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Importance of radiological examination in the evaluation of canal fillings performed with bioceramic sealers

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Abstract. Bioceramic-based fillers have been evaluated in several *in vitro* studies but *in vivo* studies are still limited. The present study examined 36 postoperative radiographic analyses that were divided into four groups, of which three used bioceramic-based fillers, namely Total Fill, BioRoot RCS and Biodentine, while the fourth group was used as control and implemented the resin-based AH Plus Jet sealer. The present results did not indicate significant differences in radiopacity between sealers at a certain level of obturation. Biodentine-based fillers have a radiodensity close to that of dentin, which makes it difficult for the physician to radiologically assess the correctness of the canal filling.

Introduction

The radiological appearance is one of the most impart properties of the sealers used in endodontic treatments (1). An ideal sealer should be tacky when the two components are mixed (paste-paste or powder-liquid), to ensure good adhesion between the gutta-percha cone and the dentin, ensuring a good hermetic root canal seal. Moreover, it must also be radiopaque so that it can be visualized on radiographs. The sealer should be bacteriostatic or at least it should not promote bacterial growth. Furthermore, the sealer should slowly harden with a slow grip, be insoluble in body fluids and well tolerated by periapical tissues, and must be soluble in ordinary solvents if reprocessing is required (1).

The possibility of pushing sealers into the periapical tissue has increased with the diversification of sealing techniques. Since root filling extrusion cannot be completely prevented, there is a chance that the subsequent foreign body reaction will result in persistent apical periodontitis (2). In a previous study, cytotoxicity and cytokine production were measured to determine the amount of debris, and extruded material was found to be the source of higher levels of both (3).

Economides *et al* (4) conducted the first study on the impact of endodontic sealers on ions concentration in major organs. The authors measured the concentration of zinc and calcium in the brain and kidneys in mice which were implanted with Ah Plus Jet sealer, observing an increase in zinc concentration. Khalil and Eid (5) also observed an increased inflammatory response in the liver in white albino rats after exposure to ProRoot MTA and DiaRoot BioAggregate. The effects could be tracked up to 30 days after exposure.

Other studies showed increased concentrations of chromium, a known carcinogen, when using materials such as Biodentine, Micro Mega MTA and BioAggregate (6); however, metal concentrations remained below safe limits. It is the opinion of the present authors that overextensions with sealers should be avoided as much as possible or kept to a minimum (6). Moreover, meta-analysis studies showed that sealer overextension negatively affected the healing of periapical lesions (7).

Postoperative radiography remains the easiest method through which the correctness of the treatment can be assessed, especially in terms of the amount of sealer that passes into the periapical tissues (8).

The radiopacity of endodontic materials was evaluated by several studies (8,9). In recent years, a new category of sealers has been introduced, which promises superior results over traditional sealers. The evaluation of this new category of sealants was performed starting from the properties of an ideal sealer, meaning that it should possess a perfect combination

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of sealing ability and biocompatibility (10,11). When these materials were positioned adjacent to periapical bone defects or extruded over the root apex, the premixed bioceramic sealers released biologically relevant ions (such as Ca^{2+} and OH), which may give potential benefits (12).

Moreover, the radiopacity of the sealers must be comparable to a 3-mm aluminum standard, according to the ISO 6876:2001 specification.

Evaluation of sealers should be performed both *in vitro* and *in vivo* using postoperative radiographs. Radiation doses during exposure decreased with the introduction of digital radiology, possibly leading to a weaker radiological image; digital software is routinely used to compensate for this shortcoming.

Materials and methods

Study design. The present study was performed on 52 patients who were treated for orthodontic lesions at the Endodontic Clinic of the Faculty of Dental Medicine Craiova from 2020-2022. All patients provided written informed consent to participate. The study was approved by the University and Scientific Ethics and Deontology Commission of the University of Medicine and Pharmacy in Craiova and patients' information was anonymized.

