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ORIGINAL ARTICLE

Rodrigo Borges Fonseca · Carolina Assaf Branco · Paulo Vinícius Soares · Lourenço Correr-Sobrinho · Francisco Haiter-Neto · Alfredo Júlio Fernandes-Neto · Carlos José Soares

Radiodensity of base, liner and luting dental materials

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Abstract The aim of this study was to determine the radiodensity of base, liner and luting dental materials and to compare them with human enamel and dentin. Four classes of materials were examined: conventional glass ionomers (CG)—Vitro Cem, Ketac Bond, Vidrion F, Vidrion C; resin-modified glass ionomers (RMGI)—Fuji II LC, Vitrebond; resinous cement (RC)—Rely-X ARC; and zinc phosphate cement (ZP)—Cimento LS. Five 2-mm-thick standard samples of each material and five 2-mm-thick enamel and dentin samples were produced. An aluminum step wedge served as control. Samples were positioned over a phosphor plate of Digora digital system, exposed to X-ray, and the radiodensity obtained in the software Digora for Windows 2.0. Data were submitted to Kruskal–Wallis and Dunnett multiple comparisons test (α=0.05). According to statistical analysis, the following sequence in degree of radiodensity could be seen among the groups: Cimento LS (ZP) > Vitro Cem (CG) = Fuji II LC (RMGI) = Rely-X ARC (RC) = Vitrebond (RMGI) > Ketac Bond (CG) > enamel = Vidrion F (CG) > Vidrion C (CG) = dentin. The presence of radiopaque fillers such as zinc, strontium, zirconium, barium, and lanthanium rather than material type seems to be the most important factor when analyzing material radiodensity. Almost all investigated materials presented an accepted radiodensity.

Keywords Radiodensity · Dental materials · Dental hard tissues · Composition · Digital radiographs

R. B. Fonseca · L. Correr-Sobrinho (✉)
Área de Materiais Dentários,
Faculdade de Odontologia de Piracicaba,
Universidade Estadual de Campinas,
Av. Limeira, n° 901, Caixa Postal 52, CEP 13414-903,
Piracicaba, São Paulo, Brazil
e-mail: sobrinho@fop.unicamp.br
Tel.: +55-19-34125200
Fax: +55-19-34210144

C. A. Branco · A. J. Fernandes-Neto
Department of Occlusion and Fixed Prosthodontics,
Dental School, Federal University of Uberlândia,
Uberlândia, Brazil

P. V. Soares · C. J. Soares
Department of Operative Dentistry and Dental Materials,
Dental School, Federal University of Uberlândia,
Uberlândia, Brazil

F. Haiter-Neto
Department of Oral Radiology, Piracicaba Dental School,
University of Campinas,
Piracicaba, São Paulo, Brazil

Introduction

It is generally accepted that materials should be sufficiently radiopaque to be detected against a background of enamel and dentin, facilitating the evaluation of restorations in every region of the mouth and enabling the detection of secondary caries, marginal defects, contour of restoration, contact with adjacent teeth, cement overhangs, and interfacial gaps [1, 6, 11, 12, 17, 18]. The radiopacity degree required for ideal clinical performance can vary within the same class of material [11]. In spite of that, if used as a liner or base, some authors consider that it should be equal or more than dentin to assure that the material would not be mistaken for carious dentin [13]; however, other authors consider that restorative materials need a degree of radiopacity slightly higher than that of enamel [5, 11, 12, 16, 17, 19].

Several factors may affect the radiopacity of dental materials, but the composition seems to be the most important one [11, 12, 16]. In addition, the material thickness [11, 12], the angulation of the X-ray beam, the methodology employed for evaluation [17], the type of X-ray film, the age of developing and fixing solutions [5], and the alteration in the power/liquid ratio [11] can also have an influence. Common methods for evaluation of density of radiographic images employ conventional X-ray films and densitometers [1–3, 11, 12, 16] or spectrophotometers [22]. Since 1987, alternatives to silver-halide receptors for intraoral radiographic imaging have included CCD-based systems and storage phosphor technology [7]. Digital intraoral radiography reduces patients' exposure to X-rays

