doi:10.1111/j.1365-2591.2007.01246.x

Radiopacity of root filling materials using digital radiography

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Abstract

Carvalho-Junior JR, Correr-Sobrinho L, Correr AB, Sinhoreti MAC, Consani S, Sousa-Neto MD. Radiopacity of root filling materials using digital radiography. *International Endodontic Journal*, **40**, 514–520, 2007.

Aim To evaluate radiopacity of root filling materials using digital radiography.

Methodology The sealers tested were AH Plus™, Endofill®, EndoREZ™ and Epiphany™. Gutta-percha (Dentsply Maillefer) and Resilon™ cones were also tested. Acrylic plates, containing six wells, measuring 1 mm in depth and 5 mm in diameter, were prepared for the test, and filled with the materials. The test samples were radiographed together with an aluminium stepwedge calibrated in millimetres, according to ANSI/ADA Specification 57. For the radiographic exposures, digital imaging plates and an X-ray machine at 70 kVp and 8 mA were used. The object-to-focus distance was 30 cm, and the exposure time, 0.2 s. After the laser optic reading process, the software determined the radiopacity of the standardized areas, using grey-scale values, calculating the average radiographic density for each material.

Results The decreasing values of radiopacity of the studied materials, expressed in millimetres of aluminium equivalent, were: Resilon™ (13.0), AH Plus™ (11.2), gutta-percha (9.8), Epiphany™ (8.0), Endofill® (6.9) and EndoREZ™ (6.6).

Conclusion All materials had radiopacity values above 3 mm of aluminium recommended by ANSI/ADA Specification 57.

Keywords: digital X-ray phosphor plate, image-analysis programme, radiopacity, root canal filling materials.

Received 9 July 2006; accepted 2 January 2007

Introduction

Radiopacity is one of the properties required for intra-oral dental materials (Eliasson & Haasken 1979). Root canal sealers should also have sufficient radiopacity to allow for a clear distinction between the materials and surrounding anatomic structures (Beyer-Olsen & Ørstavik 1981, Katz *et al.* 1990), and to facilitate the evaluation of the quality of the root fillings, which can be undertaken only through radiographic examination (Goldman *et al.* 1989).

To determine radiopacity of root canal sealers, the American National Standard/American Dental Association (ANSI/ADA 2000) Specification No. 57 for endodontic sealing materials establishes that they must have a radiopacity not less than that equivalent to 3 mm of aluminium; that the radiographic images must be obtained by the chemical processing of radiographic film, using developing and fixation solutions, rinsing and drying; and that the radiopacity must be evaluated by an optical densitometer.

Tagger & Katz (2003) proposed a method to evaluate the radiopacity of canal sealers by digitizing the chemically processed radiographic films and using specialized radiographic software and hardware, eliminating the need for an optical densitometer. Radiographic software allows for a more detailed analysis of the digital image, which is shown on a computer

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screen, and can be evaluated graphically or by the grey-pixel value, which is a numerical value given to represent the different shades between black and white that vary from 0 to 255 pixels, where 0 represents black and 255, white (Nummikoski *et al.* 1992, Wagner & Schneider 1992, Wenzel 1993). However, to process chemically radiographic film it is necessary to use developing and fixation fluids, as well as to dry the film. These processes are time consuming (McDonnell & Price 1993) and add further procedures that may negatively interfere with the final quality of the radiographic image (Syriopoulos *et al.* 2000). In an attempt to eliminate chemical processing of radiographic film during the evaluation of density measurement of resin composites, Silveira (2002) used storage phosphor images enhanced with Digora™ software (Digora™ system, Soredex Orion, Helsinki, Finland). The author reported that comparison of the density measurement of different composite materials by the digital system was satisfactory, because an immediate image was obtained on the screen and because the radiopacity data was expressed in grey-pixel values. The grey-pixel values may be converted into millimetres of aluminium equivalent, permitting the measurement of the radiopacity of the studied materials (Sabbagh *et al.* 2004).

The objective of this study was to evaluate the radiopacity of AH Plus™, Endofill®, EndoREZ™ and Epiphany™ sealers, and gutta-percha and Resilon™ cones, using digital radiography and pixel grey-scale measurement.

Materials and methods

The tested materials along with the manufacturers are listed in Table 1.

