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Original Research Article

Radiopacity of bulkfill resin composites using digital radiography system

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Abstract

Introduction: Restorative material radiopacity is a desired feature in Dentistry. A restorative material that presents low radiopacity makes difficult the diagnosis of carious lesions and the evaluation of the contour and excess of the restorative material because marginal steps cannot be detected. **Objective:** The objective of this study was to evaluate the radiopacity of ten bulkfill resin composites and a microhybrid composite, compared with enamel and dentin, using a complementary metal-oxide semiconductor (CMOS) digital radiographic system. **Material and methods:** Dental specimens and 4 specimens of each restorative material were made with thicknesses of 2 mm, 3 mm and 4 mm, totaling 132 discs of resin composite. The specimens with the dental fragments, along with an aluminum scale, were X-rayed (70 kVp, 7 mA, 30 cm and 0.40 s) using a Snap Shot CMOS semiconductor receiver. The radiopacity was measured by histogram with the ImageJ program. Statistical analysis was performed using the Kruskal-Wallis test followed by Dunn's post hoc test. **Results:** Only Opus Bulkfill Flow and Voco Admira Fusion X-Base showed radiopacity below that of enamel and above that of dentin, with a thickness of 2 mm. At 3 mm and 4 mm, no evaluated material showed radiopacity below that of enamel and that of dentin. **Conclusion:** It can be concluded that the resin composites showed higher radiopacity with increasing thickness. In the dental market, there are restorative bulkfill resin materials with radiopacity lower than that of dentin.

Introduction

Due to their considerable improvement since their invention, photopolymerizable resin-based restorative materials are currently widely used for large and deep cavities with variable success [16]. In addition, concern with dental aesthetics has greatly increased the use of resinous materials for restorative procedures [3].

However, conventional resinous materials require application in multiple small increments to reduce the polymerization stress and ensure the curing depth. Therefore, they require a longer clinical time for restorative procedures [7]. Multiple increments may also increase the chance of porosity or contamination between layers [5].

Low-viscosity composites, called “flow”, have improved handling characteristics, facilitating the adaptation of the restorative material to the walls of the cavity preparation when used as a base, in addition to reinforcing the remaining dental structure [16].

Since 1998, a class of restorative materials called Ormocers (ORganically MOdified CERamics) has been developed as an alternative to the matrix of organic monomers [2]. This material is composed of inorganic-organic co-polymers with non-metallic inorganic filler particles modified with silane [8] and does not require diluent [1].

Currently, the market has been looking for products that enable faster and simpler clinical care by reducing the curing time and allowing for higher composite increments [7]. Bulkfill composites were launched on the market as a new category of materials both of high and of low viscosity. These materials can be used in cavities over 4 mm deep, seeking to simplify the restorative procedure, and their properties are equivalent to those of conventional resins. Recently, several bulkfill flow resin composites were introduced by the dental materials industry, with mechanical properties similar to those of conventional composites [16]. The bulkfill composites have a lower number of fillers, and the filler particles have a larger size to guarantee the depth of the cure. In addition, they contain photoinitiators [12].

Despite improvements in the composites, some specifications need to be met, such as the radiopacity of the restorative material. A restorative material that presents low radiopacity makes difficult the diagnosis of carious lesions and the evaluation of the contour and excess of the restorative material because marginal steps cannot be detected [14]. In addition, radiopacity is a tool for assessing the long-term success of a restoration [1].

Among the properties of restorative materials, radiopacity is a prerequisite established by ISO/DP4049, from the International Organization for Standardization [16], and American National Standards Institute/American Dental Association specification #27 [10], where it is recommended that the radiopacity of a restorative material should be equal to or greater than the radiopacity of aluminum of the same thickness and should not be less than 0.5 mm of any value stated by the manufacturer.

A restorative resin composite should have a radiopacity sufficiently distinct from that of the dental tissues, which allows the evaluation of the marginal adaptation and the detection of secondary caries, in addition to the verification of the adaptation of the material in the cavity preparation, integrity of the proximal contour, points of contact, protrusions, eventual lack of material [16] and proximity of the material to the dental pulp in radiographic images [10].

The variation in the radiographic density of restorative resin materials has been a main complaint among dentists because it can induce error, assuming the presence of infiltrations in the restorations [10].

The radiopacity of the composites is affected by several factors, such as the thickness of the material and the type of radiographic film used; however, the composition of the material seems to be the most important factor [3], i.e., the presence of glass and ceramic particles containing heavy metals [11].

