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Radiopacity of Premixed and Two-Component Calcium Silicate-Based Root Canal Sealers

SUMMARY

Background/Aim: *Radiopacity enables radiographic visualization, which is significant in diagnostic procedures and assessment of the quality of endodontic filling. It is important to compare newly developed endodontic sealers with materials that are already in clinical use in order to promote evidence-based dentistry. The aim of our study was to evaluate radiopacity of different calcium silicate-based sealers in comparison with control, epoxy resin–based sealer. The null hypothesis was that there were no statistically significant differences in radiopacity of the tested sealers.* ***Material and Methods:*** *Premixed (TotalFill BC Sealer, EndoSequence BC Sealer, Ceraseal, Bio-C Sealer), two-component (BioRoot RCS, MTA Fillapex, Bioceramic Root Canal Sealer, GuttaFlow Bioseal) calcium silicate-based sealers and AH Plus, as a control, were used. Specimens were radiographed using a Radiovisiography (RVG-4) CCD (charge-coupled devices)-based digital sensor.* ***Results:*** *Ceraseal had the highest, while Bioceramic Root Canal Sealer had the lowest radiopacity. Bioceramic Root Canal Sealer and MTA Fillapex had radiopacity significantly lower than all other sealers. Radiopacity level of AH Plus, was similar to premixed and significantly higher than radiopacities of all two-component endodontic sealers.* ***Conclusions:*** *Calcium silicate-based sealers radiopacity ranged from slightly above minimal required value (3mm), to a value higher than control sealer. Premixed endodontic sealers showed similar radiopacity as AH Plus which suggests that their clinical performance, in terms of visibility on dental radiograms, should be similar.*

Key words: Radiography; CCD Digital Sensor; Endodontic Filling

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Introduction

Root canal obturation is a very important step in root canal therapy which aims to obtain hermetic sealing of endodontic space. After efficient chemo-mechanical cleaning and shaping, sealing of the root canal system is usually obtained by three-dimensional obturation with gutta-percha cones combined with a root canal sealer. Root canal sealers are used to fill minor space discrepancies between gutta-percha cones and canal walls as well as root canal irregularities, accessory and lateral canals. Adequate root canal sealing prevents communication between periapical tissues and oral cavity with consequent bacterial microleakage and possible reinfection[1].

A trend to create bioactive, biologically acceptable materials includes, among other areas in dentistry, endodontic sealers due to their direct contact with periapical tissues through the apical foramen. Calcium silicate sealers are based on mineral trioxide aggregate (MTA) which was introduced in dentistry due to its bioactivity and ability to interact with surrounding tissues and provide biological signals able to activate stem cells[2,3]. Biological properties of these materials are related to hydroxyapatite formation on their surface as a result of calcium hydroxide ions production during hydration process[4,5]. Besides hydroxyapatite precipitation, these materials show alkaline pH, antibacterial activity and ability to create a tight seal between the canal and sealer by its diffusion into dentinal tubules and formation of mechanical interlocking to a dentinal wall[6]. Calcium silicate-based sealers are available as one-component, premixed materials that use residual moisture from root canal for setting and two-component sealers with setting reaction initiated after mixing of components.

Radiopacity is an important physical property of endodontic sealers that enables radiographic visualization which is significant in diagnostic procedures and assessment of the quality of endodontic filling. Adequate radiopacity is necessary for distinction of the root canal filling material from surrounding dental and periapical tissues and for detection of voids in the obturation. However, too radiopaque materials may mask voids and other imperfections in the filling, giving the false impression of filling compactness[7]. On the other hand, low radiopacity of endodontic sealers can be misinterpreted as absence of the sealer in zones where it is found in small amounts. During our clinical experience we also noted that the radiopacity of sealers could be helpful in the estimation of sealer removal during endodontic retreatment.

International Organization for Standardization (ISO) determined that 1mm thick sample of an endodontic sealer should have a radiopacity equivalent to at least 3 mm of aluminum[8]. Although this standard established that radiopacity should be evaluated on radiographic film, widespread use of digital radiography, due to easier image processing and analysis, made digital technique more clinically relevant than conventional radiography. Several studies revealed that radiopacities of endodontic materials differ on conventional films and on digital images and suggested that it is due to differences in image acquisition technology[9,10]. Namely, beside materials' composition, its radiopacity levels are also dependent on the type and sensitivity of x-ray detector. While x-ray beam consists of a broad spectrum of photons with specific energies, detectors (conventional films or different types of digital sensors) have specific sensitivity to photons with certain energies. This means that dental materials that absorb and filter out photons with energies which the x-ray detector is most sensitive to will appear more radiopaque on that detector. Considering that digital radiography is, due to its wide use in praxis, more clinically relevant, authors of previous studies proposed that modified standardized protocols should be developed for this technique[10,11]. On the other hand, it was shown that variations of exposure parameters during digital imaging considerably changed standard deviation of the radiopacity measurements resulting in decreased precision[12]. Authors concluded that optimal exposure differs for each x-ray detector and influences the precision of radiopacity measurements[12]. If exposure time for a given target distance is not optimal, material could, on the radiographic image, be represented only using a fraction of the full grey-scale spectrum[12]. Also, it was shown that the increase of focal distance (tube to sensor) decreased radiopacity values of endodontic sealers[13]. Even slight differences between material radiopacity obtained using different sensors and/or exposure parameters can affect classification of the materials particularly if determined values are close to a given standard. Having this in mind, it is important to use the same methodological design and the same radiographic system in order to compare the radiopacities of different endodontic sealers reliably.