Five acrylic plates (2.2 cm × 4.5 cm × 1 mm), containing six wells measuring 1 mm in depth and 5 mm in diameter (Fig. 1a), were prepared and placed over a glass plate covered by cellophane sheet. Sealers were mixed according to the manufacturers' recommendations, and then introduced immediately in four of the wells. The powder/liquid ratio for the zinc oxide–eugenol-based sealer, Endofill®, was obtained as described by Sousa-Neto (1999). The application of the sealers was accomplished with the use of a syringe to avoid the appearance of bubbles. The respective applicators for EndoREZ™ and Epiphany™ sealers were used to fill the wells. Another glass plate covered with cellophane was placed on top of the sealers and any excess sealer removed, once set (chemical or light-cure). Each of the wells was filled with one of the sealers, following a sequence according to the setting time of the material, from the longest setting time to the shortest, so that the samples would be ready for radiographic evaluation after the final simultaneous setting of the materials. Each plate with the sealers was kept in a chamber at 37 °C and 95% relative humidity during the setting time of the materials. Gutta-percha and Resilon™ cones were warmed and adapted into the two remaining wells. The root canal filling materials were placed on the acrylic plates in the same position to standardize and locate the materials during the radiopacity analysis.

Digital radiography

Each one of the acrylic plates containing the root filling materials was positioned, at the time of the radiographic exposure, alongside the other acrylic plate (1.3 cm × 4.5 cm × 1 mm), containing an aluminium stepwedge, made of 1100 alloy, with thickness varying from 1 to 10 mm, in uniform steps of 1 mm each (ANSI/ADA 2000) (Fig. 1a). This set of acrylic plates, which corresponded to the size of a digital radiography phosphor plate, from the Digora™ system (Soredex Orion Corporation, Helsinki, Finland), was placed in front of this phosphor plate for digital radiography

Table 1 Radiographic densities and radiopacity, expressed in millimetres of aluminium equivalent, of root canal filling materials

Filling materials (manufacturer)	Radiographic density (mean ± SD)	Radiopacity (mmAl) (mean ± SD)
AH Plus (DeTrey/Dentsply, Konstanz, Germany)	206.42 ± 4.06	11.2 ± 0.3
Endofill (Dentsply-Latin America, Petropolis, Brazil)	180.34 ± 3.82	6.9 ± 0.3
EndoREZ (Ultradent Products Inc., South Jordan, UT)	178.18 ± 3.17	6.6 ± 0.3
Epiphany (Pentron Clinical Technologies, Wallingford, CT)	188.04 ± 6.70	8.0 ± 0.3
Gutta-percha (Dentsply-Latin America, Petropolis, Brazil)	199.04 ± 6.16	9.8 ± 0.3
Resilon (Pentron Clinical Technologies, Wallingford, CT)	214.28 ± 2.56	13.0 ± 0.3

The ANSI/ADA Specification No. 57 recommends that all root canal filling materials shall show a radiopacity not less than that equivalent to 3 mm of aluminium.

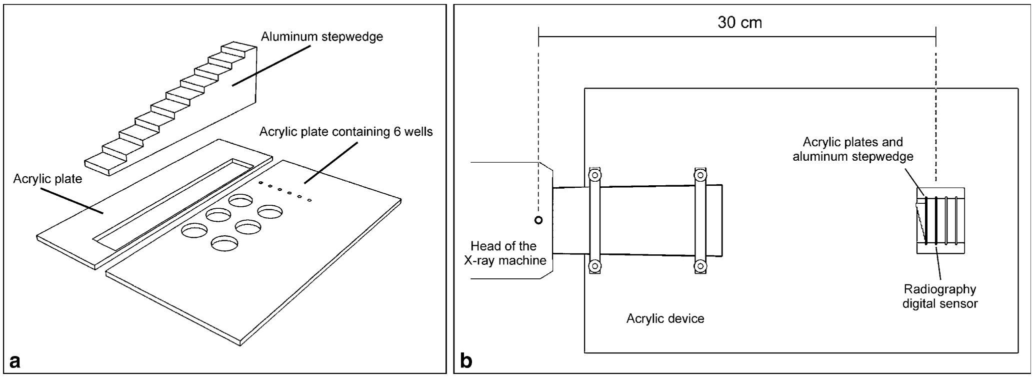

Figure 1 (a) Experimental set-up with the aluminium stepwedge and wells for root canal filling materials. (b) Upper view of experimental set-up which keeps the head of the X-ray machine central beam fixed at 30 cm and at a 90° angle to the surface of the acrylic plates/phosphor plate set.

(Fig. 1b). Care was taken to place the samples next to the aluminium stepwedge and in the middle of the phosphor plate.

