Original Article

A New Technique for Radiopacity Evaluation of Resin Cements

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Abstract

Introduction: The aim of the present study was the comparison of radiopacity of different resin cement types using direct digital radiography by calibrating the calculations on the radiogram according to the dead pixel value on the phosphor plate for the first time in literature. **Methods:** The radiopacities of currently used ten different resin cements(G-CEM, I-CEM, Choice 2, Duo Link, TheraCem, eCEMENT DC, MaxCem Elite Chroma, BisCem, NX3, and Maxcem Elite), enamel and dentin were compared with the densitometer. The digital radiographs were acquired and Image J software was used to convert the images into numerical data for analysis. After the dead pixel calibration, the equivalent aluminum thickness value of each sample was calculated by the correlation analysis method. **Results:** According to test results, although there was no significant difference between G-CEM and I-CEM, all the materials, enamel and dentin had a significant difference from each other. MaxCem Elite had the highest radiopacity while G-CEM had the lowest. **Conclusions**: eCEMENT DC, MaxCem Elite Chroma, BisCem, NX3, and Maxcem Elite had higher radiopacity than dentin. Those with lower radiopacity than dentin (G-CEM, I-CEM, Choice 2, Duo Link, and TheraCem) should be carefully used in both subgingival located or radiolucent restorations and implant-supported prostheses. Dead pixel calibration enables materials to be evaluated more accurately and this method will also make it possible for the first time in literature to compare the same samples with each other on different phosphor plates.

Keywords: Calibration, Dead Pixel, Radiopacity, Resin Cement

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Introduction

The long-term success of the fixed prosthetic restorations is influenced by the luting cement which bonds different substrates to ensure marginal sealing, adhesion, sufficient retention, and resistance (1). In recent years, resin cements have become popular due to their superior esthetics, more durable strength, low solubility, and microleakage compared with the other cements (2). They have been used for adhesive cementation of crowns, fixed partial dentures, implant-supported restorations, post-core restorations, and inlays/onlays. They have a significant impact on the outcome of especially high esthetic anterior restorations (3).

Radiopacity is an essential feature of resin cements. Because, they should be adequately radiopaque to detect marginal overhangs, open gingival margins and also, to facilitate the diagnosis of recurrent caries (3,4). Besides that, when the luting agent is not radiopaque enough, it is impossible to detect the voids and also, excess cement (4,5).

The radiopacity of resin cements is quantified by the International Organization for Standardization (ISO) and the American National Standards Institute/American Dental Association, using a pure aluminum (98% purity) step wedge as a reference (6). The radiopacities of dentin and aluminum (Al) are approximately equal for the same thickness, while the radiopacity of enamel is twice that of Al. ISO stated that the radiopacity of a material should be equal to or greater than Al of the same thickness (7,8).

Various factors can affect the radiopacity of dental materials such as material thickness, type of X-ray film, angulation of the X-ray beam, and most importantly, the composition of the material (9). In literature, there is no radiopacity study on calibrating dead pixels to eliminate the film fatigue or X-ray errors. Because of this reason, the conventional imaging method is considered to be more accurate than digital imaging methods (10,11). Moreover, there is limited data regarding the radiopacity of resin cements. Therefore, in the present study, the radiopacities of ten different resin cements were compared using direct digital radiography by calibrating the calculations on the radiogram according to the dead pixel value on the phosphor plate for the first time in literature. The null hypothesis was that there was no difference between the radiopacity of different resin cements.

Materials and Methods

In the present study, the radiopacities of currently used different resin cements, enamel, and dentin were compared with the densitometer (step wedge). The composition and the manufacturer of the resin cements are given in Table I.