Among the patients, 36 presented with different diagnoses of inflammatory pulpal diseases and acute and chronic apical periodontitis and these patients were selected for inclusion in the present study. The patients underwent clinical and retro-alveolar radiological examinations. General data were collected and recorded on an observational chart, including socio-demographic data (age group, sex, environment origin, level of education) and medical history (general clinical examination data-objectification of the clinical signs related to postoperative radiological changes, dental examination data and identification of risk factors for complications and iatrogenesis).

The same endodontic treatment protocol was followed for all patients included in the study. Patients were subjected to standard clinical practices and the materials used were not experimental but intended and commercialized for dental treatment. The patients received standard endodontic treatments.

Inclusion criteria were defined as adult patients (>18 years of age) with inflammatory pulpal diseases and acute and chronic apical periodontitis. The statistical analysis was performed starting from the analysis of data related to the patient's age, sex, environment of origin, level of education and post-operative radiological changes.

Exclusion criteria were defined as follows: patients ≤18 years of age; pregnancy; mental illnesses; breastfeeding; malignant diseases; and osteoporosis.

In the present study, 36 postoperative radiographs were used, divided into four groups. Bioceramic-based sealers were used in three groups, namely Total Fill (FKG Dentaire SA), Bioroot RCS and Biodentine (both purchased from Septodont, Ltd.), while patients treated with resin-based AH Plus Jet sealer (Dentsply-DeTrey; Dentsply Sirona) were used as controls.

Total Fill is a hydrophilic sealer that chemically binds to dentine to generate hydroxyapatite. Because of its extremely alkaline pH, unlike conventional sealers with a low contraction, it exerts an anti-bacterial while it is setting. (Fig. 1).

BioRoot RCS is a bioactive mineral root canal sealer recommended for use with Gutta-Percha (13) (Fig. 2). Gutta-percha is a widely used 'gold-standard' endodontic filling material with praiseworthy qualities of non-toxicity and biocompatibility (14).

BioRoot RCS benefits from proprietary Active BioSilicate Technology and has several bioactive qualities such as biocompatibility, hydroxyapatite production, mineralization of dentinal structure and alkaline pH (13).

Biodentine is an endodontic sealer composed of calcium silicate, primarily tricalcium silicate, with certain additives and a zirconium oxide radiopacifier. It is specifically designed to be utilized as a dentine replacement material and has undergone extensive scientific engineering (15).

Ah Plus Jet (Fig. 3) is a root canal-bonding epoxy-bisphenol resin sealer that also contains adamantine. Being an epoxy resin-based sealer, AH Plus has stronger penetration into the micro-irregularities due to its creep capacity and long setting time, which improves the mechanical interlocking between the sealer and root dentin. This may also explain the increased adherence of AH Plus Jet to the root dentin (16).

Each tooth was prepared using the Twisted Files Adaptative system (SybronEndo Corporation) using up to a 6% taper file. The endodontic system obturation was performed using the monocone and sealer technique. In each case, the master cone had a taper of 4% and the gutta-percha cones (Meta Biomed) used were of 4% taper. All accessed cavities were restored using composite restoration material VisCalor bulk (VOCO GmbH) or Ceram X (Dentsply Sirona) if the use of fiber post was recommended. Angelus Reforpost (Angelus Dental Solutions) was used because of the metal wire that makes them easier to identify radiologically. Fiber posts were bonded using dual cure bonding (All Bond 2 Dental Adhesive; BISCO, Inc.) and core build material (Build-it™ FR Core Material; Pentron Corporation).

Biodentine was used for teeth that were indicated for its use, i.e. teeth that had large apical diameters, perforations or that received direct caping or pulpotomies.

Postoperative radiography was performed using a CS2100 Kodak tube and CS7200 phosphor plates (Kodak). For the radiography, the Kerr (Kerr Dental Suisse) holder for the phosphor plate and the parallelism technique were used (Fig. 1).

Because of their similar radiological appearance, the present study compared the radiodensities of Biodentine and dentin by measuring their radiolucency values (Fig. 4). Table I reports the values obtained by measuring the radiolucency of dentin and Biodentine.

