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Evaluation of the Marginal Adaptation of Two Hydraulic Calcium Silicate Cements Used in Apical Plugs: An In Vitro Study

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Abstract: Background: The emergence of new hydraulic calcium silicate cements has revolutionized endodontics, addressing the limitations of mineral trioxide aggregate (MTA). The aim of this study is to assess and compare the marginal adaptation of two calcium silicate-based cements (White ProRoot MTA® and TotalFill® BC RRM Fast Set Putty™), when creating apical plugs for teeth with open apices. Methods: twenty-four single-rooted teeth were divided into two groups—GMTA (plug with MTA®) and GTBC (plug with TotalFill® BC RRM Fast Set Putty™)—and were sectioned at 1 mm and 2 mm from the apex. The transverse sections were analyzed with scanning electron microscopy and the marginal adaptation of the cements was measured with ImageJ® 1.3 software. Statistical analysis (IBM® SPSS® statistics software version 27) was performed and statistical significance was set at 0.05 ($p < 0.05$). Results: There was a significant difference in the apical region, favoring White ProRoot MTA®, with a lower percentage of marginal adaptation failure (1.32 ± 4.47), presenting a statistically significant difference in the apical region ($p = 0.029$) but not in the cervical region of the apical plugs ($p = 0.774$). Conclusions: White ProRoot MTA® showed superior marginal adaptation in the apical section compared to TotalFill® BC RRM Fast Set Putty™.

Keywords: apexification; apical plug; hydraulic calcium silicate cements; marginal adaptation; mineral trioxide aggregate

1. Introduction

The key objective of root canal treatment is to eradicate microorganisms within the root canal system and establish a barrier that ensures effective sealing of the canal. This is essential to prevent bacterial recontamination of the surrounding structures, including the oral cavity (and its microbiome) and periapical tissues [1–3]. After adequate chemical–mechanical preparation, the three-dimensional root filling hermetically seals the root canal system, preventing both bacterial colonization and the infiltration of oral cavity fluids into periapical tissues and thus establishing suitable conditions for periradicular tissue healing [4–7].

In situations involving pulp necrosis in teeth with compromised root formation, the therapeutic approach poses a clinical challenge, as difficulties may appear in different steps of the treatment, particularly in establishing the boundaries of instrumentation, disinfection and root canal filling [8,9]. Following deep caries lesions, developmental anomaly or trauma, an immature tooth may undergo compromised root maturation, with the absence of root apex closure and the interruption of root formation before reaching the final length [8,10]. The interruption of the root formation leads to a divergent apical configuration, rendering it challenging to attain precise control of the working length for the root filling material [9]. This configuration, coupled with the absence of apical constriction, may result in the extrusion of intracanal dressing, irrigating solutions and the obturation material into the periapical tissues, which can lead to the failure of the root canal treatment [8,11].

Current treatment techniques for necrotic teeth with open apex include apexification, the placement of an apical plug and regenerative endodontic treatment [12]. Apexification is an endodontic procedure that promotes the formation of a biological barrier or apical plug into the apical portion of the root. This process facilitates the closure of the root canal, establishes a boundary for the root filling material and prevents overfilling into the periapical tissues [13]. In contrast to regenerative endodontic treatments, apexification typically lacks the capacity to promote the thickening of dentin walls or to provide the root development of the tooth [13].

An apical plug is an alternative to the previously mentioned technique [8,14,15]. Plugs with an extension of 3–5 mm are deemed appropriate for optimizing marginal adaptation and achieving efficient sealing, thus enhancing therapeutic success [11,16]. The materials employed in this clinical procedure should possess the ability to consistently provide sealing, exhibit good biocompatibility, ensure effective adhesion to root canal walls and maintain dimensional stability. Additionally, it is imperative for these materials to be hydrophilic [17,18], with a low solubility, be easy to handle and have a short setting time and good radiopacity [19,20].

Over time, innovative endodontic cements based on calcium silicates have been developed, including mineral trioxide aggregate (MTA) and other hydraulic calcium silicate cements [21]. MTA is a biomaterial resulting from a mixture of Portland cement and bismuth oxide, with smaller amounts of SiO_2, CaO, MgO, K_2SO_4 and Na_2SO_4 [16]. Upon contact with periapical tissue, MTA can stimulate the formation of hydroxyapatite-like hard tissue [22], showing its ability to induce odontoblastic differentiation [23]. In addition to these benefits, MTA also demonstrates a low solubility, good radiopacity, antimicrobial activity, high pH and expansion after setting [24]. However, the extended setting time, handling challenges and the potential of coronal discoloration associated with MTA have prompted the investigation of new materials to overcome these issues [25,26].

