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ORIGINAL ARTICLE

Evaluation of the interface between gutta-percha and two types of sealers using scanning electron microscopy (SEM)

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Abstract
Objectives The aim of the present study was to evaluate the adaptation of a calcium silicate bioceramic (BC) sealer with either BC or conventional gutta-percha compared with that of AH Plus sealer in different root canal sections.
Materials and methods Seventy-two extracted mandibular premolars were divided randomly into six groups. After standardised chemomechanical preparation, four groups were obturated with the BC sealer and BC gutta-percha or conventional gutta-percha, and the other two groups were obturated with AH Plus sealer and conventional gutta-percha either in lateral compaction or in a single cone technique. Each root was sectioned into three sections. An impression was made from each section, and replicas were then made for scanning electron microscopy (SEM) analysis. Areas and interfacial gaps were identified using image analysis software. In addition to descriptive and explorative data analyses, linear regression analysis was performed.
Results All specimens had measurable interfacial gaps. Significantly fewer gaps were found between conventional gutta-percha and sealer compared to those observed when using the BC gutta-percha ($p < 0.001$). However, minor interfacial gaps between sealer and dentin were observed with the BC sealer ($p = 0.04$). The technique of obturation in different root canal sections did not significantly affect the sealer adaptability.
Conclusion The type of gutta-percha as well as the sealer had a noticeable impact on the adaptability.
Clinical relevance Different obturation techniques will result in similar outcomes. However, within the limitations of the study, there seems to be no advantage in using the BC gutta-percha.

Keywords Endodontics · Root canal obturation · Sealing ability and adaptation · Bioceramic sealers · Bioceramic gutta-percha · SEM analysis

Introduction

A perfect three-dimensional and gap-free obturation of the root canal is one of the main treatment paradigms in endodontics [1]. It is essential for preventing bacterial leakage between the root canal system and its surrounding tissues [2]. Any bacterial leakage might be linked to an increased probability of a root canal treatment failure [2–4]. Therefore, the formation of a perfect permanent seal with a gutta-percha core material in combination with a root canal sealer must be understood as a strong predictor of success [5]. Many types of root canal sealers have been introduced to the dental market over the years. An ideal root canal sealer should provide an excellent seal after setting, perfect dimensional stability, a reasonable setting time to ensure sufficient working time, insolubility to tissue fluids, adequate adhesion with canal walls and high biocompatibility [6]. However, most of the obturating materials do not provide an effective seal [7]. Recently, a new group of sealers, bioceramic (BC) sealers, were introduced and recommended for dental practice [3]. One of the first BC sealers to become commercially available in Europe is the TotalFill BC sealer (FKG Dentaire, La Chaux-de-Fonds, Switzerland), which has the same chemical composition as the EndoSequence BC sealer (Brasseler, Savannah, GA, USA). According to the manufacturers, this sealer should be used in

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combination with the TotalFill BC gutta-percha (FKG Dentaire, La Chaux-de-Fonds, Switzerland) impregnated and coated with a nanolayer of BC particles to improve adaptation. It was hypothesised that the adaptation between the sealer and the gutta-percha would improve [8]. However, this hypothesis has not been investigated.

The purpose of the present study was to evaluate the interface between TotalFill BC sealer and either BC or conventional gutta-percha (Roeko, Langenau, Germany) in comparison to AH Plus sealer (Dentsply DeTrey, Konstanz, Germany) with single cone and lateral compaction obturation techniques using scanning electron microscopy (SEM). Furthermore, the interface between these sealers and dentin was evaluated. The null hypothesis of this study was that there would be no difference between different materials or techniques of obturation.

Materials and methods

The study protocol adhered to the general principles of the local ethics committee for in vitro studies. No separate study number was given to this project.

Materials

This study utilised 72 healthy, caries-free, straight single-rooted extracted human mandibular premolars. The teeth were free of developmental disorders and restorations, and they exhibited complete root development. The teeth were primarily extracted for different reasons. After extraction, the teeth were stored in a sodium azide solution (0.2%). Preoperatively, a series of mesiodistal and buccolingual radiographs were taken to confirm that roots were straight and showed no internal calcifications, resorptions, or previous endodontic treatment. All teeth were randomly divided into six groups according to the obturation technique and the type of gutta-percha or sealer (Table 1).