For Biodentine, the location of the measurement was chosen using preoperative radiography where the position of the canal/perforation to be obturated could be located precisely. Subsequently, the same location was used on postoperative radiography to measure the radiolucency, although the radiolucency corresponding to the canal/perforation was no longer visible due to the same radiolucency.

Biodentine and dentin have similar radiodensity, which makes them difficult to differentiate radiologically (Fig. 4).

Postoperative radiography was performed using CS 2200 Kodak tube-intraoral x-rays system and CS7200 phosphor

Figure 1. (A) Preoperative and (B) postoperative radiography of tooth 14 (upper right 1st premolar) filled with Total fill.

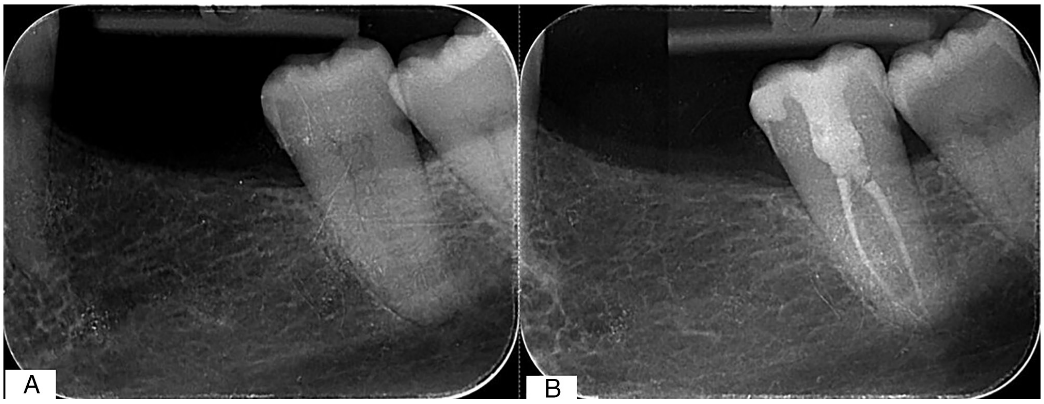

Figure 2. (A) Preoperative and (B) postoperative radiography of tooth 37 (lower left 2nd molar) filled with BioRoot RCS.

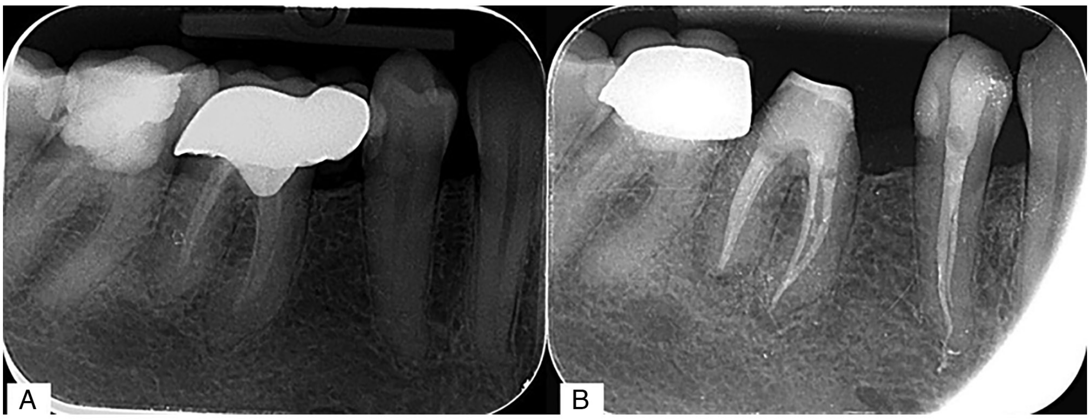

Figure 3. (A) Preoperative and (B) postoperative radiography of tooth 46 (lower right 1st molar) and tooth 44 (lower right 1st premolar) filled with Ah Plus Jet.

plates (Carestream Health). The x-rays were analyzed using the Kodak 2200 Carestream CS7200 3D Imaging Version 3.8.7 (Carestream Health). This software uses standard units of measurement in dental medicine to measure radiopacity, which is the density of the radiographic material compared to soft tissues. Radiopacity is expressed in Hounsfield units (HU), which is a measure of the apparent density of a radiographic material. In the case of this software, HU values are used to measure the level of radiopacity of dental structures and other materials used in dental treatment. Radiodensity was measured at three distances from the radiological apex (RA) as follows: Apical third (3-mm RA); medium (6-mm RA); and coronary (9-mm RA).