Lately, new hydraulic calcium silicate cements have been introduced in endodontics as alternatives to MTA [11]. These cements exhibit favorable physical and biological properties, addressing some of the limitations of previous materials and bringing hydraulic calcium silicate cements closer to the ideal standard [27]. Comprising ceramic compounds, these cements demonstrate relevant biocompatibility due to their resemblance to the biological process of hydroxyapatite formation. They also have the potential to stimulate a regenerative and osteoinductive response by absorbing substances during the bone healing process [27,28]. Bioactive compounds, especially calcium phosphate, interact with tissues and promote tissue regeneration [19]. Their composition includes tricalcium and dicalcium silicates, calcium phosphates, calcium hydroxide and zirconium oxide [28]. The interaction of these materials with dentin, particularly the infiltration of mineral content from hydraulic calcium silicate cements through the intertubular dentin, creates a surface with mineral infiltration [29].

Therefore, in the field of endodontics, hydraulic calcium silicate cements have been extensively used for repairing perforations and as endodontic cements, their success being owed to several properties such as their high pH, low cytotoxicity, low shrinkage, chemical stability non-resorption capacity and easy manipulation [28].

TotalFill® BC RRM Fast Set Putty™ (FKG, La Chaux-de-Fonds, Switzerland) is one of the latest calcium silicate-based cements introduced to the market [29]. This hydraulic calcium silicate material comprises components such as calcium disilicate, calcium trisilicate and calcium hydroxide, among other components. TotalFill® BC RRM Fast Set Putty™ is premixed, ready to use and has the ability to absorb moisture during setting [11]. Despite having a setting time of approximately four hours [11], it has demonstrated a high biocompatibility, strength, adaptation to dentin walls and it does not cause dental discoloration [29]. It is available in various forms, including paste, cements or putty [11].

The aim of this ex vivo study was to evaluate and compare the marginal adaptation of TotalFill® BC RRM Fast Set Putty™ (FKG, La Chaux-de-Fonds, Switzerland) with White ProRoot MTA® (Dentsply Maillefer, Ballaigues, Switzerland) in a model of immature teeth using scanning electron microscopy analysis. The null hypothesis is that there are no statistically significant differences in marginal adaptation between these two calcium silicate-based cements when used in apical plugs.

2. Materials and Methods

For this study, twenty-four single-rooted teeth were chosen, extracted for orthodontic or periodontal reasons, following approval from the University of Coimbra Faculty of Medicine Ethics Committee (CE_107.2017). The manuscript followed the Preferred Reporting Items for Study Designs in Endodontology, PRILE 2021 guidelines, for reporting in vitro studies of dental materials (Supplementary Materials) [30].

Periodontal structures such as the periodontal ligament and calculus were removed using Gracey curettes. Subsequently, the teeth underwent disinfection with 2.5% sodium hypochlorite and were stored in chloramine T at 4 °C, from the moment of extraction until the initiation of the study. This precaution was taken to prevent bacterial colonization.

The inclusion criteria for the sample included teeth with a straight root configuration, fully formed root and a single, permeable root canal. The exclusion criteria involved teeth with calcified or obstructed canals, internal or external resorptions, previous endodontic treatments, root fractures or fissures, caries lesions or restorations located from the cementoenamel junction to the apex, and teeth with pronounced curvatures.

To ensure proper standardization in the sample selection, the selected teeth were required to possess only one root canal and a similar internal anatomy. To achieve this, orthogonal and proximal radiographs were taken. Furthermore, the teeth underwent scrutiny under an optical microscope (Leica®M320, Wetzlar, Germany) to assess the presence of fractures, caries or fissures.

2.1. Sample Preparation

To standardize the sample, the teeth underwent sectioning at the cementoenamel junction, perpendicular to the long axis of the tooth. This was achieved using a diamond cylindrical bur (Coltène/Whaledent AG, Altstätten, Switzerland) mounted in a turbine and cooled with water. The result of this process was the acquisition of root segments, each 17 mm in length. In cases where the pulp chamber was not exposed, an access cavity was created using a spherical bur mounted in a turbine to gain access to the canal.

In order to simulate the characteristics of an immature tooth, the apical portion (2 mm) of the root was removed using a cylindrical diamond bur (Coltène/Whaledent AG, Altstätten, Switzerland) mounted in a turbine. Subsequently, both the coronal and root surfaces of the segments were polished with a carborundum disc (Dentorium Products Co., Inc., Farmingdale, NY, USA), resulting in segments with a final length of 15 mm.

The chemical–mechanical preparation of the root canals commenced with the initial exploration and permeabilization using manual ISO k15 files measuring 25 mm (Dentsply

Maillefer, Ballaigues, Switzerland). Establishing a working length of 15 mm involved inserting a manual ISO #10 K-file (Dentsply Maillefer, Ballaigues, Switzerland) until it became visible at the apical foramen. Orthograde mechanical canal preparation began with manual instrumentation with K-files #10, #15, #20 and #25 (Dentsply Maillefer, Ballaigues, Switzerland). Subsequently, mechanized instrumentation was carried out using the SX file from the Protaper Next system (Dentsply Maillefer, Ballaigues, Switzerland) up to the established working length of 15 mm. This process was executed at a constant speed of 250 rpm and a torque control of 1.2 N/cm, using an X-SMARTTM electric motor (Dentsply Maillefer, Ballaigues, Switzerland). Between each instrument, irrigation was conducted using 2.5% sodium hypochlorite with a 27G closed-end side-vented needle.