Table 1 Overview of the study groups, obturation techniques and materials

Group	Obturation technique	Gutta-percha	Sealer
1	Single cone	TotalFill BC	TotalFill BC
2	Lateral compaction	TotalFill BC	TotalFill BC
3	Single cone	Conventional	TotalFill BC
4	Lateral compaction	Conventional	TotalFill BC
5	Single cone	Conventional	AH Plus
6	Lateral compaction	Conventional	AH Plus

Endodontic treatment

All experimental procedures were performed by the same operator (M.E.) with 10 years of experience in the field of endodontics.

Each crown was removed at the cementoenamel junction with a water-cooled diamond disc (IsoMet 1000, Buehler Ltd., Lake Bluff, IL, USA) to obtain a standardised root length of 12 mm. Working length then was determined for each canal with a #15 K-file (VDW GmbH, München, Germany). The file should passively fit until its tip is just visible at the apical foramen. The working length was determined by subtracting 1 mm from the root length. Mtwo rotary files (VDW GmbH, München, Germany) were mounted on a VDW Gold motor (VDW GmbH, Munich, Germany) to prepare all root canals to a #40/04 file size. Each canal was irrigated with 10 mL 3% sodium hypochlorite (NaOCl) during instrumentation. After completion of instrumentation, canals were flushed with 3 mL ethylenediaminetetraacetic acid (EDTA, 17%) for 1 min to remove the smear layer followed by 3 mL NaOCl (3%) and then rinsed with 5 mL saline for 1 min and dried with paper points [9].

Obturation of the root canal

An overview of the techniques and materials used is shown in Table 1. Both sealers were applied according to the manufacturer's instructions into the root canal using a preloaded syringe. For the TotalFill BC sealer, the intracanal tip of the preloaded syringe was inserted into the coronal third of the canal. One to two reference markings of the sealer were dispensed into each root canal with a steady pressure for 3 s. The AH Plus sealer was applied into the root canal with the AH Plus jet. Since there is no reference marking on the mixing syringe, we applied it in the same manner as with the BC sealer for 3 s. To increase the sealer coverage of the entire root canal walls [10, 11], a Lentulo spiral was used in the root canal after sealer application 2.0 mm short of the working length. Then, a size 40 master cone 0.4 taper was lightly coated with sealer and placed slowly into the root canal to the full working length. It was made of either BC or conventional gutta-percha according to the group. For the lateral compaction groups, four to six accessory cones size 20 taper 0.2 depending on the size and cross section of root canal were laterally compacted with Ni-Ti finger spreaders size 25 (VDW GmbH, München, Germany) that initially reached to within 2 mm of the full working length. The tip of each accessory cone was lightly coated with a sealer. The excess gutta-percha was removed with the aid of a SuperEndo Alpha 2 heat source (B&L Biotech, Virginia, USA). Finally, the canal entrances were sealed with a glass ionomer (Ketac, 3M ESPE, Seefeld, Germany).

Sample preparation

The roots were stored in a phosphate-buffered saline solution (pH = 7.4) at 37 °C and incubated for 7 days to allow for the appropriate setting of the sealer [12]. Specimens then were fixed with brown compound (Kerr corporation, CA, USA) onto an acrylic plate adapted to the IsoMet cutting machine. Each root was sectioned perpendicularly to its long axis at 3, 6 and 9 mm from the apex with a diamond blade size 5 × 0.015 × ½ (LECO Corporation, MI, USA) under distilled water to obtain disk-shaped sections from the coronal, middle and apical regions with the aid of the built-in micrometre, resulting in equal sections (n = 216) of an approximate thickness of 3 mm using relatively low speeds (~ 300 rpm). The specimens were then cleaned in an ultrasonic bath (BANDELIN Sonorex, BANDELIN electronic GmbH & Co. KG, Berlin, Germany) for 2 min, and then each slice was slightly air dried and examined with a Zeiss Axioplan light microscope (Carl Zeiss, Oberkochen, Germany) which was equipped with a digital camera (AxioCam MRc5, Carl Zeiss) to confirm that neither the gutta-percha nor the sealer was dislodged after sectioning.