New calcium silicate-based sealers are constantly being developed and it is significant to obtain scientific evidence of their properties and to be able to compare them with materials that are already in clinical use in order to promote evidence-based dentistry. Additionally, sometimes manufacturers modify the composition of already known endodontic sealers by changing the type of radiopacifying agent[14]. In that context, the aim of our study was to simultaneously measure the radiopacity levels of different calcium silicate-based sealers and compare them with an epoxy resin–based sealer (AH Plus) that is considered a gold standard sealer regarding its physical properties. The null hypothesis was that there were no statistically significant differences in radiopacity of the tested sealers.

Material and Methods

Specimen preparation

Four premixed (TotalFill BC Sealer, EndoSequence BC Sealer, Ceraseal, Bio-C Sealer) and four two-component calcium silicate-based sealers (BioRoot RCS, MTA Fillapex, Bioceramic Root Canal Sealer, GuttaFlow Bioseal) were used in this study. AH Plus (an epoxy-based sealer) was used as contol (Table 1). Sealers were prepared according to the manufacturer's instructions and placed in 2 mm thick molds, with 5 mm in diameter. After setting in an incubator at 37ºC and 95% relative humidity, specimens thickness was checked with a digital caliper and then, if necessary, ground wet with 600-grit carbide paper, to the thickness of 2±0.1 mm.

Table 1. Compositions and manufacturers of tested endodontic sealers

Sealer	Manufacturer	Composition
TotalFill BC Sealer	FKG Dentaire SA, Switzerland	Zirconium oxide, calcium silicates, calcium phosphate monobasic, calcium hydroxide, filler and thickening agents
EndoSequence BC Sealer	Brasseler USA Savannah, Georgia, USA	Zirconium oxide, calcium silicates, calcium phosphate monobasic, calcium hydroxide, filler and thickening agents
Ceraseal	Meta Biomed Co., South Korea	Calcium silicates, zirconium oxide, thickening agent
Bio-C Sealer	Angelus, Brazil	Calcium silicates, calcium aluminate, calcium oxide, zirconium oxide, iron oxide, silicon dioxide, dispersing agent
BioRoot RCS	Septodont, France	Powder: tricalcium silicate, zirconium oxide and excipients Liquid: aqueous solution of calcium chloride and excipients
MTA Fillapex	Angelus, Londrina, Brazil	Base paste: salicylate resin, natural resin, calcium tungstate, nanoparticulated silica, pigments. Catalyst paste: diluting resin, mineral trioxide aggregate, nanoparticulated silica, pigments
Bioceramic Root Canal Sealer	SSWhite, New Jersey, USA	Base paste: salicylate resin, natural resin, calcium tungstate, nanoparticulated silica, pigments. Catalyst paste: diluting resin, mineral trioxide aggregate, nanoparticulated silica, pigments
GuttaFlow Bioseal	Coltène/Whaledent, Germany	Gutta-percha powder, polydimethylsiloxane, platinum catalyst, zirconium dioxide, silver (preservative), coloring, bioactive glass ceramic
AH Plus	Dentsply, DeTrey GmbH, Germany	Paste A: Bisphenol epoxy resin–A, Bisphenol epoxy resin–F, calcium tungstate, zirconium oxide, silica, iron oxide pigments. Paste B: Dibenzyldiamine, aminodiamantana, tricyclodecane–diamine, calcium tungstate, zirconium oxide, silica, silicone oil.

Radiopacity assessments

Three specimens of each sealer were radiographed alongside an aluminum stepwedge (99.6 % pure, varying in thickness from 1 to 10 mm in steps of 1 mm each) using a Radiovisiography (RVG-4) CCD-based digital sensor (Trophy Radiology, Cedex, France). We used X-ray generator (Trophy Radiology) operating at 70 kVp and 7 mA for 0.07 s with a source-to-object distance of 30 cm. Radiographic densities of the sealers on digital images were expressed as mean greyscale values using the Adobe Photoshop CS4 software (Adobe Systems, San Hose, CA). Three readings were made for each step of the aluminum stepwedge and each sealer specimen, avoiding areas with air bubbles or other iregularities. For radiopacity calculation, graph of aluminum thickness versus radiographic density was plotted with the best-fit logarithmic trend line. Subsequently, the radiographic density of each sealer was used to determine the radiopacity from the graph. Radiopacity data were expressed as mmAl/mm material (mmAl).

