.05$.

Results

The mean values and standard deviations of the resin composites, enamel, and dentin slabs are shown in Table 2.

The higher to lower radiopacity values for 1 mm samples are, respectively, Filtek Universal (4.08 mm Al), OptiShade (3.62 mm Al), Essentia Universal (3.55 mm Al), Charisma Topaz One (3.5 mm Al), Vittra APS Unique (3.25 mm Al), G-aenial A'CHORD (3.25 mm Al), Filtek Z250 (3.12 mm Al), ZenChroma (2.52 mm Al), Estelite Asteria (2.26 mm Al), Clearfil Majesty ES-2 Universal (2.06 mm Al), and Omnichroma (1.76 mm Al).

Table 2 Radiopacity values (in mm Al/1.0- and 2.0 mm specimen) of the resin composites (mean ± standard deviation)

Materials	Mean ± sd (1 mm specimen)	Mean ± sd (2 mm specimen)
Charisma topaz one	3.5 ± 0.36^{ah}	6.57 ± 0.69^{bdf}
Omnichroma	1.76 ± 0.12 g	3.43 ± 0.23^{ej}
Clearfil majesty ES-2 universal	2.06 ± 0.23^{bfi}	3.85 ± 0.22^{eij}
Vittra APS unique	3.25 ± 0.36^{ae}	5.1 ± 0.75^{acg}
ZenChroma	2.52 ± 0.14^{cei}	4.61 ± 0.3^{acgj}
G-aenial A'CHORD	3.25 ± 0.13^{ae}	6.83 ± 0.72^{bdf}
Essentia universal	3.55 ± 0.16^{ah}	6.13 ± 0.32^{cdf}
OptiShade	3.62 ± 0.19^{ah}	6.26 ± 0.28^{df}
Estelite asteria	2.26 ± 0.14^{bcg}	4.08 ± 0.15^{egj}
Filtek universal	4.08 ± 0.16 h	7.01 ± 0.42^{f}
Filtek Z250	3.12 ± 0.28^{ae}	6.06 ± 0.5^{abcdf}
Mine	1.89 ± 0.42^{cdfg}	4.14 ± 0.08^{eg}
Dentin	1.14 ± 0.67^{bdf}	3.01 ± 0.1^{j}

**Different lowercase letters indicate statistically significant differences in the column*

The higher to lower radiopacity values for 2 mm samples are, respectively, Filtek Universal (7.01 mm Al), G-aenial A'CHORD (6.83 mm Al), Charisma Topaz One (6.57 mm Al), OptiShade (6.26 mm Al), Essentia Universal (6.13 mm Al), Filtek Z250 (6.06 mm Al), Vittra APS Unique (5.1 mm Al), ZenChroma (4.61 mm Al), Estelite Asteria (4.08 mm Al), Clearfil Majesty ES-2 Universal (3.85 mm Al), and Omnichroma (3.43 mm Al).

All samples showed higher radiopacity than dentin ($p < 0.05$). Except for the Omnichroma 1 mm and 2 mm thick samples and the Clearfil Majesty ES-2 Universal 2 mm thick samples, all samples showed higher radiopacity than enamel.

The results of the study showed that increased thicknesses in the materials that were tested correlated with their radiopacity. Radiopacity values for 2 mm samples were statistically significantly higher than those for 1 mm samples ($p < 0.05$).

The values obtained by taking X-rays from a distance of 30 cm are between 1.73 and 4.18 mm Al per 1 mm, and between 3.43 and 6.98 mm Al per 2 mm. The values obtained by taking X-rays from a distance of 40 cm are between 1.79 and 3.98 mm Al per 1 mm, and between 3.8 and 7.04 mm Al per 2 mm (Table 3, Fig. 2). The cone distance did not affect the radiopacity values in both 1 and 2 mm samples ($p > 0.05$).

The highest radiopacity was seen in 3 M Filtek Universal at both distances and thicknesses. Omnichroma had the lowest radiopacity in all parameters.

Discussion

Recently, digital radiography has become increasingly common. The advantages of digital radiography over conventional radiography are lower radiation dose, environmental-friendly character as no chemical processing is required, and easy management of images [12]. Many factors can affect radiopacity, but the composition of dental materials is one of the most important factors. Additional factors are material thickness and the type of X-ray receptor [13].

According to ISO 4049 standards, which have developed standards for the radiopacity of dental materials, restorative materials should have a radiopacity similar to or higher than pure aluminum of the same thickness [14].