The acquisition of the radiographic image can be done with analog films [3]; however, the digital systems favor both the procedure itself and the measurement of the optical density of the different materials tested because the image is obtained in pixels, which are calculated in a mathematical matrix, facilitating the measurement of the radiographic density [15]. Digital systems in dentistry were introduced starting from 1989 [3] and are increasingly present in the daily practice of clinical dentistry [4].

Currently, two different concepts of digital detectors for image acquisition are available on the market: the direct digital sensor of a charge-coupled device (CCD) or the complementary metal-oxide semiconductor (CMOS) type and an indirect digital system of the photostimulated phosphor plate (PSP) type [9].

Therefore, the objective of this study is to evaluate the radiopacity of bulkfill resins, inserted or not in human teeth, of different thicknesses compared with dental fragments by means of a CMOS digital system.

Material and methods

After the evaluation and approval of the research project by the Human Research Ethics Committee under number 2.019.739, three recently extracted human dental elements were randomly selected. The dental elements were donated by patients who had exodontia indicated for orthodontic or periodontal reasons. After cleaning and the removal of debris, they underwent clinical inspection confirming the absence of cavities.

The three dental elements were sectioned in predetermined thicknesses of 2 mm, 3 mm and 4 mm using a precision cutting machine (IsoMet 1000, BUEHLER, USA). The thickness of each dental fragment was measured with a digital caliper (Metrotools, São Paulo, SP, Brazil). Until the beginning of the measurements, the dental specimens were stored in distilled water at 4ºC.

Eleven restorative resin materials were selected, of which ten were bulkfill resin composites and one was a microhybrid resin composite. Among the ten bulkfill resin composites evaluated, two are considered ormocers (table I).

Table I – Resin materials used in the study

Product	Manufacturer	Type of material	Lot
Admira Fusion x-Base Syringe®	VOCO	Bullkfill ormocer	1739095
Admira Fusion x-Tra®	VOCO GmbH, Germany	Bulkfill ormocer	1722221
Aura®	SDI, Australia	Bulkfill	160676
Filtek™ Bulkfill	3 M ESPE, Sumaré, SP, Brazil	Bulkfill	N689744
Filtek™ Bulkfill Flow	3 M ESPE, Sumaré, SP, Brazil	Bulkfill flow	1719900474
Opus Bulkfill®	FGM, Joinville, SC, Brazil	Bulkfill	030817
Opus Bulkfill Flow®	FGM, Joinville, SC, Brazil	Bulkfill flow	110417
Tetric® N-Cerem Bulkfill	Ivoclar Vivadent, Schaan, Liechtenstein	Bulkfill	U03089
SureFil® SDR flow+	Densply, Milford, DE, USA	Bulkfill flow	161025
X-Tra Base®	VOCO GmbH, Germany	Bulkfill flow	1721335
Filtek™ Z 250	3 M ESPE, Sumaré, SP, Brazil	Micro hybrid	1727500637

For the preparation of the test specimens, three translucent acrylic plates were produced by the researcher and used as molds, with thicknesses of 2 mm, 3 mm and 4 mm. Three holes 4 mm in diameter were made on each plate. The holes were filled with bulkfill resin composites, with insertion spatula number 03 for the resin material (Prisma, Pirituba, SP, Brazil), according to the instructions of each manufacturer. Then, another increment was made in one of the holes of each plate – four disks of each material (n=4) – for each thickness – 2 mm, 3 mm and 4 mm – totaling 12 disks of each material. In total, 132 disks of resin materials were produced. During the preparation, the molds were positioned on a glass plate, and another glass plate was positioned above the material to ensure the regularity of the material. A polyester matrix strip (Maquira, Maringá, PR, Brazil) was placed between the glass slides and the resinous material, which resulted in specimens with smooth surfaces. The specimens were photoactivated with a 2300 mW/cm^2 power LED (Woodpecker Led, Guilin, China) according to the manufacturers' recommendations. The translucency of the acrylic plate allowed the photopolymerization of the material on the lateral faces of the specimens. A pachymeter (Metrotools, São Paulo, SP, Brazil) was used to verify the thickness of the discs.