To replicate an open apex, a retrograde divergent preparation of the canal was carried out, involving the apical foramen of each tooth. This was achieved using the mechanized ProFile Orifice Shaper® files (Dentsply Maillefer, Ballaigues, Switzerland) OS#1 (06/20), OS#2 (06/25) and OS#3 (06/30) sequentially introduced 5 mm apically with the X-SMARTTM electric motor. The instrumentation speed was set at 250 rpm and torque control at 1.2 N/cm. The irrigation protocol mirrored that recommended during orthograde instrumentation.

The final irrigation protocol involved using 1 mL of 17% ethylenediaminetetraacetic acid (EDTA) (Magnum Dental AS, Tartu, Estonia) for 1 min, followed by neutralization with 2 mL of 0.9% saline solution (NaCl). The canals were then dried with paper points (Dentsply, Johnson City, TN, USA), and the integrity of the canal was assessed through an optical microscope (Leica® M320, Wetzlar, Germany).

2.2. Group Formation

After the preparation of the samples, they were manually and randomly divided into two experimental groups, GMTA and GTBC. Each group consisted of 12 root segments, based on the specific endodontic cements designated for use:

- GMTA group: White ProRoot MTA® (GMTA, n = 12);
- GTBC group: TotalFill® BC RRM Fast Set Putty™ (GTBC, n = 12).

2.3. Endodontic Cements

TotalFill® BC RRM Fast Set Putty™ (FKG, La Chaux-de-Fonds, Switzerland) and White ProRoot MTA® (Dentsply Maillefer, Ballaigues, Switzerland) were the calcium silicate-based endodontic cements that were tested in the study. The manufacturer, composition and lot numbers are detailed in Table 1.

Table 1. Manufacturer, composition and lot no. of the endodontic cements used.

Material	Manufacturer	Composition	Lot No.
TotalFill BC RRM Fast Set Putty®	FKG, La Chaux-de-Fonds, Switzerland	Tricalcium silicate, dicalcium silicate, zirconium oxide, tantalum pentoxide, calcium sulfate (anhydrous) and calcium phosphate monobasic	2201FSPS
White ProRoot WMTA®	Dentsply Maillefer, Ballaigues, Switzerland	Dicalcium silicate, tricalcium silicate, tricalcium aluminate, bismuth oxide, calcium sulfate, aluminum oxide, magnesium oxide and iron oxide	0000337969

2.4. Execution of the Apical Plug

In both groups, apical plugs of approximately 5 mm were created in the prepared tooth segments. While White ProRoot MTA® was mixed following the manufacturer's instructions; TotalFill® BC RRM Fast Set Putty™, being a premixed material ready for use, required no preparation. Both materials were introduced into the root canals of the segments using a MAP system (micro apical placement system) (Dentsply Maillefer, Ballaigues, Switzerland) with a diameter of 1.1 mm. Compaction was carried out with the aid of Schilder Pluggers (Dentsply Maillefer, Ballaigues, Switzerland), using an initial stop to mark a length of 15 mm. Subsequent increments of 1 mm each were executed until the final stop indicated a length of 10 mm, thus creating a 5 mm apical plug (Figure 1A,B). The entire procedure was conducted with magnification under the observation of a surgical microscope (Leica® M320, Wetzlar, Germany).

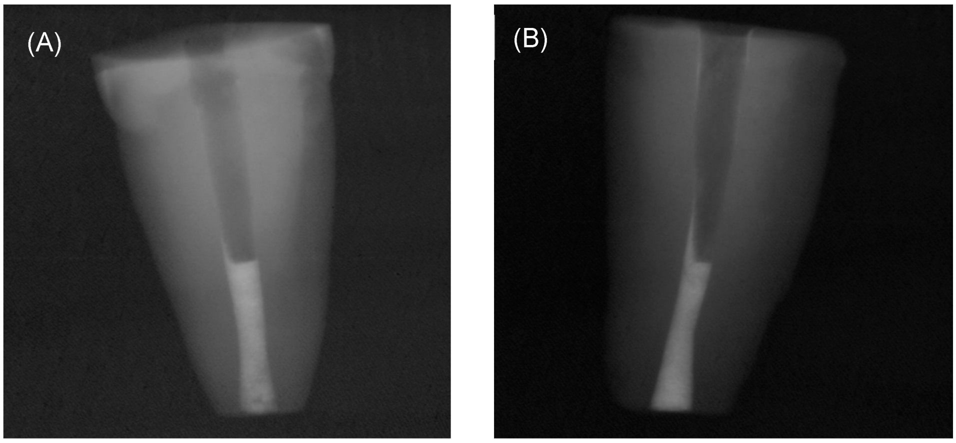

Figure 1. Radiographic image after placement of apical plug (**A**) with White ProRoot MTA® and with TotalFill® BC RRM Fast Set Putty™ (**B**).