Subsequently to the last working steps, an impression was made using a vinyl polysiloxane impression material (Aquasil Dentsply/caulk, Konstanz, Germany) to create a replica for SEM analysis. Replicas of the slices were fabricated immediately using a self-curing epoxy material (Agar Scientific Ltd., Essex, UK) and then stored in a Hybaid Shake 'N' Stack thermo-oven (HBSNSR110, Thermo Electron Corporation, Massachusetts, USA) for 2 days at 60 °C.

SEM imaging

The replicas were then mounted on aluminium stubs (Plano, Wetzlar, Germany), gold palladium-sputtered (Polaron Range SC 7620 Sputter Coater, Quorum Technologies Ltd., Ashford, UK), and examined with an SEM microscope (Zeiss Supra 55 VP, Carl Zeiss AG, Oberkochen, Germany), which was maintained at approximately 10 kV. Specimen imaging was performed using a secondary electron detector, and for each specimen, one photomicrograph was taken of the whole root canal area at a magnification between ×35 and ×1000, depending on the sample size and the working distance (WD) of the SEM. The use of an indirect method for scanning was favoured over a direct one to avoid potential damage to specimens due to over-drying [13].

Image analysis

ImageJ software was used to analyse all images (ImageJ 1.5 1a, Wayne Rasband, National Institutes of Health, USA) (Fig. 1). For each image, the scale measurements were set using the "KHKs Measure/Clear/Fill_Stacks" Utility plugin (http://www.dent.med.uni-muenchen.de/~kkunzelm/exponent-0.96.3/index.php?section=81) to mark and differentiate the area of the root canal from the surrounding area. Next, the thresholds of the gutta-percha and sealers as well as the gaps were registered and assigned a value through the subtraction of each component from the value 255. Masking of all components was performed, and as a final step, segmentation was performed by the "Seeded_region_growing" plugin (http://www.dent.med.uni-muenchen.de/~kkunzelm/exponent-0.96.3/index.php?section=50) to accurately measure the area of the gutta-percha, sealer and gaps between the interfaces of sealer and gutta-percha or sealer and dentin.

Finally, the cross section of each image was evaluated by measuring the ratio of long to short canal diameter. The shape of the root canal was considered *long oval* when the ratio of long to short canal diameter of each section was ≥ 2 (i.e., when one dimension was at least two times that of a measurement made at right angles) and *round* (*or slightly oval*) when the ratio of long to short canal diameter was < 2 [14].