The acquisition of all radiographic images was performed with a periapical X-ray machine (Astex Equipamentos Radiológicos, Ltda, São Paulo, SP, Brazil) of the institution's radiology clinic, with standardized factors of 70 kVp, 7 mA and a 48 cm focus-receiver distance. The horizontal position of the radiographic receivers and the focus-receiver distance was ensured through the use of a device made of wood. This device has a ring at one of its ends to fit the locating cylinder of the X-ray head. At the other end, there is a straight platform at a straight angle relative to the beam. All images were taken with the same radiographic parameters. CliniView software (Instrumentarium Dental, Tuusula, Finland) was initially used to open the images; however, the X-ray images were later exported and stored as JPEGs (figure 1).

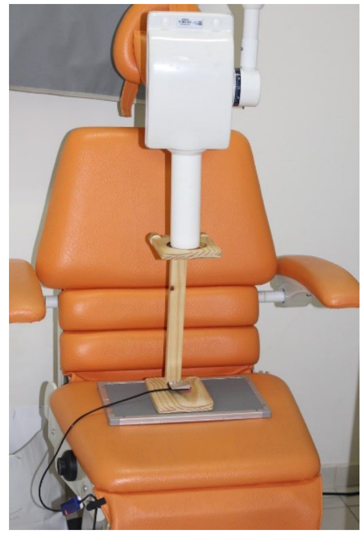

Figure 1 – Acquisition of the image

In each exposition, a disc of each bulkfill resin composite and a disc of the microhybrid resin composite of the same thickness and with the specimen of the dental element sectioned were grouped together with an aluminum scale. The exposures for each of the four specimens produced for each thickness were repeated. Then, four radiographs were generated for each of 2 mm, 3 mm and 4 mm, totaling 12 radiographic images. The dental fragment was repeated for equal thicknesses, and the aluminum scale was repeated in all images. The aluminum scale had nine gradations of 1 mm each and met the required regulations (Margraf Dental, Jenkintown, PA, USA).

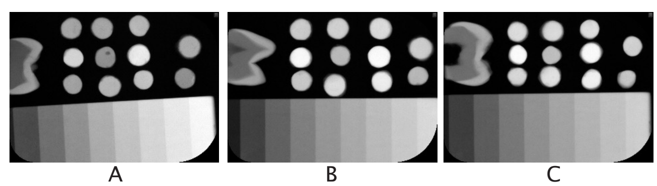

Figure 2 – Radiographic images obtained with the CMOS receiver: A) with 2 mm specimens; B) with 3 mm specimens; C) with 4 mm specimens

The sample composed of the resin discs was subjected to radiographic exposure using a direct CMOS intra-oral sensor, size 2, SnapShot system (Instrumentarium Dental, Tuusula, Finland, resolution 26.3 line pairs/mm and 19 μm pixel size) for 0.40 seconds and a 48 cm distance. The sensor was stabilized with a pink modelling wax 7 to ensure its position. Immediately after exposure, the radiographic images were exported as JPEGs and stored (figures 2A, B and C).

No radiographic images were modified with improvement filters. The analysis of the radiopacity (pixels) of the samples was performed by the researcher in an objective way, using the ImageJ dental imaging program (National Institutes of Health NIH, Bethesda, MA, USA) using a 17-inch LCD monitor (LG, Seoul, Korea, model 5000:1). The program provides an average of gray values per area of interest delimited by the cursor, obtained in a histogram. The histogram is an analysis of the radiographic density that in this work corresponds to the radiopacity; therefore, we will use the terms radiographic density and radiopacity as synonyms.

In the specimens, a central area and three standard areas were selected and previously determined in each of the other elements of the radiographic image (human tooth fragments and scale) in each exposition, and in the dental specimen, measurements were obtained on the enamel and dentin. Regions of the specimen with defects or filling voids were avoided (figure 3).