Table I: The composition of the materials used in the present study

Name	Composition	Manufacturer
G-CEM LinkForce	Bis-GMA, Bis-MEPP, Urethanedimethacrylate, Dimethacrylate, Barium glass, Initiator, Pigments	GC Corporation, Tokyo, Japan
I-CEM self-adhesive	acidified urethane, di-, tri-, and multifunctional acrylate monomers, 49% filler by weight of sub-micron and micron sized particles	Heraeus Kulzer, Hanau, Germany
Choice 2	Urethane Dimethacrylate, BisGMA, Tetrahydrofurfuryl Methacrylate	Bisco, USA
Duo Link	Bis-GMA, triethyleneglycol dimethacrylate, urethane dimethacrylate; glass filler	Bisco, USA
TheraCem	Portland Cement, Ytterbium w/ Barium Glass, Ytterbium Fluoride, BisGMA, 10-Methacryloyloxydecyl Dihydrogen Phosphate, 2-Hydroxyethyl Methacrylate, Tert-butyl Perbenzoate	Bisco, USA
BisCem	Bis-GMA, Unpolymerized dimethacrylate monomer, Glass Filler, Phosphate acidic monomer	Bisco, USA
Maxcem Elite	30-60% Barium aluminoborosilicate glass, 10-30% Ytterbium fluoride, 5-10% 1,6-hexanediyl bismethacrylate, 5-10% 2-hydroxy-1,3-propanediyl bismethacrylate, 1-5% 7,7,9(or 7,9,9)-trimethyl-4,13-dioxo-3,14- dioxa-5,12-diazahexadecane-1,16-diyl bismethacrylate, 1-5% 3-trimethoxysilylpropyl methacrylate, 1-5% Fumed silica	Kerr, USA
MaxCem Elite Chroma	2-hydroxyethyl methacrylate, 2-hydroxy-1,3-propanediyl bismethacrylate, 7,7,9(or 7,9,9)-trimethyl-4,13-dioxo-3,14- dioxa-5,12-diazahexadecane-1,16-diyl bismethacrylate, Propylidynetrimethanol, ethoxylated, esters with acrylic acid, 1-5% Ytteribium trifluoride	Kerr, USA

NX3	Barium aluminoborosilicate glass, Ytterbium fluoride, Ethoxylated bisphenol-A dimethacrylate, Urethane dimethacrylate, Triethylene glycol dimethacrylate, Hydroxyethylmethacrylate, Fumed silica, Bisphenol-A diglycidyl methacrylate, Ethyldimethylaminobenzoate, Peppermint oil	Kerr, USA
eCEMENT DC	10 -20% Ytterbium Fluoride, Bisphenol A Diglycidylmethacrylate, Urethane Dimethacrylate, Ytterbium Oxide-Silica, Tetrahydrofurfuryl Methacrylate, Trimethylolpropane Trimethacrylate, Bisphenol A Diglycidylmethacrylate, Dibenzoyl Peroxide	Bisco, USA

Preparation of the samples

Resin cement samples were prepared according to the manufacturer's instructions using plastic sample planchettes with a diameter of 5 mm, a height of 1 mm, and a volume of 78.5 mm^3. Five samples from each group were selected and stored in water at 37 ^{0}C until the imaging. Enamel and dentin samples with a thickness of 1 mm were obtained by longitudinal sections of freshly extracted molars and premolars. The thickness of all samples was checked with a digital caliper.

Digital radiography

99.5% pure aluminum eleven-step densitometer with each step of 1 mm height, 20 mm width , and 50 mm length was used as a reference in comparison of the radiopacity values of the samples. According to ISO 4049:2019 standards, the radiopacity of the restorative material must be greater than aluminum of the same thickness.

The dental x-ray source (Carestream CS2100) was set at a focal object distance of 30 cm, 70 kVp, and 7 mA 0.3s. A total of 50 resin cement samples (5 samples from each resin cement), and 1 mm enamel/dentin samples were fixed on a 5.7 x 7.6 cm material without penetrometer radiodensity and X-rayed vertically after placing on a phosphor plate (Carestream pp, size 4). The present study involved two phosphor plates that X-rayed under the same conditions. These phosphor plates were scanned at the ultra-high resolution specification of the Carestream 7600 phosphor plate scanner. The obtained radiography was exported in TIFF and JPEG formats with Carestream Software.

The evaluation of the digital radiography

After the digital radiographs were acquired, ImageJ software (version 1.52v, National Institutes of Health, USA) was used to convert the images into numerical data for analysis (Figure 1).

Figure 1. Converting radiography to numeric data with image J program

This software has 256 bit image processing feature which means that it can detect and parse image values in 256 different values (0–255). A value of 0 is a radiolucent (black) image, and a value of 255 is a radiopaque (white) image. During the analysis, three measurements were conducted for each sample, each step of the penetrometer, dead pixel and enamel/dentin, separately for the molar and premolar radiography sets. Thus, 15 measurements were made for each sample group and 384 measurements in total (192 measurements for each radiography set).

