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Source / Izvornik: **Dental Materials Journal, 2012, 31, 47 - 53**

Journal article, Published version
Rad u časopisu, Objavljena verzija rada (izdavačev PDF)

https://doi.org/10.4012/dmj.2011-119

Dental Materials Journal 2012; 31(1): 47–53

Radiopacity of composite dental materials using a digital X-ray system

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The aim of this study was to evaluate the radiopacity of 32 current dental composite materials with digital technique. Digital radiographs with CCD sensor along with an aluminum step wedge, 1-mm-thick tooth slice and 1mm thick composite specimen were taken in five different combinations of exposition/voltage. The radiopacity in pixels was determined using Digora 2.6. software. The equivalent in thickness of aluminum for each material was then calculated from the calibration curve. 74.9% of all tested materials in all exposure combinations had radiopacity between 2 mm and 4 mm aluminum equivalent. The radiopacity of composites ranged from 0.61 mm Al (Gradia Direct Anterior) to 4.78 mm Al (Te-Econom). The average radiopacity for enamel and dentine was 2.05 and 1.11 mm Al. The use of digital technique for radiopacity is an easy, reliable, fast and precise way to analyze different dental materials. Most of the tested composite materials fulfill the requested criteria for radiopacity with a few exceptions.

Keywords: Radiodensity, Dental materials, Dental digital radiography, Aluminum step wedge, Resin composite

INTRODUCTION

Dental materials should be sufficiently radiopaque to be detected against a background of enamel and dentin, resulting in correct evaluation of restoration in every region and providing the detection of secondary caries, marginal defects, contour of restoration, and contact with adjacent teeth, cement overhangs and interfacial gaps[1-6]. Radiographs are useful not only to evaluate restoration, but also to monitor its long-term stability[7]. The advantages of radiopaque over radiolucent materials are the ease of detection of recurrent dental caries, as well as the observation of the radiographic interface between the materials and tooth substrates[2]. Dental diagnosis relies on radiology, and it is essential to distinguish intraoral placed material, such as composite resin or cement, from surrounding anatomical structures. Radiopacity of the material must be sufficiently different from tooth tissue to be distinguished equally it must be radiopaque enough that it can be distinguished from a void[8]. According to the International Standards Organization (ISO), the radiopacity of material should be equal to or greater than the same thickness of aluminum and should not be less than 0.5 mm of any value claimed by the manufacturer[9].

A digital system for dentistry was produced in 1989 and since then digital radiography has found its way into dental practice[10]. Several types of sensor may be used: charge-coupled devices (CCD), complementary metal oxide semiconductor (CMOS) and photo-stimulable phosphor plates (imaging plates). The most important advantage of digital clinic radiographic systems is the greater sensitivity of the detector in comparison with silver halide film, which results in decreased exposure (radiation dose) of the patient[8]. In digital imaging, the gray scale is inverted in comparison with optical density such that white is allotted a value of 255 (for an 8-bit image) and black is 0. Traditional film development, unless preformed carefully, can produce significant variations in the final radiograph and digital method should provide more consistent results[9,11].

Only few studies investigated the radiopacity of dental composite resins in recent ten years and since that many new dental composite materials have been introduced to dental market[5,12,13]. It is necessary to investigate radiopacity of 32 recent composite dental materials with digital technique.

The main purpose of this study is to evaluate the radiopacity of different composite dental materials on the market in five different exposure times. Evaluation of dental materials will also include digital technique for measuring radiopacity.