Table 1 Restorative materials used in the study

Type	Commercial name	Manufacturer	Composition
Zinc phosphate (ZP)	Cimento LS	Vigodent, Rio de Janeiro, Brazil	Powder: ZnO and MgOl; liquid: phosphoric acid, water, and Al_2PO_3
Conventional glass ionomer (CG)	Vitro Cem	DFL, Rio de Janeiro, Brazil	Powder: strontium and aluminum silicate, FeO, and dehydrated polyacrylic acid; liquid: polyacrylic acid, tartaric acid, and distilled water
Conventional glass ionomer (CG)	Ketac Bond	3M-ESPE, St. Paul, MN, USA	Powder: calcium–aluminum–lanthanium–fluorosilica glass, pigments; liquid: polycarboxylic acid, tartaric acid, water, and conservation agents
Conventional glass ionomer (CG)	Vidrion F	SS White, São Paulo, Brazil	Powder: Na, Ca, aluminofluorosilicate glass, $BaSO_4$, FeO, and dehydrated polyacrylic acid; liquid: tartaric acid and distilled water
Conventional glass ionomer (CG)	Vidrion C	SS White, São Paulo, Brazil	Powder: Na, Ca, aluminofluorosilicate glass, and dehydrated polyacrylic acid; liquid: tartaric acid and distilled water
Resin-modified glass ionomer (RMGI)	Fuji II LC	GC Corp., Tokyo, Japan	Powder: aluminofluorosilicate glass, ZnO, pigment; liquid: polyacrylic acid, HEMA, water, and photoinitiator
Resin-modified glass ionomer (RMGI)	Vitrebond	3M-ESPE, St. Paul, MN, USA	Powder: fluoroaluminosilicate glass powder with SiO_2, AlF_3, ZnO, SrO, cryolite, NH4F, MgO, and P_2O_5; liquid: modified polyacrylic acid with pendant methacrylate groups, HEMA, water, and photoinitiator
Dual resinous cement (RC)	Rely-X ARC	3M-ESPE, St. Paul, MN, USA	Bis-GMA, TEGDMA, silica and zirconium fillers 67.5% (wt%), photoinitiator

BisGMA Bisphenol-A diglycidyl ether dimethacrylate, *HEMA* 2-hydroxyethylmethacrylate, *TEGDMA* triethylene glycol dimethacrylate

[21], permits the improvement of image quality by image manipulation, is faster, easy to use, and cheaper than conventional techniques [20], and also enables the attainment of an accurate evaluation of radiodensity [8].

From the literature, it is known that highly radiopaque materials make a radiographic diagnosis more difficult [6], while radioluscent materials will show up as a separate layer [1]; then it seems necessary to evaluate the radiopacity of materials for different restorative purposes compared to hard dental tissues. Because secondary caries or gaps may occur exactly under materials that are placed in direct contact with tooth structure, the radiodensity evaluation of liner, base, and luting materials seems important. The aim of this study was to determine the radiodensity of different base, lining, and luting dental materials and to compare them with enamel and dentin from human teeth. The null hypothesis to be tested was that there was no difference between the radiodensity of these different materials and tooth structures.

Materials and methods

Eight different base, lining, and luting dental materials were employed in this study. Material types, commercial names, manufacturers, and composition are listed in Table 1. In addition to the dental materials, five recently extracted human third molars were selected and stored in 0.2% thymol. All human teeth were collected from patients who had signed an informed consent, in accordance with the ethics committee of the Federal University of Uberlândia. Five 2-mm-thick standard samples of each material were produced according to the manufacturers' instructions and inserted in a 2-mm-thick stainless steel mold with 4.0 mm in diameter. Chemical-cured materials were allowed to set during the period recommended by each manufacturer. Photopolymerizable materials were light-cured for 40 s with an XL3000 curing unit (3M-ESPE, St. Paul, USA) at 850 mW/cm^2. After removal of the samples from the mold, the thickness was checked with a digital caliper in order to fit 2.0±0.1 mm.

The teeth were sectioned transversally with a diamond saw (KgSorensen, Barueri, Brazil) and ground with a 600-grit silicon carbide paper under a stream of running water to produce enamel and middle dentin samples of 2.0 mm in thickness. The samples were stored in moist conditions at 37°C until the radiographic procedures were conducted. An

Table 2 Means and standard deviations (in pixels), and results of statistical analysis of materials and tooth structures radiodensity by Kruskal–Wallis and Dunnett multiple comparisons tests (α=0.05)

