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Evaluation of the Radiopacity of Luting Cements by Digital Radiography

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Abstract

Purpose: The aim of this study was to evaluate the radiopacity of eight contemporary luting cements using direct digital radiography.
Materials and Methods: Ten specimens, (5 mm diameter, 1 mm high) were prepared for each material tested (RelyX ARC, RelyX U100, RelyX Unicem, Nexus 2, Nexus 3, Metacem, Breeze, Adhesor zinc phosphate). The specimens were stored in a moist chamber at 37°C until completely set, then radiographed using a Kodak digital sensor and an aluminum step wedge with variable thicknesses (1 to 13 mm in 1-mm increments) used for reference. A Kodak 2100 intraoral X-ray unit was operated at 60 kV, 7 mA, and 0.20 seconds. According to international standards, the radiopacity of the specimens was compared with that of the aluminum step wedge using the equal-density area tool of the Kodak Dental Imaging software (ver. 6.7). Data were analyzed by ANOVA and Tukey's test.
Results: Adhesor zinc phosphate cement showed the highest radiopacity of all materials and dentin. Breeze showed the lowest radiopacity ($p < 0.05$). No significant difference in radiopacity was observed between dentin and RelyX ARC, Nexus 2, or Metacem ($p > 0.05$). The radiopacities of Nexus 3 and RelyX Unicem were significantly higher than those of other resin cements and dentin ($p < 0.05$).
Conclusions: All materials showed radiopacity above the minimum recommended by the International Organization for Standardization and the American National Standards/American Dental Association. Breeze had less radiopacity than dentin.

Dental luting cements are used to cement fixed partial dentures to abutments and post/dowel restorations into root canals. Radiopacity is a fundamental factor in the application of luting materials. The advantages of radiopaque over radiolucent materials are the easy detection of recurrent dental caries and observation of the radiographic interface between the materials and tooth substrates.[1,2] Thus, the Council on Dental Materials, Instruments and Equipment[3] revised the requirements for resin-based restorative materials, adding radiopacity to the existing biological, physical, and mechanical requirements.

Several factors may affect the radiopacity of dental materials, but composition seems to be the most important.[4,5] Additional factors include material thickness,[4-6] X-ray beam angulation, evaluation methodology,[4,7] type of X-ray film, and alteration of the powder/liquid ratio of luting materials.[4,6]

One of the most highly recommended methods to measure radiopacity is the use of an aluminum step wedge as a reference standard. The International Organization for Standardization (ISO) and American National Standards Institute/American Dental Association (ANSI/ADA) have published standardized procedures for quantifying the radiopacity of several types of dental material, using a ≥98% pure aluminum wedge as a reference.[8,9] In most published studies, the aluminum step wedge has been used with an occlusal film to determine optical density values of various dental materials, such as glass ionomer cements, resin composites, and root canal sealers.

Commonly used methods for the evaluation of radiographic image density employ conventional X-ray films and densitometers[4-6,10-13] or spectrophotometers.[14] Since 1987, alternatives to silver halide receptors for intraoral radiographic imaging have included charged couple device (CCD)-based systems and

Table 1 Chemical compositions of luting materials

Luting cement	*Chemical composition*	*Manufacturer*	Shade
RelyX ARC	Paste A: 68% by weight bis-GMA, triethylene glycol dimethacrylate (TEGDMA), zirconia/silica filler, pigments, amine, and photoinitiator system; Paste B: 67% by weight zirconia/silica filler, benzoyl peroxide	3M ESPE AG Dental Products, Seefeld, Germany	A3
RelyX Unicem	Powder: silanized glass powder, silane-treated silica, substituted pyrimidine, calcium hydroxide, sodium persulfate	3M ESPE AG Dental Products, Seefeld, Germany	A2
RelyX U100	Base: glass powder, methacrylated phosphoric acid esters, TEGDMA, silane-treated silica, sodium persulfate; Catalyst: glass powder, substituted dimethacrylate, silane-treated silica, sodium p-toluenesulfinate, calcium hydroxide	3M ESPE AG Dental Products, Seefeld, Germany	A2
Nexus 2	Base: Bis-GMA, camphoroquinone, barium aluminoborosilicate glass; Catalyst: Bis-GMA, TEGDMA, barium aluminoborosilicate glass	Kerr Co., Orange, CA	White
Nexus 3	Hydroxyethyl methacrylate (HEMA), 2-pyridylthiourea (PTU), cumene hydroperoxide (CHPO), uncured methacrylate ester monomers, titanium dioxide (TiO_2), pigments	Kerr Co., Orange, CA	White
Breeze	Bis-GMA, UDMA, TEGDMA, HEMA, 4-MET, silane-treated barium glass, silica (amorphous), Ca-Al-F-silicate	Pentron Clinical Technologies, Wallingford, CT	A2
Metacem	Uncured methacrylate ester monomer	META Biomed Inc., Horsham, PA	A1
Adhesor zinc phosphate cement	Zinc oxide, magnesium oxide, orthophosphoric acid	SpofaDental a.s. Markova, Jičín, Czech Republic	White