MATERIALS AND METHODS

Specimen preparation

The materials evaluated in this study were commercially available and commonly used composite materials. The selected materials are shown in Table 1. Three specimens of each material were produced according to the manufacturer's instructions and inserted in 1 mm thick stainless steel cylinders with internal 4.1 mm-diameter. After filling the cylinder to capacity, the material's surface was covered with a glass slide; pressure of 150 g was applied to force out excess material. The specimens were light cured using LED polymerization lamp (Elipar Freelight 2, 3M ESPE, St. Paul, USA) with a power of 1000 mW/cm^2 and wavelength of 430–450 nm for 40 s on each side. Chemical-cured material (Degufill SC) was allowed to set during the period recommended by the manufacturer. After removing the material from the cylinder, the specimens were polished using 400, 600 and 1000 grit sandpaper, cleansed with 70% ethyl alcohol and measured with a digital micrometer to verify that

Received May 16, 2011: Accepted Sep 2, 2011
doi:10.4012/dmj.2011-119 JOI JST.JSTAGE/dmj/2011-119

Table 1 List of materials tested in this study

Product	Shade	Filler % (wt/vol)	Type	Manufacturer
Admira	B3	77/63	ormocer	Voco GmbH, Cuxhaven,Germany
Amaris	O3	80/NA	microhybrid	Voco GmbH, Cuxhaven,Germany
Amaris	TN	80/NA	microhybrid	Voco GmbH, Cuxhaven,Germany
Amelogen Plus	A2	76/NA	microhybrid	Ultradent, South, South Jordan, USA
Arabesk Top	A3	77/56	microhybrid	Voco GmbH,Cuxhaven, Germany
Artemis	B2 Enamel	77/NA	microhybrid	Ivoclar Vivadent, Schaan, Liechtenstein
Ceram X Duo	D2	76/57	nanofilled	Dentsply DeTrey Gmbh, Konstanz, Germany
Ceram X Mono	M5	76/57	nanofilled	Dentsply DeTrey Gmbh, Konstanz, Germany
Charisma Opal	A3	NA/64	microfilled	Heraeus Kulzer GmbH, Hanau, Germany
Clearfil Majesty Posterior	A3	92/82	nanofilled/nano superfilled	Kuraray Medical INC, Okayama, Japan
Degufill SC	Universal	NA/62	microhybrid	Dentsply Detrey, Konstanz, Germany USA
Estet-X	X2	77.5/60	nanofilled	Dentsply DeTrey Gmbh, Konstanz, Germany
Filtek Z250	A3	82/60	microhybrid	3M/Espe, St. Paul, MN, USA
Filtek Silorane	A3	76/NA	microhybrid	3M/Espe, St. Paul, MN, USA
Filtek Supreme	C2B	82/59	nanofilled	3M/Espe, St. Paul, MN, USA
Filtek Supreme XT	A3D	78.5/59.5	nanofilled	3M/Espe, St. Paul, MN, USA
Filtek Ultimate	A3 Enamel	78.5/63.3	nanofilled	3M/Espe, St. Paul, MN, USA
Fulfil	A2	75/NA	submicron hybrid	Dentsply DeTrey Gmbh, Konstanz, Germany
Gradia Direct Posterior	A2	77/65	mycrohybrid	GC Dental Products Corp, Tokyo, Japan
Gradia Direct Anterior	A3	73/64	microhybrid	GC Dental Products Corp, Tokyo, Japan
Gradia Direct X	A3	NA/NA	microfilled	GC Dental Products Corp, Tokyo, Japan
Grandio	A3	87/71.4	nanofilled	Voco GmbH, Cuxhaven, Germany
Herculite HRV Ultra Enamel	A3	79/59	nanofilled	Kerr Corporation, Orange, CA, USA
Kalore	A2	80/NA	nanofilled	GC Dental Products Corp, Tokyo, Japan
Quix Fil	Universal	86/66	Bulk-filling	Dentsply DeTrey Gmbh, Konstanz, Germany
Tetric Ceram HB	C2	80.4/NA	microhybrid	Ivoclar Vivadent, Schaan, Liechtenstein
Tetric Ceram	D3	78.6/60	microhybrid	Ivoclar Vivadent, Schaan, Liechtenstein
Te-Econom	B3	81.2/NA	microhybrid	Ivoclar Vivadent, Schaan, Liechtenstein
Tetric Evoceram	A3	83/68	nanofilled	Ivoclar Vivadent, Schaan, Liechtenstein
TPH3 Spectrum	B1	77/57	submicron hybrid	Dentsply DeTrey Gmbh, Konstanz, Germany
Valux Plus	B2	NA/66	microhybrid	3M/Espe, St. Paul, MN, USA
Venus	HKA 2.5	78/61	microhybrid	Heraeus Kulzer GmbH, Hanau, Germany

NA: not available.