Group	Means±SD	Sum of the ranks
Cimento LS (ZP)	202.59±2.34	143.00^A
Vitro Cem (CG)	149.60±11.16	112.43^B
Fuji II LC (RMGI)	147.43±12.06	108.70^B
Rely-X ARC (RC)	142.86±8.32	101.07^B
Vitrebond (RMGI)	139.81±10.36	94.87^B
Ketac Bond (CG)	128.07±4.69	72.93^C
Enamel	104.45±4.88	45.20^D
Vidrion F (CG)	103.99±7.58	43.80^D
Vidrion C (CG)	88.85±5.88	18.20^E
Dentin	80.78±16.03	14.80^E

Different letters mean significant statistical differences (p<0.05)
ZP zinc phosphate, *CG* conventional glass ionomer, *RMGI* resin modified glass ionomer, *RC* resin cement, *SD* standard deviation values

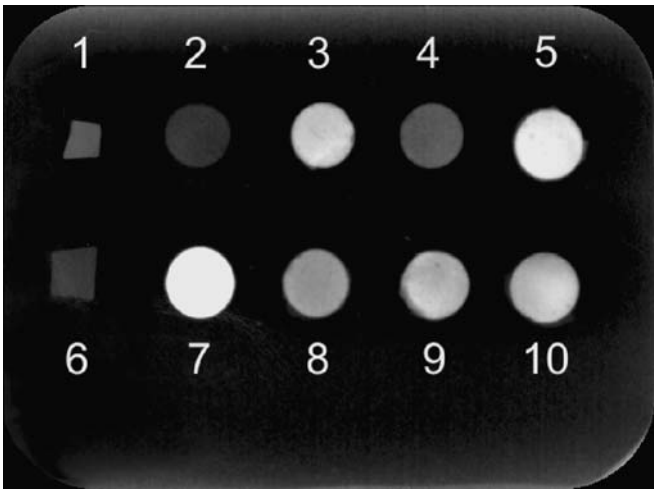

Fig. 1 Digital radiograph of the studied materials and tooth structures. *1* Enamel, *2* Vidrion C, *3* Fuji II LC, *4* Vidrion F, *5* Vitro Cem, *6* dentin, *7* Cimento LS, *8* Ketac Bond, *9* Vitrebond, *10* Rely-X ARC

aluminum step wedge, ranging from 1.0 to 9.0 mm in thickness, served as a control.

The samples were positioned over a phosphor plate and the radiographic exposition was performed using an X-ray machine – GE 1000 (General Electric, Milwaukee, WI, USA) – exposing it for 0.2 s at 70 kV and 10 mA, with a source-to-sample distance of 40 cm. Three exposures were performed for each sample. The radiographs were transferred from the phosphor plate to the computer via a Digora scanner (Digora, Soredex, Helsinki, Finland).

The radiodensity (in pixels) of the samples were determined with the resident software provided by the manufacturer. The Digora system has a Windows-based software, Digora for Windows 2.0, which is capable to measure density curves of digital radiographies obtained by X-ray impregnation on the image phosphor plate. The radiodensity of each radiographed structure or material was obtained by clicking with the software cursor right above the digital image. Each digital image had its radiodensity measured immediately after scanning, without any modification in contrast or brightness. This software shows data concerning the highest and the lowest radiodensity of the sample, and an average value, which was considered to be the sample's initial radiodensity. As each sample was submitted to three exposures, the sample's final radiodensity was considered to be the mean of those values.

The Shapiro–Wilk test of normality revealed that the data did not present a normal and homogeneous distribution (p=0.000). Then, the Kruskal–Wallis and Dunnett multiple comparisons tests (α=0.05) were employed for statistical analysis. The aluminum step wedge was also compared to each group by Kruskal–Wallis and Dunnett multiple comparisons tests (α=0.05).

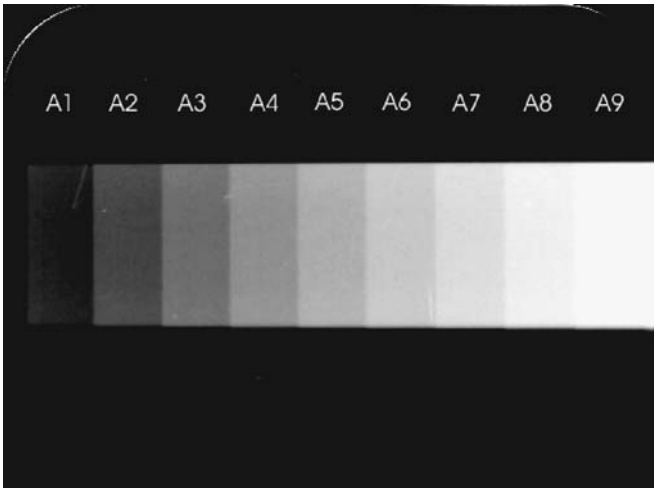

Fig. 2 Digital radiograph of the aluminum step wedge. *A1* 1.0 mm, *A2* 2.0 mm, *A3* 3.0 mm, *A4* 4.0 mm, *A5* 5.0 mm, *A6* 6.0 mm, *A7* 7.0 mm, *A8* 8.0 mm, *A9* 9.0 mm

