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ORIGINAL ARTICLE

Micro-CT Analysis of Apical Plug Using Various Premixed Bio-ceramic Putties: An *In Vitro* Study

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ABSTRACT

Objective: Root growth and apical closure continue after tooth eruption. Root growth may cease if pulp viability is lost due to caries or trauma during this period. Successful endodontic treatment is challenging in these cases due to wide root canals and lack of apical stops. New premixed bioceramic root repair putties offer superior handling and healing properties. The aim of this study is to evaluate the filling ability and volumetric changes of three bioceramic putties (BIO-C Repair, NeoMTA Putty, and EndoSequence BC RRM Fast Set Putty) using micro-CT analysis.

Methods: Thirty-six freshly extracted single-rooted teeth with straight root canals were used, divided into three groups based on the materials. Immature teeth were simulated. Pre- and post-obturated micro-CT images were taken for each root. Voids were calculated as the percentage difference between canal space volume and repair material volume. The data were then analysed statistically using one-way analysis of variance (ANOVA) with the level of significance set at $\alpha=0.05$.

Results: All groups showed marginal gaps and/or internal voids after root-end filling. No significant difference between groups in canal and material volumes was detected at 3 mm ($p>0.05$). However, void percentage differences were significant ($p=0.003$); Bio-C Repair (9.28±3.27%) and EndoSequence BC RRM (6.7±2.72%) were significantly higher with no difference between them, while NeoMTA Putty (3.73±1.69%) was significantly lower.

Conclusion: NeoMTA Putty exhibited the least volumetric alterations after setting, compared to EndoSequence BC RRM and BIO-C Repair. Enhanced long-term stability as a minimal dimensional change contributes to the material's durability and effectiveness over time, potentially leading to better treatment outcomes making NeoMTA Putty a reliable choice for various endodontic applications, potentially leading to improved success rates and patient outcomes.

Keywords: Apexification, micro-computed tomography, MTA putty, premixed bio-ceramic, simulated immature teeth, young permeant teeth

HIGHLIGHTS

- Sealing Ability: NeoMTA Putty exhibited superior dimensional stability with the least volumetric alterations and lowest percentage of voids compared to EndoSequence BC RRM and Bio-C Repair.
- Micro-CT Analysis: High-resolution 3D imaging enabled precise evaluation of canal space, repair material, and void detection, proving invaluable for assessing bioceramic putties.
- Clinical Implications: Findings are particularly relevant for treating immature teeth with wide root canals, potentially improving success rates through more effective sealing and healing promotion.
- Comparative Performance: NeoMTA Putty showed optimal volumetric stability, but all tested bioceramic putties demonstrated good marginal adaptation and filling ability.

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INTRODUCTION

The sealing ability is a critical determinant of endodontic therapy success, as it prevents microorganisms from infiltrating the periapical regions (1). Traumatic injuries to teeth are common facial injuries that can compromise pulp viability, halting root development and apical closure. This creates a challenge for endodontic treatment due to the presence of wide root canals without apical constriction (2). Various treatment protocols can address this issue, including traditional calcium hydroxide apexification, single-visit apexification using mineral trioxide aggregate (MTA), and regenerative endodontic procedures (REPs). REPs, in particular, offer the potential for continued root development and apical closure by promoting tissue regeneration and restoring tooth vitality. The treatment choice should consider factors such as the stage of tooth development, presence of infection, and patient compliance, focusing on achieving an effective seal and long-term tooth preservation (1, 3).

Microleakage is a significant factor contributing to the failure of single-session apexification treatments. Various factors, including the filling technique, plug thickness, and the composition of the plug material, influence these procedures' success. To ensure an effective seal and prevent the ingress of oral fluids and microorganisms, the ideal plug material must exhibit three crucial properties: dimensional stability, adaptability to canal walls, and excellent retention. These characteristics are essential for creating a durable barrier that maintains the integrity of the root canal system and promotes long-term treatment success (3, 4).