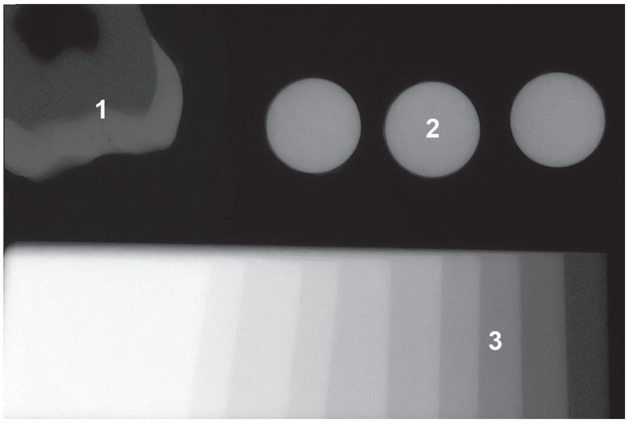

Fig. 1 Digital image obtained from CCD sensor containing tooth structure and tested composite materials. 1- Tooth structure. 2- Tested composite materials. 3-Aluminum step wedge.

the thickness remained at the critical tolerance of 1±0.01mm. The Ethics committee of the School of Dental Medicine, University of Zagreb, Croatia approved the study. The tooth for enamel/dentine specimen was extracted for orthodontic reasons. An enamel and dentine 1 mm specimen was also prepared by longitudinal sectioning of a freshly extracted third molar using a slow speed diamond saw Isomet 1000 (Buehler, Illinois, USA) with a constant speed of 250–300 rpm. The tooth specimen was then stored in water. The step wedge was fabricated by riveting together ten 1 mm thick plates of aluminum alloy of 1100 purity of 99.5% Al. The chemical composition of aluminum used for fabricating the step wedge is as follows: 0.0014% of Cu, 0.0019% of Mn, 0.0017% of Mg, 0.06% of Si, 0.37% of Fe, 0.0089% of Zn and 0.025% of Ti. The plates were 10.0 mm wide and the aluminum wedge ranged from 1 to 10 mm. The digital X-ray machine Prostyle Intra 50–70 kV (Planmeca Oy, Helsinki, Finland) with the digital CCD sensor DiXi3 B1 (Planmeca Oy, Helsinki, Finland) was used in this study. Three specimens of each material along with the aluminum step wedge and a tooth specimen were positioned over the sensor on each of the radiographs. Each specimen was radiographed three times using five different combinations of exposure time and voltage with a source-to-sample constant distance of 30 cm. These combinations were considered for properly exposed digital image, and they are in accordance with manufacturer instructions. With these combinations of voltage/exposition, we can analyze the possible differences between specimens of composite materials.

The combinations of voltage and exposures are: 1) 60 kV and 0.06 s, 2) 60 kV and 0.08 s, 3) 63 kV and 0.06 s, 4) 63 kV and 0.08 s, 5) 63 kV and 0.1 s.