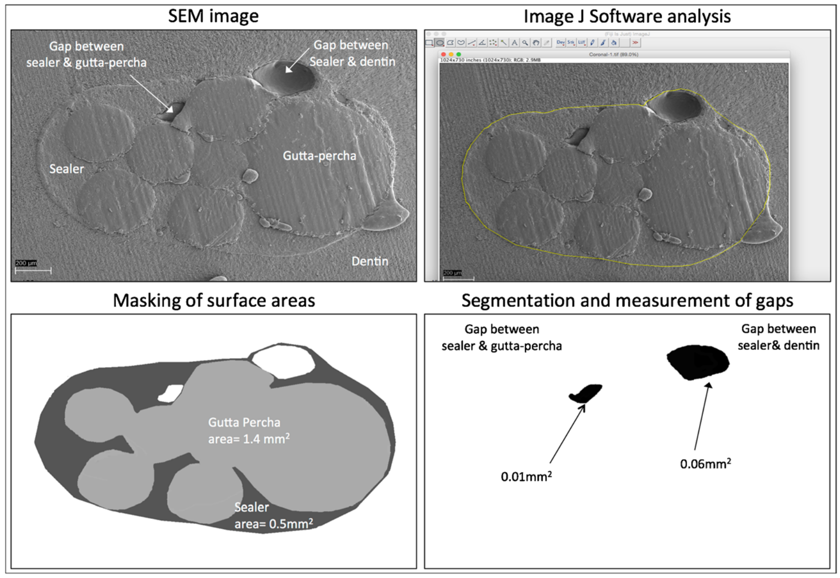
Statistical analysis

The data were entered into an Access database (Microsoft Office, Access 2010®, Unterschleißheim, Germany). All descriptive and explorative analyses were performed using R version 3.2.1 (R Core Team, 2015). Descriptive statistics were calculated for all outcomes, such as the surface area of gutta-percha and sealer, the gap between sealer and gutta-percha and the gap between sealer and dentin. The outcomes were not normally distributed under Shapiro-Wilk tests. Pairwise comparisons between the canal section levels (Table 2), the technique of obturation, the type of gutta-percha and the type of sealer (Table 3) were analysed using the Mann-Whitney U test. An unadjusted linear regression model was developed for each outcome of interest versus the group. Furthermore, to explore the influence of any confounders, a multiple linear regression model was established for each outcome, adjusting for obturation (single cone or lateral compaction), gutta-percha (BC or conventional), root section (coronal, middle or apical), sealer material (TotalFill or AH Plus) and the shape of the root canal (round or long oval). The adjusted estimates, their corresponding 95% confidence intervals and p values were calculated. A two-tailed α significance level of 0.05 and a 95% confidence level were used for all analyses.

Results

The mean percentage of the surface area of gutta-percha and sealer as well as the mean percentage of the interfacial gaps in different root canal sections are shown in Table 2. When analysing the areas of gutta-percha and sealer, it became

Fig. 1 All SEM images were analysed according to the shown standard procedures



obvious that the lateral compaction groups (2, 4 and 6) were associated with a higher percentage of gutta-percha as well as a lower percentage of sealer. Furthermore, an increasing area of gutta-percha and a decreasing area of sealer towards the apical region were recorded. A significant difference was found between the coronal and apical sections with respect to the interfacial gaps between the sealer and the gutta-percha.

The mean percentage of the surface areas and the interfacial gaps in different groups are shown in Table 3. Some significant pairwise differences were observed for both the surface

Table 2 Mean percentage and standard deviation (SD) of the study groups stratified with respect to canal sections

Mean % (sd)	Surface area		Gaps between	
	Gutta-percha	Sealer	Sealer and gutta-percha	Sealer and dentin
Coronal section				
Group 1	46.7 (13.7)	52.9 (13.8)	0.2 (0.2)	0.2 (0.3)
Group 2	75.3 (11.9)	23.9 (12.1)	0.6 (0.8)	0.2 (0.2)
Group 3	27.3 (13.1)	72.5 (13.1)	0.1 (0.1)	0.1 (0.1)
Group 4	73.5 (12.9)	26.3 (12.8)	0.1 (0.1)	0.1 (0.1)
Group 5	17.3 (11.8)	82.6 (11.8)	0.0 (0.1)	0.0 (0.1)
Group 6	72.6 (10.8)	26.8 (10.9)	0.1 (0.2)	0.5 (1.0)
Middle section				
Group 1	60.3 (15.3)	38.6 (15.1)	0.5 (0.5)	0.6 (0.8)
Group 2	80.3 (7.7)	19.4 (7.5)	0.2 (0.3)	0.1 (0.2)
Group 3	48.5 (16.9)	51.2 (17.0)	0.2 (0.2)	0.2 (0.3)
Group 4	86.8 (7.0)	13.0 (7.1)	0.1 (0.1)	0.1 (0.1)
Group 5	42.0 (14.7)	57.8 (14.9)	0.1 (0.1)	0.1 (0.1)
Group 6	86.1 (8.9)	13.0 (8.5)	0.2 (0.2)	0.7 (0.9)
Apical section				
Group 1	76.6 (16.2)	22.7 (15.8)	0.2 (0.2)	0.5 (0.6)
Group 2	83.2 (11.1)	16.2 (11.2)	0.2 (0.3)	0.4 (0.4)
Group 3	80.9 (12.4)	18.7 (12.3)	0.2 (0.3)	0.2 (0.1)
Group 4	89.0 (4.8)	10.6 (4.8)	0.2 (0.3)	0.2 (0.2)
Group 5	69.1 (16.9)	30.7 (16.9)	0.1 (0.0)	0.1 (0.1)
Group 6	84.0 (15.7)	15.5 (15.6)	0.3 (0.4)	0.2 (0.2)