Accordingly, the material should have at least the radiopacity of dentin tissue of the same thickness [8]. Some

Table 3 Radiopacity values (in mm Al/1 and 2 mm specimen) of the resin composite disks, enamel, and dentin specimens (1- and 2 mm specimen) with 30- and 40 mm distance (mean ± standard deviation)

Resin composite materials	Mean ± sd (30 cm distance 1 mm)	Mean ± sd (30 cm distance 2 mm)	Mean ± sd (40 cm distance 1 mm)	Mean ± sd (40 cm distance 2 mm)
Charisma topaz one	3.45 ± 0.35	6.62 ± 0.66	3.54 ± 0.4	6.52 ± 0.38
Omnichroma	1.73 ± 0.12	3.43 ± 0.2	1.79 ± 0.13	3.44 ± 0.28
Clearfil majesty ES-2 Universal	2.05 ± 0.27	3.9 ± 0.3	2.07 ± 0.22	3.8 ± 0.12
Vittra APS unique	3.23 ± 0.35	4.93 ± 0.9	3.27 ± 0.41	5.26 ± 0.62
ZenChroma	2.51 ± 0.15	4.67 ± 0.37	2.53 ± 0.16	4.55 ± 0.23
G-aenial A'CHORD	3.25 ± 0.14	6.94 ± 0.65	3.26 ± 0.13	6.71 ± 0.84
Essentia universal	3.62 ± 0.11	6.23 ± 0.32	3.48 ± 0.18	6.04 ± 0.31
OptiShade	3.63 ± 0.24	6.30 ± 0.37	3.61 ± 0.16	6.22 ± 0.2
Estelite asteria	2.26 ± 0.08	4.07 ± 0.14	2.25 ± 0.19	4.09 ± 0.18
3 M Filtek universal	4.18 ± 0.10	6.98 ± 0.53	3.98 ± 0.16	7.04 ± 0.34
3 M Filtek Z250	3.04 ± 0.12	6.20 ± 0.40	3.21 ± 0.38	5.93 ± 0.6

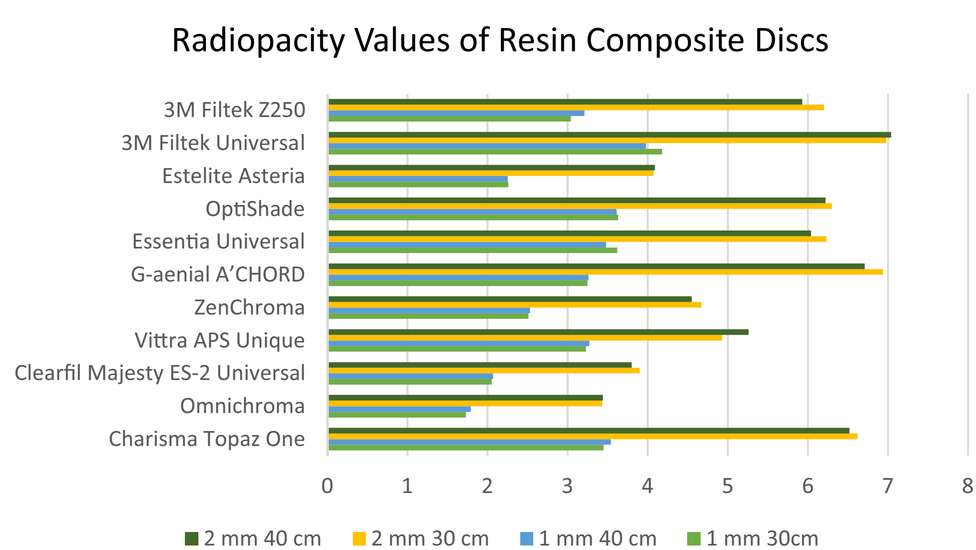

Fig. 2 The mean values of radiopacity (millimeters of aluminum) of 11 resin composites with 2 mm thickness 30 cm distances, 2 mm thickness 40 cm distances, 1 mm thickness 30 cm distances, and 1 mm thickness 40 cm distances

studies suggested that restorative materials have equal or higher radiopacities than enamel tissue to determine secondary caries and defects at the gingival margin [15, 16]. In addition, excessive radiopacity may cause an illusion called as Mach B and effect. This phenomenon is an optical illusion related to the perception of the boundary between light and a darker area as darker. Therefore, materials should have an optimum radiopacity, slightly greater than enamel tissue [17].