Various dental materials have been proposed as potential apical plug materials, including amalgam, mineral trioxide aggregate (MTA), calcium-enriched mixture (CEM) cement, and Biodentine (1). Bioceramics, in particular, have gained attention due to their exceptional biocompatibility, which stems from their similarity to biological hydroxyapatite. During the hydration process, bioceramics generate compounds such as hydroxyapatites that can stimulate regenerative reactions in the human body. When mineral hydroxyapatite interfaces with bone, osteoconduction promotes new bone growth. Additionally, bioceramics possess an inherent ability to stimulate bone tissue formation by absorbing bone-promoting substances during nearby healing processes. The precipitation of apatite at the material-dentin interface can significantly enhance the sealing ability of bioceramic materials. This property is crucial for creating an effective barrier against microbial infiltration and promoting periapical healing. The combination of biocompatibility, osteoconductivity, and improved sealing ability makes bioceramic materials particularly promising for use as apical plug materials in endodontic treatments (5).

MTA was the first bioceramic material utilized in endodontics and is widely regarded as the most effective treatment for immature teeth. However, it has notable limitations, including handling difficulties, extended setting times, and the potential for discoloration of the remaining tooth structure. Advancements have been made in MTA properties to overcome these challenges. In 2007, Innovative BioCeramix, Inc. (IBC, Vancouver, British Columbia, Canada), introduced the iRoot SP injectable root canal sealer, a premixed, ready-to-use calcium silicate-based product. Additionally, Brasseler USA launched the EndoSequence BC RRM-Fast Set Putty in North America in 2008, providing a premixed bioceramic option for endodontic applications. These innovations aim to enhance the handling and performance of bioceramic materials while minimizing aesthetic concerns (6).

These premixed putties are ready to use and are available either as a paste in a syringe or as putty in a jar. They contain zinc and tantalum oxide as radiopacifying agents, replacing the bismuth oxide found in MTA. As a result, they do not set within their packaging but harden in the presence of moisture once applied, and they do not cause tooth discoloration. Additionally, these materials are biocompatible, hydrophilic, insoluble, dimensionally stable, and highly alkaline (6).

EndoSequence BC RRM Paste, developed by Brasseler in Savannah, GA, USA, is a newly introduced bioceramic material known for its favorable handling characteristics, similar to Cavit. According to Rencher et al. (7), EndoSequence BC RRM sets within 20 minutes of contact with tissues. NeoMTA, a bioceramic cement produced by Avalon Biomed, received FDA approval in 2014 and entered the US market in 2015. This premixed material comprises tantalum oxide, tricalcium silicate, calcium aluminate, dicalcium silicate, tricalcium aluminate, and calcium sulfate. It releases calcium and hydroxide ions, promoting hydroxyapatite formation on its surface, which enhances sealing and supports healing. NeoMTA is resin-free, ensuring optimal bioactivity, and is color-stable and non-staining. It includes tantalum oxide for radiopacity and excludes bismuth oxide, which can cause tooth discoloration. Due to its recent introduction, there is limited evidence regarding its sealing ability (4).

BIO-C Repair (Angelus company, Londrina, Brazil) is a newly developed silicate-based cement that offers improved handling characteristics. According to the manufacturer, its plasticizing component enhances plasticity, making it easier to manipulate and place during clinical procedures. This material demonstrates cytotoxicity, biocompatibility, and biomineralization properties comparable to MTA and white MTA. Studies have shown that BIO-C Repair exhibits enhanced cell viability and adhesion in the presence of stem cells while maintaining a similar pH to other materials. These properties suggest that BIO-C Repair possesses favorable bioactive qualities, making it a promising option for endodontic applications (8, 9).

Introducing three-dimensional (3D) computed tomography (CT) imaging techniques has addressed several limitations of conventional methods. This non-destructive approach allows for the evaluation of root canal fillings and provides 3D volume measurements of root canal spaces without the need to section specimens, thereby preventing material loss. Micro-CT is particularly useful for objectively analyzing the structure of teeth, enabling both quantitative and qualitative image analysis. Furthermore, it can differentiate between obturation materials, voids, and tooth structures, offering a comprehensive view of the internal anatomy (10, 11).