Table 3 Mean percentage and standard deviation (SD) of the study groups with respect to the obturation technique, type of gutta-percha type of sealer material, root canal sections and the shape of root canal

Mean % (sd)	Surface area		Gap between	
	Gutta-percha	Sealer	Sealer and gutta-percha	Sealer and dentine
Group 1	61.2 (19.2)	38.1 (19.2)	0.3 (0.4)	0.4 (0.6)
Group 2	79.6 (10.6)	19.8 (10.7)	0.3 (0.5)	0.2 (0.3)
Group 3	52.3 (26.3)	47.5 (26.4)	0.2 (0.2)	0.1 (0.2)
Group 4	83.1 (11.1)	16.6 (11.1)	0.1 (0.2)	0.1 (0.1)
Group 5	42.8 (25.7)	57.1 (25.8)	0.1 (0.1)	0.1 (0.1)
Group 6	80.9 (13.2)	18.4 (13.1)	0.2 (0.3)	0.5 (0.8)
Single cone	52.1 (24.9)[a]	47.5 (25.0)[a]	0.2 (0.3)	0.2 (0.4)[a]
Lateral compaction	81.2 (11.7)[a]	18.3 (11.7)[a]	0.2 (0.4)	0.3 (0.5)[a]
Coated gutta-percha	70.4 (18.0)	29.0 (17.9)	0.3 (0.5)[b]	0.3 (0.5)[b]
Non-coated gutta-percha	64.8 (26.7)	34.9 (26.9)	0.1 (0.2)[b]	0.2 (0.5)[b]
TotalFill	69.0 (21.9)	30.5 (22.0)	0.2 (0.4)[c]	0.2 (0.4)
AH Plus	61.8 (27.9)	37.7 (28.1)	0.1 (0.2)[c]	0.3 (0.6)
Coronal section	52.1 (26.4)[de]	47.5 (26.6)[de]	0.2 (0.4)	0.2 (0.5)[e]
Middle section	67.3 (21.7)[df]	32.2 (21.8)[df]	0.2 (0.3)	0.3 (0.6)
Apical section	80.5 (14.5)[ef]	19.1 (14.4)[ef]	0.2 (0.3)	0.3 (0.4)[e]
Round shape canal	68.2 (23.1)[g]	31.4 (23.2)[g]	0.2 (0.3)	0.3 (0.5)
Long oval shape canal	54.4 (29.8)[g]	45.3 (29.9)[g]	0.2 (0.2)	0.1 (0.2)

Pairwise comparisons were made between the combined groups using the Mann-Whitney U test

[a] Indicates statistical significance between single and lateral compaction

[b] Indicates statistical significance between coated and non-coated gutta-percha

[c] Indicates statistical significance between TotalFill and AH Plus

[d] Indicates statistical significance between coronal and middle sections

[e] Indicates statistical significance between coronal and apical sections

[f] Indicates statistical significance between middle and apical sections

[g] Indicates statistical significance between round and long oval shaped canals

areas and the interfacial gaps. When adjusting for other influencing factors in the linear regression models (Tables 4 and 5), different variables significantly influenced the sealing ability and adaptation of the root canal filling. When analysing the areas of gutta-percha and sealer, it became obvious that the obturation technique, type of gutta-percha and sealer had a significant effect on both variables (Table 4). The linear regression analysis of the sealing ability and adaptation revealed that the type of gutta-percha and sealer was found to have an impact on the percentage of the interfacial gaps (Table 5). Interestingly, conventional gutta-percha was associated with a lower percentage of interfacial gaps between gutta-percha and sealer ($p < 0.001$) and between sealer and dentin ($p = 0.04$), whereas the AH Plus sealer showed more gaps between sealer and dentin compared with the BC sealer ($p = 0.04$). Furthermore, interfacial gaps were equally distributed in all root canal sections.

