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Article

The Influence of Thermomechanical Compaction on the Marginal Adaptation of 4 Different Hydraulic Sealers: A Comparative Ex Vivo Study

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Abstract: Since there are no data in the literature regarding the comparison of the marginal adaptation of hydraulic sealers when used with a single-cone technique or through thermomechanical compaction, this study aimed to evaluate the behavior of four different endodontic sealers used with the two above-mentioned obturation techniques by evaluating the marginal gap existing between the obturation materials and the dentinal walls through scanning electron microscopy. Given this objective, a total of 104 single-rooted, straight canal teeth were selected and divided into four subgroups according to the selected endodontic sealer ((AH) Plus Bioceramic Sealer (AHP), EndoSequence BC Sealer HiFlow (ES), C-Root SP (CR), and GuttaFlow Bioseal (GF)). Each tooth was decoronated and instrumented with the HyFlex EDM/CM systematics up to 30.04. After irrigation procedures, the teeth of each subgroup were divided into two groups and obturated according to two different obturation techniques: the single-cone technique (SC) and the thermomechanical compaction technique (TC). After the required sealer setting time, each tooth was sectioned in three parts at 3, 6, and 9 mm from the apex, and each section was observed with a scanning electron microscope. The marginal gap of each sample was measured using G* Power Software v3.1, and the statistical analysis was performed using the Kruskal–Wallis test, followed by a post hoc Dunn's test. Results showed that there were not any statistically significant differences in terms of the marginal gap between the two different above-mentioned obturation techniques for each sealer, except for the middle third of root canals, where a statistically significant difference was found for AHP, ES, and GF sealers. In conclusion, the thermomechanical compaction of hydraulic sealers and gutta-percha guarantees better sealing than the single-cone technique when the root canal shape is not rounded.

Keywords: endodontic sealer; hydraulic sealer; marginal gap; scanning electron microscopy; thermomechanical compaction

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1. Introduction

The main goals of root canal treatments (RCTs) are undoubtedly the prevention or the resolution of periapical lesions and the retention of the function of the treated teeth as much as possible [1,2]. The outcome of the primary endodontic treatment has been thoroughly assessed in several studies and reviews during the past decades, and all of them concluded that RCTs are valid and conservative options for planning oral rehabilitation [3–5]. The most significant factors leading to RCT failure are fundamentally related to the etiopathogenesis of endodontic diseases: the bacteria [6]. In fact, apical periodontitis is caused by endodontic microorganisms and their by-products, and thus, its successful treatment strictly depends on the efficiency of bacteria eradication and recontamination prevention [7,8]. Therefore, the basic goal of RCTs is to eliminate microorganisms from the root canal system and to remove any biological substrate which could aid microbial growth, such as pulp tissue remnants, through adequate chemo-mechanical disinfection of the endodontic system [7,9,10]. Moreover, the quality of chemo-mechanical debridement is not the sole factor able to affect the long-term clinical outcome. As a matter of fact, a tridimensional root canal filling is required to preclude bacterial recolonization of the endodontic system [11]. As stated by Liang et al., the quality of both the root canal obturation and the coronal restoration influence the success rates of RCTs, confirming that satisfactory root fillings are associated with an optimum root canal treatment outcome [12].

In light of the above, the selection of proper obturation materials, in terms of gutta-percha and the endodontic sealer, and the selection of the most adequate obturation technique play a crucial role in determining the sealing ability of the root apex and the quality of the root canal filling. As stated by Komabayashi et al., the ideal properties of root canal sealers should meet compulsory requisites both in terms of biological and physiochemical properties [13]. Firstly, the ideal sealer should guarantee a tridimensional microscopic seal such that bacteria cannot pass through the root canal system; it should possess antimicrobial activity, and it should not be cytotoxic, not causing an inflammatory response in host tissues [13]. Moreover, it should satisfy some minimum standard requirements in terms of flowability, setting time, film thickness, radiopacity, solubility, and sealing ability [13]. According to this, different endodontic sealer compositions have been proposed and the most widely used are fundamentally the zinc oxide–eugenol-based (ZOE) and the epoxy resin-based sealers [13]. According to this, as stated by Mannocci et al., and by Lee et al. [14,15], epoxy resin-based sealers have been correlated with higher adhesion to dentin and gutta-percha and higher marginal adaptation to the root canal wall, tubular penetration, and adaptation to the peritubular dentine [16].

Despite this, in recent decades, calcium silicate-based sealers, also called hydraulic sealers, have gained popularity due to their excellent biological and physiochemical properties. The chemical basis of the setting mechanism of these sealers consists of a hydration reaction in which water is absorbed from dentin tubules, and a calcium silicate hydrate gel and calcium hydroxide are produced. Moreover, the latter is able to react with the phosphate ions to precipitate and form hydroxyapatite (HA) within the canals [17,18]. The increasingly widespread use of hydraulic sealers is essentially due to their enhanced properties: high biocompatibility (nontoxicity); high chemical stability within the biological environment; shrinkage absence; expansion after setting; the absence of an inflammatory response in the case of extrusion into the periapical space; HA formation; high pH (strongly antibacterial); hydrophilicity; excellent sealing ability; and ease of use [17–21].