Statistical analysis. Data distribution for each material and any of the three distances from the RA was analyzed using the Anderson-Darling normality test and all datasets conformed to the Gaussian distribution; therefore, the parametric unpaired Student's t-test or one-way ANOVA followed by Tukey's post hoc test were used to compare two or multiple groups, respectively. The comparison was made between the radiodensity values under the effect of the 4 sealers and the corresponding

Table I. Sealers' radiopacities and their comparisons at 3-, 6- and 9-mm RA levels.

	Radiodensity at different RA levels		
Sealer	3-mm RA (n=9)	6-mm RA (n=9)	9-mm RA (n=9)
BioRoot RCS	102.11±7.39	117.22±2.39	128.44±10.33
Totalfill	116.33±5.59	132.78±6.83	151.78±4.09
Ah Plus Jet	120.78±7.61	143.00±8.28	158.22±10.52
P-value[a]	0.00001781	0.00000004	0.00000049
Biodentine	-	-	113.22±10.64
Dentine	-	-	115.44±10.74
P-value[b]	-	-	0.64971325

[a]One-way ANOVA followed by Tukey's post hoc test. [b]Student's t-test. RA, radiological apex.

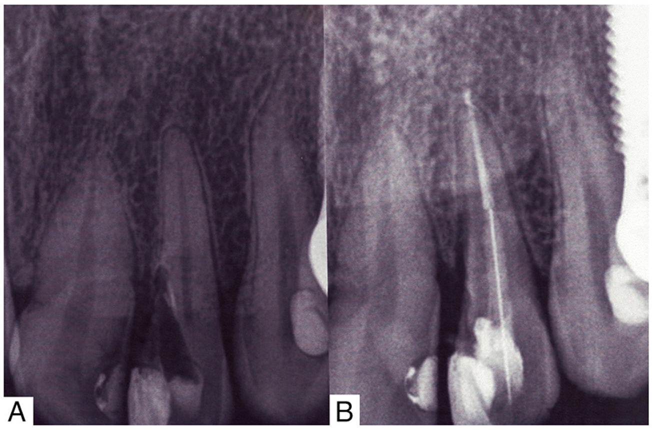

Figure 4. (A) Preoperative and (B) postoperative radiography of tooth 22 (maxillary left lateral incisor) with a cervical perforation filled with Biodentine.

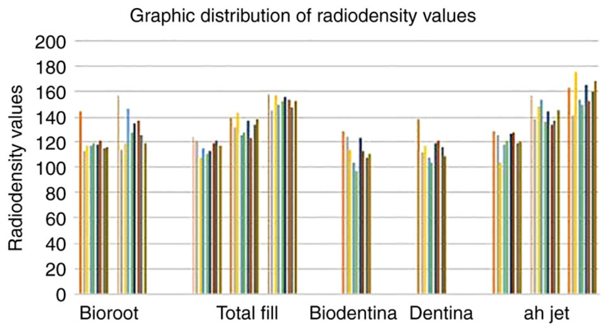

Figure 5. Graphical distribution of radiodensity values measured at 3, 6 and 9 mm from the apex.

values of dentine. Statistical analysis of clinical and paraclinical data was performed in Microsoft Excel 2019 with the XLSTAT 2019.6 data analysis add-on for Excel (Microsoft Corporation).

Results

Regarding the patient's characteristics, such as age, sex, background and level of education (Table SI), no statistically significant differences were found. Instead, statistically significant differences were found regarding the radiotransparency of different root canal obturation materials.