Radiographic images of the root filling samples and the aluminium stepwedge, were obtained using the Spectro 70X X-ray machine (Dabi Atlante, Ribeirão Preto, SP, Brazil), at 70 kVp and 8 mA. The object-to-focus distance was 30 cm (ANSI/ADA 2000). The exposure time was 0.2 s, as recommended by Dabi Atlante technicians for the exposure time of digital X-ray phosphor plates. A voltage stabilizer was used to standardize the voltage of the X-ray machine.

An initial exposure only of the phosphor plate was performed using the exposure factors described above, and the plate was scanned using the appropriated tool (Calibration mode) from the Digora™ for Windows 5.1 software. The same phosphor plate was used for all exposures to avoid possible differences between plates.

For the positioning of the phosphor plate and to assure that the incidence and the object-to-focus distance were standardized, an acrylic device with metallic holders was prepared, following a model proposing by Silveira (2002). This device maintained the head of the X-ray machine in the same position, which had its central beam directed at a 90 ° angle to the surface of the acrylic plates/phosphor plate set-up (Fig. 2). A rectangular collimator (Dabi Atlante, Ribeirão Preto, SP, Brazil), 3 cm × 4 cm in height was attached at the extremity of the cylinder to reduce secondary radiation.

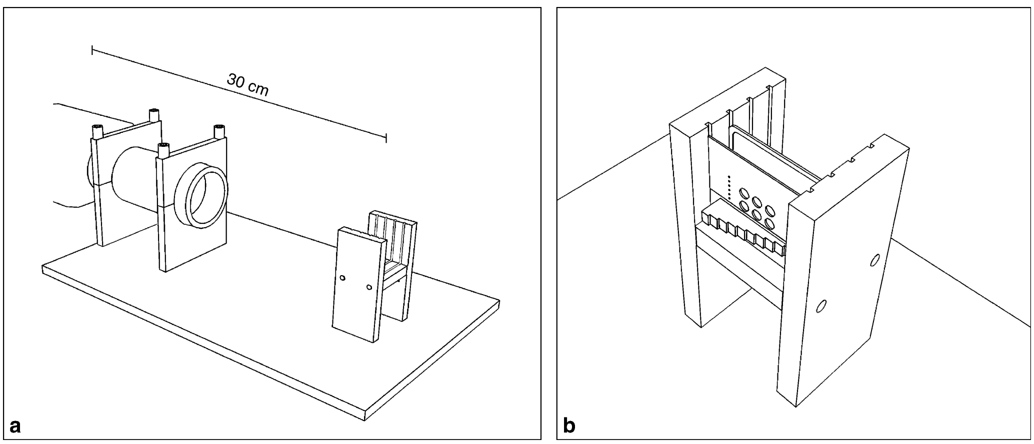

Figure 2 (a) Lateral view of the experimental set-up used to fix X-ray machine central beam and the acrylic plates/phosphor plate set. (b) Detail view of the experimental set-up with the aluminium stepwedge, wells for root canal filling materials and radiography digital phosphor plate.

Exposed imaging plates of the test samples were scanned immediately after exposure using the Digora™ plate scanner following the manufacturer's standard instructions to provide the gold standard images. The phosphor plate was then cleared and re-used. The images were viewed using Digora™ for Windows 5.1 software. The grey-scale values of the regions of interest of materials and aluminium stepwedge steps corresponded to 30×30 pixels, identified by the coordinates dX and dY. According to Martins *et al.* (2006), the pixel size of a phosphor plate scanned at 360 dpi resolution is estimated at $70\ \mu m \times 70\ \mu m$. Therefore, the regions of interest were approximately $2\ mm^2$. For each analysed region of interest, the initial coordinates were noted and the average values of grey levels were described by the function 'density mean'. The regions were selected by avoiding areas containing air bubbles inside the sealer material. This procedure was repeated three times for each specimen, and the average calculated. Data were presented using descriptive statistics. The measurement was undertaken by one evaluator, and the evaluator was blinded to the identity of the materials. A radiographic digital image can be seen in Fig. 3.

Results

Table 1 shows the mean values and standard deviations of the radiographic densities and radiopacities of the materials investigated. Radiopacity was expressed in millimetres of aluminium equivalent. All materials showed radiopacity above 3 mm of aluminium recommended by ANSI/ADA Specification 57.

Table 2 shows the mean values and standard deviations of the radiographic densities of the steps of the aluminium stepwedge.

A graph of the radiographic density versus the thickness of the aluminium was drawn and a calibration curve generated using logarithmic regression. These gave straight line plots from which the mean net radiographic density of the materials and their equivalents related to the thickness of the aluminium were derived (Fig. 4).

