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Evaluation of conventional and digital radiography capacities for distinguishing dental materials on radiograms depending on the present radiopacifying agent

Ispitivanje kapaciteta konvencionalne i digitalne radiografije za utvrđivanje razlika kod materijala na radiogramu zavisno od prisutnog kontrastnog sredstva

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Abstract

Bacgroun/Aim. The radiopacity of an endodontic material can considerably vary as measured on film and a digital sensor. Digital radiography offers numerous advantages over convential film-based radiography in dental clinical practice regarding both diagnostic capabilities and postintervention procedures. The aim of this study was to investigate the capacity of conventional and charge-conpled device (CCD) based digital radiography to detect material on radiograph depending on the radio-pacifying agent present in the material. **Methods.** Experimental cements were formulated by mixing Portland cement with the following radiopacifying agents: zinc oxide (ZnO), zirconium oxide (ZrO_2), titanium dioxide (TiO_2), barium sulphate ($BaSO_4$), iodoform (CHI_3), bismuth oxide (Bi_2O_3) and ytterbium trifluoride (YbF_3). In addition, 5 endodontic materials comprising Endomethasone®, Diaket®, N_2®, Roth 801® and Acroseal® were investigated to serve as control. Per three specimens of each material were radiographed alongside an aluminum step wedge on film (Eastman Kodak Company®, Rochester, NY) and a CCD-based digital sensor (Trophy Radiologie®, Cedex, France). Radiopacity values were calculated by converting the radiographic densities of the specimens expressed as a mean optical densities or mean grey scale values into equivalent thickness of aluminum. **Results.** Two-way ANOVA detected no significant differences with respect to the imaging system ($p > 0.05$), but the differences were significant with respect to radiopacifier ($p < 0.001$) and the interaction of the two factors ($p < 0.05$). Paired *t*-test revealed significant differences between the methods used for pure Portland cement, all concentrations of $BaSO_4$ and CHI_3, 10% and 20% additions of ZrO_2 and Bi_2O_3 and 10% and 30% addition of YbF_3 ($p < 0.05$). **Conclusion.** The materials which incorporate CHI_3 or $BaSO_4$ as radiopacifying agents are expected to be significantly more radiopaque on a digital sensor than on film. During clinical practice one should concern to the quality of contrast assessement obtained by digital according to conventional radiography.

Key words:
radiography, dental; radiography, dental, digital; contrast media; dental cements.

Apstrakt

Uvod/Cilj. Radiokontrastnost jednog endodontskog materijala može znatno varirati u zavisnosti od toga da li je određivano na filmu ili digitalnim senzorom. Digitalna radiografija pruža mnogobrojne prednosti u odnosu na konvencionalnu radiografiju u svakodnevnoj stomatološkoj kliničkoj praksi, kako u pogledu dijagnostičkih mogućnosti, tako i u praćenju rezultata lečenja. Cilj ove studije bio je da se ispitaju mogućnost i konvencionalne i *charge-conpled device* (CCD) digitalne radiografije za vizualizaciju materijala na radiogramu u zavisnosti od kontrastnog sredstva prisutnog u materijalu. **Metode.** Eksperimentalni cementi su pripremljeni dodavanjem sledećih kontrastnih sredstava u Portland cement: cink-oksid (ZnO), cirkonijum-oksid (ZrO_2), titanijum-dioksid (TiO_2), barijum-sulfat ($BaSO_4$), jodoform (CHI_3), bizmut-oksid (Bi_2O_3) i iterbijum-trifluorid (YbF_3). Takođe, ispitivano je pet kontrolnih endodontskih cementa: Endomethasone®, Diaket®, N_2®, Roth 801® i Acroseal®. Po tri uzorka svakog materijala su radiografisana pored aluminijumskog stepeničastog etalona na filmu (Eastman Kodak Company, Rochester, NY) i CCD digitalnom senzoru (Trophy Radiologie, Cedex, France). Vrednosti rendgenkontrastnosti izračunavane su konverzijom radiografskih