The radiopacity values of the same samples and the same densitometer lines were different in each phosphor plate. The radiopaque area that was not exposed to x-rays was measured as 245, and the radiolucent part with the highest exposure was measured as 0. Dead pixel measurements, which were the reference point of the phosphor plate in the radiographs, were processed as standard radiopaque density. These differences over the same area were equal to dead pixel value of the phosphor plates.

The dead pixel measurements on the phosphor plates were 245 which should be 255. Because of this reason, the difference between them was interpreted as base and fog density, all measurements were calibrated and clear density values were calculated.

The mean and standard deviation (SD) of the radiodensity values were analyzed with the linear line equation data using the Curve Expert 1.4 software (Figure 2) and the equivalent aluminum thickness value of each sample was calculated by the correlation analysis method. Also for statistical validation, Kolmogorov-Smirnov and Shapiro-Wilk normality tests and one-sample t-test were used (SPSS software, version 22.0, USA) at the significance level of 0.01.

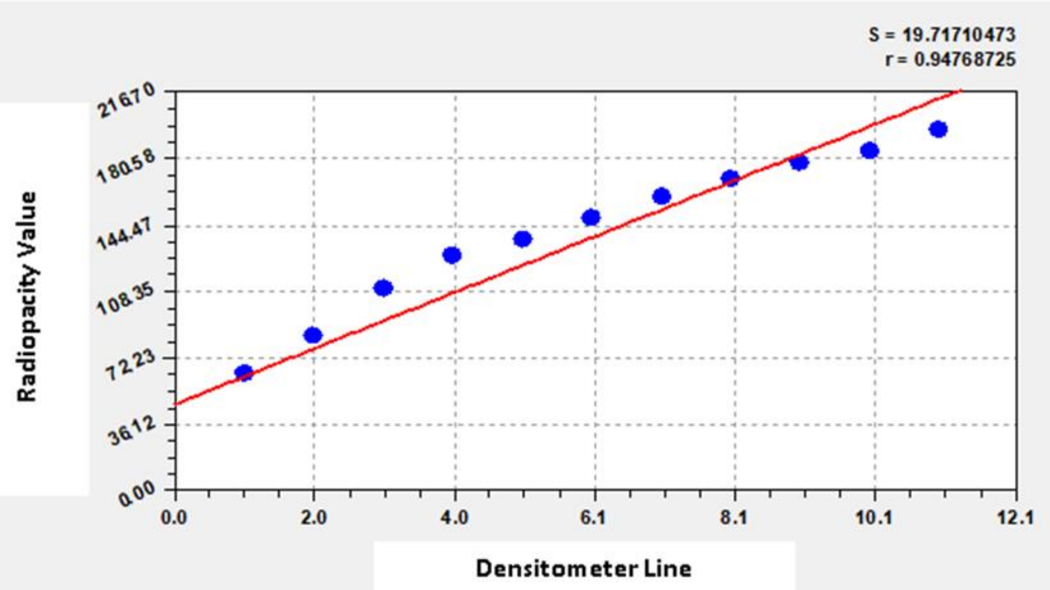

Figure 2: Comparison of the radiopacity value of cements with the densitometer line

Results

According to the result of the Shapiro-Wilk (P: 0.421 > 0.01) normality test, the data show the normal distribution and were compatible with the linear line equation data analysis using the Curve Expert software. Since the radiopacity values of the samples changed at the same rate at each step, the correlation coefficient is 1 which can be calculated in the linear graph.

One-sample t-test indicated a statistically significant difference between the materials (P < 0.01). Although there was no significant difference between G-CEM and I-CEM, all the materials, enamel, and dentin had a significant difference from each other (Table II).