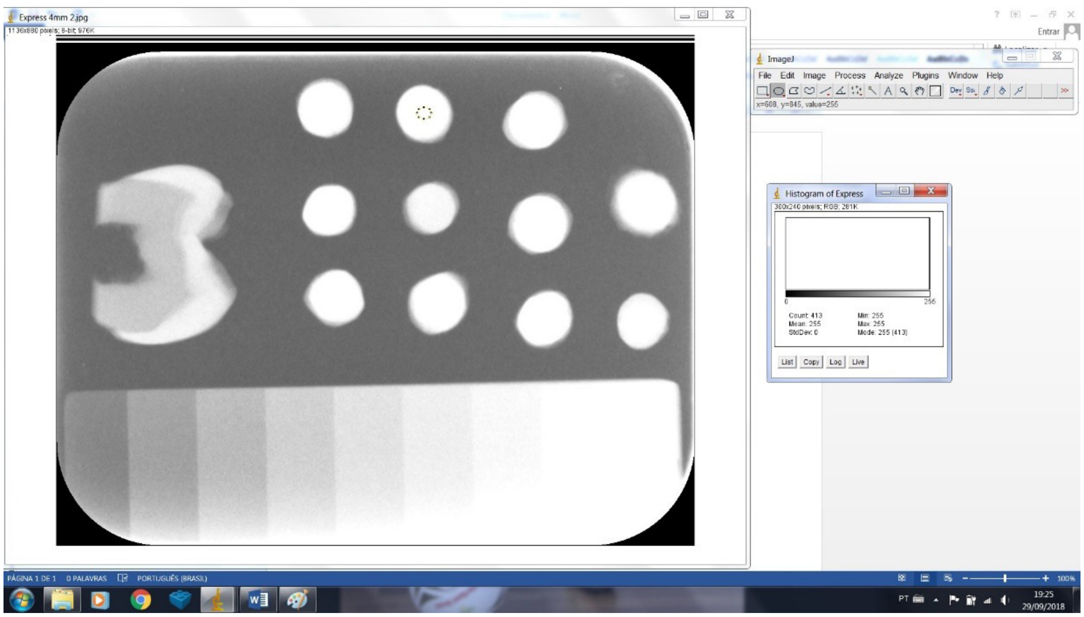

Figure 3 – Obtaining radiopacity values through the ImageJ program

The numerical values obtained in the measurements were organized in an Excel spreadsheet (Microsoft, USA).

Statistical analysis was performed using IBM Statistical Package for Social Sciences (SPSS) software. From the normality test done using the Shapiro-Wilk test, the non-parametric Kruskal-Wallis test followed by a Dunn's post hoc test was used for the numerical evaluation of the thickness of the specimen.

After 30 days of data collection, a new radiopacity measurement was performed to test the reproducibility of the examiner, and the parametric Student's T test or the Wilcoxon T test was used. The reproducibility test showed no significant difference between the collections, which makes the result reliable.

Results

Table II shows the radiopacity values obtained from 2-mm thick specimens, enamel, and dentin and the aluminum scale (steps 1-9) using the complementary metal-oxide semiconductor radiographic receptor. The median resin composite Opus Bulkfill Flow showed radiopacity above that observed in dentin but below that of enamel. The highest radiopacity median among the brands tested was observed for Tetric N-Ceram Bulkfill.

Table II – Radiopacity of the resin composites with a thickness of 2 mm – CMOS receiver – descriptive data

Commercial brands	Median	Minimum	Maximum
(1) Aura	163.50	161.00	168.00
(2) Surefil Bulkfill Flow SDR[a]	210.00	209.00	216.00
(3) Filtek Bulkfill Flow	159.50	157.00	166.00
(4) Opus Bulkfill	166.00	163.00	199.00
(5) Opus Bulkfill Flow[b]	142.00	139.00	143.00
(6) Voco Admira Fusion X-Tra	177.00	169.00	179.00
(7) Filtek Bulkfill	187.50	168.00	201.00
(8) Tetric N-Ceram Bulkfill[b,c]	233.00	206.00	245.00
(9) Voco X-Tra Base[d]	196,50	193.00	204.00
(10) Filtek Z250 XT	167.50	164.00	179.00
(11) Voco Admira Fusion X Base[e]	145.00	142.00	152.00
(12) Enamel[f]	149.50	147.00	151.00
(13) Dentin[a,c,g]	79.00	77.00	80.00
(14) Step 1[a,c,d,h]	31.50	31.00	32.00
(15) Step 2[a,c,d,i]	74.00	71.00	74.00
(16) Step 3[a,c,j]	110.00	109.00	112.00
(17) Step 4	143.50	143.00	144.00
(18) Step 5	171.00	170.00	172.00
(19) Step 6[h,k]	193.00	192.00	195.00
(20) Step 7[g,h,i,j]	211.50	210.00	213.00
(21) Step 8[b,g,h,i,j]	228.50	226.00	230.00
(22) Step 9[b,e,f,g,h,i,j,k]	245.50	244.00	247.00

Legend: Descriptive Analysis using SPSS: same letters indicate a statistically significant difference according to the Kruskal-Wallis test and Dunn's post hoc test, adopting a level of significance of 0.05

The radiopacity values obtained with the CMOS receptor from the 3-mm thick specimens, enamel, and dentin and the aluminum scale (steps 1-9) are shown in table III. The brands Surefil Bulkfill Flow and Tetric N-Ceram presented the highest median values of radiopacity among the resin composites evaluated. Median values less than those of enamel and dentin were not observed.