storage phosphor technology.[15] The use of digital intraoral radiography is becoming more common due to the numerous advantages of this modality, including the availability of many software packages for the quantitative analysis of radiographs, improving diagnosis, and treatment decisions.[16,17]

Many luting cements have been introduced to clinicians recently in response to the demand for materials with improved characteristics providing performance clinically superior to that of existing materials. Luting cement radiopacity is an important property in the evaluation of intra- and extracoronal restoration fillings, the detection of recurrent dental caries, and the observation of the radiographic interface between the dowel material and root canal dentin; however, limited information is available about the radiopacity of contemporary luting cements. Thus, the aim of this study was to evaluate the radiopacity of eight contemporary luting cements using direct digital radiography. The hypothesis was that the radiopacity of tested resin luting cements would meet the minimum limit, defined by the ISO and ANSI/ADA as the radiopacity equivalent to that of the same thickness of dentin.

Materials and methods

This study evaluated the radiopacity of eight luting cements: RelyX ARC, RelyX U100, RelyX Unicem, Nexus 2, Nexus 3, Metacem, Breeze, and Adhesor zinc phosphate. The manufacturers and compositions of these luting cements are listed in Table 1.

Ten specimens (5 mm diameter, 1 mm high) were prepared for each material tested. The materials were manipulated according to the manufacturers' instructions and then introduced immediately into wells. Specimens were stored in a moist chamber at 37°C until completely set. For radiographic exposure, each acrylic plate containing a luting cement was positioned next to another acrylic plate containing an aluminum step wedge (1100 alloy, 1 to 13 mm thickness in 1-mm intervals).[9,18]

Standardized radiographic images of the specimens and reference aluminum step wedges were obtained with a Kodak digital sensor (Eastman Kodak Co., Rochester, NY). A Kodak 6100 intraoral X-ray unit was operated at 60 kV, 7 mA, and 0.20 seconds with a 30-cm object-focus distance. The mean gray values of each aluminum step wedge and selected materials were measured by outlining a region of interest using the equal-density area tool of the Kodak dental imaging software (ver. 6.7; Fig 1). Regions were selected by avoiding areas containing air bubbles and other anomalies. This procedure was repeated five times for each specimen and aluminum step wedge, and average values were calculated. The mean gray value of the material was then converted to millimeters of aluminum equivalent using Curve Expert 1.3 software (Fig 2). Measurements were taken by one evaluator blinded to the identities of the materials. Data were analyzed by ANOVA and Tukey's test.