Table II: The mean and standard deviation of radiopacity values of the resin cements

	Mean and SD of radiopacity values (mm Al)	Min.-Max. radiopacity values (mm Al)
G-CEM LinkForce	0,51[a] ± 0,007	0,50 - 0,52
I-CEM self-adhesive	0,54[a] ± 0,010	0,53 - 0,55
Choice 2	0,66[b] ± 0,015	0,64 - 0,68
Duo Link	1,04[c] ± 0,010	1,03 - 1,05
TheraCem	1,13[d] ± 0,014	1,11 - 1,15
Dentin	1,30[e] ± 0	1,30 - 1,30
eCEMENT DC	2,10[f] ± 0,015	2,08 - 2,12
MaxCem Elite Chroma	2,32[g] ± 0,020	2,30 - 2,34
Enamel	2,40[h] ± 0,010	2,39 - 2,41
BisCem	2,73[i] ± 0,007	2,72 - 2,74
NX3	3,53[j] ± 0,020	3,51 - 3,55
Maxcem Elite	4,08[k] ± 0,025	4,05 - 4,11

MaxCem Elite had the highest radiopacity while G-CEM had the lowest. eCEMENT DC, MaxCem Elite Chroma, BisCem, NX3, and Maxcem Elite had higher radiopacity than dentin, while the radiopacity values of G-CEM, I-CEM, Choice 2, Duo Link, and TheraCem were lower than dentin (Figure 3).

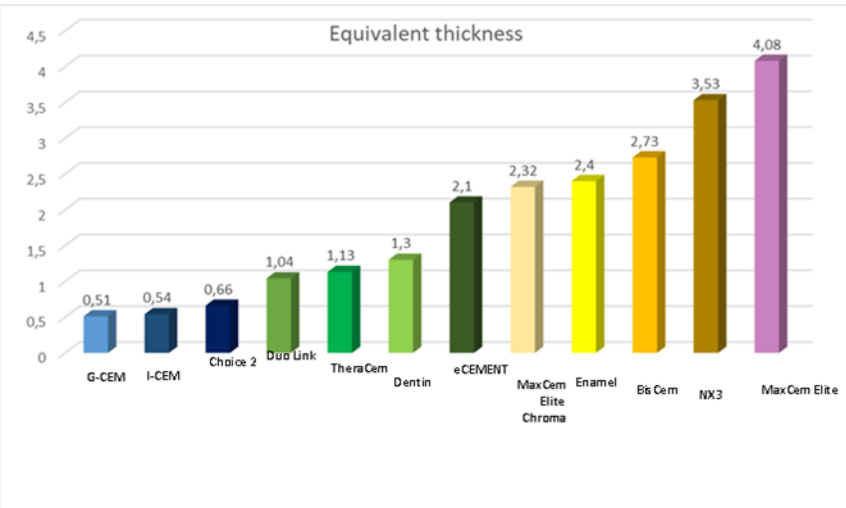

Figure 3: The equivalent aluminum thickness value of each sample

Discussion

Dental cements should have sufficient radiopacity which provides appropriate contrast between enamel/dentin and resin material, being able to control the marginal adaptation and to diagnose the recurrent caries and defective proximal contours (3). This was confirmed by Furtos et al as they stated that the radiopacity of resin cements should be higher than dentin, which might be better similar to enamel or even slightly higher than it for better clinical detection (12,13). In the present study, the

radiopacities of current ten different resin cements were compared and only three of them (BisCem, NX3, and MaxCem Elite) met these criteria as they had higher values than enamel. Moreover, the radiopacity values of most of the resin cements were below even dentin. Therefore, the null hypothesis was rejected as there was a significant difference between all materials except G-CEM and I-CEM.

On the other hand, difficulties in defining an optimum radiopacity standard for dental materials have been indicated in the literature. It was stated that an excessively radiopaque material may prevent the diagnosis of carious lesions adjacent to the restoration and cause the "Mach Band" effect. It causes an increase in contrast between light and dark areas, leading to misdiagnosis of carious lesions. In addition, its comprehension may differ according to the observers (14). In the present study, this effect may be observed with NX3 and MaxCem Elite, which had higher radiopacity than enamel. Nevertheless, it is not possible to say that the radiopacity of these materials exceeds the acceptable limit since there is no recommended value for this (15).