The prevalence of the long oval canal shape was relatively low throughout the study groups. The mean values of the ratio of the cross section in the coronal, middle and apical sections were 1.8, 1.3 and 1.1 respectively. However, this difference had no influence on the interfacial gaps.

Discussion

Minimising the gaps between the sealer and gutta-percha and/or dentin interfaces is clinically relevant; as little as 1% shrinkage of root canal sealers can result in imperfections that are large enough for the penetration of bacteria or their by-products [15, 16]. In the present study, we evaluated the adaptation of a calcium silicate BC sealer with BC and conventional gutta-percha and compared it with that of an epoxy resin sealer with conventional gutta-percha in different root canal sections. Considering the results from the linear regression model, the initially formulated hypothesis was rejected due to the documented significant differences. In detail, the conventional gutta-percha was found to be superior to the BC gutta-percha in terms of the interfacial gap between the gutta-percha and the sealer (Table 5). This finding is interesting because the manufacturers claim that the sealing ability should be improved by chemically binding or mechanically impregnating a coating over the surface of gutta-percha cones so that the chemistry and surface energy of the coating are similar to those of the sealer [17, 18]. Possible reasons for our results could be attributed to the difficulties in

Table 4 Adjusted estimates, 95% confidence intervals (95% CI) and the corresponding *p* values from the multiple linear regression model of the surface areas of the gutta-percha and the sealer

Linear regression model		Surface area of gutta-percha		Surface area of sealer	
		Estimate % (95% CI)	*p* value	Estimate % (95% CI)	*p* value
Groups	1*	61.2 (55.0; 67.4)	–	38.1 (31.9; 44.3)	–
	2	+ 18.4 (9.7; 27.1)	< 0.001	− 18.3 (− 27.0; − 9.5)	< 0.001
	3	− 8.9 (−17.7; − 0.2)	0.05	9.4 (0.6; 18.1)	0.04
	4	+ 21.9 (13.2; 30.6)	< 0.001	− 21.5 (− 30.2; − 12.7)	< 0.001
	5	− 18.4 (− 27.1; −9.7)	< 0.001	19.0 (10.3; 27.7)	< 0.001
	6	+ 19.7 (11.0; 28.4)	< 0.001	− 19.7 (− 28.4; − 11.0)	< 0.001
Technique of obturation	Single*	41.1 (35.7; 46.5)	< 0.001	58.3 (52.9; 63.7)	< 0.001
	Lateral	+ 29.1 (25.0; 33.2)		− 29.3 (− 33.3; − 25.2)	
Type of gutta-percha	Coated*	41.1 (35.7; 46.5)	0.01	58.3 (52.9; 63.7)	0.008
	Non-coated	− 2.7 (− 7.7; 2.3)		3.1 (− 1.9; 8.1)	
Type of sealer	TotalFill*	41.1 (35.7; 46.5)	0.02	58.3 (52.9; 63.7)	0.03
	AH Plus	− 5.8 (− 10.8; − 0.8)		5.7 (0.7; 10.7)	
Root section	Coronal*	41.1 (35.7; 46.5)	< 0.001	*58.3 (52.9; 63.7)*	< 0.001
	Middle	*15.2 (10.2; 20.2)*		*− 15.4 (− 20.4; − 10.3)*	
	Apical	28.4 (23.4; 33.4)		− 28.4 (− 33.5; − 23.4)	
Shape of root canal	Round	41.1 (35.7; 46.5)	0.84	58.3 (52.9; 63.7)	0.87
	Long oval	+ 0.7 (− 6.4; 7.9)		− 0.6 (− 7.8; 6.6)	

A model was performed for group; and another model was performed adjusting for obturation technique, type of gutta-percha, type of sealer, root section and the shape of root canal

*Reference

Table 5 Adjusted estimates, 95% confidence intervals (95% CI) and the corresponding *p* values from the multiple linear regression model of the gaps between gutta-percha and sealer and between sealer and dentin