Hydraulic sealers have been recently introduced in endodontics as materials eligible for root canal obturations, due to their biocompatibility and bioactivity, as well as their physiochemical properties [22]. According to Camilleri, hydraulic sealers can be classified based on their chemical composition or their clinical application [23]. According to the clinical context, hydraulic sealers can be divided into intracoronal, intraradicular, and extraradicular materials, whilst, considering the chemical constitution, they can be classified as hydraulic aluminate cement or hydraulic calcium silicate-based cement. Moreover, the latter can be divided into two different categories according to the cement components: Portland cement and calcium silicate-based cement [23].

In addition to the sealer composition, several obturation techniques have been proposed to enhance the tridimensional obturation of the root canal system, guaranteeing a tight seal of canals and of all anatomical irregularities, such as isthmus, lateral canals, loops, apical delta, etc. Several studies have demonstrated that the obturation techniques using heated gutta-percha show better results in terms of sealing ability and resolution of periapical lesions in comparison to single-cone obturation and cold lateral condensation in the case of ZOE or epoxy resin-based sealers [24,25]. Despite this, the literature regarding the effect of heating on the physiochemical properties of hydraulic sealers is controversial, and data strictly depend on their chemical compositions and temperature ranges [26]. Moreover, there are no data on the relationship between thermomechanical compaction and the hydraulic sealers in terms of the marginal gap adaptation between the filling materials and dentinal walls.

Considering these past studies, the aim of the present study was to evaluate and compare the marginal adaptation of three different hydraulic sealers (AH Plus Bioceramic Sealer (AHP) (Dentsply Sirona, Germany), EndoSequence BC Sealer HiFlow (ES) (BCH, Brasseler USA), and C-Root SP (CR) (Innovative BioCeramix, Inc., Beijing, China)) and GuttaFlow Bioseal after the thermomechanical compaction technique or the single-cone technique. The null hypothesis was that there are no differences in terms of marginal gaps between each sealer used with thermomechanical compaction and single-cone techniques.

2. Materials and Methods

2.1. Ethics Committee Approval and Sample size calculation

This ex vivo study protocol was approved by the Institutional Ethics Committee of Saveetha Dental College & Hospital (Scientific Review Board ref no: SRB/SDC/FACULTY/22/ENDO/049).

The sample size (n = 104) was calculated using G* Power Software v3.1 (Heinrich Heine, University of Düsseldorf, Düsseldorf, Germany) by setting an alpha-type error of 0.05, a beta power of 0.90, and an effect size of 0.80, based on previously published research that investigated the marginal gap and the interfacial adaptation of different bioceramic sealers [27]. A total of 80 teeth (20 teeth per endodontic sealer) were indicated as the ideal size required for speculating significant differences. However, an additional 6 samples per group were added to compensate for unexpected values arising from the thermomechanical compaction of the bioceramic sealers since there are no data in this regard in the literature. Based on these parameters, a total of 26 teeth per group were selected according to the endodontic sealer used.

2.2. Group and Subgroup Determination

The selected teeth were randomly allocated into 4 groups (n = 26) according to the 4 endodontic sealers selected for the research: AH Plus Bioceramic Sealer (AHP) (Dentsply Sirona, Germany), EndoSequence BC Sealer HiFlow (ES) (BCH, Brasseler, Savannah, GA, USA), C-Root SP (CR) (Innovative BioCeramix, Inc., Beijing, China), and GuttaFlow Bioseal (GF) (Coltène/Whaledent, AG, Altstatten, Switzerland) (Table 1). Each group was divided into 2 subgroups, each composed of 13 teeth, according to the obturation technique used: thermomechanical compaction (TC) or the single-cone technique (SC).

Table 1. Schematic representation of the four endodontic sealers used in the experiment categorized according to the chemical matrix, presentation, and composition.

Product Name	Chemical Matrix	Presentation	Composition
AH Plus Bioceramic	Tricalcium silicate	Single paste	Zirconium Dioxide, Tricalcium silicate, Dimethyl sulfoxide, Lithium carbonate, and Thickening Agents.
EndoSequence BC Sealer HiFlow	Tricalcium and dicalcium silicates	Single paste	Zirconium Oxide, Tricalcium Silicate, Dicalcium Silicate, Calcium Hydroxide, and Fillers Agents.
C-Root SP	Strontium silicates	Single paste	Zirconium Oxide, Strontium Silicates, Calcium Phosphates, Calcium Hydroxide, Tantalum Oxide, and Filler Agents.
GuttaFlow Bioseal	Polydimethylsiloxane containing Bioglass	Double paste (two components automatically mixed at a ratio of 1:1)	Gutta-percha powder, Polydimethylsiloxane, Platinum Catalyst, Zirconium Dioxide, Coloring, and Bioglass.

2.3. Sample Selection and Root Canal Treatment

A total of 104 recently extracted single-rooted lower incisors (centrals or laterals) were selected for the research. To preserve the humidity of the dentinal tubules, after extraction, each tooth was disinfected with 5% sodium hypochlorite at 37 °C for 5 days and after that immediately immersed and stored in distilled water at ambient temperature (25 °C) for a period of a maximum of three months, after which it was considered not suitable for being included in the study. The anatomy of each tooth was evaluated through CBCT, and only incisors with a single straight (0–10° degrees of curvature) canal with a comparable transverse diameter (slightly oval in each coronal, middle, and apical third) in each root third were included. Endodontically treated teeth, teeth with restorations that include the cement–enamel junction (CEJ), teeth with posts, and teeth that showed resorption or anatomy different from the above-mentioned specifications or with abnormal morphology were excluded.