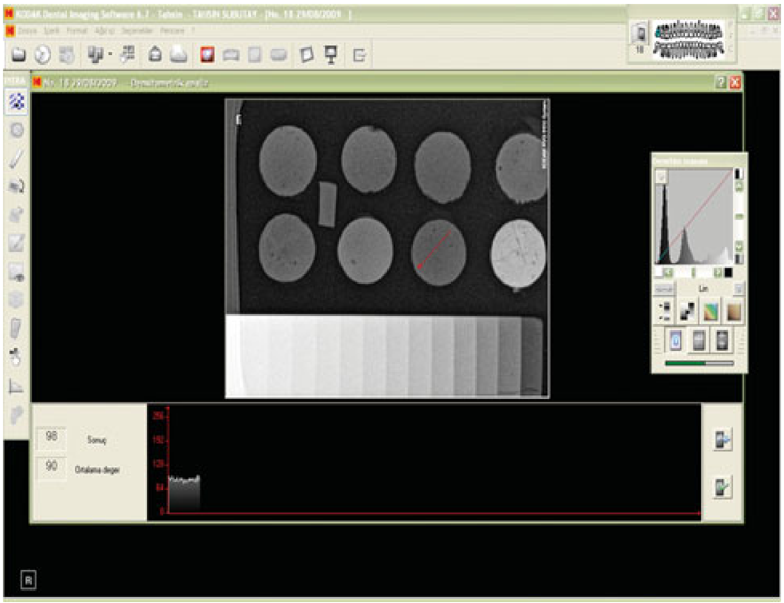

Figure 1 Computer screen image taken during the measurement of luting cement radiopacity using Kodak dental imaging software (ver. 6.7).

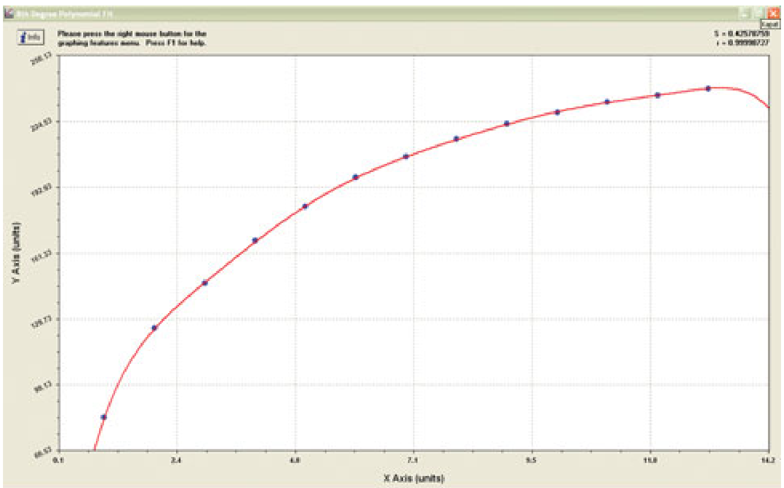

Figure 2 Logistic regression calibration curve obtained with the Curve Expert software (ver. 1.3).

Results

The mean radiopacity values ranged from 1.29 to 6 mm aluminum/mm material (Table 2). Zinc phosphate cement showed the highest radiopacity of all materials and dentin. Among resin cements, radiopacity was significantly higher for Nexus 3 and RelyX Unicem than for the other resin cements ($p < 0.05$). The radiopacities of Metacem, Nexus 2, RelyX ARC, and RelyX U100 were similar to that of dentin ($p > 0.05$). Breeze showed the lowest radiopacity ($p < 0.05$).

Table 2 Mean radiopacity values of dentin and luting materials

Luting cement/material	Radiopacity (mm aluminum)
Dentin	1.32 ± 0.05
RelyX ARC	1.68 ± 0.07
RelyX U100	1.53 ± 0.04
Nexus 2	1.58 ± 0.07
Nexus 3	2.51 ± 0.27
Metacem	1.36 ± 0.08
Breeze	1.29 ± 0.06
RelyX Unicem	2.68 ± 0.08
Adhesor zinc phosphate cement	6.00 ± 0.33

Discussion

In this study, we compared the radiopacities of contemporary luting cements with that of dentin. Dental imaging software was used to obtain precise and accurate numerical values, which were compared with the mean values of aluminum step wedges and dentin. Four of eight luting cements showed radiopacities similar to that of dentin, whereas Nexus 3, RelyX Unicem, and zinc phosphate cements yielded higher values. Breeze showed the lowest radiopacity. Radiopacity has been considered an important requirement for resin materials[19] because it provides a proper contrast between enamel/dentin and resin material, improving the radiographic diagnosis of recurrent caries, faulty proximal contour, and marginal adaptation.[9,20] With the increasing use of esthetic restorations, radiopacity has also been valued in base materials and resin-based cements because it enables the detection of cement margin overhangs and under-restorations.[21-24] The results of this study supported the hypothesis that the radiopacity of resin luting cements would be adequate, according to ISO and ANSI/ADA standards, for all materials tested except Breeze.