Discussion

Digital X-ray systems have been used previously to evaluate the radiopacity of dental materials (Silveira 2002, Sabbagh *et al.* 2004, Gu *et al.* 2006). The proposed experimental model used digital images of root filling materials and steps of an aluminium stepwedge, acquired using an X-ray digital periodical phosphor plate and a scanning, capturing and reading digital system. This system does not need conventional periodical radiographic film or its chemical processing, thus saving time (McDonnell & Price 1993) and decreasing stages that could interfere with the final radiographic quality (Daubers *et al.* 1992, Gurdal & Akdeniz 1998, Syriopoulos *et al.* 2000). Furthermore, it was verified that one of the radiographic films, from group D, recommended by ANSI/ADA Specification No. 57 (ANSI/ADA 2000) is no longer available in the market. Sabbagh *et al.* (2004) measured the radiopacity of resin-based materials in film radiographs and storage phosphor plate using two different exposure times (0.32 and 0.16 s). The authors concluded that

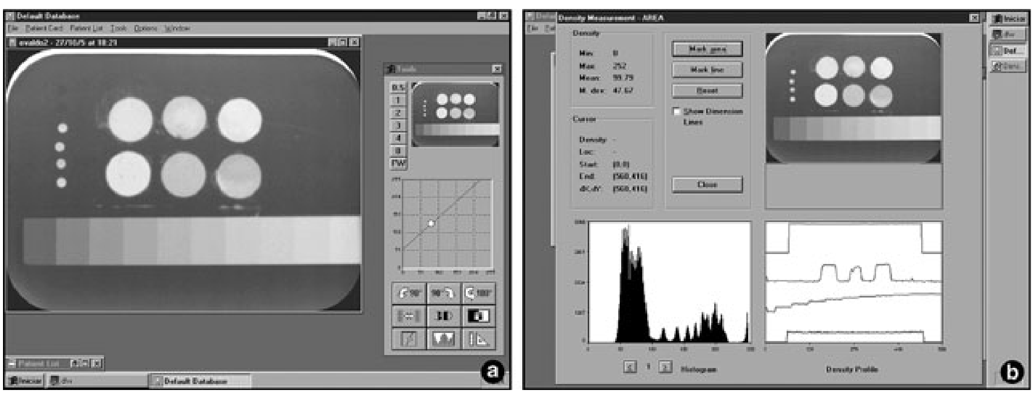

Figure 3 (a) Standard image on the computer screen after reading of the radiography digital phosphor plate by the laser optic reader of the Digora system. (b) Computer screen during the quantification of the radiopacity of materials by Digora for windows 5.1 software.

Table 2 Radiographic densities of steps of aluminium stepwedge

Steps of aluminium stepwedge (mm)	Radiographic density (mean ± SD)
1	79.98 ± 10.35
2	110.15 ± 7.83
3	132.47 ± 6.71
4	149.81 ± 5.97
5	163.20 ± 5.20
6	174.31 ± 4.90
7	183.30 ± 4.23
8	190.67 ± 4.01
9	195.66 ± 3.39
10	196.88 ± 3.87

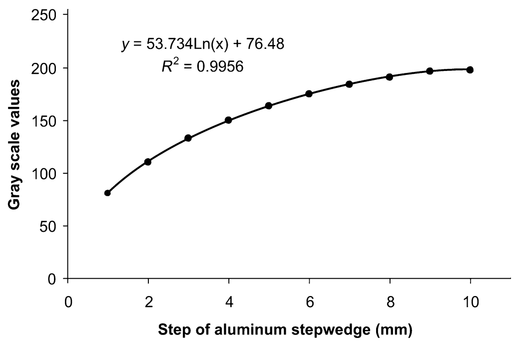

Figure 4 Calibration curve generated of the grey-scale values versus the thickness of the aluminium, using logarithmic regression.

the radiopacity obtained with the Digora™ system correlated with conventional X-ray films, and exposure time did not affect digital radiopacity, because of the wide latitude of the phosphor plate. Also, the image is processed, stored and evaluated entirely on the same machine, eliminating the use of an optical densitometer for evaluation.

The acrylic device with metallic holders, used in this experiment, maintained the same object-to-focus distance, which when associated with the same exposure time creates little change in absorbance of aluminium alloy 1100 stepwedges (Gu *et al.* 2006). As a result, if a digital technique is used, it is unnecessary to measure the absorbance of the stepwedge in every radiograph so long as the target distance and exposure time remain unchanged (Gu *et al.* 2006).

Aluminium was used for the stepwedge because it has a linear absorption coefficient similar to that of enamel, relating the similarity in the variation of aluminium to hydroxyapatite (Williams & Billington 1987, Goshima & Goshima 1989).