Results

Table 2 shows the results of radiodensity measurements together with the statistical analysis. Means and standard deviations are presented just to enable an easier comprehension. However, because data were not normally distributed, the sum of the ranks, provided by the nonparametric analysis, is also provided. The Kruskal–Wallis test showed a highly significant difference among the experimental groups (p<0.000) and Dunnett multiple comparisons test showed that Cimento LS (ZP) was the most radiopaque material and Vidrion C (CG) the most radioluscent one. According to statistical analysis, the following sequence in degree of radiodensity could be seen among the groups: Cimento LS (ZP) > Vitro Cem (CG) = Fuji II LC (RMGI) = Rely-X ARC (RC) = Vitrebond (RMGI) > Ketack Bond (CG) > enamel = Vidrion F (CG) > Vidrion C (CG) = dentin (Table 2). Figure 1 shows a radiographic image of the groups, and Fig. 2 shows the aluminum step wedge. Figure 3 presents the comparison between the aluminum step wedge and experimental groups.

Discussion

When an X-ray beam interacts with matter, the X-ray photons are either absorbed by its atoms or scattered without loss of energy. Irrespective of the type of X-ray-to-matter interactions, it is always directly proportional to either the atomic number of the absorber or to its electric density [9]. Thus, depending on the atomic composition of the matter, the radiodensity of a radiographic image will be differently influenced. Besides atomic composition, the density of each atom in the matter, its physical structure, and its thickness may also influence radiodensity [8]. In this study, samples with a standardized 2-mm thickness ensured no influence of this factor on radiodensity. Thus, the differences could be due to the atomic composition, density of atoms, and physical arrangement of materials or tooth tissues.

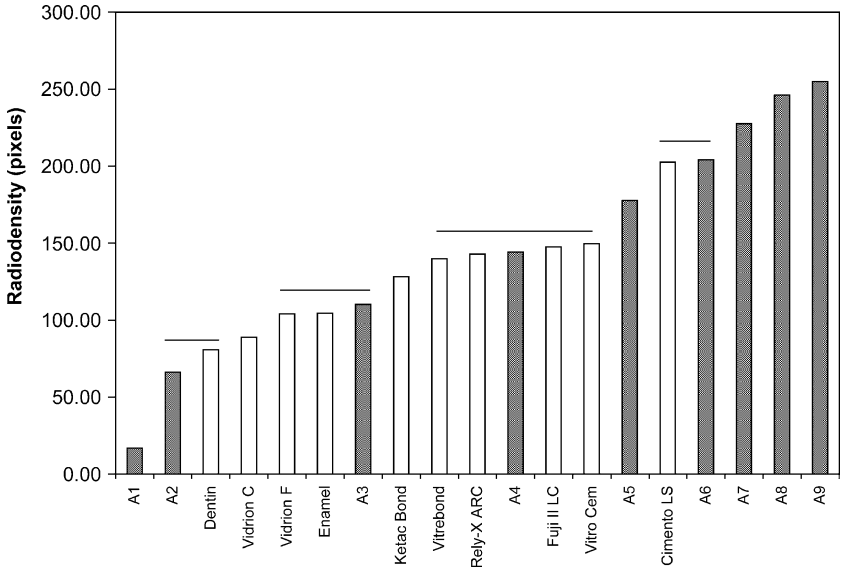

Fig. 3 Comparison between experimental groups and aluminum step wedge. Means connected by the same *horizontal line* are similar by the Kruskal–Wallis and Dunnett multiple comparisons tests ($p>0.05$). A1–A9, 1.0–9.0-mm-thick aluminum

Dental enamel is composed of 92–96% of inorganic matter, 1–2% of organic material, and 3–4% of water (wt%) [10]. Most of the inorganic matter is $Ca_{10}(PO_4)_6(OH)_2$, hydroxyapatite, but other atomic elements can be detected as P, Cu, K, Cl, Zn, Fe, Ti, Sr, V, Mn, and Zr [15]. On the other hand, dentin has a reduced inorganic content and is considered to be a hydrated biological composite composed of 70% inorganic material, 18% organic matrix, and 12% water (wt%) [13]. These different compositions, plus the fact that the physical arrangement of enamel prisms differs from that of dentin tubules, may definitively account for the higher radiopacity of enamel as observed in this and other studies [8].