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gustina uzoraka izraženih optičkim gustinama ili stepenom tona sivo-bele skale u odgovarajuću debljinu aluminijuma. **Rezultati.** Dvostrukom analizom varijanse nije ustanovljena statistički značajna razlika između primenjenih metoda radiografisanja ($p > 0.05$), ali su vrsta kontrastnog sredstva ($p < 0.001$) i interakcija ova dva faktora ($p < 0.05$) bili značajno različiti. Upareni *t*-test pokazao je statistički značajnu razliku između korišćenih metoda za čisti Portland cement, sve koncentracije $BaSO_4$ i CHI_3, 10% i 20% dodatka ZrO_2 i Bi_2O_3 i 10% i 30% dodatka YbF_3 ($p < 0.05$). **Zaključak.** Očekuje se da materijali koji sadrže CHI_3 ili $BaSO_4$ kao kontrastna sredstva budu lakše uočljivi na digitalnom senzoru nego na konvencionalnom dentalnom filmu. U kliničkom radu mora se imati u vidu kvalitet procene kontrasta koju pokazuje digitalna slika u odnosu na sliku dobijenu konvencionalnom radiografijom.

Ključne reči:
radiografija, stomatološka; radiografija, stomatološka, digitalna; kontrastna sredstva; zub, cement.

Introduction

An ideal root canal sealer should present, among other physical properties, sufficient radiopacity to allow distinction from bone and dentine on radiographs [1] and to facilitate the evaluation of the quality of endodontic treatment [2]. In addition, assessments of the voids within the restoration are facilitated when material experiences adequate radiopacity [3]. Radiopacity of an endodontic material should be compared to dental hard tissues; however, the radiopacity of human dentin varies considerably depending on the individual, age and storage conditions [4]. Therefore, aluminum alloy 1100 is chosen as the reference standard for measuring radiopacity because literature data show that its radiopacity is similar to dentine [5]. According to the American National Standard Institute/American Dental Association (ANSI/ADA) no. 57 endodontic filling material should present a difference in radiopacity equivalent to at least 2 mm Al in comparison to the bone or dentine [6] while the International Organization for Standardization (ISO) 6876 requires a minimal radiopacity equivalent to 3 mm Al [7].

The ISO protocol stipulates that the radiopacity of root canal sealer should be calculated by converting the optical density of the specimen measured on film by densitometer into a equivalent thickness of aluminum. Tagger and Katz [8] modified the method by performing digitization of radiographic films and correlating the radiodensity of the specimens expressed as a grey scale value (0–255) with the thickness of aluminum. Gu et al. [9] introduced direct digital radiography for radiopacity assessments that requires the use of digital sensors and computer radiographic image analysis. It is noteworthy that the ISO 4049 for polymer-based filling, restorative and luting materials [10], in contrast to the ISO 6876, recently adopted the method to allow for digital sensors.

The radiopacity of an endodontic material can considerably vary as measured on film and by a digital sensor. For example, Epiphany® sealer (Pentron Clinical Technologies, Wallingford, CT) has been reported to be equivalent to 7.34 mm Al as determined by Gendex® digital radiography (Gendex Dental Systems, Milano, Italy) [11], 8.0 mm Al as measured by Digora® digital radiography (Soredex Orion Corporation, Helsinki, Finland) [12], 8.2 mm Al as measured by Kodak® digital sensor (Eastman Kodak Company, Rochester, NY) [13], 8.8 mm Al as measured by digitized film [14] and 10.35 mm Al as measured by densitometry [15]. Yet, Roekoseal® (Coltene/Whaledent, Langenau, Germany) experiences the radiopacity that complies with the ISO 6876 according to film radiography (3.17 mm Al), but is not acceptable as obtained from digital assessments (2.83 mm Al) [14]. However, the physical cause of this discrepancy is still the matter of debate. It has been found that resin-based restorative materials that incorporate barium as a radiopacifier appear averagely 13% more radiopaque on a storage phosphor plate digital sensor (PSP) than on film [16]. Similar approximation was noted for barium containing endodontic sealers as analyzed by a charge-conpled device (CCD) based digital and film radiography [11]. It is surprising that the impact of elemental composition upon the differences in radiopacity, as obtained by densitometric and digital measurements, has not yet been investigated.