The tooth segments, divided into their respective groups, were placed in containers with floral sponges that had been previously soaked in saline solution to simulate the periapical soft tissue environment. In order to replicate conditions compatible with the in vivo environment and facilitate the proper setting of the cements, the specimens were stored at room temperature and 100% relative humidity for a period of 4 days.

2.5. Marginal Adaptation

All segments from both groups were incrementally sectioned (1 mm and 2 mm from the apex) using a carborundum disc (Dentorium Products Co., Inc., Farmingdale, NY, USA) mounted on a handpiece, with constant irrigation and perpendicular to the long axis of the tooth. This procedure resulted in 48 cuts, corresponding to two fragments for each sample—one apical and one cervical of the plug. Thus, for the evaluation of marginal adaptation, a total of 12 apical samples (1 mm from the apex) and 12 cervical samples (2 mm from the apex) were included for both White ProRoot MTA® and TotalFill® BC RRM Fast Set Putty™.

The fragments were polished with an 800 µm carbide silicone disc (Hermes Schleifmittel GmbH, Hamburg, Germany) under water irrigation. This step aimed to eliminate debris resulting from cutting and optimizing the visualization of the samples.

The assessment of marginal adaptation between the endodontic cements used and the canal walls was conducted using a scanning electron microscope (SEM, Hitachi FLEXSEM 1000-Higashitoyoi, Kudamatsu City, Yamaguchi Prefecture, Tokyo, Japan). Images were captured at different magnifications: 190×, 250×, 270×, 500× and 1000× at 10 kV (Figure 2). For each tooth's apical plug, two SEM images were collected—one for the apical cut and another for the cervical cut—allowing for the evaluation of any possible differences in material adaptation between the two locations.

The determination of the perimeter of gaps and the perimeter of the root canal in the sections was carried out by two independent evaluators (M.M.F. and S.F.) using the ImageJ® 1.3 software (National Institutes of Health, Madison, WI, USA). The marginal adaptation discrepancy was calculated for each sample following the formula:

$$\text{Percentage of marginal adaptation discrepancy} = (\text{perimeter of gaps} \times 100)/\text{perimeter of the root canal}.$$