The tooth crowns were decoronated at 1 mm apical to the CEJ, using a flexible diamond disk (Novo dental products, Mumbai) under copious water irrigation to yield root sections of 12 mm in length. Apical patency was verified using k-file #10 (Mani Inc., Tochigi, Japan), and the working length was determined by subtracting 0.5 mm from the whole length of the root, determined by inserting the K-file #10 until it was visible at the apex under ×10 magnification. The instrumentation procedures were performed using HyFlex EDM/CM systematics (Coltene/Whaledent, Altstätten, Switzerland), composed by 15/03, 20/04, 25/~, and 30/04, according to the manufacturer's instructions. Irrigation cycles of 20 **s** with NaOCl at 5% (Niclor 5, Ogna Laboratori Farmaceutici, Milano, Italy) were performed after each instrument insertion by delivering irrigants with IrriFlex (27 mm, 30 G, 0.04 taper) (Produits Dentaires SA, Vevey, Switzerland). The final irrigation was performed in three cycles (60 s each), using, respectively, 5% NaOCl, 17% EDTA (Ogna Laboratori Farmaceutici, Milano, Italy), and again 5% NaOCl, activated with EndoActivator (Dentsply Sirona, Tulsa, OK, USA) using the medium tip.

After the canals were completely dried with sterile 30.04 paper points (Coltene/Whaledent, Altstätten, Switzerland), obturation procedures were performed according to the filling technique of the subgroup selected. Regarding the single-cone obturation technique, it was performed by filling the canal with the selected endodontic sealer by inserting the tip of the syringe up to the middle of the canal (6 mm). After that, the selected gutta-percha master cone 30.04 (Coltene/Whaledent, Altstätten, Switzerland) was gently inserted in the canal to the working length, performing slight pumping movements (up and down movements three times until it reached the working length). Regarding the thermomechanical obturation technique, it was performed as described above with the adjunct of the thermomechanical compaction, performed using a #25 stainless steel Gutta-Condensor (Dentsply Maillefer) rotated with a speed ranging from 8000 to 10,000 rpm for 5 to 10 s. The Gutta-Condensor was pushed to within 3–4 mm of the apex to prevent gutta-percha extrusion.

2.4. Sample Preparation for Scanning Electron Microscopy Analysis

After obturation procedures, samples were placed in a chamber at 37 °C and 95% RH (relative humidity) for one week to allow for the complete setting of the sealer. After one week, samples were sectioned by performing 3 cuts for each tooth at 3, 6, and 9 mm from the apex in an apical–coronal direction using a diamond disc (Sweden & Martina, Disco 913, L. 0 mm, 15, Ø ISO 220, Shank HP 913/220HP, fine grain with Mesh 200–230 and 74–62 micron) with a discharge spiral that crossed the surface; this solution guaranteed an abundant discharge of the abraded material, avoiding the overheating of materials and tissues. Three sections of 3 mm were obtained by cutting each tooth's root at the level of coronal, middle, and apical thirds, and each section was observed under a variable pressure scanning electron microscope.

2.5. Scanning Electron Microscope (SEM) Evaluation and Marginal Gap Analysis

The samples were directly settled onto a carbon planchet stub without a conductive coating and observed with the variable pressure SEM Hitachi SU-3500 (Hitachi Japan), setting the operating conditions at 30 Pa and 5 kV. Images were captured at several magnifications between 50× and 250×. Measurements were carried out on photos at 250× magnification. The marginal gap was measured using ImageJ software (Wayne Rasband; National Institute of Health, Bethesda, MD, USA) according to the methodology proposed by Shokouhinejad et al. [28]. Following this, micrographs obtained from the SEM observation of each tooth section were digitally divided into 8 slices for the measurement of the gap in transverse sections. Precisely, the marginal gaps were evaluated using the freehand selection tool and the line selection tool of ImageJ software at the 8 points selected for the measurements, only after the parameters for measurements had been set correctly using the set scale and the scale bars of the pictures. For each section, the maximum value in terms of distance (μm) between the sealing materials (gutta-percha and/or endodontic sealer) and root canal wall was recorded, and the overall maximum gap value for each specimen was calculated by calculating the average of all the 8 slice values recorded (Figure 1). This procedure was repeated for each section of each tooth. The statistical analysis was then performed considering the overall maximum gap of each sectioned sample.