Statistical analyses

The data were tested for normality of distribution by Kolmogorov–Smirnov test and analyzed using analysis of variance (ANOVA) with a post hoc Bonferroni test for comparison of the differences between the groups. SPSS 16.0 for Windows (SPSS Inc., Chiago, IL, USA) statistical software was used for all analysis, statistical significance was set at 0.05.

Results

Figure 1. shows digital radiograph of Ceraseal sealer and aluminum stepwedge. Figure 2. shows the mean values with standard deviations of the radiopacities expressed in equivalent thickness of aluminium (mm Al) and statistical differences among examined endodontic sealers. Ceraseal had the highest mean radiopacity, while Bioceramic Root Canal Sealer had the lowest radiopacity value. Bioceramic Root Canal Sealer and MTA Fillapex had radiopacity levels significantly lower than all other sealers. Radiopacity of control, AH Plus sealer, was similar to all premixed calcium silicate-based sealers. On the other hand, AH Plus had significantly higher radiopacity than all two-component endodontic sealers.

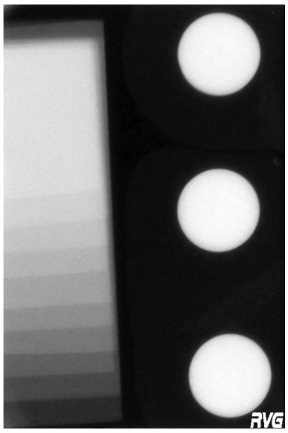

Figure 1. Digital radiograph of Ceraseal sealer and aluminum stepwedge

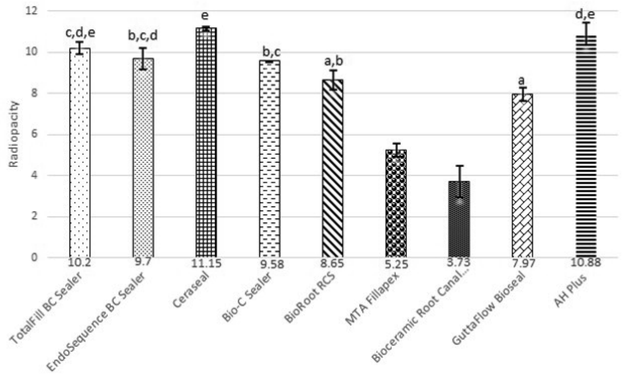

Figure 2. Mean values and standard deviations of the radiopacities of investigated endodontic sealers expressed in equivalent thickness of aluminium (mm Al). Means followed by a common letter are not significantly different

Discussion

Significant differences in radiopacity values were found among the tested root canal sealers. Therefore, the null hypothesis can be rejected.

Dental materials with atomic number higher than human hard tissues absorb/reflect more X-rays and can be distinguished radiographically. Materials that do not provide radiopacity sufficient to be adequately visualised, require addition of radiopacifying agents to optimize their radiographic appearance. It was shown that molecular structure, physical density and method of synthesis and incorporation of radiopacifiers affect the radiopacity level of dental materials[15, 16]. Also, the presence of different radiopacifying agents, in the same proportion, in endodontic materials, could result in different radiopacity values. Namely, Duarte *et al.* 2009 observed that following radiopacifiers could have decreasing order of radiopacity: bismuth oxide, lead oxide, bismuth subnitrate, iodoform, zirconium oxide, bismuth carbonate, calcium tungstate, barium sulphate, and zinc oxide[17].

In the present study Bioceramic Root Canal Sealer expressed the lowest radiopacity followed by MTA-Fillapex which could be a consequence of their composition. These sealers have calcium tungstate as opacifying agent which showed to have lower radiopacity than radiopacifiers present in other examined sealers[17]. It is interesting to note that the difference between these two sealers was significant although they have the same compositions, according to their manufacturers. As Bioceramic Root Canal Sealer became available relatively recently we found no independent reports regarding its radiopacity and it was not possible to compare our results with previous ones. Radiopacity values of MTA-Fillapex were difficult to compare with those of previous reports because the sealer investigated in our study was the modified version - bismuth oxide free but containing calcium tungstate[14]. The addition of radiopacifiers to dental materials should enable their assessment on a radiograph without negative alteration of their other properties. Bismuth oxide does not act as an inert radiopacifying filler and affects the hydration mechanisms of calcium silicates and becomes incorporated in its structure[18]. This opacifier could be leached from the material and adversely affect its biological response[19, 20]. Also, bismuth oxide may cause tooth discoloration, particularly in contact with sodium hypochlorite used as canal irrigant which may remain in the root canal dentin[21, 22].