Acrylic, transparent, radiolucent and low-cost plates were used in the preparation of the test samples. The wells made in the acrylic plates were decreased from 10 mm, according to ANSI/ADA Specification No. 57 (ANSI/ADA 2000), to 5 mm, reducing the volume of material used for the preparation of the sample, and allowing for more samples to be placed in the central part of the X-ray digital periapical phosphor plate. According to Tagger & Katz (2003), this smaller diameter well and, consequently, smaller surface available for evaluation is largely compensated by the main advantage of the method used, where the image can be meticulously examined and directly measured on the computer screen under high magnification. This makes it possible to choose a representative homogeneous area for measurement, different from the method that used an optical densitometer, in which three distant regions must be measured to balance out the effect of localized irregularities not seen by the naked eye. Disposable syringes were used to place the sealers inside the wells, allowing for the decrease in air bubbles inside the sealer material.

Digital images can be processed to determine details that do not appear on a nondigitalized film. On a nondigitalized film, the human eye cannot identify 255 shades of grey. On a computer screen, a digital system can differentiate all of these different shades of grey on a digital image (Farman & Scarfe 1994).

The steps of the aluminium stepwedge imaged using a 0.2-s exposure and 30-cm object-to-focus distance were represented on a scale of approximately 79.98–196.88 rather than the full 0–255. When 1 mm of an aluminium alloy image cannot be visualized (grey-scale value of 0), it has been considered that an overexposure has occurred. An underexposed image has a background fog. Overexposed images 'black out' objects of low radiopacity (Gu *et al.* 2006). The exposure time used (0.2 s) was sufficient to allow the visualization of 1 mm of aluminium alloy 1100.

ANSI/ADA (2000) recommends that aluminium stepwedges must be fabricated with thicknesses varying from 1 to 10 mm, in uniform steps of 1 mm each. The absolute white (grey-scale value of 255) can be found when the aluminium stepwedge is fabricated with a thickness up to 10 mm. Gu *et al.* (2006) found grey-scale value of 255, using aluminium stepwedges with thicknesses varying from 1 to 15 mm.

The decreasing values of radiopacity of the materials were Resilon™, AH Plus™, gutta-percha, Epiphany™, Endofill® and EndoREZ™. An analysis of the formulations of the materials studied showed that all have radiopacifier agents, compatible with high atomic weight substances (molecular weight, Mw), which according to Goshima & Goshima (1989) determines the radiopacity of the material. Resilon™ consists of thermoplastic synthetic polymer (polyester)-based cones containing low fusion polycaprolactones and urethane dimethacrylate (UDMA; Mw = 470) as an outer polymeric sheath. Resilon™ is a substitute material, in place of the gutta-percha, to be used with a metacrylate resin-based sealer. Bioactive glass, barium sulphate, bismuth oxychloride and 'red iron oxide' are incorporated as fillers in both the inner core and outer surface. The filler component is approximately 65% by weight (Jia 2005), what can explain its higher radiopacity. The AH Plus™, a two component paste root canal sealer, based on polymerization reaction of epoxy resin-amines (Cohen *et al.* 2000), contains zirconium oxide which contributes to its having a greater radiopacity in relation to the other sealers tested (Tanomaru *et al.* 2004). Gutta-percha cones have radiopacifier agents of barium sulphate and zinc oxide (Gurgel-Filho *et al.* 2003). Epiphany™, is a metacrylate resin-based sealer, containing ethoxylate bisphenylglycidyl dimethacrylate (BisGMA; Mw = 512), UDMA, and hydrophilic dysfunctional metacrylates, associated with particles charged with calcium hydroxide, barium sulphate, and silicon, with a high atomic weight or in greater concentration. The total filler content in the sealer is approximately 70% by weight (Leonard *et al.* 1996). Endofill®, a zinc oxide–eugenol-based sealer, has barium sulphate, zinc oxide and bismuth subcarbonate (Kopper *et al.* 2003). EndoREZ™, a methacrylate (UDMA; Mw = 470)-based endodontic sealer with fillers, which is a hydrophilic two-part chemical set material (Zmener *et al.* 2005).

In view of the widespread availability and advantages of digital radiography over film, it is perhaps time for a new specification to be devised by ANSI/ADA that recognizes advances in imaging.

Conclusion

Using digital radiography all the materials studied performed according to ANSI/ADA (2000) Specification No. 57, with a radiopacity above 3 mm of aluminium.

Acknowledgements

The authors thank CAPES for supporting this study.

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