TABLE 1. Premixed calcium silicate-based materials used as apical plug filling

Material (Manufacturer)	Batch number	Composition	Manufacturer
Bio-C Repair	55582	Tricalcium Silicate (C3S), Dicalcium Silicate (C2S), Tricalcium Aluminate, Calcium Oxide, Zirconium Oxide Silicon Oxide, Polyethylene Glycol and Iron Oxide	Angelus Industry, Londrina, Brazil),
NeoMTA putty	2022041901	Tricalcium silicate, dicalcium silicate, tantalum oxide, tricalcium aluminate and calcium Sulfate	Avalon Biomed Inc., Bradenton, FL, USA
EndoSequence BC RRM-FS	2103FSPS	Tricalcium silicate, dicalcium silicate, calcium phosphate monobasic, calcium hydroxide, colloidal silica, water-free thickening agent tantalum oxide.	Brasseler, Savannah, GA, USA

This study evaluated the sealing ability of three premixed tricalcium silicate putties (EndoSequence BC RRM, NeoMTA Putty, and BIO-C Repair) when used for apical plugging in simulated immature teeth. The evaluation was conducted using micro-computed tomography (Micro-CT). The null hypothesis posited that there would be no significant differences among the experimental materials regarding volumetric changes, marginal gap formation, and internal void presence after root-end filling.

MATERIALS AND METHODS

The present study is a randomized *in vitro* investigation conducted in the Endodontics and Pediatric departments. Thirty-six freshly extracted, anonymized, single-rooted teeth with straight root canals were used. A pre-operative X-ray was performed to ensure all root canals were Type I and free from caries, cracks, or fractures. Teeth were extracted due to periodontal issues or for orthodontic reasons. Ethical approval was obtained in April 2023 under the primary code (P-PD-22-21) and final code (REC-PD-23-07) following the Declaration of Helsinki. The manuscript follows the PRILE Checklist for *in vitro* endodontic studies.

Sample Size Calculation

Based on Delikan and Aksu (4) and using G Power statistical power analysis software (version 3.1.9.4), a total sample size of n=36 (subdivided into 12 per group) was determined to be sufficient to detect a large effect size (W=0.58) with a statistical power (1-β error) of 0.8 (80%) and a significance level (α error) of 0.05 (5%) for a two-sided hypothesis test.

Sample Preparation and Grouping

The collected teeth were washed under running water, and any remaining soft tissue fragments were removed from their root surfaces. The teeth were then stored in a sterile saline solution. Tooth length was standardized using a low-speed diamond disk (Diabor, Istanbul, Türkiye) under water coolant. Decapitation of the crowns was achieved, leaving approximately 3 mm coronal to the cementoenamel junction (CEJ), and resection of the root end was performed, leaving about 10 mm apical to the CEJ to standardize the root length to approximately 13 mm±1 mm.

Immature teeth were simulated by cleaning and shaping the root canals using the M3 ProGold NiTi rotary system (manufactured by United Dental (UDG) in China) a size of 25/0.06. Root canals were irrigated with 2 ml/1 min of 2.6% NaOCl and 2 ml saline solution between each rotary file. The apical diameter was enlarged using size 4 (1.1 mm) Pesso reamers (Dentsply Maillefer, Tulsa, OK, USA) to standardize all root canal dimensions. The canals were then irrigated with 5 ml/2 min of 17% EDTA to remove the smear layer formed during preparation, followed by 5 ml of distilled water and dried with paper points (Dentsply, Maillefer, Switzerland). The composition and manufacturer of the materials used in the study are presented in Table 1.

The prepared roots were subjected to allocation, randomization, and blinding procedures before being divided into three groups (n=12 per group). A random sequence was generated using an online random sequence generator (https://www.random.org/sequences).

- Group BC: Roots filled with EndoSequence BC RRM putty (control group).
- