Imaging Science in Dentistry 2018; 48: 97-101
https://doi.org/10.5624/isd.2018.48.2.97

Radiopacity of contemporary luting cements using conventional and digital radiography

Seo-Young An[1], Chang-Hyeon An[1], Karp-Sik Choi[1], Kyung-Hoe Huh[2], Won-Jin Yi[2], Min-Suk Heo[2], Sam-Sun Lee[2], Soon-Chul Choi[2,*]

[1]*Department of Oral and Maxillofacial Radiology, School of Dentistry, Kyungpook National University, Daegu, Korea*
[2]*Department of Oral and Maxillofacial Radiology, School of Dentistry, Seoul National University, Seoul, Korea*

ABSTRACT

Purpose: This study evaluated the radiopacity of contemporary luting cements using conventional and digital radiography.
Materials and Methods: Disc specimens (N=24, n=6 per group, ø7 mm × 1 mm) were prepared using 4 resin-based luting cements (Duolink, Multilink N, Panavia F 2.0, and U-cem). The specimens were radiographed using films, a complementary metal oxide semiconductor (CMOS) sensor, and a photostimulable phosphor plate (PSP) with a 10-step aluminum step wedge (1 mm incremental steps) and a 1-mm-thick tooth cut. The settings were 70 kVp, 4 mA, and 30 cm, with an exposure time of 0.2 s for the films and 0.1 s for the CMOS sensor and PSP. The films were scanned using a scanner. The radiopacity of the luting cements and tooth was measured using a densitometer for the film and NIH ImageJ software for the images obtained from the CMOS sensor, PSP, and scanned films. The data were analyzed using the Kruskal-Wallis and Mann-Whitney U tests.
Results: Multilink (3.44-4.33) showed the highest radiopacity, followed by U-cem (1.81-2.88), Panavia F 2.0 (1.51-2.69), and Duolink (1.48-2.59). The R^2 values of the optical density of the aluminum step wedge were 0.9923 for the films, 0.9989 for the PSP, 0.9986 for the scanned films, and 0.9266 for the CMOS sensor in the linear regression models.
Conclusion: The radiopacities of the luting materials were greater than those of aluminum or dentin at the same thickness. PSP is recommended as a detector for radiopacity measurements because of its accuracy and convenience. ***(Imaging Sci Dent 2018; 48: 97-101)***

KEY WORDS: Dental Materials; Radiography; Dental Enamel; Dentin

Introduction

Radiopacity is an essential requirement of dental materials such as cement or resin because it allows for proper contrast between the tooth tissue and the materials.[1-4] Sufficient radiopacity of dental material facilitates a better diagnosis of secondary caries, interfacial gaps, faulty proximal contours, and excess cement, and distinguishes the material from a void.[3,5-8] Quantitative standards for the radiopacity of several dental materials were established by the International Organization for Standardization (ISO)[4] and the American National Standards Institute/American Dental Association,[2] using a pure aluminum (98% purity) step wedge as a reference.

Radiopacity is commonly evaluated using conventional X-ray films, densitometers, and spectrometers.[9] Digital intraoral radiography has become increasingly common in dental practices since its introduction in 1989. Several types of sensors such as charge-coupled devices, complementary metal oxide semiconductors (CMOSs), and photostimulable phosphor plates (PSPs) have been used. In digital imaging, the gray scale has an inverse relationship with optical density, with black being assigned a value of 0 and white a value of 255 (for an 8-bit system), which

---

*This study was supported by grant No. 04-2013-0069 from the SNUDH Research Fund.
Received January 24, 2018; Revised March 2, 2018; Accepted March 17, 2018
*Correspondence to : Prof. Soon-Chul Choi
Department of Oral and Maxillofacial Radiology, School of Dentistry, Seoul National University, Daehak-ro 101, Jongno-gu, Seoul 03080, Korea
Tel) 82-2-2072-2622, Fax) 82-2-744-3919, E-mail) raychoi@snu.ac.kr

Imaging Science in Dentistry · pISSN 2233-7822 eISSN 2233-7830

enables easy and precise measurements. Furthermore, compared to conventional films, digital radiographic systems allow the use of reduced radiation doses.[10]

The purpose of this study was to examine the radiopacity of 4 contemporary luting cements using films, a CMOS sensor, PSP, and scanned films.

Materials and Methods

Specimen preparation

The luting cements used in this study are listed in Table 1. Disc specimens were prepared (N = 24, n = 6 per group; diameter: 7 mm, thickness: 1 mm). The cements were mixed according to the manufacturer's instructions and compressed between 2 glass slides in a mold. Light curing was performed with a curing light source (Elipar TriLight; 3MESPE, Seefeld, Germany; standard mode). Using a built-in radiometer, an output intensity of 750 mW/cm^2 was maintained during the experiment. The thickness of the light-cured specimens was measured using a digital micrometer (293-821 LCD Digimatic Micrometer; Mitutoyo, Kawasaki, Japan) with a critical tolerance of 1 ± 0.01 mm. Longitudinal sections of a freshly extracted premolar were also prepared with thicknesses of 1 mm by the using a slow-speed diamond saw (Isomet, Buehler, IL, USA). An aluminum step wedge (1.0 mm increments, 10 steps) was machined from a 99.5% pure aluminum block (Alu-Keil; PEHA Medikal Geräte GmbH, Sulzbach, Germany).

Imaging and analysis

Images of the luting cements, step wedge, and teeth were taken using films (Kodak InSight Dental Film; Carestream Health, Inc., Rochester, NY, USA), a CMOS sensor (Kodak RVG 6100; Carestream Health, Inc., Rochester, NY, USA), and a PSP (CS 7600 image plate No. 4; Carestream Health, Inc., Rochester, NY, USA) using a dental X-ray machine (Kodak 2200 Intraoral X-ray System; Carestream Health, Inc., Rochester, NY, USA) operating at 4 mA, 30 cm, and with a total filtration equivalent to 2.5 mm of aluminum. The exposure time was 0.2 s for the films and 0.1 s for the CMOS sensor and PSP. A special holder was fabricated to ensure constant exposure conditions by maintaining the location of the detector and X-ray machine. The films were processed manually according to the manufacturer's guidelines, scanned with a scanner (Epson Perfection V370 Photo Scanner, NY, USA), and saved in 8-bit TIFF format. The raw digital images, free of image processing, from the CMOS sensor and PSP were saved in 8-bit TIFF format for subsequent radiopacity analysis.

Table 1. Luting cements tested in this study

Product	Manufacturer	Lot number	Shade
Duolink	Bisco, Schamburg, USA	1300004782	Translucent
Multilink N	Ivoclar Vivadent, NY, USA	S34718	Transparent
Panavia F2.0	Kuraray, Tokyo, Japan	051402	Light
U-cem	Vericom, An-Yang, Korea	UC3431UA	Universal

Using the films, the optical density of the step wedge, luting cements, and tooth slices were measured 5 times using a densitometer (Denistoquick 2; PEHA med., Sulzbach, Germany), and a plot of optical density as a function of the thickness of the aluminum step wedge was generated. The gray values of the step wedge, luting cements, and tooth slices were analyzed using NIH ImageJ software (available at http://rsb.info.nih.gov/ij/) in the digital images from the CMOS sensor, PSP, and scanned films. Five regions of interest (10 × 10 pixels in size) were measured for the luting cements, enamel, and dentin, as well as for each of the 10 steps of the aluminum step wedge. The gray value was recorded as the mean of 5 readings. Subsequently, the gray value was converted into absorbance using the following equation: $A = -\log(T) = -\log(1 - G/255)$, where A is the absorbance, T is the transmission, and G is the gray value (0 to 255).[11] The absorbance of the aluminum steps was plotted as a function of the corresponding thickness.

Statistical analysis

The radiopacity of the luting cements, dentin, and enamel was reported in terms of equivalent aluminum thickness as the mean ± standard deviation. SPSS for Windows version 18.0 (SPSS Inc., Chicago, IL, USA) was used for data analysis. To compare the radiopacity of the luting cements, the Kruskal-Wallis and Mann-Whitney U tests were performed. P values $< .05$ were considered to indicate statistical significance.

Results

Table 2 presents the optical density and absorbance of the aluminum step wedge. Optical density was plotted as a function of step thickness, and the R^2 value was 0.9923 for the films (Fig. 1). The corresponding R^2 values were 0.9989 for PSP, 0.9986 for the scanned films, and 0.9266 for the CMOS sensor in the linear regression models (Fig. 2). Table 3 and Fig. 3 show the radiopacity of the luting cements and tooth according to the various methods, expressed as aluminum-equivalent millimeters (mm Al). The

Table 2. Optical density and absorbance of an aluminum step wedge measured using various methods

Aluminum steps in millimeters	Optical density	Absorbance		
	Film	CMOS sensor	PSP	Scanned film
1	130.4±1.3	0.127±0.001	0.401±0.005	0.124±0.005
2	112.0±0.0	0.226±0.001	0.509±0.003	0.158±0.007
3	99.0±0.0	0.320±0.002	0.604±0.007	0.189±0.009
4	88.0±0.0	0.421±0.002	0.699±0.005	0.218±0.010
5	80.0±0.0	0.520±0.002	0.801±0.014	0.246±0.013
6	73.2±0.4	0.631±0.003	0.895±0.007	0.269±0.014
7	67.4±0.5	0.762±0.004	0.996±0.001	0.297±0.014
8	61.2±0.8	0.917±0.003	1.088±0.005	0.327±0.014
9	56.0±0.0	1.135±0.008	1.176±0.014	0.356±0.018
10	51.8±0.4	1.578±0.022	1.314±0.006	0.383±0.019

CMOS, complementary metal oxide semiconductor; PSP, photostimulable phosphor plate.

Table 3. The equivalent aluminum thickness of the luting cements, enamel, and dentin in millimeters measured using various methods

Method	Duolink	Panavia F2.0	U-cem	Multilink N	Dentin	Enamel
CMOS sensor	2.59±0.20^a	2.69±0.02^a	2.88±0.19^a	4.33±0.06^a	2.02±0.05^a	2.53±0.09^a
PSP	1.40±0.26^b	1.19±0.25^b	2.05±0.19^b	4.36±0.29^a	0.91±0.21^b	1.81±0.26^b
Film	1.27±0.03^c	1.31±0.05^b	1.72±0.15^c	3.69±0.20^b	1.19±0.06^c	1.62±0.13^c
Scanned film	1.48±0.13^d	1.51±0.14^b	1.81±0.22^c	3.44±0.49^b	1.41±0.13^d	1.92±0.23^b

Superscript letters indicate significant differences. CMOS, complementary metal oxide semiconductor; PSP, photostimulable phosphor plate.

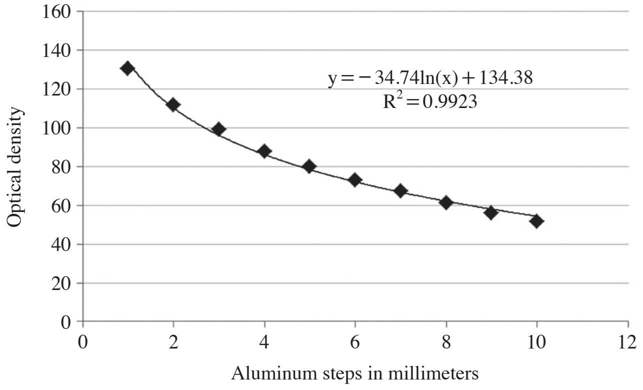

Fig. 1. Optical density as a function of step thickness with the corresponding R^2 value.

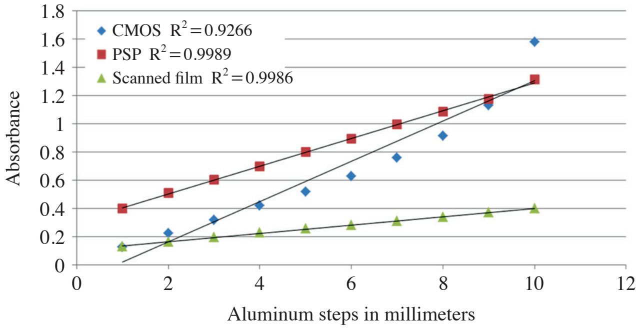

Fig. 2. Linear models for an aluminum step wedge with corresponding R^2 values obtained from the CMOS sensor, PSP, and scanned film. CMOS, complementary metal oxide semiconductor; PSP, photostimulable phosphor plate.

radiopacity values determined using the CMOS sensor were significantly higher than those obtained using the other detectors.

Discussion

In this in vitro study, the radiopacity of 4 commercial luting cements was assessed using films, a CMOS sensor, PSP, and scanned films, and the radiopacity values obtained using each method were compared. The values of the luting cements were compared with the mean thickness of an aluminum step wedge, and all materials tested in this study had radiopacity values above the minimum recommended by ISO 4049/2009.[4]

Radiology plays a significant role in the diagnosis of various lesions in the head and neck region. Considerable differences in radiopacity are required to definitively differentiate restorative materials from the surrounding structures. The ISO 4049 specification requires the minimum radiopacity of restorative materials to be equal to or greater than that of an equivalent thickness of aluminum, which is also greater than that of dentin.[4,12] An appropri-

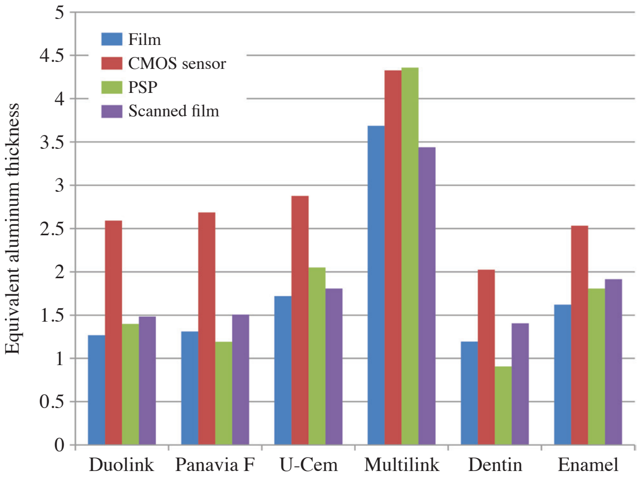

Fig. 3. Equivalent aluminum thickness of the luting cements, enamel, and dentin in millimeter. CMOS, complementary metal oxide semiconductor; PSP, photostimulable phosphor plate.

ate radiopacity, slightly greater than that of enamel, can assist in diagnosing secondary carious lesions adjacent to the restoration and in determining the homogeneity of the luting cement.[13,14] Excessive radiopacity, as in amalgam, interferes with the diagnosis of recurrent caries and the detection of voids in areas covered by the restoration, impeding diagnostic discrimination.[15-18] In contrast, the use of materials with similar or lower radiopacity than that of dentin can lead to diagnostic difficulties.[5] In this study, PSP showed the lowest radiopacity values (dentin, 0.91 mm Al; enamel, 1.81 mm Al) and the CMOS sensor showed the highest values (dentin, 2.02 mm Al; enamel, 2.53 mm Al). Using a cut tooth as a secondary standard may be useful for evaluating the radiopacity of materials, since the radiopacity of dentin is not always 1 Al mm. The radiopacity of the same dental material can be different depending on the exposure conditions.[19] In this study, radiopacity differed significantly depending on the measurement method. PSP was the most accurate, considering its high R^2 value in the linear regression model with the aluminum step wedge.

Digital image analysis is believed to exhibit the same degree of accuracy as transmission densitometry and can produce measurements equivalent to those obtained with film, but with reduced noise, providing precise and trustworthy values for comparative radiopacity studies. Moreover, digital radiography does not require film development, a process that introduces additional variation in the final radiographs. Transmission densitometry measures the optical density, a logarithmic measure of the ratio of transmitted to incident light through the film image. In digital image analysis, radiographic density is evaluated directly using the gray scale of the pixels, assigning them values on a scale of 0 to 255 using computer software. A digital system yielded higher radiopacity values than conventional methods in a previous study, but it is difficult to compare these methods directly because they have radically different characteristics.[21] In this study, the radiopacity of luting cements varied according to the method used, and the PSP values were close to the previously reported results.[20] The CMOS sensor showed the highest radiopacity and the worst accuracy, likely because of its different innate preprocessing as compared to other systems.

According to the ISO recommendations (4049:2009), radiopacity should be expressed as equivalent thickness of aluminum compared with an aluminum step wedge.[4] The linear regression of the logarithm of the optical density as a function of the thickness of the aluminum step wedge was plotted, and the purity of the aluminum step wedge was found to influence the accuracy of this method. Aluminum with a 4% copper impurity created a systematic error of 1.25% and yielded poorer results than those obtained using high-purity wedges. Therefore, the aluminum content of the wedge should be at least 98% by mass, and alloys with more than 0.05% copper or 1.0% iron should not be used. In this study, a 99.5% pure aluminum block was used for step wedge fabrication to ensure measurement accuracy.[15]

In conclusion, the radiopacity of all tested luting cements showed a greater equivalent aluminum thickness than biological tissues, meeting the ISO requirements. Based on our findings, PSP is recommended as a detector for radiopacity measurements due to its superior accuracy and convenience compared to films, scanned films, and CMOS sensors.

References

1. Tsuge T. Radiopacity of conventional, resin-modified glass ionomer, and resin-based luting materials. J Oral Sci 2009; 51: 223-30.
2. American National Standards Institute/American Dental Association. ANSI/ADA: Specification no. 57 endodontic sealing material. Chicago: ADA; 2000.
3. Fraga RC, Luca-Fraga LR, Pimenta LA. Physical properties of resinous cements: an in vitro study. J Oral Rehabil 2000; 27: 1064-7.
4. International Standard Organization. ISO 4049:2009. Dentistry - polymer-based restorative materials. 4th ed. Geneva: International Organization for Standardization; 2009.
5. Attar N, Tam LE, McComb D. Mechanical and physical prop-

erties of contemporary dental luting agents. J Prosthet Dent 2003; 89: 127-34.

6. Soares CJ, Santana FR, Fonseca RB, Martins LR, Neto FH. In vitro analysis of the radiodensity of indirect composites and ceramic inlay systems and its influence on the detection of cement overhangs. Clin Oral Investig 2007; 11: 331-6.
7. Wilson TG Jr. The positive relationship between excess cement and peri-implant disease: a prospective clinical endoscopic study. J Periodontol 2009; 80: 1388-92.
8. Dukic W, Delija B, Derossi D, Dadic I. Radiopacity of composite dental materials using a digital X-ray system. Dent Mater J 2012; 31: 47-53.
9. Altintas SH, Yildirim T, Kayipmaz S, Usumez A. Evaluation of the radiopacity of luting cements by digital radiography. J Prosthodont 2013; 22: 282-6.
10. Nomoto R, Mishima A, Kobayashi K, McCabe JF, Darvell BW, Watts DC, et al. Quantitative determination of radio-opacity: equivalence of digital and film X-ray systems. Dent Mater 2008; 24: 141-7.
11. Poorsattar Bejeh Mir A, Poorsattar Bejeh Mir M. Assessment of radiopacity of restorative composite resins with various target distances and exposure times and a modified aluminum step wedge. Imaging Sci Dent 2012; 42: 163-7.
12. Amirouche-Korichi A, Mouzali M, Watts DC. Effects of monomer ratios and highly radiopaque fillers on degree of conversion and shrinkage-strain of dental resin composites. Dent Mater 2009; 25: 1411-8.
13. Akerboom HB, Kreulen CM, van Amerongen WE, Mol A. Radiopacity of posterior composite resins, composite resin luting cements, and glass ionomer lining cements. J Prosthet Dent 1993; 70: 351-5.
14. Kurşun Ş, Dinç G, Oztaş B, Yüksel S, Kamburoğlu K. The visibility of secondary caries under bonding agents with two different imaging modalities. Dent Mater J 2012; 31: 975-9.
15. Watts DC, McCabe JF. Aluminium radiopacity standards for dentistry: an international survey. J Dent 1999; 27: 73-8.
16. Duarte MA, Demarchi AC, Yamashita JC, Kuga MC, Fraga Sde C. pH and calcium ion release of 2 root-end filling materials. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2003; 95: 345-7.
17. Camilleri J, Montesin FE, Di Silvio L, Pitt Ford TR. The chemical constitution and biocompatibility of accelerated Portland cement for endodontic use. Int Endod J 2005; 38: 834-42.
18. Tanomaru-Filho M, da Silva GF, Duarte MA, Goncalves M, Tanomaru JM. Radiopacity evaluation of root-end filling materials by digitization of images. J Appl Oral Sci 2008; 16: 376-9.
19. An SY, Lee DH, Lee KB. Radiopacity for contemporary luting cements using digital radiography under various exposure conditions. J Prosthodont 2015; 24: 642-6.
20. 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: 20120153.
21. 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: 207-14.