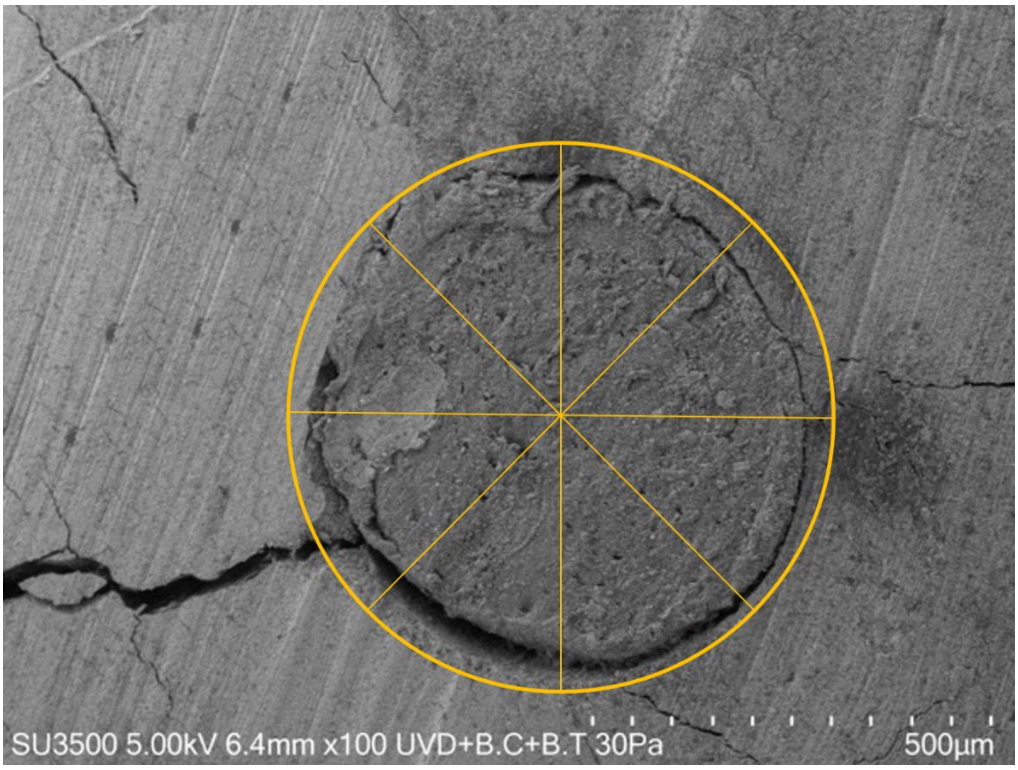

Figure 1. SEM micrograph showing the measurement methodology. Each transverse section was divided into 8 slices and the major value in terms of the marginal gap of each slice was recorded using ImageJ software. The overall maximum gap value for each specimen resulted from calculating the average of all 8 slice values recorded.

2.6. Statistical Analysis

Statistical analysis was conducted using R software (version 4.2.0., R Foundation for Statistical Computing, Vienna, Austria). The normality distribution of continuous variables was evaluated both through visual and analytical methods with the Shapiro–Wilk test. Since the data did not follow a normal distribution, the Kruskal–Wallis test was used to compare the interfacial marginal adaptation among the four experimental groups at the three root levels (Ct, Mt, and At) according to the obturation technique used (TC or SC).

Post hoc Dunn's test was done for pairwise comparison between the experimental groups at a 95% confidence level.

3. Results

Data obtained from the SEM observations and digital measurements of the marginal gaps are schematically summarized in Table 2 and visually represented in Figure 2. Figures 3–5 represent explanatory images arising from SEM observations of the four different endodontic sealers at the three different levels (Ct, Mt, and At) used with the two different obturation techniques.

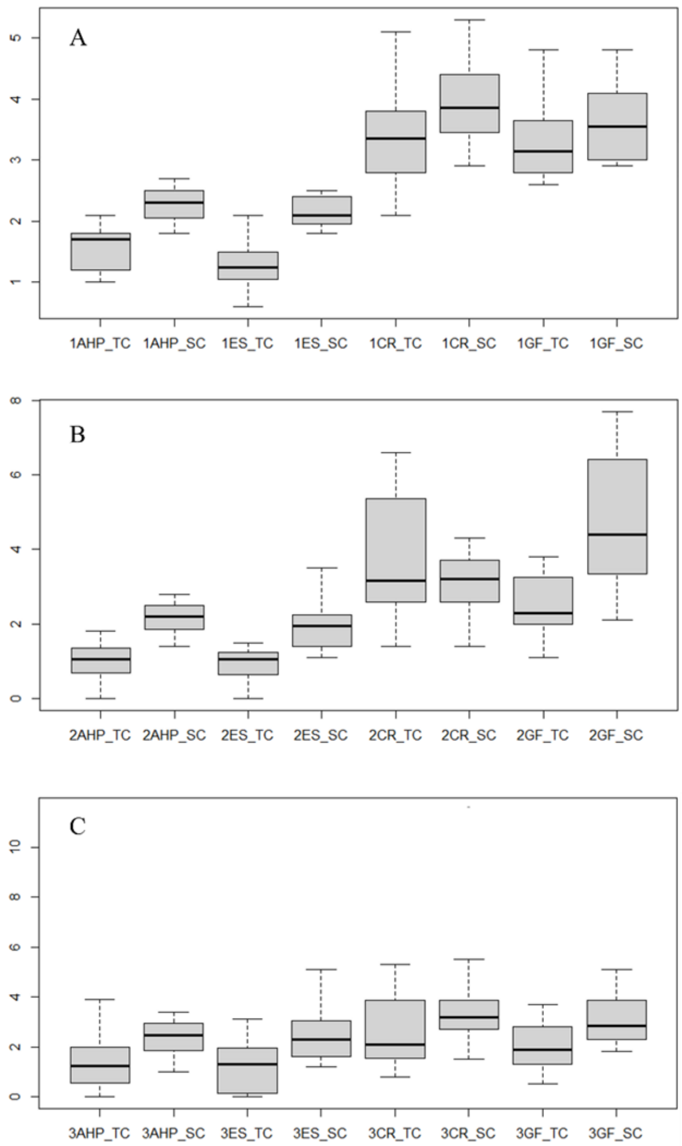

Figure 2. Visual representation of mean values and respective standard deviations of marginal gap measurements (µm) divided according to the endodontic sealer (AH Plus Bioceramic Sealer (AHP), EndoSequence BC Sealer HiFlow (ES), C-Root SP (CR), and GuttaFlow Bioseal (GF)) and the selected obturation technique (single-cone technique (SC) and thermomechanical condensation (TC)). Image (**A**) shows represented data regarding the marginal gap measured in the root canal apical third; image (**B**) shows represented data regarding the marginal gap measured in the root canal middle third, whilst image (**C**) shows represented data regarding the marginal gap measured in the root canal coronal third.