Dental materials are constantly reformulated, and one of the desired goals is to make them radiopaque enough to enable the attainment of valuable information during radiographic examinations [17]. In this study, six out of eight evaluated materials showed a degree of radiodensity higher than that of enamel and dentin, as recommended by several authors [6, 11, 12, 16, 17, 19]. The two other materials showed degrees of radiodensity between the ones of enamel and dentin. Because of these differences, the null hypothesis had to be rejected. Differences in composition seem to be the principal reason for the observed occurrences. The addition of chemical elements with high atomic numbers such as zinc, strontium, zirconium, barium, and lanthanium results in more radiopaque materials [2, 11, 12, 17]. Then, the more radiopaque the elements are, the more radiopaque a material will be. Zinc phosphate cements have long been considered a highly radiopaque material due to its high content of zinc oxide and, as found by Attar et al. [2], this was the most radiopaque material in this study. Conventional glass ionomers are usually radioluscent [11, 12], but new formulations have changed this tendency. In this study, Vitro Cem and Ketac Bond, two conventional glass ionomers, presented higher radiodensity than enamel; this is attributed to the addition of strontium and lanthanium (Table 1), respectively. On the other hand, Vidrion F was similar to enamel and Vidrion C just similar to dentin. Vidrion F is a lining material and it is more viscous than Vidrion C (glass ionomer for cementation). The higher viscosity and the presence of $BaSO_4$ and FeO seem to render higher radiodensity for the former.

Resin-modified glass ionomers are not always radiopaque [12]. In addition to the presence of radiopaque glasses, it is important to consider the polymer matrix, the chemical nature of the filler, their size, density, and addition level [4]. In this study, the two resin-modified glass ionomers, Fuji II LC and Vitremer, presented higher radiodensity than enamel, which was similar to a resin-based cement, Rely-X ARC. Fuji II LC and Vitremer present 2-hydroxyethylmethacrylate as the resinous component which does not seem to offer an important contribution on radiodensity. In spite of that, they contain zinc and strontium oxides which resulted in the high degree of radiodensity. The resin cement Rely-X ARC has 67.5% (wt%) of silica and zirconium fillers and monomers of high molecular weight (bisphenol-A diglycidyl ether dimethacrylate and triethylene glycol dimethacrylate). Turgut et al. [17] showed resins with the same monomers, but with different types of fillers, as radioluscent materials. Thus, it seems that the filler found in Rely-X ARC seems to be responsible for the observed radiodensity.

Similar to Attar et al. [2], this study found a zinc phosphate cement (Cimento LS) presenting radiodensity values equivalent to 6.0 mm of aluminum (Al), but Rely-X ARC was two times more radiodense in the present study (4.0 vs 2.0 mm Al). It is possible that this is the result of the use of 2.0-mm-thick samples against the 1.0-mm-thick ones in their study. In addition, enamel and dentin samples from this study present themselves as more radiodense (3.0 and 2.0 mm Al, respectively) than the results from other studies that employed 1.0-mm-thick samples [2, 16, 17, 22], but similar to Bouschlicher et al. [3] who employed 2.0-mm-thick samples. The effect of the sample thickness

was also confirmed on Ketac Bond and Fuji II LC which showed a higher degree of radiodensity (in millimeters of Al) in this study than in others [16, 22].

Different classes of materials were evaluated and, within the same class, there was a variation in radiodensity. Considering that a material must be radiopaque, the clinician must pay careful attention to the composition rather than to the material classification. In addition, if different materials are to be used, Akerboom et al. [1] also recommend the use of materials with similar radiodensity in order to facilitate future radiographic observations. The diagnosis facility is improved with materials slightly more radiopaque than enamel, but a correct technique should also be performed because the angulation of the X-ray beam can superimpose radiopaque materials over defects or carious dentin [17]. According to the methodology employed and within the limitations of this study, it was seen that the zinc phosphate cement, the two conventional glass ionomers, the resin cement, and the two resin-modified glass ionomers were more radiopaque than enamel and dentin. One conventional glass ionomer was similar to enamel and more radiopaque than dentin and another one was just similar to dentin.

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