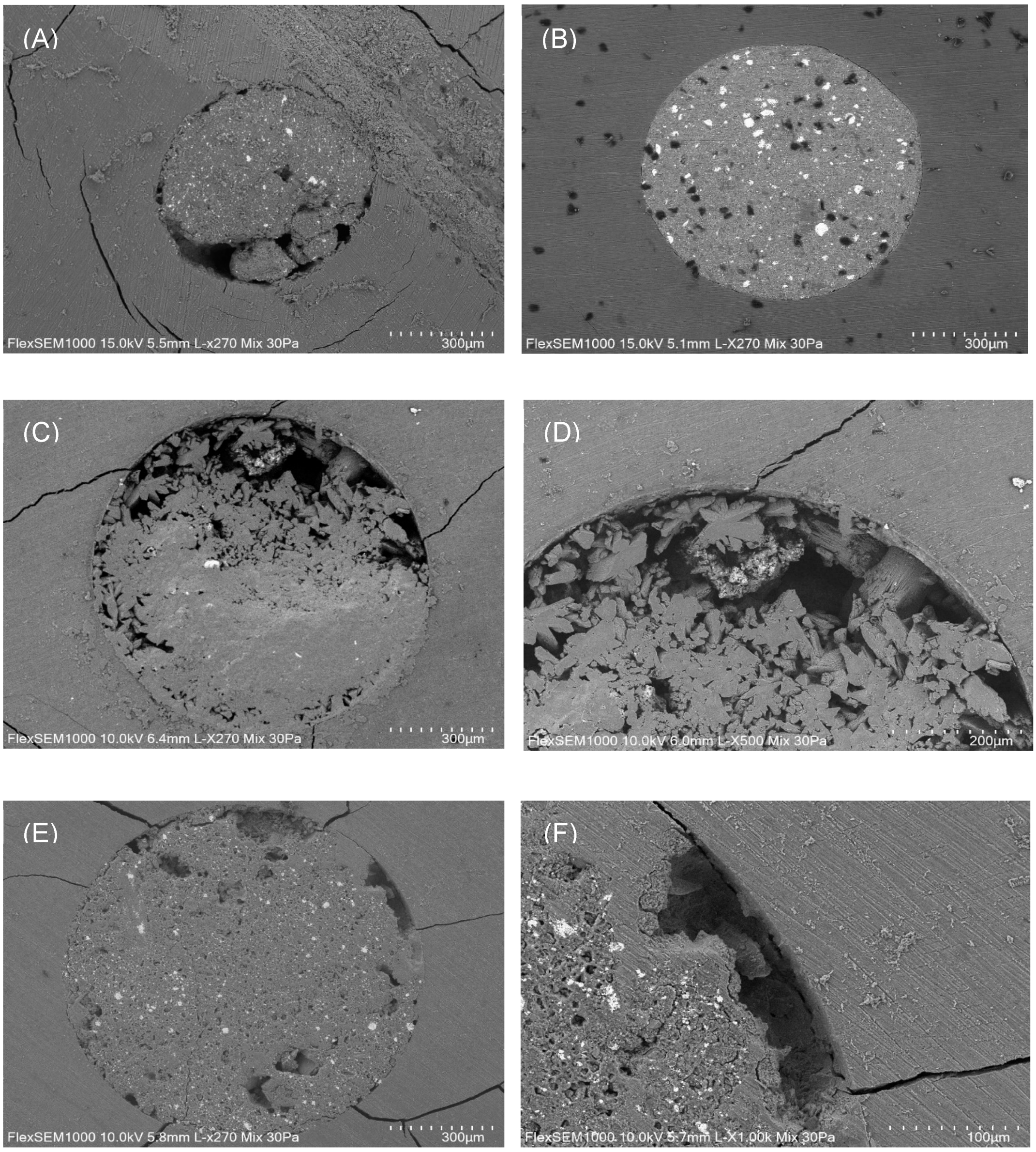

Figure 2. Scanning electron microscopy image. (**A**) White ProRoot MTA® plug in the apical region; (**B**) TotalFill® BC RRM Fast Set Putty™ plug in the apical region (270× magnification). (**C**) TotalFill® BC RRM Fast Set Putty™ plug in the cervical region (270×) and (**D**) 500×. (**E**): White ProRoot MTA® plug in the cervical region (270) and (**F**) 1000× of amplification.

2.6. Statistical Analysis

The statistical analysis was performed using the Mann–Whitney test with IBM® SPSS® version 27 statistics software (SPSS Inc., IBM Company, Armonk, NY, USA). Statistical significance was set at 0.05 ($p < 0.05$).

3. Results

The mean percentages and standard deviations of marginal adaptation discrepancy were calculated for the 24 samples, considering the measurements in the apical and cervical regions. The internal consistency for measurements between operators was assessed using Cronbach's alpha test, and a coefficient of 0.893 was obtained, which indicates good consistency according to the qualitative classification.

The results of this study consist of a two-way analysis, comparing both the regions (apical versus cervical) and the materials (White ProRoot MTA® versus TotalFill® BC RRM Fast Set Putty™).

3.1. Apical versus Cervical Section of the Plugs

Considering the cut of the sample, White ProRoot MTA® showed a lower percentage of marginal adaptation discrepancy in the apical region (1.32 ± 4.37) compared to the cervical region (7.51 ± 14.47). However, no statistically significant difference was found between the marginal adaptation discrepancy in the apical and cervical zones of its plugs (p = 0.173). Regarding TotalFill® BC RRM Fast Set Putty™, the marginal adaptation discrepancy was slightly higher in the apical region (7.92 ± 11.94) compared to the cervical region (7.34 ± 14.68). However, no statistical difference was observed between the measurements of the apical and cervical zones for this material either (p = 0.311) (Figure 3).