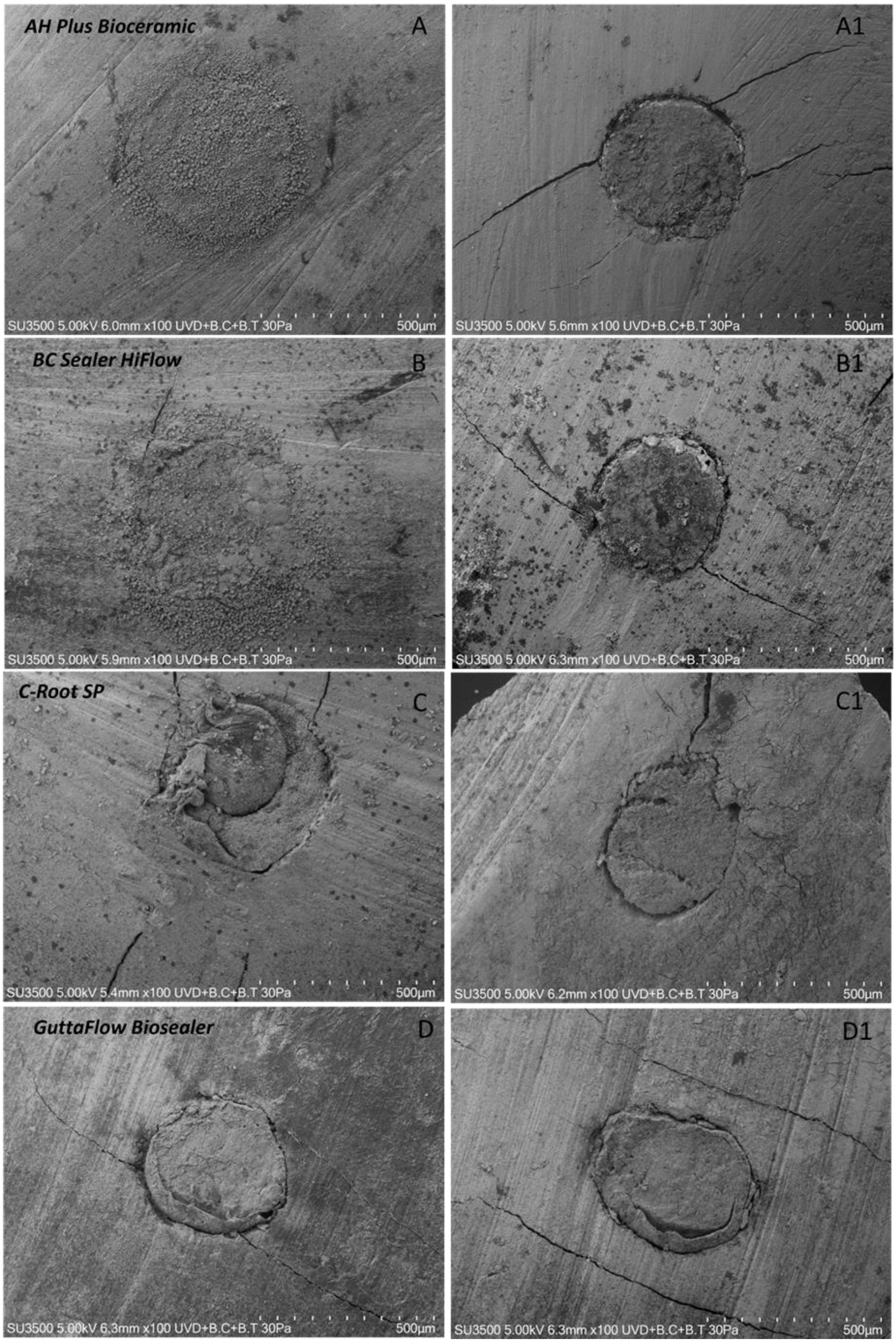

Figure 3. SEM micrographs showing the apical sections of the root canal obturated according to the selected sealer (described in the left column) and the obturation technique used (left column shows single-cone technique, right column shows thermomechanical compaction). (**A**) AH Plus Bioceramic used with SC technique; (**A1**) AH Plus Bioceramic used with TC technique; (**B**) BC Sealer HiFlow used with SC technique; (**B1**) BC Sealer HiFlow used with TC technique; (**C**) C-Root SP used with SC technique; (**C1**) C-Root SP used with TC technique; (**D**) GuttaFlow Biosealer used with SC technique; (**D1**) GuttaFlow Biosealer used with TC technique.