This study evaluated radiopacity parameters using the methodology proposed by Carvalho-Junior et al,[18] with sectorization of the calibration curve of each image. The mathematical expression represents the relationship between the radiographic density of standard aluminum wedge steps and the thickness of dentin. The density of any other object radiographed simultaneously is referenced to the equivalent thickness of aluminum.[8,24] Carvalho-Junior et al[18] demonstrated the practicality, accuracy, and sensitivity of this methodology in an evaluation of the radiopacity of root filling materials. The aluminum step wedge was chosen as the standard for measuring radiopacity because it enables the comparison of specimens with specific sample thicknesses of aluminum step wedges under typical radiographic conditions.[17,25] Digital radiography was used to evaluate the radiopacity of luting materials in this study. Radiographic software enables a more detailed analysis of the digital image, which is shown on a computer screen and can be evaluated graphically or by the gray pixel value.[18] In addition to reducing the operator's potential exposure to radiation and eliminating the need for film development chemicals, digital radiography provides consistency. Unless performed carefully, traditional film development can produce significant variations in the final radiograph. Film images must also be scanned or photographed for software-based analysis. These processes require extra time. Thus, a digital method should provide more consistent results.[26] Several authors have proposed the evaluation of restorative material radiopacity in comparison with the radiopacity of the same thicknesses of enamel and dentin, using an aluminum step wedge as an internal standard.[21,27] The relative radiopacities of materials, enamel, and dentin are expressed as aluminum equivalent values (in mm).

The radiopacity of a restorative material must be in accordance with ISO Standard 404911, with an acceptable inferior limit defined as a radiopacity equivalent to that of the same thickness of dentin. Although no superior limit has been established, some authors consider that it should exist because very radiopaque materials, such as amalgam, impair radiographic identification of marginal adaptation, recurrent caries, and other defects.[20,24,28,29] ISO/DP 404911 and some authors consider that restorative materials should have a radiopacity equivalent to at least the same thickness of aluminum to allow for diagnostic identification, and have emphasized the importance of the use of dental tissue cuts as a secondary standard.[24,29]

Under the experimental conditions used in this study, the radiopacity values of materials and dentin, in increasing order, were: Breeze, dentin, Metacem, RelyX U100, Nexus 2, RelyX ARC, Nexus 3, RelyX Unicem, and Adhesor. The radiopacity of Adhesor zinc phosphate cement was equivalent to 6 mm aluminum, which is identical to that reported by Attar et al.[11] The radiopacity value of RelyX Unicem obtained in this study (2.68 mm aluminum) was similar to values obtained previously using digitized film (2.7 and 2.57 mm aluminum)[26,30] and photostimulable phosphor plates (2.88 mm aluminum).[31] However, no study has examined the radiopacity of Nexus 2, Nexus 3, Metacem, Breeze, or RelyX U100. Thus, this study is the first to measure the radiopacity of these cements in comparison with dentin. We found radiopacity values equal to or exceeding that of dentin in seven of eight evaluated cements. The use of materials with a low radiopacity may lead to incorrect diagnoses. In addition, knowledge of the radiographic properties of luting materials may be important in root canal treatments and convenient for evaluating dowel restorations. Two resin cements (Nexus 3, RelyX Unicem) yielded values approaching those of the ISO and ANSI/ADA standards for root canal materials ($\geq$3 mm aluminum). Only Breeze had a significantly lower radiopacity value than dentin. Turgut et al[7] reported resins with monomers that yielded the same values as radiolucent materials, but fillers that yielded different values. Differences in composition seem to be the principal reason for the observed variation in radiopacity.

Conclusion

All materials except Breeze yielded radiopacity values that complied with the recommendations of the ISO and ANSI/ADA. Breeze showed less radiopacity than dentin. Among resin materials, Nexus 3 and RelyX Unicem had values close to those recommended by ISO and ANSI/ADA for root canal materials. These two materials can be used as intraradicular luting materials. Therefore, a radiopacity value equal to or slightly greater than that of dentin is desirable for luting materials.

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