Radiological images were used to compare the radiodensity of dentine with that of Biodentine sealer (Table SII). Moreover, radiodensity values were measured for each of the other three sealers at the aforementioned three RA levels (Table SIII; Fig. 5). All sealers had good radiopacity and could be easily detected radiologically.

The statistical analysis of the average radiodensity values for the three materials showed that at the 3-mm RA level, there was a highly significant difference between BioRoot RCS and AhPlus Jet and Total Fill; subsequent post hoc analysis revealed statistically significant differences in radiodensity values between BioRoot RCS and the other two materials, but not between any other group combination, even if Ah Plus Jet radiodensities were numerically higher than Total Fill radiodensities. At a 6-mm RA level, the radiodensity of the three materials was significantly different; Tukey's post hoc analysis revealed that the increase from BioRoot RCS to Total Fill was statistically significant, as well as the increase from Total Fill to Ah plus Jet, but no other group differences were statistically significant. At the 9-mm RA level, there was also a statistically significant difference between the radiodensities of BioRoot RCS and those of Ah Plus Jet or Total Fill. Although the average radiodensities of Ah Plus Jet or Total Fill were not significantly different, the former was numerically higher. The radiodensities of Biodentine and dentin did not differ significantly (P=0.649) (Table I).

Although Ah Plus Jet, a sealer recognized for good radiopacity, showed higher radiodensity values, Bioceramic sealers offer good radiopacity comparable to the other fillers, with TotalFill offering the best values (Table I).

The present results indicated that there were significant differences in radiopacity between sealers, at certain levels of obturation. Radiodensity values increased from the apical to coronary location because the volume of sealer and gutta-percha was larger at the coronary.

Discussion

Traditional sealers give good obturation combined with gutta-percha, especially when used in warm techniques (17). The development of the bioceramic sealer introduced a new material with high biocompatibility (18). Sealers based on bioceramics are a group of sealers that contain calcium silicate or calcium phosphate. Calcium phosphate enhances the setting properties of bioceramic sealers, resulting in a crystalline structure similar to hydroxyapatite that improves the sealer adhesion to the dentin (19).

The method of obturation of the root canals with bioceramic materials is important since it has a prognostic value on the postoperative healing potential, especially after the iatrogenesis that follows the endodontic treatment, the effectiveness of the treatment and the maintenance of the results over time. Moreover, it allows for the identification of structural changes in the endodontic space, but also periapical, which is associated with the prediction of post-iatrogenic healing, provides a complex picture of the pulp pathology (10).

The present study aimed to assess the radiopacity of bioceramic sealers compared with a common sealer, Ah Plus Jet canal sealer. The success of endodontic treatment depends on microbial control, cleaning, shaping and obturating the root canal, using gutta-percha associated with a fluid sealer to provide hermetic sealing in all dimensions (20,21). According to Shah *et al* (22), the materials used to seal the endodontic system must differ radiologically from adjacent tissues as well as from dentin. For the physician, the evaluation of the quality of the filling is necessary to assess the correctness of the endodontic treatment performed. A correctly completed filling contributes significantly to the success of endodontic treatment (23,24) The methods by which the doctor can assess the quality of the filling are represented by postoperative radiography or cone beam CT (CBCT). Because CBCT brings a high dose of radiation to the patient, compared with classic X-ray, and due to its high financial cost, RIO radiography remains the most common method for assessing the quality of treatment.

To the best of our knowledge, there are only a few reports evaluating the clinical radiological features. Most previous studies were performed using 1-mm thick sealer discs compared with a 3-mm thick aluminum disc. If we consider that the thickness of a lateral canal is often <1 mm, several studies suggested that a 4-mm thick aluminum disc should be used as standard (25). It should also be taken into account that the tooth is surrounded by tissues with different radiopacities that overlap over the filling, for this reason, the clinical radiological features may differ from *in vitro* studies. As the recommended technique for bioceramic sealers, physicians most frequently use the monocone technique (26). It is known that bioceramic changes when it is used with a technique that uses thermoplasticized gutta-percha. The monocone technique was shown to allow a large amount of sealer next to the cone, but still, third its amount decreased in the apical making it much harder to be identified (27).