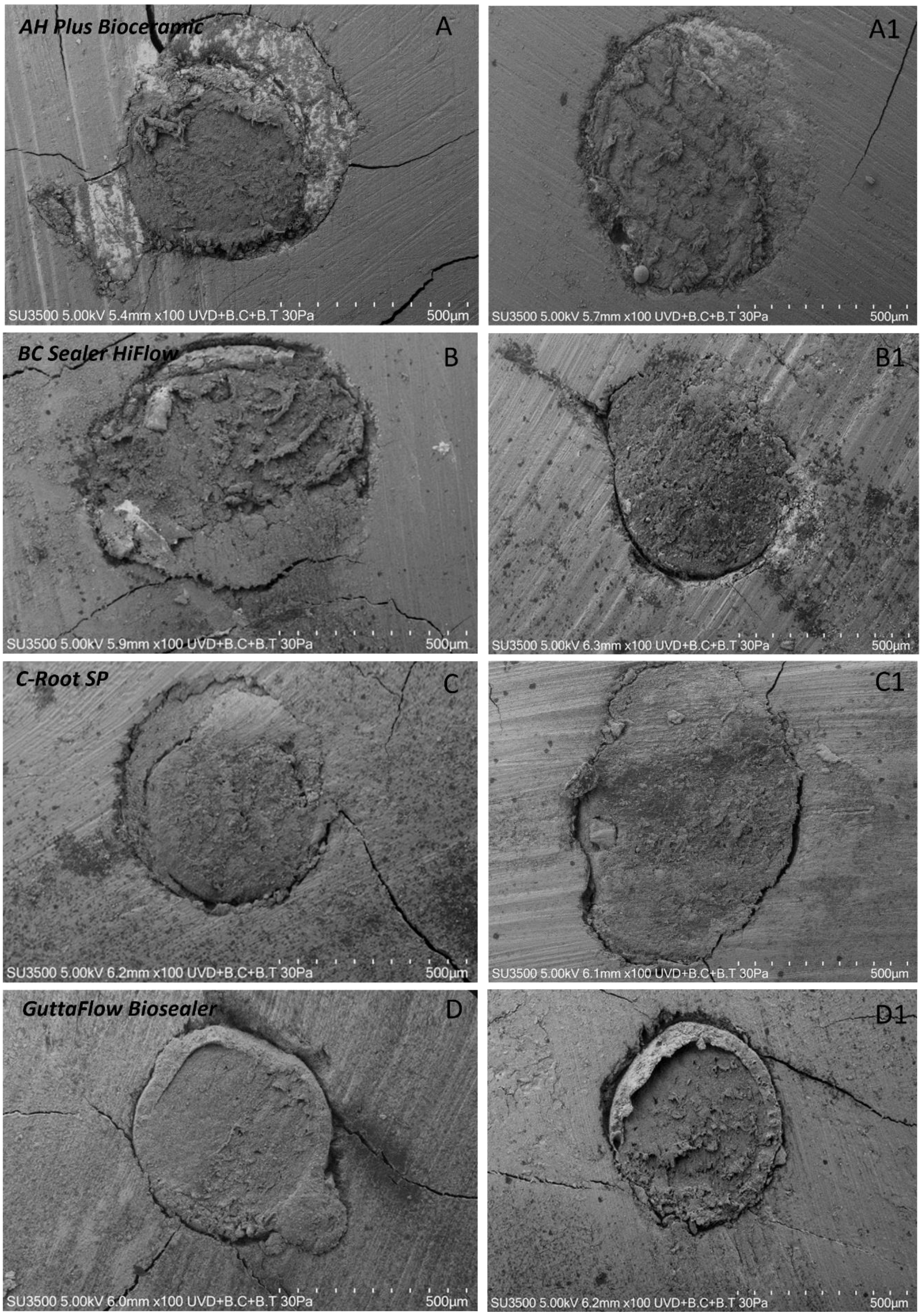

Figure 4. SEM micrographs showing the middle sections of the root canal obturated according to the selected sealer (described in the left column) and the obturation technique used (left column shows single-cone technique, right column shows thermomechanical compaction). (**A**) AH Plus Bioceramic used with SC technique; (**A1**) AH Plus Bioceramic used with TC technique; (**B**) BC Sealer HiFlow used with SC technique; (**B1**) BC Sealer HiFlow used with TC technique; (**C**) C-Root SP used with SC technique; (**C1**) C-Root SP used with TC technique; (**D**) GuttaFlow Biosealer used with SC technique; (**D1**) GuttaFlow Biosealer used with TC technique.