Digital imaging

The pictures, free of any enhancement in contrast or picture quality, were imported into Plannmeca Dimaxis Pro 4.0 software and exported in 8-bit TIFF format for

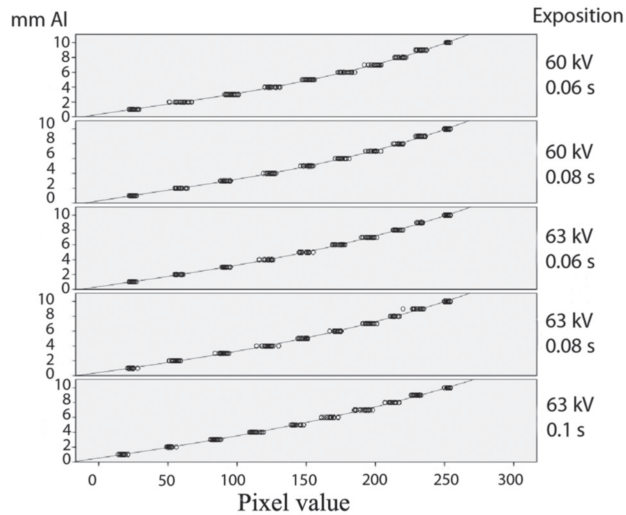

Fig. 2 The curves of pixel values versus mm Al for each exposition.

later radiopacity analysis (Fig.1). The radiopacity in pixels of the specimen was determined by a different type of software, Digora for Windows 2.6 (Soredex, Tuusula, Finland). Digora is a Windows based software capable of measuring density curves of digital radiographies obtained by digital X-ray impregnation on the CCD sensor. The "density measurement" tool automatically measures the gray shade values in the picture. Using the mouse cursor above the digital image, five different positions in all three material specimens were measured. Particular care was taken to analyze only those regions which were free of air bubbles, gaps or similar defects. In a similar procedure, a tooth slice with enamel and dentine was also measured in five different regions. The same procedure was conducted for five different exposures.

The aluminum step wedge (99.5% Al) was used as an internal standard for measuring the equivalent radiopacity of different materials in comparison to the thickness of the aluminum step wedge. In 30 random radiographs, each of the 10 steps of the aluminum step-wedge is measured for density and a density graph *versus* the thickness of aluminum alloy at each step was constructed[14,15]. Consequently, a calibration curve was plotted using the best-fit logarithmic regression analysis for selected data. The equivalent in thickness of aluminum for each material was calculated from the calibration curve (Fig.2). Also, the gray scale value corresponds to the attenuation of the material. The measured gray value for each dental material and aluminum corresponds to the amount of attenuation of X-ray transmission through the materials. That value is converted into absorbance using the following formula:

$$A=-\log_{10}(T)=-\log_{10}(1-G/255)$$

Where A is the absorbance, T is the transmittance, and G is the gray scale value of the item[16]. The same procedure was implemented for five different exposures. A Kruskal-Wallis test was preformed to compare the mean values for different types of different dental materials. The results obtained were statistically analyzed using PASW Statistics 18 software (SPSS Inc., Chicago, USA).

RESULTS

The Kolmogorov-Smirnov test showed that radiopacity (in mm Al) is not a normally distributed variable (p<0.05), so we have to compare the mean values of

Table 2 Regressions and regression errors

Exposition	Regression parameters (SD) a	b	c	d	R^2	Mean residuals
60 kV 0.06 s	0.332 (0.059)	0.028 (0.002)	−2.36E-05 (0.000)	2.59E-07 (0.000)	0.998	0.018
60 kV 0.08 s	0.310 (0.045)	0.029 (0.001)	−2.96E-05 (0.000)	2.62E-07 (0.000)	0.999	0.011
63 kV 0.06 s	0.362 (0.044)	0.027 (0.001)	−1.231E-06 (0.000)	1.787E-07 (0.000)	0.999	0.011
63 kV 0.08 s	0.418 (0.056)	0.026 (0.002)	8.753E-06 (0.000)	1.537E-07 (0.000)	0.998	0.018
63 kV 0.1 s	0.522 (0.043)	0.028 (0.001)	1.382E-05 (0.000)	1.050E-07 (0.000)	0.998	0.015