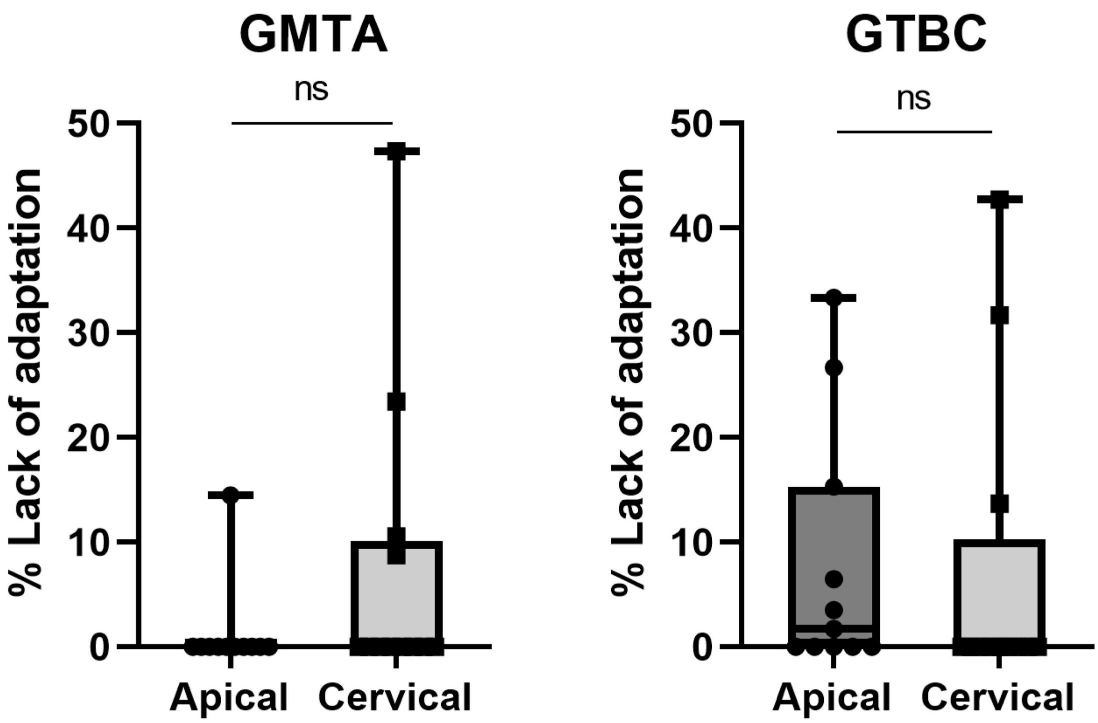

Figure 3. Graphical representation of the percentages of marginal adaptation discrepancy between the apical and cervical zones of the White ProRoot MTA® group and between the apical and cervical zones of the TotalFill® BC RRM Fast Set Putty™ group. Boxplots represent the median, interquartile range and level of statistical significance between groups: ns—not significant.

3.2. White ProRoot MTA versus TotalFill® BC RRM Fast Set Putty™ in Both Sections of the Plug

Regarding the comparison between the two materials, the results were examined by comparing the apical and cervical zones of each material. In the apical zone, the mean percentage of marginal adaptation discrepancy was higher for TotalFill® BC RRM Fast Set Putty™ (7.92 ± 11.94) than for White ProRoot MTA® (1.32 ± 4.37) with a statistically significant difference (p = 0.029). In the cervical zone, TotalFill® BC RRM Fast Set Putty™ showed a lower mean percentage of marginal adaptation discrepancy (7.34 ± 14.68) than White ProRoot MTA® (7.51 ± 14.47), but no statistically significant difference was found (p = 0.774) (Figure 4).

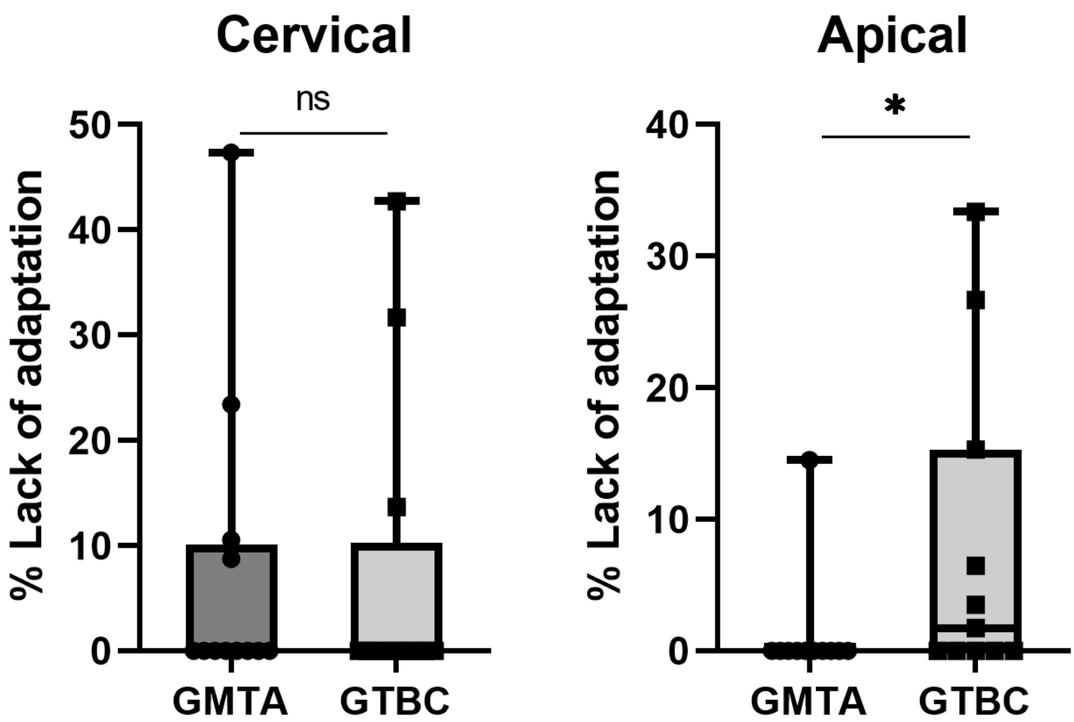

Figure 4. Graphical representation of the mean percentages of marginal adaptation discrepancy between the White ProRoot MTA and TotalFill® BC RRM Fast Set Putty™ groups in the cervical zone and between the White ProRoot MTA and TotalFill® BC RRM Fast Set Putty™ groups in the apical zone. Boxplots represent the median, interquartile range and level of statistical significance between groups: ns—not significant; *—$p < 0.05$; GMTA—White ProRoot MTA® group; GTBC—TotalFill® BC RRM Fast Set Putty™ group.