Table III – Radiopacity of resin composites with a thickness of 3 mm – CMOS receiver – descriptive data

Commercial brands	Median	Minimum	Maximum
(1) Aura	209.00	201.00	213.00
(2) Surefil Bulkfill Flow SDR[a]	248.00	242.00	250.00
(3) Filtek Bulkfill Flow	200.00	199.00	204.00
(4) Opus Bulkfill[b]	208.50	202.00	216.00
(5) Opus Bulkfill Flow	189.50	183.00	191.00
(6) Voco Admira Fusion X-Tra[c]	218.50	218.00	222.00
(7) Filtek Bulkfill[d]	222.00	215.00	228.00
(8) Tetric N-Ceram Bulkfill[e]	247.00	244.00	249.00

To be continued...

Continuation of table III

Commercial brands	Median	Minimum	Maximum
(9) Voco X-Tra Base[f]	235.00	233.00	240.00
(10) Filtek Z250 XT	205.50	203.00	212.00
(11) Voco Admira Fusion X Base	185.00	182.00	188.00
(12) Enamel[a,e]	161.50	160.00	165.00
(13) Dentin[a,e,f]	102.50	101.00	105.00
(14) Step 1[a,b,c,d,e,f, g]	28.50	28.00	29.00
(15) Step 2[a,c,d,e,f,h]	64.50	64.00	67.00
(16) Step 3[a,c,d,e,f]	97.50	97.00	100.00
(17) Step 4[a,e,f]	126.50	126.00	129.00
(18) Step 5[a,e]	151.00	149.00	153.00
(19) Step 6	169.50	169.00	173.00
(20) Step 7	186.50	185.00	190.00
(21) Step 8	201.50	199.00	204.00
(22) Step 9[g,h]	216.00	215.00	220.00

Legend: Descriptive Analysis using SPSS: same letters indicate a statistically significant difference according to the Kruskal-Wallis test and Dunn's post hoc test, adopting a level of significance of 0.05

Table IV shows the radiopacity values obtained with the CMOS receptor for the 4-mm thick specimens, enamel, and dentin and the aluminum scale (steps 1-9). There were no resin composites with a median radiopacity below those of enamel and dentin, and the highest median value of the radiopacity found was for the Surefil Bulkfill Flow brand.

Step 1 of the aluminum scale did not show changes in radiopacity values at the three measurement points; the gross value found is provided in the table.

Table IV – Radiopacity of the resin composites with a thickness of 4 mm – CMOS receiver – descriptive data

Commercial brands	Median	Minimum	Maximum
(1) Aura[a]	217.50	213.00	219.00
(2) Surefil Bulkfill Flow SDR[b]	251.00	243.00	251.00
(3) Filtek Bulkfill Flow	211.00	204.00	214.00
(4) Opus Bulkfill[c]	214.50	212.00	216.00
(5) Opus Bulkfill Flow	192.50	189.00	194.00
(6) Voco Admira Fusion X-Tra[d]	224.00	218.00	225.00
(7) Filtek Bulkfill[e]	225.00	222.00	226.00
(8) Tetric N-Ceram Bulkfill[f]	247.50	241.00	250.00
(9) Voco X-Tra Base[g]	235.50	234.00	240.00
(10) Filtek Z250 XT	212.00	206.00	213.00
(11) Voco Admira Fusion X Base	195.00	192.00	197.00
(12) Enamel	166.50	164.00	168.00
(13) Dentin[b,e,f,g]	107.00	106.00	108.00
(14) Step 1[a,b,c,d,e,f,g]	26.00	26.00	26.00
(15) Step 2[a,b,d,e,f,g]	60.00	59.00	61.00

To be continued...