Linear regression model		Gap between the gutta-percha and the sealer		Gap between the sealer and the dentin	
		Estimate % (95% CI)	*p* value	Estimate % (95% CI)	*p* value
Groups	1*	0.3 (0.2; 0.4)	–	0.4 (0.3; 0.6)	–
	2	+ 0.0 (− 0.1; 0.2)	0.50	− 0.2 (− 0.4; 0.0)	0.07
	3	− 0.1 (− 0.3; 0.0)	0.10	− 0.3 (0.5; − 0.1)	0.003
	4	− 0.1 (− 0.3; 0.0)	0.06	− 0.3 (− 0.5; − 0.1)	0.003
	5	− 0.2 (− 0.4; − 0.1)	0.003	− 0.4 (− 0.6; − 0.2)	< 0.001
	6	− 0.1 (− 0.2; 0.1)	0.40	0.1 (− 0.2; 0.3)	0.60
Technique of obturation	Single*	0.3 (0.2; 0.4)	0.14	0.3 (0.1; 0.4)	0.23
	Lateral	0.1 (− 0.0; 0.1)		0.1 (− 0.0; 0.2)	
Type of gutta-percha	Coated*	0.3 (0.2; 0.4)	< 0.001	0.3 (0.1; 0.4)	0.04
	Non-coated	− 0.2 (− 0.3; − 0.1)		− 0.2 (− 0.4; − 0.1)	
Type of sealer	TotalFill*	0.3 (0.2; 0.4)	0.84	0.3 (0.1; 0.4)	0.04
	AH Plus	− 0.0 (− 0.1; 0.1)		0.2 (0.0; 0.3)	
Root section	Coronal*	0.3 (0.2; 0.4)	0.98	0.3 (0.1; 0.4)	0.40
	Middle	0.0 (− 0.1; 0.1)		0.1 (− 0.0; 0.3)	
	Apical	0.0 (− 0.1; 0.1)		0.1 (− 0.1; 0.2)	
Shape of root canal	Round*	0.3 (0.2; 0.4)	0.76	0.3 (0.1; 0.4)	0.35
	Long oval	− 0.0 (− 0.2; 0.1)		− 0.1 (− 0.3; 0.1)	

A model was performed for groups, and another model was performed adjusting for obturation technique, type of gutta-percha, type of sealer the root section and the shape of the root canal

* Reference

creating a uniform coating over the entire surface of a gutta-percha cone [18]. Furthermore, this coating might theoretically produce a tertiary monoblock with three adhesive interfaces [19], and it was found that the magnitude of stress created within the root canal during force application increases with the number of interfaces [20]. With regard to the type of root canal sealer (Table 5), there was no significant difference in the interfacial gaps found between the two types of sealers and the gutta-percha. This result contradicts previous findings reported by Zhang et al. [21], who found that the iRoot SP BC sealer had better adaptation with gutta-percha compared with AH Plus sealer.

Considering the gaps between the sealer and the dentin (Table 5), minimal interfacial gaps in the tested variables were found with a significant difference between the type of sealer where the BC sealer resulted in lower gaps compared to the AH Plus sealer; this could be attributed to the alkaline caustic effect of the calcium silicate sealer's hydration products which has been reported to degrade the collagenous component of the interfacial dentin, which may then facilitate the penetration of sealers into the dentinal tubules [22]. In addition, the bioceramic sealer is hydrophilic, possessing a low-contact angle that would allow the sealer to spread easily over the canal wall providing adaptation. Furthermore, the extremely fine particle size and the optimal premixed consistency introduced with a capillary tip introductory system might have enhanced its penetration to the full length of the canal [17, 23]. This finding contradicts with the results of Zhang et al. [21], who concluded that the iRoot SP BC sealer was equivalent to AH Plus sealer in apical sealing ability and Al-Haddad et al. [24] who found that the EndoSequence BC sealer exhibited more interfacial gaps compared with AH Plus sealer.