Table 3 Absorbance values for Aluminum step wedge

		60 kV 0.06 s		60 kV 0.08 s		63 kV 0.06 s		63 kV 0.08 s		63 kV 0.1 s	
Aluminum mm		Pix	Abs	Pix	Abs	Pix	Abs	Pix	Abs	Pix	Abs
A1	Mean value	24.90	0.04	24.30	0.04	24.10	0.04	23.60	0.04	17.65	0.03
	SD	1.98	0.00	1.52	0.00	1.33	0.00	1.76	0.00	1.72	0.00
A2	Mean value	59.9	0.12	58.90	0.11	57.60	0.11	55.30	0.11	51.40	0.09
	SD	4.59	0.01	2.79	0.01	2.11	0.01	2.39	0.01	1.54	0.00
A3	Mean value	95.75	0.21	92.00	0.19	91.45	0.19	89.65	0.19	84.15	0.17
	SD	3.19	0.01	2.41	0.01	1.67	0.00	2.43	0.01	2.06	0.01
A4	Mean value	125.20	0.29	124.40	0.29	122.30	0.28	121.90	0.28	112.90	0.25
	SD	3.44	0.01	2.30	0.01	2.98	0.01	3.42	0.01	2.86	0.01
A5	Mean value	152.35	0.39	151.45	0.39	149.75	0.38	148.10	0.38	142.80	0.36
	SD	2.49	0.01	2.39	0.01	3.13	0.01	2.40	0.01	3.02	0.01
A6	Mean value	178.65	0.52	175.85	0.51	173.70	0.50	172.65	0.49	167.80	0.47
	SD	3.68	0.02	2.64	0.01	3.03	0.02	2.23	0.01	3.55	0.02
A7	Mean value	199.70	0.67	198.65	0.66	196.30	0.64	195.55	0.63	191.00	0.60
	SD	3.33	0.03	2.43	0.02	2.98	0.02	2.96	0.02	4.28	0.03
A8	Mean value	218.35	0.84	217.20	0.83	215.15	0.81	213.90	0.79	212.65	0.78
	SD	2.52	0.03	2.09	0.02	1.93	0.02	1.74	0.02	2.82	0.03
A9	Mean value	232.65	1.06	233.20	1.07	232.65	1.06	229.60	1.01	229.60	1.00
	SD	2.39	0.05	2.29	0.05	1.23	0.02	3.49	0.06	2.26	0.04
A10	Mean value	252.40	2.01	251.85	1.97	252.35	2.06	252.00	2.00	252.60	2.07
	SD	0.68	0.13	1.49	0.26	1.49	0.28	1.56	0.27	1.23	0.24

SD-standard deviation, Pix- Pixels, Abs-absorbancy, A1–A10; aluminium steps in mm.

different types of composite materials with values of dentine and enamel using Mann-Whitney U test with significance p=0.01. The equations of the best-fitting curves and their associated errors for all different combinations of voltage and exposition are provided in Table 2. The calibration curve of thickness of aluminum *versus* pixel values was plotted using the best-fit logarithmic regression to this data. The 3rd degree polynomial is a mathematical curve which best represents the given data. Figure 2 shows 3rd degree polynomial, for each combination of voltage and exposition. The absorbance of the aluminum step-wedge at different combinations of exposure is in Table 3. The radiopacity of composite materials are shown in Table 4. All of the tested materials show significant difference (p<0.001) in comparison with enamel and dentine. However, almost in each combination of exposure/voltage there were few composite materials which exhibited radiopacity equal to or slightly greater than dentin or enamel, but with statistical significance. The radiopacity