Therefore, the aim of this study was to evaluate the capacity of radiographic methods, conventional and digital CCD-based radiography, in differentiation of dental material's radiopacity.

Methods

Experimental endodontic cements were prepared by mixing one of seven radiopacifiers with Portland cement (PC) (Italcementi SPA®, Bergamo, Italy). The following radiopacifying agents were used: zinc oxide (ZnO) (Alkaloid, Skoplje, Macedonia), zirconium oxide (ZrO_2) (Kemika, Zagreb, Croatia), titanium dioxide (TiO_2) (Moss Hemos, Belgrade, Serbia), barium sulfate ($BaSO_4$) (Kemika), iodoform (CHI_3) (Galenika, Belgrade, Serbia), bismuth oxide (Bi_2O_3) (Alfa Aesar, Karlsruhe, Germany) and ytterbium trifluoride (YbF_3) (Alfa Aesar Word Hill, USA). Radiopacifiers were added to PC replacing 10%, 20% and 30% of the cement powder by weight. In addition, 5 commonly used root canal sealers were evaluated in this study. The commercial names, manufacturers, compositions and recommended power to liquid (P/L) or base to catalyst (B/C) paste ratios are listed in Table 1.

Each experimental cement was mixed in the ratio of 1 g powder per 0.37 mL distilled water and poured into metal ring mold (8 mm in diameter and 1 mm in thickness) placed on the glass slab. Another glass slab was used to press the cement onto the mold to obtain specimen of standardized thickness. After removal from the mold specimens cements were kept in an incubator at 37°C and 95% humidity for 24 hours for complete setting. The thickness of the specimens was controlled with a digital caliper (Mitutoyo, Tokyo, Japan). If necessary, specimens were ground wet with 600-grit silicon carbide paper to standard thickness. Commercial endodontic sealers were prepared with the accordance to manufacturer's instructions (Table 1). An electronic analytic balance (Mettler, Zurich, Switzerland) was useed to weight cement powder while syringe to measure liquid and two pastes of Acroseal®.

Table 1

Commercial names, manufacturers, composition and power to liquid/base to catalyst ratio of investigated endodontic materials

Commercial name	Manufacturer	Composition	Powder to liquid/base to catalyst paste ratio
Endomethasone®	Septodont Specialities, Saint Maur, France	Powder: zinc oxide, diodthymol, barium sulphate and hydrocortisone acetate. Liquid: eugenol and peppermint oil.	0.46 g : 0.15 mL
N_2®	Ghimas, Bologna, Italy	Powder: zinc oxide (69%), bismuth nitrate (2%), bismuth subcarbonate (5%), titanium dioxide (2%), lewad tetraoxide (12%), barium sulphate (2%) and iron oxide. Liquid: eugenol, peanut oil, rose oil and lavender oil.	0.84 g : 0.25 mL
Roth 801®	Roth International Limited, Chicago, IL, USA	Powder:zinc oxide (40%), staybelite resin (30%), bismuth subcarbonate (15%) and barium sulphate (15%). Liquid: eugenol and oil of sweet almond.	0.13 g : 0.03 mL
Diaket®	ESPE, Seefeld, Germany	Powder: zinc oxide (97%) and bismuth phosphate (3%). Liquid: prophionyl acetophenone nd vinyl isobutyl ether.	0.2 g : 0.05 mL
Acroseal®	Septodont Specialities, Saint Maur, France	Base: calcium hydroxide, diglycidyl ether of bisphenol A (DGEBA), and bismuth carbonate. Catalyst: glycyrrhetic acid (enoxolone) methenamine and bismuth carbonate.	1 mL base paste : 1 mL catalyst paste

Per three specimens of each cement were radiographed alongside an aluminum step wedge made of 99.6% pure aluminum alloy 1100 with the thickness varying from 1 mm to 10 mm in uniform steps of 1 mm each. The images were taken using an x-ray generator (Gendex GX, Lake Zurich, IL) operating at 70 kVp, 7 mA and a focus to target distance of 35 cm. The specimens were radiographed on Extraspeed occlusal film (Eastman Kodak Company) with a 0.32 s exposure. The films were processed in an automatic developing machine (Dent-X 9000, AFP Imaging Co., Elmsford, NY, USA) using the same developer at 28°C and standard processing time of 6 min. Each specimen was also radiographed using a radiovisiography (RGV-4) sensor (Trophy Radiologie, Cedex, France) with the exposure time of 0.074 s. Radiographic densities on film were expressed as mean optical densities measured by a transmission densitometer (X Rite 341, Grand Rapids, MI) while radiographic densities on digital images were expressed as mean grey scale values using the Adobe Photoshop CS4 software (Adobe Systems, San Hose, CA). Three readings were made for each specimen and each step of the step wedge. To determine the radiopacity of the cements, a graph was plotted for the logarithm of the thickness of the aluminum step wedge versus the corresponding radiographic density of the step wedge. The radiographic densities of the materials were then used to calculate radiopacity from this graph. The data were subjected to two-way ANOVA and paired *t*-test ($p < 0.05$).

Results

Figure 1 depicts digitized conventional and digital radiographs of Acroseal® alongside with aluminum step wedge.

Radiographs of experimental cement with 30% addition of barium sulfate taken by using two radiographic systems are shown in Figure 2.

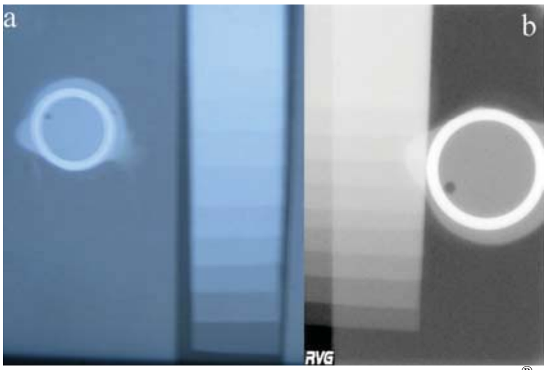

Fig. 1 – Film (a) and digital (b) images of Acroseal®.

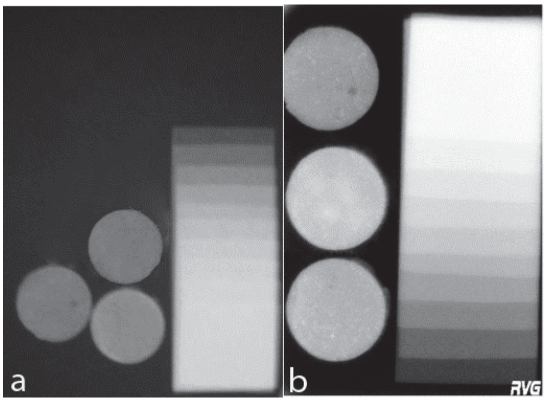

Fig. 2 – Film (a) and digital (b) images of Portland cement with 30% addition of barium sulfate alongside aluminum stepwedge.

The measured mean radiopacity values of commercial experimental cements are shown in Figures 3 and 4. Addition of Bi_2O_3 at 30% resulted in the highest radiopacities on both film and digital sensor (8.68 and 8.03 mm Al, respectively) whilst 30% addition of CHI_3 induced the highest differences between two imaging systems (50.2%). Two-way ANOVA testing indicated no significant differences with regards to imaging system ($p > 0.05$), but it was significant with respect to radiopacifier type ($p < 0.001$) and the interaction of two factors ($p < 0.05$).

Figure 5 presents the percentage difference between the results obtained by each radiographic methods for the investigated cements.

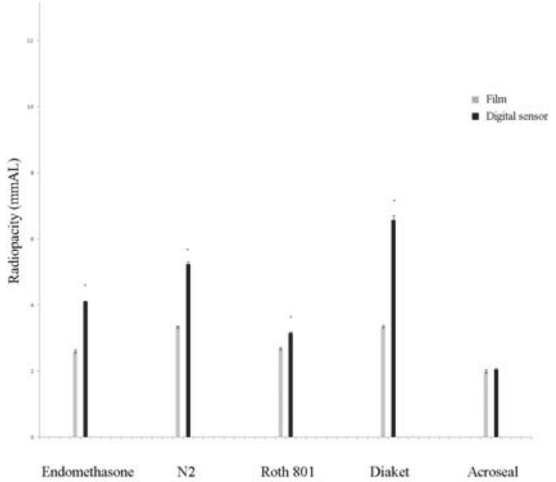

Fig. 3 – Radiopacity of the tested endodontic materials expressed as an equivalent thickness of aluminum.
*** – statistically significant difference on the digital sensor related to that on film (paired *t*-test; $p < 0.05$).**

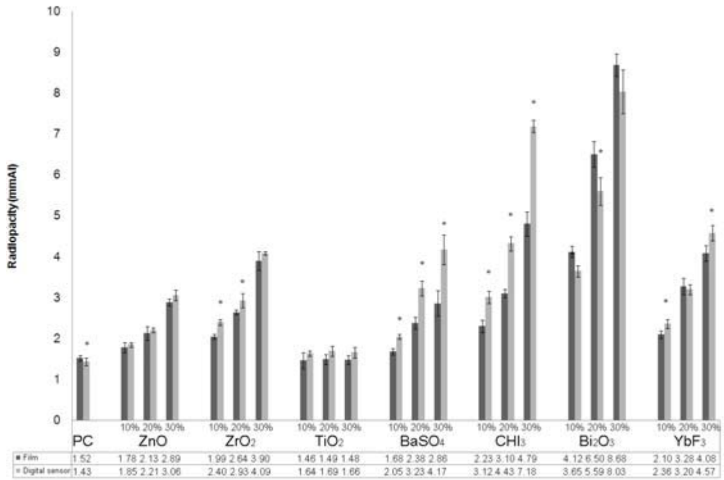

Fig. 4 – The mean radiopacity values and standard deviations expressed in thickness of aluminum (Al) for Portland mixtures. The columns marked with * represent groups with significantly different radiopacity on digital sensor when compared with film (paired *t*-test; $p < 0.05$).

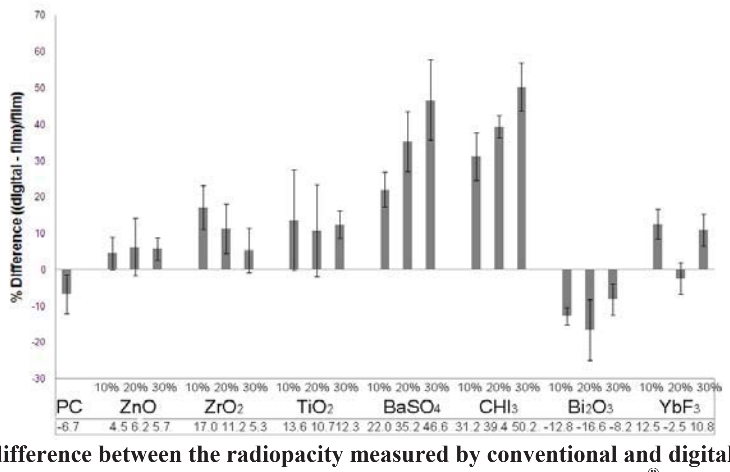

Fig. 5 – The percentage difference between the radiopacity measured by conventional and digital charge-conpled device (CCD)-based radiography. The positive values indicate increased radiopacity on the RVG® sensor compared with the film.

Discussion

A number of investigations have been carried out to compare digital to film radiography with respect to the diagnostic accuracy of secondary decay [17], root fractures [18] and root canal length [19]. This study focused on examining the impact of various radiopacifiers on the differences in radiopacity of dental materials in 2 different radiographic image modalities: film and CCD-based digital radiographs. Addition of CHI_3 and $BaSO_4$ induced the most significant differences; addition of 30% CHI_3 and $BaSO_4$ caused the experimental cements to present 50.2% and 46.6% more radiopaque on digital sensor, respectively.

Several factors affect the radiopacity of dental materials: a technique used for evaluation, specimen's thickness, particle size related to the water absorption of the material, film development, atomic numbers of materials' constituents and P/L respectively B/C paste ratio [20]. Among those factors the atomic number of materials' constituents is the most important one since it influences the radiopacity raised even to the exponent of four.

With a few exceptions, dental materials tended to appear more radiopaque on the digital sensor than on film. This is in agreement with the results of the previous study in which the CCD-based digital sensor was compared to film [21], but in contrast with an investigation that compared the radiopacity of endodontic sealers on film and PSP digital sensor [14]. The addition of 20% YbF_3 and all mixtures of Bi_2O_3 induced higher radiopacity values obtained by densitometric analysis. The results found for 20% additions of ZnO, ZrO_2, $BaSO_4$ and Bi_2O_3 as imaged on film are consistent with the outcome of Hungaro Duarte et al. [22] observed by digitization of radiographic films, but the 20% addition of CHI_3 led to the divergent results. Bortoluzzi et al. [23] used indirect digital technique and found similar results as it was found in the present study using conventional film radiography for 20% addition of Bi_2O_3, $BaSO_4$ and CHI_3, but significantly higher radiopacity for 20% addition of ZrO_2. In the previous reports densitometric analysis of radiographic films exhibited the results for TiO_2, ZnO, $BaSO_4$ and Bi_2O_3 additions that corroborate the results of the current study [23, 24]. The barium containing materials such as InnoEndo® (Haraeus-Kulzer, Armonk, NY), Epiphany® sealer (Pentron clinical technologies), Pulpdent RCS® (Pulpdent Corporation, Watertown, MA) and Nogenol® (GC America Inc., Alsip, IL) are reported to appear 44.1%, 9.4%, 17% and 12.5%, respectively, more radiopaque on PSP digital system than on conventional film radiography. Conversely, Bi_2O_3 containing materials Ez-Fill® (Essential Dental Systems, South Hackensack, NJ), Ez-Fill Express® (Essential Dental Systems) and Resilon® (Pentron Clinical Technologies) were averagely 3% more radiopaque on film-based radiography [11]. Although these results are consistent with the findings of the present investigation, manufacturers do not claim the percentage of the radiopacifiers incorporated within materials; thereby, exact correlation could not be observed.

Diaket® and N_2® were the most radiopaque materials in the present study; ZnO and bismuth in the form of bismuth subnitrate, bismuth phosphate and bismuth subcarbonate conferred radiopacity to the sealers. The difference in radiopacity on film versus a digital sensor raised as the percentage of ZnO in the material raised; the greatest difference was found for Diaket® with 97% of ZnO, lower difference was found for N_2® with 69% of ZnO and the lowest difference was found for Roth 801® with 40% of ZnO. In this study, Diaket® experienced radiopacity equivalent to 3.35 mm Al on the film and 6.57 mm Al on a digital sensor; in previous studies it was as radiopaque as 1.29 mm Al and 2.19 mm Al by conventional radiography measurements [13] and 6.5 mm Al [14] and 2 mm Al [13] on a digital sensor. However, it should be highlighted that the results found by Baksi et al. [14] (2.19 mm Al on film and 2 mm Al on a digital sensor) differ from the results found by other authors for all sealers investigated in that study. Endomethasone® exhibited radiopacity of 2.6 mm Al and 4.1 mm Al on film and a digital sensor, respectively, which is contaminant with the results of Gaur [25] who found it to be 3 mm Al and 4 mm Al, respectively. The results found for the radiopacity of Acroseal® (2 mm Al and 2.05 mm Al on film and a digital sensor, respectively) are in agreement with the results found by Baksi et al. [14] (2.04 mm Al on film and 1.9 mm Al on a digital sensor), but significantly lower than of Tanomaru-Filho et al. [26] (4.03 mm Al) who used indirect digital technique. Although Acroseal® contains bismuth carbonate as a radiopacifying agent and it is expected to present high level of radiopacity due to a high atomic number of bismuth, it exhibited lower radiopacity, which means that this component is presented in relatively low quantity.