The results revealed a significant difference related to the technique of obturation, in which the single cone technique showed a high percentage of sealer surface area and a low percentage of gutta-percha surface area (Table 4). However, this difference had no influence on the number of interfacial gaps (Table 5). This result is in line with the results of Zhang et al. [21], who found no difference in the sealing ability of the iRoot SP BC sealer using the single-cone technique and AH Plus using the continuous-wave compaction technique. With respect to the root canal sections, a significant difference was found; the apical section showed a low percentage of sealer and a high percentage of gutta-percha, although the interfacial gaps were not affected in various root sections (Table 5). However, Al-Haddad et al. [24] reported that the coronal level had significantly fewer gaps than the apical and middle levels. Regarding the type of sealer, it seems to be obvious that the higher surface area of sealer is associated with more interfacial gaps. Previous studies showed that thin layers of sealer are preferred in modern endodontics because the sealer might shrink during setting and dissolve over time, producing leakage [25]. Furthermore, the lower thickness promotes the long-term sealing ability of root canal fillings [26]. However, this finding was not applicable to the BC sealer, in which reduced volumetric shrinkage was observed with high sealer thickness. This result might be attributed to the expansion of the BC sealer by less than 0.1% after setting [18, 23].

In the present study, we performed univariate descriptive statistics (Table 3) and found that the shape of the root canal significantly influenced the surface area of the gutta-percha and sealer, which is in line with the results of Wu et al. [27]. Therefore, we included this variable as a confounder into the regression model and found that the influence of this variable was lost after adjusting for other confounders (Tables 4 and 5). Furthermore, the interfacial gaps were not affected.

Different methods have been used to evaluate the sealing ability and adaptation of different endodontic filling materials over time [15, 18, 28]. Leakage tests include dye, radioisotopes, bacterial and lipopolysaccharide penetration methods, and other models include fluorometry, electro-chemical and fluid transport and enzymatic detection methods. None of these methods is completely reliable in quantifying the seal of the obturated root canals [18]. In addition, leakage studies do not determine which of the two interfaces, dentin sealer or gutta-percha sealer, is leaking. They also do not provide any insight into the mechanism that may lead to apical sealing by a combination of two different materials [29]. These test discrepancies have led to a critical evaluation of studies using in vitro study leakage models alone [18, 30, 31]. Laboratory microCT analysis is another method that may allow imaging of root canal fillings non-destructively; however, differences in radio-opacities between the root canal filling materials and dentin remain a challenge [32]. These differences influence the contrast of these materials: For example, using a lower tube voltage setting for materials with a relatively high radio-opacity (e.g., AH plus) to favour the contrast in the transmission image may result in more severe beam hardening and photon starvation, therefore underestimating the quality of the root filling [33]. On the other hand, using higher tube voltage could underestimate the prevalence of voids and provide poorer contrast in materials with a reduced radiopacity such as calcium silicate-based materials [34]. Furthermore, a prolonged scan time will result in loss of water and subsequently produce dimensional changes affecting the interfaces of root canal fillings [32].

In the present study, SEM was used to determine the marginal adaptation and sealing ability of root canal sealer to gutta-percha and/or dentine interfaces on the various levels of sectioning. All the relevant areas were marked up and measured on the SEM images to quantify any quality defects.

The conventional preparation of biological samples before SEM observation may be associated with the introduction of many artefacts. The effect of high-vacuum evaporation is associated with cracks of hard tissue samples in addition to the separation of the filling material from the surrounding tooth.

Furthermore, there may be dimensional changes of the tooth and/or filling material [35]. Therefore, to eliminate these artefacts, the use of resin replicas has been suggested [13, 35, 36], as interfacial gaps were found to be similar between natural teeth and replicas [35].

Conclusions

To our knowledge, there is no information in the literature comparing the sealing ability and adaptation of BC sealers and gutta-percha; therefore, this study aimed to evaluate the relationship between BC sealers and gutta-percha. It was concluded that all tested root canal fillings exhibited minor interfacial gaps. In addition to this overall assessment, the use of conventional gutta-percha showed a slightly more favourable outcome regarding adaptability than the use of BC gutta-percha. The BC sealer showed better adaptability than the AH Plus sealer. It could be further concluded that the single cone technique resulted in a similar outcome to the lateral compaction technique; thus, the single cone technique is preferred due its ease of handling.

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Compliance with ethical standards

Conflicts of interest The authors declare that they have no conflicts of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors. All procedures performed in this study were performed in accordance with the ethical standards of the institutional and/or national research committee.

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