Manufacturers use various opacifying compounds. For example, Biodentine and Totall Fill contain zirconium oxide while BioRoot RCS contains zirconium oxide and povidone, which provide a much more intense radiopacity (28).

The reason for such a difference might be due to some study results which showed that zirconium oxide possesses biocompatible characteristics and is indicated as a bioinert material with favorable mechanical properties and resistance to corrosion (28).

A highly radiopaque sealer will provide images that can confuse the doctor in evaluating the filling with a very homogeneous appearance, while a highly radiolucent sealer might give the impression that the filling is incomplete, which is the case with Biodentine. This drawback originated from the first indication of Biodentine as a dentine replacement material. In this situation, the same radiopacity could be an advantage (29). In a different situation, like with retrograde filling material, large amounts of materials could be left in the bone or simply confuse different clinicians on the presence of the filling (30).

Dammaschke *et al* (31), in the evaluation of the radiological aspect, concluded that dentine was difficult to differentiate from Biodentine, a result that was also confirmed by Tanalp *et al* (32). In an *in vitro* study, the Biodentine filler showed a greater radiopacity than a 3-mm thickness aluminum standard (33), which was also confirmed by Camilleri *et al* (34). Nonetheless, Coaguila-Llerena *et al* (35) showed that Biodentine failed to exceed the 3-mm aluminum standard. These results should be interpreted carefully as conditions of experimentation, storage and other factors may influence the results of radiopacity studies.

Dželetović *et al* (36) performed *in vitro* study comparing Ah Plus Jet with several bioceramic sealers and concluded that Ah Plus Jet had a radiopacity higher than that of BioRoot RCS. Prüllage *et al* (30) also found no statistical differences between Ah Plus Jet and BioRoot RCS *in vitro*.

Hrab *et al* (37) performed *in vitro* studies to determine that Total fill had radiopacity above 3 mm aluminum (38). Thus, all the sealers studied fall within the ISO standard (38,39). An interesting correlation was found by Miyashita *et al* (40) who showed that in the case of sealers that presented a good radiopacity in two dimensions, the probability that they presented artifacts during the CBCT evaluation increased. Therefore, a sealer with a lower radiopacity could be favored in the future, as the frequency of CBCT use increases.

Although in the present study, the Ah Plus Jet sealer still had higher values in terms of radiodensity, statistically all sealers behaved the same and offered a possibly good radiological evaluation, which was confirmed by other studies as well.

Unlike previous *in vitro* studies, the present study was performed *in vivo*, emphasizing the importance of a good radiological evaluation of fillings made with bioceramic materials, well tolerated by the periapical tissues, which decreased the number of endodontic treatment failures.

In conclusion, Biodentine-based sealants showed a radiodensity close to that of dentin, which made it quite difficult for the physician to assess radiologically the correctness of the canal filling. The results of the current study showed that there were statistical differences between the Ah jet sealer, a resin-based sealer recognized for good radiopacity, and bioceramic-based sealers, which offer very good radiopacity close to that offered by Ah Plus Jet. The current study provided important insights that could facilitate the implementation, validation and continuous improvement of the materials used in canal obturation.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Authors' contributions

CA, MT and CP conceived the study. LG and CA designed the study. CC and AGN confirm the authenticity of all the raw data.

CP, OD and AGN provided resources. MT, OD and CA were responsible for data curation. CC and CP drafted and wrote the manuscript. CP, CA and LG wrote, edited and reviewed the manuscript. CA acquired the radiographic images. AGN, MJT, OAD, LG and CA made substantial contributions to the acquisition, analysis, and interpretation of data for the research. HM supervised the study. MT managed the project. All authors read and approved the final manuscript.

Ethics approval and consent to participate

The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Ethics Committee of the University of Medicine and Pharmacy of Craiova (approval reference no. 26/20.05.2022). Written informed consent was obtained from the subjects involved in the study.

Patient consent for publication

The patients involved in the study provided written consent for the publication of their radiographic images.

Competing interests

The authors declare that they have no competing interests.

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