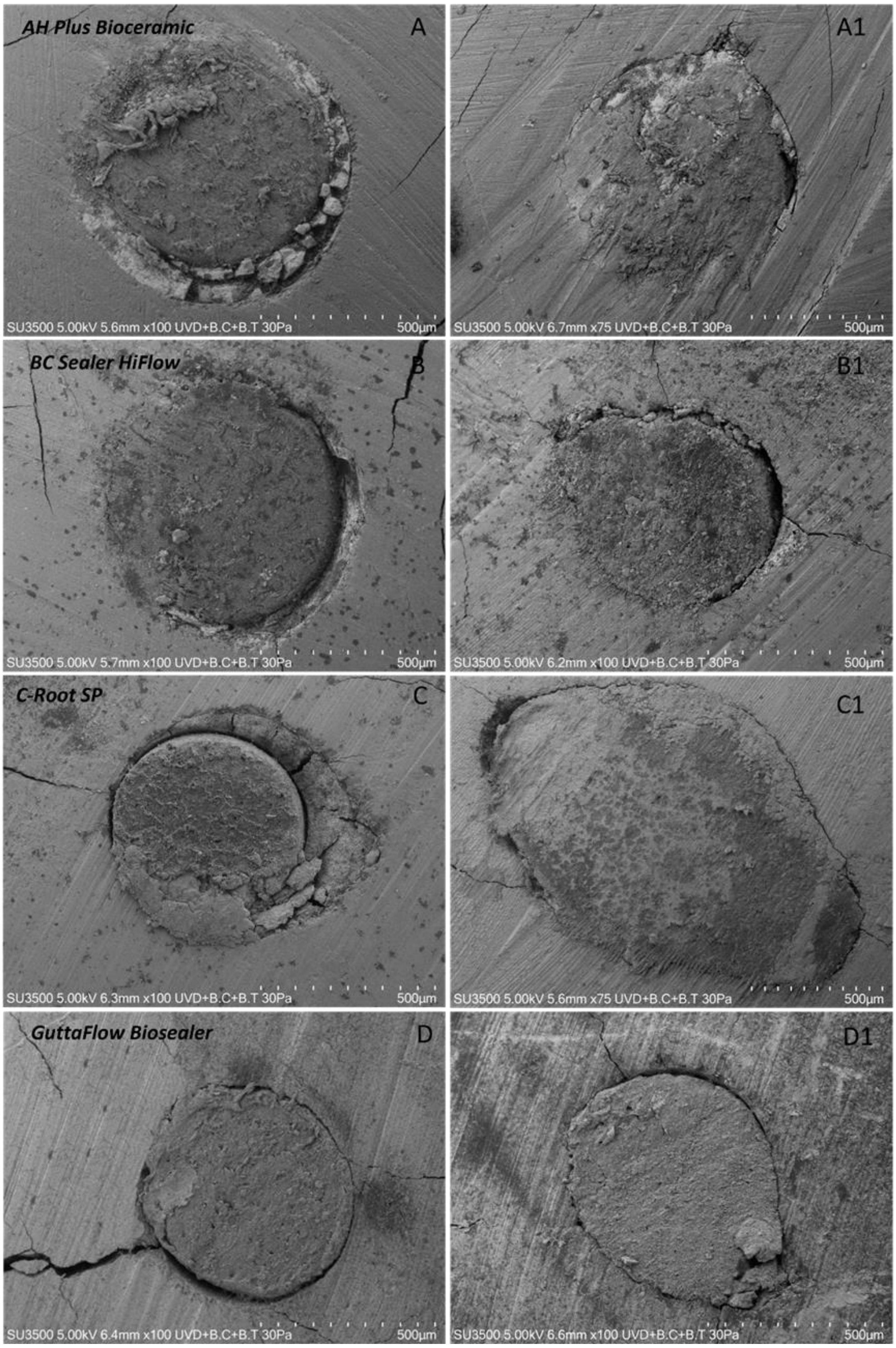

Figure 5. SEM micrographs showing the coronal sections of the root canal obturated according to the selected sealer (described in the left column) and the obturation technique used (left column shows single-cone technique, right column shows thermomechanical compaction). (**A**) AH Plus Bioceramic used with SC technique; (**A1**) AH Plus Bioceramic used with TC technique; (**B**) BC Sealer HiFlow used with SC technique; (**B1**) BC Sealer HiFlow used with TC technique; (**C**) C-Root SP used with SC technique; (**C1**) C-Root SP used with TC technique; (**D**) GuttaFlow Biosealer used with SC technique; (**D1**) GuttaFlow Biosealer used with TC technique.

Table 2. Schematic representation of marginal gap measurements divided according to the endodontic sealer (AH Plus Bioceramic Sealer (AHP), EndoSequence BC Sealer HiFlow (ES), C-Root SP (CR), and GuttaFlow Bioseal (GF)) and the selected obturation technique (single-cone technique (SC) and thermomechanical condensation (TC)). In each column, means sharing the same letter are related by a statistically significant difference ($p < 0.05$).

Obturation Techniques According to the Endodontic Sealer Selected		Marginal Gap (Mean ± Standard Deviation) [μm]		
		Apical Third	Middle Third	Coronal Third
AHP	TC	1.54 ± 0.36 (a,f,l,o)	1.09 ± 0.61 (a,e,g,i,o)	1.37 ± 1.07 (a,c)
	SC	2.28 ± 0.27 (b,g,p)	2.28 ± 0.68 (a,c)	2.66 ± 1.38
ES	TC	1.29 ± 0.35 (c,h,m,q)	0.98 ± 0.67 (b,c,f,h,l)	1.21 ± 0.99 (b,d)
	SC	2.13 ± 0.23 (d,e,i,n,r)	2.03 ± 0.80 (b,d,m)	2.52 ± 1.09
CR	TC	3.44 ± 0.86 (a,c,e)	3.68 ± 1.66 (e,f)	2.64 ± 1.53
	SC	3.91 ± 0.69 (f,g,h,i)	3.17 ± 1.05 (g,h)	3.98 ± 2.61 (a,b)
GF	TC	3.26 ± 0.63 (l,m,n)	2.81 ± 1.64 (i,l)	2.06 ± 0.91
	SC	3.64 ± 0.63 (o,p,q,r)	4.64 ± 1.92 (c,i,m)	3.46 ± 2.11 (c,d)

According to the collected data and the performed statistical analyses, regarding the apical and coronal sections, there was no statistically significant difference in terms of the marginal gap between the sealers and the dentinal walls between the two different obturation techniques used ($p > 0.05$). Thus, the single-cone technique and the thermomechanical compaction provided the same results for each sealer in the above-mentioned sections. Despite this, considering the middle third of the teeth, a statistically significant difference ($p < 0.05$) was noted in each sealer between the two different obturation techniques, except for the CR group. Specifically, thermomechanical compaction resulted in a significantly minor marginal gap in comparison to the single-cone technique.