Continuation of table IV

Commercial brands	Median	Minimum	Maximum
(16) Step 3[b,d,e,f,g]	92.00	91.00	92.00
(17) Step 4[b,f,g]	119.00	117.00	119.00
(18) Step 5[b,f]	141.50	139.00	143.00
(19) Step 6[b]	159.00	157.00	161.00
(20) Step 7[b,f]	175.50	173.00	177.00
(21) Step 8	188.50	186.00	191.00
(22) Step 9	204.50	201.00	205.00

Legend: Descriptive Analysis using SPSS: same letters indicate a statistically significant difference according to the Kruskal-Wallis test and Dunn's post hoc test, adopting a level of significance of 0.05

Discussion

When a professional chooses to use bulkfill materials, it is understood that the material will be used in cavities of 4 mm or more, and in this situation, the materials have not been tested [7]. Therefore, this study evaluated the radiopacity of restorative materials in 2 mm, 3 mm and 4 mm specimens, aiming to simulate the clinical situation indicated for the use of bulkfill composites.

The increase in the thickness of the restorative material resulted in greater radiopacity in all materials tested. This perception corroborates the finding of other authors [6] who also stated that one of the factors responsible for the radiopacity of a restorative material is its thickness. However, the inorganic filler composition of the resin composite still appears to be the most important factor determining its radiopacity [6]. In this way, the Surefil SDR flow and Tetric N-Cerem Bulkfill products presented higher radiopacity in the three thicknesses evaluated; these commercial brands contain the radiopacifying components barium and aluminum and ytterbium and barium, respectively. Ytterbium and barium, among the chemical elements used as radiopacifying agents, are those with the highest atomic number.

In addition to the type of radiopacifying agent, the amount of this agent incorporated in the product is also important in determining the radiographic density of the material [6]; thus, the presence of a high atomic number element does not always guarantee the ideal radiopacity of the product. Some authors have proved that not only the radiopacifying element determines the radiopacity of resin composites but also the amount of the agent in the material, showing that the higher the amount of inorganic filler, the higher the radiopacity of the product.

Because Voco Admira Fusion X-Base and Opus Bulkfill Flow are materials of low viscosity, that is, they are fluid resins, it is understood that there is less inorganic filler in their compositions [13]. Both, at a thickness of 2 mm, presented radiopacities above that of dentin but below that of the enamel, which may compromise the safety of its use in the main indication for fluid resins, which is the initial increment. When a restorative material with a radiopacity below that of dental tissues is used as an initial increment, it may mimic the image of a recurrent carious lesion and lead to the unnecessary replacement of the restoration, which is characterized as an iatrogenesis. Ideally, in this case, the manufacturers shoul increase the radiopacity of the fluid material without increasing the amount of filler, that is, using chemical elements of a greater atomic number.

Both restorative resin materials organically modified by ceramic have silicon as a radiopacifying agent, as reported by the manufacturer, which is a lower atomic number element when compared to the other elements used. However, Voco Admira Fusion X-Tra was more radiopaque than was Voco Admira Fusion X-Base in all tested situations and showed different averages of radiopacity, which indicates a variation in the amount of inorganic filler of each product.

The Tetric N-Ceram and Voco X-Tra Base resin composites showed higher stability regarding radiopacity values; that is, they presented a smaller value difference for two different thicknesses, leading to the understanding that the composition of the product is a determining factor for the radiopacity of the material because Voco X-Tra Base uses ytterbium and aluminum as radiopacifying agents. This fact is important because, in clinical routine, cavity preparations vary widely, and this stability assures the professional that future radiographic evaluations will not lead to mistakes, regardless of the thickness of the material.

The differences in radiopacity between the studied materials are described in the tables and are easily observed. However, significant differences are not found for all materials when compared with the enamel, dentin, and aluminum steps because the nonparametric method has less power to detect subtle differences. This method was chosen based on criteria related to the number of observations made and the normality test. Because of this, the descriptive analysis of the data is fundamental in this study.

The CMOS radiographic system proved to be reliable and practical as a resource for the evaluation of the radiopacity of restorative materials. The CMOS system has an automatic processing system and a high spatial resolution, and CMOS sensors have an increased perception for low-contrast details and have been widely used in dental offices and clinics.[16] The indication of the use of digital techniques to evaluate the radiopacity of resin materials is easy, reliable, fast and accurate [4].

The analysis of the radiopacity of restorative materials continues to be important to avoid wrong diagnoses and the replacement of restorations that are intact, mainly due to the constant launch of new products in the dental market. In addition, studies should be carried out to verify how much organic fillers influence the radiopacity of resin composites because the addition of radiopaque monomers can be an alternative to increase the radiopacity of resin composites. Other studies should also be carried out to obtain a radiopacity threshold for resin materials because it is known that excess radiopacity may also compromise the radiographic evaluation of restorations, generating optical illusions and wrong diagnoses.