Table 4 Radiopacity of composite materials at different exposures

Composite materials/ Radiopacity Al (SD)	60 kV 0.06 s	60 kV 0.08 s	63 kV 0.06 s	63 kV 0.08 s	63 kV 0.1 s
Te-Econom B3	4.72 (0.09)	4.63 (0.08)	4.78 (0.08)	4.77 (0.08)	4.73 (0.09)
Tetric Ceram D3	4.44 (0.16)	4.49 (0.18)	4.52 (0.10)	4.53 (0.15)	4.64 (0.15)
Quix Fil Universal	4.08 (0.13)	3.97 (0.10)	4.01 (0.07)	4.10 (0.09)	4.26 (0.09)
Tetric Ceram HB C2	4.01 (0.07)	3.89 (0.16)	4.04 (0.09)	4.03 (0.10)	3.90 (0.14)
Tetric Evoceram A3	3.95 (0.18)	3.96 (0.16)	4.00 (0.18)	3.94 (0.22)	4.19 (0.17)
Ceram X D2	3.64 (0.15)	3.56 (0.15)	3.77 (0.25)	3.75 (0.21)	3.85 (0.13)
Ceram X Mono M5	3.59 (0.21)	3.59 (0.14)	3.71 (0.13)	3.73 (0.18)	3.78 (0.17)
TPH3 Spectrum B1	3.55 (0.11)	3.55 (0.16)	3.68 (0.12)	3.70 (0.14)	3.62 (0.10)
Fulfil A2	3.54 (0.07)	3.56 (0.14)	3.55 (0.10)	3.61 (0.10)	3.54 (0.10)
Estet-X A2	3.36 (0.11)	3.35 (0.14)	3.46 (0.13)	3.54 (0.13)	3.31 (0.10)
Amelogen Plus A2	3.28 (0.12)	3.28 (0.11)	3.34 (0.09)	3.39 (0.15)	3.34 (0.11)
Valux Plus B2	3.18 (0.08)	3.17 (0.09)	3.16 (0.11)	3.10 (0.14)	3.22 (0.09)
Clearfil Majesty Posterior A3	2.95 (0.12)	2.93 (0.12)	2.80 (0.08)	2.91 (0.06)	3.03 (0.11)
Filtek Z250 A3	2.92 (0.07)	2.95 (0.08)	2.98 (0.07)	2.91 (0.06)	3.00 (0.09)
Venus HKA 2.5	2.86 (0.09)	2.85 (0.08)	2.89 (0.11)	2.88 (0.11)	2.95 (0.09)
Charisma Opal A3	2.82 (0.13)	2.83 (0.10)	2.73 (0.07)	2.85 (0.10)	2.90 (0.12)
Filtek Ultimate A3 Enamel	2.77 (0.17)	2.68 (0.11)	2.70 (0.11)	2.74 (0.14)	2.81 (0.08)
Grandio A3	2.72 (0.17)	2.67 (0.1)	2.68 (0.14)	2.68 (0.09)	2.79 (0.14)
Kalore A2	2.70 (0.08)	2.67 (0.1)	2.64 (0.06)	2.67 (0.10)	2.67 (0.12)
Artemis B2 Enamel	2.58 (0.15)	2.63 (0.13)	2.66 (0.06)	2.66 (0.11)	2.60 (0.10)
Filtek Supreme XT A3D	2.56 (0.09)	2.53 (0.10)	2.70 (0.11)	2.62 (0.09)	2.59 (0.07)
Admira B3	2.55 (0.14)	2.58 (0.10)	2.66 (0.11)	2.57 (0.08)	2.65 (0.13)
Filtek Supreme C2B	2.45 (0.09)	2.55 (0.10)	2.41 (0.10)	2.46 (0.07)	2.42 (0.11)
Herculite HRV Ultra Enamel A3	2.43 (0.08)	2.39 (0.06)	2.38 (0.06)	2.42 (0.08)	2.41 (0.15)
Arabesk Top A3	2.36 (0.06)	2.32 (0.05)	2.38 (0.17)	2.37 (0.09)	2.36 (0.08)
Gradia Direct X A3	2.31 (0.06)	2.26 (0.08)	2.27 (0.08)	2.25 (0.07)	2.22 (0.08)
Amaris 03	2.25 (0.15)	2.20 (0.09)	2.25 (0.13)	2.24 (0.09)	2.29 (0.11)
Enamel	2.07 (0.05)	2.08 (0.05)	2.03 (0.1)	2.04 (0.09)	2.08 (0.1)
Amaris TN	2.07 (0.09)[a]	2.02 (0.08)	2.01 (0.1)	2.02 (0.05)	2.08 (0.07)[b]
Degufill SC Universal	1.99 (0.09)	1.85 (0.11)	1.92 (0.13)	1.9 (0.09)	1.82 (0.1)
Gradia Direct Posterior A2	1.58 (0.12)	1.58 (0.07)	1.54 (0.07)	1.55 (0.05)	1.47 (0.07)
Filtek Silorane A3	1.55 (0.09)	1.50 (0.13)	1.55 (0.09)	1.53 (0.06)	1.37 (0.07)
Dentin	1.12 (0.08)	1.10 (0.06)	1.09 (0.08)	1.11 (0.08)	1.13 (0.08)
Gradia Direct Anterior A3	0.65 (0.05)	0.61 (0.03)	0.66 (0.05)	0.69 (0.03)	0.74 (0.02)