4. Discussion

The bacterial microleakage of root canals can be minimized or avoided through effective and complete adaptation between root canal filling materials and root canal walls [11], particularly endodontic cements, which should maximize marginal adaptation to the root canal walls. This is crucial to seal irregularities that could potentially allow bacterial infiltration into the root canal system, ultimately preventing endodontic failure [31].

The correlation between the marginal adaptation and sealing ability of a material has been a topic of debate. Some studies, such as Abdal et al. [32] and Yoshimura et al. [33], have found no direct association between these two properties. On the other hand, several studies establish a clear correlation between these variables [34–39]. For instance, the study by Stabholz et al. [38] investigated the correlation between marginal adaptation and the sealing ability of endodontic materials [40]. The existing literature reflects a diversity of findings and perspectives.

This study aimed to explore differences in adaptation between the apical and cervical regions of the plug. The results indicated that in both the GMTA group ($p = 0.173$) and the GTBC group ($p = 0.311$), there were no statistically significant differences between the two regions. The marginal adaptation remained relatively consistent across the entire 5 mm length of the plugs, highlighting homogeneity and uniformity in the distribution of the two materials within the sample plugs.

In terms of the comparison of marginal adaptation between White ProRoot MTA® and TotalFill® BC RRM Fast Set Putty™, the present study revealed statistically significant differences ($p = 0.029$) in the apical region. Specifically, White ProRoot MTA® exhibited a lower mean lack of marginal adaptation (1.32 ± 4.37) compared to TotalFill® BC RRM Fast Set Putty™ (7.92 ± 11.94). As for the cervical region, the differences in the lack of marginal adaptation between White ProRoot MTA® (7.51 ± 14.47) and TotalFill® BC RRM Fast

Set Putty™ (7.34 ± 14.68) were minimal and no statistically significant differences were observed ($p = 0.774$). It is worth noting that the results obtained in this study may diverge from those of research studies, potentially influenced by variations in sample processing, preparation and evaluation methodologies. The null hypothesis was accepted for the cervical section, with no statistically significant differences in marginal adaptation between the two cements. However, it was rejected for the apical section, revealing that White ProRoot MTA® exhibited superior marginal adaptation with statistically significant differences.

Designing an in vitro model of an open apex poses challenges, due to the complexity of simulating the anatomical relationship between the tooth and periapical tissues [41]. In this study, a methodology was employed which uses floral sponges to simulate the periapical tissue environment, with a retrograde instrumentation technique described in a previous study [9,42]. The preparation of the root segments was standardized to ensure uniform dimensions across all teeth. It effectively replicates the characteristics of immature teeth with open apices, providing a controlled and comparable foundation for the evaluation of marginal adaptation with the two calcium silicate-based cements tested. Apical plugs of approximately 5 mm were prepared, guided by findings from Lertmalapong et al. [11], who concluded that apical plugs with a thickness of 4 mm exhibited superior marginal adaptation and sealing ability. Additionally, Prati et al. [43] highlighted that a greater depth of plug material could lead to increased expansion, subsequently reducing gaps. The lack of statistically significant differences between the two materials presented in our study, in the cervical region, is aligned with findings from some studies, which have concluded that there are no statistically significant differences when White ProRoot MTA® is compared with various hydraulic calcium silicate cements, despite the different methodologies used [44–47].

The significant differences observed in this study regarding the marginal adaptation of the two materials may be associated with their physical and chemical properties, including volumetric changes and solubility, as well as their presentation form and application. These factors play a role in how the material adapts to the root canal walls and seals the apical region, influencing the overall success of the root canal treatment.

The superior results associated with White ProRoot MTA® in the apical region may be attributed to its dimensional stability, volumetric expansion capacity, easy application and low compressive force during setting [24,48–50].

In the study by Guo et al. [51], TotalFill® BC RRM Fast Set Putty™ demonstrated a higher compressive strength during setting, notably surpassing that of White ProRoot MTA®. This higher compressive strength could potentially be a contributing factor to the greater lack of marginal adaptation observed in TotalFill® BC RRM Fast Set Putty™. Another plausible explanation for the lower adaptation of TotalFill® BC RRM Fast Set Putty™ compared to White ProRoot MTA® in this study is linked to its working time, which ideally needs to be short, and to the consistency of the material, which may be relatively challenging to insert and handle in the root canal [8]. Additionally, TotalFill® BC RRM Fast Set Putty™ is recognized for its low porosity [52], which may contribute to its high compressibility [51].