The differences in the radiopacity of experimental cements on film and CCD-based digital sensor presumably arise from the different sensitivity of the detector used. Since a typical x-ray beam contains a rather broad spectrum of photon energies, all of the energies do not produce the same level of contrast. Silver on x-ray film is most sensitive to 26 keV, while iodine in a CCD-based digital x-ray sensor is most sensitive to 37 keV photons. Thus, elements that selectively filter out high energy photons (when compared to aluminum alloy 1100) should appear more radiopaque on CCD sensor; elements that preferentially filter out photons with energies less than 35 keV (compared to aluminum alloy 1100) should appear more radiopaque on film. Furthermore, if a dental material and an x-ray detector have similar compositions, the material will absorb most of the energies which the x-ray detector is most sensitive to. Hence, the material will appear more radiopaque on that detector versus a detector with different composition. Among investigated radiopacifiers, chemical elements incorporated in CHI_3 and $BaSO_4$ (iodine and barium), have ideal K-absorption edge (33 keV for iodine and 37 keV for barium) to absorb most of the energies that a CCD-based detector is most sensitive to. Therefore, in the present study, CHI_3 and $BaSO_4$ induced significantly higher radiopacity values on digital sensor than on film.

PC used in the current study has very similar composition as mineral trioxide aggregate (MTA) [27, 28], except for the presence of Bi_2O_3, which is contained in MTA at 20% ratio to improve its radiopacity. However, Bi_2O_3 adversely affects some of the material's properties by retarding its setting time [29], increasing the porosity [30], decreasing the compressive strength [29] and interfacing its hydration mechanism [31]. Thus, alternative radiopacifiers have been proposed to be associated with PC. According to the results of this study, the minimum radiopacifiers' amounts that allow the PC to reach 3 mm Al were 30% ZnO, 30% ZrO_2, 20% $BaSO_4$, 20% YbF_3, 10% CHI_3 and 10% Bi_2O_3 as measured by digital radiography and 30% ZrO_2, 20% CHI_3, 20% YbF_3 and 10% Bi_2O_3 as determined by conventional radiography. Neither concentration of ZnO and $BaSO_4$ ensured satisfactory radiopacity of the PC on conventional radiography while TiO_2 was not able to enhance the radiopacity neither on film nor the digital sensor. The interference of potential radiopacifiers with other physical and biological properties of PC should be further examined. The results of the present and previous studies [24, 27] imply, however, that Bi_2O_3 content may be reduced in MTA from 20% to 10% in order to minimize its adverse effects on material's properties.

To remind, the ISO 6876 stipulates that an endodontic material must present the radiopacity equivalent to at least 3 mm Al. In contrast to the ISO 4049 for polymer based restorative, filling and luting materials [10] which adopted the method to allow for digital sensor measurements, the ISO 6876 does not address this issue. Several researchers suggested that ISO 6876 needs modifications for electronic imaging [14, 26].

Conclusion

The obtained results reveal that characterization of cement type cannot be established using radiography. However, materials that incorporate CHI_3 or Bi_2O_3 are expected to be highly radiopaque. Conversely, materials that incorporate TiO_2 as a radiopacifying agent should be less radiopaque. These results are of practical importance concerning that the radiopacity of CHI_3 or $BaSO_4$ containing materials as recorded on film is not indicative of radiopacity as recorded on charge-conpled device-based digital sensor. Because material's composition influences the differences in radiopacity it is imperative to be taken into consideration when trying to establish any correlation between radiopacity values obtained by film and a digital radiography. Collectively, these lines of evidence suggest that the clinician must be cautious when comparing radiographs made by different methods because sudden decrease in radiopacity due to the choice of radiographic method may lead to suspicion of resorption or loss of restoration integrity. Barium in PSP digital system is sensitive to similar photon energies (38 keV) as iodine in chage-conpled device-based digital sensor (37 keV); thus, the results of this investigation are expected to be applicable to most intraoral digital systems. Some further work would be useful to ascertain the source of the remaining variations between the two imaging systems.

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