Regarding the comparison between the different endodontic sealers in terms of sealing ability, AHP and ES showed the lowest marginal gap formations with comparable results between them, with no statistically significant differences in any root canal third ($p > 0.05$). Moreover, they showed a lower marginal gap formation in comparison to CR and GF in each section, with statistically significant differences ($p < 0.05$), resulting in better interfacial adaptation.

4. Discussion

Since there are no data regarding the marginal adaptation of hydraulic sealers used with a thermomechanical compaction technique, this study aimed to evaluate and compare the marginal adaptations of three different hydraulic sealers and GuttaFlow Bioseal used with a thermomechanical compaction technique or a single-cone technique. According to the obtained results and the statistical analysis, the null hypothesis was partially rejected. A statistically significant difference between the TC and SC techniques among sealers was found only in the middle third of root canals, except for the CR sealer. These results could potentially be explained by the nonrounded geometry of root canals in their middle third. Moreover, as is shown in Figure 5, the cross-sectional area at 6 mm was slightly oval in shape, and the sole pumping action with the master gutta-percha cone was not able to guarantee a three-dimensional thigh seal. On the contrary, the thermomechanical compaction guaranteed adequate lateral pressure of the obturation materials against the dentinal walls, reducing the marginal gap in this zone. Otherwise, in the apical and coronal thirds, where the transverse root geometry was almost rounded, no statistically significant differences were found. As a matter of fact, despite the fact that the coronal third of the teeth was not completely round, the SEM micrographs at higher magnifications showed coronal cross-sectional areas that were less oval than the middle ones after the instrumentation procedures with HyFlex CM/EDM systematics, which provided a nonconstant tapered enlargement of the root canal system. The lack of statistical significance for the CR sealer used with the two different obturation techniques was probably due to the alteration of its physiochemical properties that resulted from heat development due to the thermomechanical compaction. As demonstrated by several studies, thermomechanical compaction is able to develop heat due to the frictional component resulting from the contact between the stainless steel instrument and the obturation materials, increasing the temperature up to 75–85 °C [29–31]. Regarding this, Donnermeyer et al., demonstrated that the effect of heating on the physiochemical properties of hydraulic sealers strictly depends on several factors, such as the chemical composition, the temperature level, and the actual exposure time to heat [32]. Different from AHP and ES, the CR sealer is not composed of tricalcium or dicalcium silicates, but instead of strontium silicates, and this difference in the chemical matrix could be the explanation for its different behavior during heating. Furthermore, ES was specifically developed to allow for the use of warm obturation techniques together with a calcium silicate-based sealer, without compromising the hydration reaction which stands as the basis of hydraulic sealer hardening. As a matter of fact, it has been demonstrated that ES is not considerably altered by thermal treatment [32–34].

The AH Plus Bioceramic sealer is a tricalcium silicate-based sealer recently introduced in the market, with promising results in terms of physiochemical properties in comparison to other endodontic sealers [35,36]. Despite this, to date, there are no data regarding its physiochemical properties during heat application when used with warm obturation techniques. The present study is the first study that indirectly evaluates its behavior during heating approximately to 75–85 °C. Regarding this, AHP showed comparable results to ES, without any statistically significant differences in terms of interfacial adaptation, whilst it resulted in a statistically significant, lower marginal gap in comparison to CR and GF in the apical and middle thirds of the root canals when used both with the TC and SC technique. Moreover, at the level of the coronal third, AHP and ES used with thermomechanical compaction showed a statistically significant better marginal adaptation in comparison to CR and GF used with the single-cone technique (Table 2). The latter endodontic sealer is a recently introduced innovative sealer based on a polydimethylsiloxane chemical matrix containing bioglass, with an adjunct of gutta-percha powder. According to different studies, GF has shown proper physiochemical characteristics [37,38], with low solubility and porosity, alkalization capacity [35], and good dentin penetrability [39]. Despite this, it has shown lower flowability and setting time in comparison to other endodontic sealers, such as TotalFill BC Sealer (FKG Dentaire SA, La Chaux-de-Fonds, Switzerland) and AH Plus epoxy-based sealer (FKG Dentaire SA, La Chaux-de-Fonds, Switzerland) [37].

According to De-Deus et al., the interfacial gap evaluation through sectioning/microscopy has several limitations [40]. First of all, it is a destructive method, with the possibility of specimen damage, such as partial loss of the sample and heat generation, which could jeopardize the SEM observation of the obturation materials. Moreover, it does not allow for the adaptation details of the entire root canal system to be viewed three-dimensionally. Due to this, Micro-CT scans, a nondestructive technique, is considered the gold standard research tool for the qualitative and quantitative analysis of root canal fillings.

Despite this, in the present methodological setup, the root sections were realized following procedures that guaranteed the absence of materials overheating. Moreover, due to the variable pressure scanning electron microscope Hitachi SU-3500, dehydration of the specimen and application of an ultra-thin coating of an electrically conducting metal were not needed to allow for SEM observation, reducing the damage caused by preparation procedures [40]. Moreover, another limitation of interfacial gap measurement through digital software is the difficulty in establishing an overall value for each root section. To overcome this in the present study, the methodology proposed by Shokouhinejad et al., was adopted [28]. The overall value describing the interfacial adaptation between the obturation material and the dentinal walls was defined by calculating the average of the maximum marginal gap of each slice of the root section.

5. Conclusions

According to the results, it can be concluded that the thermomechanical compaction of hydraulic sealers and gutta-percha guarantees better sealing and a lower marginal gap than does the single-cone technique when the root canal shape is not rounded, and the master gutta-percha point does not three-dimensionally fit in the endodontic space.

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