No statistical significance in comparison with enamel: [a](p=0.775), [b](p=0.731). SD-standard deviation.

of composites ranged from 0.61 mm Al (Gradia Direct Anterior) to 4.78 mm Al (Te-Econom).

DISCUSSION

Thirty-two composite dental materials used in this study were chosen in order to evaluate a range of radiopacity. The lowest radiopacity requirement is 1 mm of aluminum alloy 1100, according to ISO and ANSI/ADA requirements[9]. The least stringent ISO dental protocols require at least 98.0% aluminum purity with no more than 1% iron and 0.1% copper[9, 17,18]. The aluminum step wedge used in this study was of 99.5% purity, with no more than 0.37% iron or 0.0014% copper. It has been shown that using a step wedge of an aluminum alloy with 4% copper would lead to radiopacity measurements a full 50% lower than the ones taken with 99.5% aluminum. A 0.1% copper should create a 1.25% systematic error[18].

Digital radiology does not involve film development, a process that introduces variation in the final radiograph[9,11,12]. The absorbance of the aluminum alloy 1100 step wedge changes very little between digital radiographs taken at the same exposure time and target distance. As a result, if a digital technique is used, it is not necessary to measure the absorbance of the step wedge in every radiograph as long as the target distance and exposure remain unchanged[16]. The digital image analysis has been considered of the same accuracy as transmission densitometry and can be equivalent to film but with less noise, providing precise and trustworthy numerical values and comparative radiodensity studies[8,12,13,19-21]. In transmission densitometry we obtain optical density, which is a logarithmic measure of the ratio of transmitted to incident light through the film image, while in digital image analysis we have radiographic density directly, because the pixels already have their determined gray shades, directly providing the values at a scale of 0 to 255 through the program[12,16]. Also, it is not necessary to perform any subtraction (as done in conventional X-ray films) when calculating the radiopacity[13]. It is reported that variability in radiopacity of values of the same restorative materials among different studies depend on many factors including film speed, exposure time, voltage used and the age of developing and fixing solutions[22].

The radiopacity of a restorative material serves as a valuable diagnostic tool, especially when evaluating the quality and long-term success of the restorations. Radiopacity allows a proper contrast between enamel/ dentin and restorative material, allowing the radiographic diagnosis of recurrent caries, inadequate proximal contours and marginal adaptation[23]. Marginal defects and secondary caries are usually located on the gingival part of Class II restorations[5]. The first increment of restorative material must be sufficiently radiopaque to clearly evaluate the tooth-restoration interface[24]. It has been recommended that the radiopacity of resin composites should be equal to or greater than that of the enamel[5,13,21,22,25]. Less radiopaque flowable and packable composites may cause some confusion regarding the diagnosis of secondary caries when used in posterior cavities[13,21]. Materials with a radiopacity less than enamel were reported not to be suitable for use, especially as an initial increment in areas prone to secondary caries[24]. However, it was reported that the higher radiopacity of amalgam restorations may lead to under- and over-scoring secondary caries and marginal defects compared to composite restorations. Caries lesions and marginal defects may be over-diagnosed with high radiopaque restorations, so moderate radiopacity might be more favorable and will make caries detection easier[26]. Distinguishing the restoration radiographically from tooth structures was reported to be more visible in areas primarily composed of dentin because of the lower dentin radiopacity compared to composite materials. The remaining enamel and dentin adjacent to and superimposed on the restoration along with the cavity morphology influence the radiographic evaluation. It is reported that high radiopacity of restorative materials decreased this influence[27].