1 mm of aluminum has a radiopacity equivalent to dentin, and enamel is twice as radiopaque as dentin (16) and it almost confirms the accuracy of our results (dentin: 1.30 mm Al, enamel: 2.40 mm Al). This minimal variation may be related to different content rates of the dental tissues. This can be true for dental materials as although their radiopacity can be affected by various factors, the composition may have the most significant effect (17). This is mainly related to the inorganic content and the matrix has a little impact.1 Especially the inorganic fillers can make a difference in the radiopacity of the materials as the filler elements with high atomic numbers (18,19) such as strontium, zinc, zirconium, ytterbium, titanium, tantalum, indium, barium and lanthanum increase the radiopacity of the resin cements (13,20). This was confirmed by our results as Maxcem Elite and NX3 which had the highest radiopacity values, contain barium aluminoborosilicate glass and ytterbium fluoride. And ytterbium (Z=70) and barium (Z=56) are the elements with the highest atomic number (21). Although both MaxCem Elite Chroma and eCEMENT DC contain the same element, namely ytterbium, their radiopacity values were lower than the enamel. This may be related to the amount as the percentage of the elements in the composition is also important for radiopacity (21,22). The other resin cement that had higher radiopacity value than enamel is BisCem and this can be explained by the glass filler acting as a radiopacifier. Additionally, all these cements which had higher radiopacity values than dentin, can be used in the implant supported restorations. Because dentin has an equivalent radiopacity to the alveolar bone (16).

All the other cements (G-CEM, I-CEM, Choice 2, Duo Link and TheraCem) had lower radiopacity values than dentin. G-CEM had the lowest radiopacity value despite its barium glass content. The reason may be the percentage of barium glass as it is unclear on the manufacturer's instructions. This is also true for Duo Link as the glass filler content did not increase the radiopacity value. The radiopacity of Duo Link (1.04 mm Al) and also Maxcem Elite (4.08 mm Al) was lower than the previous study (1.71 to 1.99 mm Al, 5.14-5.48 mm Al) On the other hand, the radiopacity of BisCem (2.73 mm Al) was higher than the same study (1.82-2.12 mm Al) (23). This can be explained by the fact that the radiopacity of the same material cannot be the same in different studies due to many methodological factors such as film, X-ray machines, radiographic processing, image analysis, and the purity of the Al step wedge (20,24). In addition, the dead pixel calibration in the present study may cause such differences.

Although TheraCem had the highest value among them, its value was still lower than dentin with a statistically significant difference. This was a contradictory result because of its ytterbium fluoride and barium glass contents. It can be possible to say that the composition of the materials should be analyzed in detail, as it is taken from the manufacturer's data and needs to be confirmed. In conclusion, these cements should be carefully used in subgingivally located restorations. Because, the resin cements with higher radiopacity are better for these restorations (25), like BisCem, NX3 and MaxCem Elite in our study. The use of these cements is also important in radiolucent restorations such as laminate veneers, fiber posts and inlay-onlays (3). On the other hand, their optical properties should be considered for the highly esthetic restorations. Since the materials have been developed continuously, new researches are necessary. Also, the chemical composition of the materials should be analyzed in detail in further studies.

In the literature, radiopacity studies compared a phosphor plate with different brands of phosphor plate and scanner in the control group to verify the reliability of the results (26, 27). However, many variables such as x-ray parameters, phosphor plate fatigue, and phosphor plate scanner may lead to different radiopacity values (20). Although dead pixels are only used for the determination of direction nowadays, they actually provide fog, background radiation or calibration values. Dead pixel value equivalent to the 10th-grade radiopaque image of 99.9% pure aluminum densitometer should give the value 255 when it is converted into a numerical value with the Image J program (calculations are made over 256 gray tones, 255 radiopaque, and 0 radiolucent) (21, 28). The radiopacity values can differ for the same sample due to many reasons. In the present study, dead pixel calibration enables us to equalize them and compare the same samples on different phosphor plates with each other.

Conclusions

Within the limitation of the study, it can be concluded that the resin cements had higher radiopacity than dentin (eCEMENT DC, MaxCem Elite Chroma, BisCem, NX3, Maxcem Elite) can be used in restorative procedures. Those with lower radiopacity than dentin (G-CEM, I-CEM, Choice 2, Duo Link, and TheraCem) should be carefully used in both subgingival located or radiolucent restorations and implant-supported prostheses. For this kind of restoration, it can be better to use the highly radiopaque cements (NX3 and MaxCem Elite). Dead pixel calibration enables materials to be evaluated more accurately and this method will also make it possible for the first time in literature to compare the same samples with each other on different phosphor plates.

Conflict of interest

The authors declare that they have no conflict of interest.

Acknowledgement

Not applicable.

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