The graphical boxplot representation clearly shows the superior performance of White ProRoot MTA® in the apical section despite its standard deviation.

The boxplot graph allows the identification of the few outliers that influenced the standard deviation. These outliers appear to be linked to the material's sensitivity to the application technique or sensitivity to the humidity of the canal system or may be associated with the microscopy protocol.

In accordance with the American National Standards Institute (ANSI)/American Dental Association (ADA) Specification 57, the solubility of cements should not exceed 3% of their mass. Exceeding this limit may result in the development of gaps between the material and the canal walls, leading to diminished marginal adaptation [19]. Therefore, low solubility is a critical property for endodontic cements to prevent their dissolution into the periapical tissues [53]. Numerous studies have reported that TotalFill® BC RRM Fast Set Putty™ exhibits a solubility above 3% [54–56]. In a study by Torres et al. [56], the solubility of TotalFill® BC RRM Fast Set Putty™ was assessed in both distilled water and phosphate-buffered saline (PBS), a saline solution whose concentration simulates that of the human body. These authors concluded that TotalFill® BC RRM Fast Set Putty™ had a significantly greater solubility and volumetric loss than AH Plus. Despite the solubility of this hydraulic calcium silicate cement being relatively low, it remains above the minimum recommended by International Organization for Standardization (ISO) ISO 6876 [27,56]. In contrast, White ProRoot MTA® has demonstrated lower solubility values, even in biological fluids [50,57,58]. This difference could potentially explain the outcomes observed in the present study, especially concerning the comparison in the apical region between White ProRoot MTA® and TotalFill® BC RRM Fast Set Putty™.

In addition to solubility, the chemical composition of hydraulic calcium silicate cements also plays a crucial role in tubular penetration. Hydrophilic materials tend to penetrate dentinal tubules more deeply than hydrophobic materials [17]. Studies have shown that hydraulic calcium silicate cements exhibit superior marginal adaptation when compared to epoxy resin-based materials, attributed to the small particle size of hydraulic calcium silicate cement materials, facilitating enhanced penetration through dentinal tubules [18]. This favorable characteristic of hydraulic calcium silicate cements materials may contribute to the positive outcomes obtained in this study for both tested materials.

Various methodologies are employed to compare the marginal adaptation of materials used in apical plugs. Techniques for assessing the sealing ability of materials include bacterial infiltration [59], dye penetration [60], fluid filtration [61] and the use of radioisotopes [8]. In this study, scanning electron microscopy (SEM) was chosen to evaluate the marginal adaptation by analyzing the perimeter of the gaps between the materials used in the plugs and the canal walls. The selection of scanning electron microscopy was justified by its advantages over optical microscopy, including higher precision, greater resolution and superior magnification capabilities for analyzing the interface between materials and root canal walls [36,62]. Unfortunately, this method is less explored in studies on the same topic. Despite several studies using dye penetration to assess marginal adaptation and microleakage, limitations of this method have been documented such as dye dissolution during the process and difficulties in observing the maximum penetration [63]. Furthermore, the size of molecules, pH and chemical reactivity of the dye can disrupt the extent of penetration and influence the outcomes [64]. As a result, scanning electron microscopy is recognized as a reliable approach for assessing marginal adaptation [65].

Concerning electron microscopes and their impact on samples, a higher power has the potential to increase artifacts or cracks in the hard tissues of the samples [36,66–68]. This phenomenon may arise due to the contraction and expansion of both the material and the tooth [11]. Since the use of SEM in this study could have introduced artifacts that might potentially influence the interpretation of the images collected, the samples underwent careful observation under an optical microscope before and after SEM analysis. Samples with cracks affecting the material–dentin interface were excluded, in line with a similar approach adopted by Ayatollahi et al. [62]. Other images showing cracks which did not occur in the targeted area of the study (i.e., the canal dentin and material interface) were deemed suitable for the study as they did not compromise the results.

Certainly, while this study suggests that White ProRoot MTA® exhibits superior marginal adaptation compared to TotalFill® BC RRM Fast Set Putty™, further research with a larger sample size is warranted. Additionally, future studies should incorporate volumetric measurements of compressive forces and direct assessment of the solubility of both materials.

5. Conclusions

Considering the limitations of this study, it can be deduced that White ProRoot MTA® demonstrates superior marginal adaptation compared to TotalFill® BC RRM Fast Set Putty™ in the apical section when used in the apexification of teeth with open apices requiring an apical plug.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/app14020480/s1, Flowchart with the Preferred Reporting Items for Study Designs in Endodontology, PRILE 2021 guidelines, for reporting in vitro studies of dental materials.

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