Dental materials are constantly reformulated and the desired goals are to make them radiopaque enough to enable a radiographical evaluation. Introduction of chemical elements with high atomic numbers such as zinc, strontium, zirconium, barium and lanthanum result in more radiopaque materials[3-5,28]. The more radiopaque the elements are, the more radiopaque the material will be. According to our results, the Tetric group of composite materials (Te-Econom, Ceram and Evoceram) showed the highest radiopacity in Al equivalent. The materials had 2.2 and 4.2 times greater radiopacity in comparison to enamel and dentin, for voltage and exposition of 60 kV and 0.06 s. Tetric composite materials contain Yttrium (Y atomic number 39) and Ytterbium (Yb atomic number 70), which can result in a high level of radiopacity[21]. Also, Barium (Ba atomic number 56) is the element most commonly incorporated into composite restorative materials to increase radiopacity. In our study, 74.9% of all tested materials in all exposure combinations had radiopacity between 2 mm and 4 mm of aluminum. Only one material showed radiopacity below dentin in all exposure combinations. This can be explained in accordance with the manufacturer's propositions, that this composite material should be used only for anterior restorations. According to manufacturer's technical manual, there is no data about radiopacity for Gradia Direct Anterior, and manufacturer states that only Gradia Direct Posterior is radiopaque. Also, Gradia Direct Anterior material lacks in its composition the Fluoro-Alumino-Silicate Glass, which can be found in Gradia Direct Posterior and it may have influence in its radiopacity. The correct and detailed chemical compositions of dental composites are scarce, and for most dental materials manufacturers this is confidential data. So, we could not connect the correlation among filler content (the correct chemical elements) and type with radiopacity due to the limited composition data among tested materials. Also, the composition of filler and its content can vary from what the manufacturer claims, and we suggest the detailed chemical analysis of each composite material to determine its exact composition.

Although, adding chemical elements with high atomic numbers in composite filler, can have direct impact on radiopacity[3-5,13,28]. Sabbagh and others reported linear correlation between the percentage of fillers by weight using the Digora digital system for radiopacity analysis[13]. Our opinion is that all restoratives including posterior, anterior and lining materials should have sufficient radiopacity to be easily detected in radiographical examinations. Another study had a similar conclusion[5]. Also, five materials showed radiopacity below enamel, and one material showed no statististical difference in radiopacity of enamel. All of the tested materials met or exceeded the ISO equivalent radiopacity requirement for composite materials. Sabbagh and others reported that the radiopacity of an object on traditional Ultraspeed D film (ISO 14–28) can differ by roughly 10% from that of the object on a phosphor plate[13]. It is quite possible that the digital sensor used in this study produces radiopacity values that may differ from those measured on traditional film. Because the use of traditional film in X-ray is declining in everyday use, digital X-ray systems should represent future work on radiopacity analysis, resulting in standardization of study protocols.

CONCLUSION

All tested composite materials except one have ISO 4049 standard and showed radiopacity value greater than an aluminum equivalent of 1 mm. If used in posterior restorations, their decreased radiopacity may compromise diagnosis of caries or restorative material-tooth interface. The use of digital technique for radiopacity in this study is an easy, reliable, fast and precise way to analyze the different dental materials. Also, it can be comparable to other radiopacity studies using the digital technique.

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