Sabbagh et al. investigated the radiopacities of resin-based materials with Digora digital systems [18]. They reported that there is a linear correlation between the amount of filler by weight and radiopacity. Adding chemical elements with a high atomic number in the resin composite matrix results in higher radiopacity with increased x-ray absorption. If the restoration volume is 70% or more and the amount of radiopaque filler particles is 20%, the radiopacity of the resin composite will be higher than human enamel. The difference in radiopacity suggested that resin composites could show high radiopacities with higher atomic number elements even in lower percentage filler by volume and weight [19]. The higher the atomic number of the element added to the filler, the greater the X-ray-absorbing capacity, which can result in increased radiopacity of the restorative material. The highest radiopacity is provided by ytterbium ($Z=70$), followed by barium ($Z=56$), yttrium ($Z=39$), strontium ($Z=38$), zinc ($Z=30$), silicon ($Z=14$), and aluminum ($Z=13$) [19, 20].

Recently, single-shade resin composites, which have improved by minimizing the technical sensitivity to simplishade composite resin composites, have been introduced to the market and are frequently used by dentists. When the literature was examined, no study was found about the radiopacities of these materials [21]. Therefore, in our study, we aimed to evaluate the radiopacity of five single-shade and six simplishade resin composites using the digital technique. Filtek Universal showed the highest radiopacity in this study, followed by Optishade. Although the weight percent of Optishade (81w%) was higher than Filtek Universal (76.5 w%), the radiopacity of Optishade was lower. High radiopacity is thought to cause different radiopacities due to the high atomic number of ytterbium trifluoride (YbF_3) and different YbF_3 ratios. Omnichroma had the lowest radiopacity value but still had a higher radiopacity value than dentin. Therefore, our first null hypothesis—*"There will be no difference in the radiopacity of the materials to be used"*—was rejected.

Sarıdag and others reported [22] that radiopacity of direct and indirect resin composites varied according to material thickness, brand, and type; 2 mm thick resin composites showed higher radiopacity than 1 mm thick resin composites. Our study supports that, as the thickness of the materials increases, their radiopacity increases significantly. Therefore, the second of our null hypotheses—*"The thickness of the materials will significantly affect the radiopacity"*—was accepted.

Various studies have been conducted using PSP, CMOS, and CCD devices to compare the radiopacity of dental materials. PSP was found to be the most accurate device among them and also materials showed the lowest radiopacities when evaluated in PSP radiographs. CMOS sensors showed the highest radiopacities and worst accuracy [23]. In this study, PSP was used for radiopacity evaluation. It was thought that Omnichroma might have radiopacity values similar to or greater than enamel when evaluated with CMOS sensors.

Changing the radiographic exposure time and target distance are the factors affecting the radiopacity of restorative materials. Gu et al. [24] reported that varying exposure times and target distance did not affect the radiopacities of the three different dental materials measured. Similar to the previous study, no difference was found in the radiopacity values of the resin composites when the film–cone distance was changed in this study. Therefore, our third null hypothesis—*"There will be no difference in the radiopacity of the materials when the film cone distance is changed"*—was accepted.

Today, single and simplified resin composites are commonly used materials for restorations. Their different color adaptation properties have made them popular in dental clinics. Several studies [25–28] have been conducted about their color adaptation, mechanical properties, surface roughness, etc. However, there are no studies about their radiopacities. In this study, the radiopacity of 11 different composite materials has been evaluated but there were some limitations. One of the main limitations of this study was the lack of stimulation of the oral environment. Radiopacities of materials can be affected by many factors such as soft tissues, oral fluids, and other dental structures. In addition, the release of ions such as barium, silicon, and strontium from the material can reduce the radiopacity. Further studies are needed in oral conditions and simulating the aging procedure.

Conclusion

Within the limitations of this study, the tested resin composites were found to be more radiopaque than dentin. The samples passed the International Organization for Standardization for radiopacity values. Radiopacity values were affected by the material type and thickness. Cone distance did not affect the radiopacity of tested resin composites.

Acknowledgements We would like to thank Prof. Dr. Bilal Yasa for his support.

Author contributions DK contributed to the conceptualization, methodology, writing, reviewing and editing; ÖE contributed to statistical analysis and writing, reviewing and editing.

Funding: This work was supported by the researchers.

Declarations

Conflict of interest The authors declare no competing interests.

Ethics approval This study was approved by the Ethics Committee of Biruni University (2015-KAEK-71-22-08).

Informed consent All participants were freely invited, and those who accepted signed an informed consent approved and stamped by the local ethics committee.

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