Conclusion

The radiopacity of the restorative materials showed variations according to thickness; it was observed that the greater the thickness of the material used, the greater its radiopacity. The 2-mm thick specimens of Opus Bulkfill Flow and Voco Admira Fusion X Base obtained radiopacity values below that of the enamel and above that of the dentin. Both are fluid resins and may compromise safety for initial increment use. Although it is a fundamental property, not all the resin composites studied present radiopacity above that of enamel.

References

1. Hitij T, Fidler A. Radiopacity of dental restorative materials. Clin Oral Investig. 2013;17(4):1167-77.

2. Kalra S, Singh A, Gupta M, Chadha V. Ormocer: an aesthetic direct restorative material; An in vitro study comparing the marginal sealing ability of organically modified ceramics and a hybrid composite using an ormocer-based bonding agent and a conventional fifth-generation bonding agent. Contemp Clin Dent. 2012 ;3(1):48-53.

3. Kapila R, Matsuda Y, Araki K, Okano T, Nishikawa K, Sano T. Radiopacity measurement of restorative resins using film and three digital systems for comparison with ISO 4049: International Standard. Bull Tokyo Dent Coll. 2015;56(4):207-14.

4. Kim JH, Abdala-Júnior R, Munhoz L, Cortes ARG, Watanabe PCA, Costa C et al. Comparison between different cone-beam computed tomography devices in the detection of mechanically simulated peri-implant bone defects. Imaging Sci Dent. 2020;50(2):133-9.

5. Kumagai RY, Zeidan LC, Rodrigues JA, Reis AF, Roulet JF. Bond strength of a flowable bulk-fill resin composite in class II MOD cavities. J Adhes Dent. 2015;17(5):427-32.

6. Lachowski KM, Botta SB, Lascala CA, Matos AB, Sobral MA. Study of the radio-opacity of base and liner dental materials using a digital radiography system. Dentomaxillofac Radiol. 2013;42(2):20120153.

7. Leprince JG, Palin WM, Vanacker J, Sabbagh J, Devaux J, Leloup G. Physico-mechanical characteristics of commercially available bulk-fill composites. J Dent. 2014;42(8):993-1000.

8. Manhart J. Nanohybrid-ORMOCER®-Füllungsmaterial für die Bulk-Fill-Technik. Stomatol. 2015;112(6):266-7.

9. Oliveira AE, Almeida SM, Paganini GA, Haiter Neto F, Bóscolo FN. Comparative study of two digital radiographic storage phosphor systems. Braz Dent J. 2000;11(2):111-6.

10. Raitz R, Moruzzi PD, Vieira G, Fenyo-Pereira M. Radiopacity of 28 composite resins for teeth restorations. J Contemp Dent Pract. 2016;17(2):136-42.

11. Saridag S, Helvacioglu-Yigit D, Alniacik G, Özcan M. Radiopacity measurements of direct and indirect resin composites at different thicknesses using digital image analysis. Dent Mater J. 2015;34(1):13-8.

12. Sousa-Lima RX, Silva L, Chaves L, Geraldeli S, Alonso R, Borges B. Extensive assessment of the physical, mechanical, and adhesion behavior of a low-viscosity bulk fill composite and a traditional resin composite in tooth cavities. Oper Dent. 2017;42(5):E159-66.

13. Tarcin B, Gumru B, Peker S, Ovecoglu HS. Evaluation of radiopacity of bulk-fill flowable composites using digital radiography. Oper Dent. 2016;41(4):424-31.

14. Tveit AB, Espelid I. Radiographic diagnosis of caries and marginal defects in connection wit radiopaque composite fillings. Dent Mater. 1986;2(4):159-62.

15. Wenzel A, Haiter-Neto F, Frydenberg M, Kirkevang LL. Variable-resolution cone-beam computerized tomography with enhancement filtration compared with intraoral photostimulable phosphor radiography in detection of transverse root fractures in an in vitro model. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2009;108(6):939-45.

16. Yildirim T, Ayar MK, Akdag MS, Yesilyurt C. Radiopacity of bulk fill flowable resin composite materials. Niger J Clin Pract. 2017;20(2):200-4.