We found only one study that used digital imaging system for investigating radiopacity of the latest version of MTA-Fillapex containing calcium tungstate[23]. Reported radiopacity was equivalent to 3.04 mmAl and lower than in present study which could be the consequence of different digital sensors used, phosphor plate in the study of Lopes et al. and CCD sensor in ours[23]. On the other hand, results of the mentioned study for GuttaFlow Bioseal sealer (7.02 mmAl) were not far from ours (7.97 mmAl)[23]. We assume that discrepant results for two sealers could be due to differences in interactions between opacifying agents present in these sealers and photons with specific energies which the x-ray detectors are most sensitive to. Additionally, Camargo *et al*., using the same radiographic system as Lopes et al., reported similar results to ours for GuttaFlow Bioseal (7.44 mmAl)[23, 24].

According to data found in literature, radiopacity of EndoSequence BC Sealer ranged between 4.7 and 10.8 mmAl in studies that used digital radiographic systems[25, 26]. Our results (9.7 mmAl) were closer to higher values from observed range and discrepances between the studies could be the consequence of different sensors/exposure parameters used in these studies. We noted that the radiopacity of EndoSequence BC Sealer was not significantly different from the values for TotalFill BC Sealer and that probably was due to the fact that the compositions of these sealers are based on the same patent[27]. Ceraseal and Bio-C Sealer are relatively recently developed sealers and there is only one report in scientific literature for each of them that regards radiopacity. In the study of Park *et al*. Ceraseal had radiopacity of 5.94 mmAl which was much lower than in our study (11.15 mmAl)[28]. This difference could be attributed to shorter tube-to-sensor distance (10 cm vs 30 cm) and/or sensor type used in the mentioned study. On the other hand, the difference was not so significant between our results (9.58 mmAl) and radiopacity levels obtained for Bio-C Sealer in the study of Antunes *et al*. (7.11 mmAl), athough they used a different digital sensor (CMOS-Complementary Metal Oxide Semiconductor)[29]. Similarly, radiopacity values for BioRoot RCS (8.65 mmAl) in our study were in accordance with findings reported in the mentioned study of Antunes et al. (7.96 mmAl), as well as with results of Khalil *et al.* (8.3 mmAl), who used photostimulable phosphor plates[29, 30].

Beside previously mentioned causes of relatively wide range of radiopacity values, observed in scientific literature, several authors proposed that these variations could origin from the mixing process of two-component endodontic sealers. Namely, they suggested that possible variations in ratio of sealers components and/or air bubbles entrapment could influence radiopacity level of the material[31, 32]. Additionally, it was shown that the composition of sealer samples could be uneven due to segregation between the components in packings and that the radiopacifying agent could be deposited at one end of sealers packaging, presenting higher radiopacity[33]. Also, it is interesting that Watts et al. noted small variations of radiopacity between successive specimens of dental materials, which he termed 'radiographic inhomogeneity' and attributed it to variations in density of the material[34].

Premixed calcium silicate-based sealers showed relatively high radiopacity, similar to control epoxy-based sealer, although, beside zirconium oxide, AH Plus contains two more components with high radiopacity. Having in mind that zirconium oxide is the main radiopacifying agent in tested premixed sealers its ratio was high enough to reach and even overcome radiopacity of AH Plus. This could be seen, for instance, from the safety data sheet of Ceraseal sealer stating that zirconium dioxide makes up to 50 Wt.% of this sealer[35].

In clinical setting, radiopacity of the root canal filling is influenced by a combined effect of dentin, bone, soft tissues, gutta-percha cones and endodontic sealer. Relative thickness of the sealer and gutta-percha has a major effect on radiopacity of the filling, particularly at the apical part, where the amount of canal filling is considerably reduced[36]. Consequently, this reduced thickness of the sealer might be a problem for proper clinical evaluation, although, material can have radiopacity slightly above that specified by standards, *in vitro*. In spite of limitations in transferring *in vitro* results to clinical situation, laboratory examinations offer valuable evidence comparing recently developed and widely used materials.

Conclusions

Calcium silicate-based sealers examined in our study showed significant differences between its radiopacity values ranging from slightly above minimal value, required by ISO standards, to the value higher than the control sealer. Premixed endodontic sealers, as the newest result of dental material technology, showed similar level of radiopacity as AH Plus, epoxy resin–based sealer, which suggests that their clinical performance in term of visibility on dental radiograms should be similar.

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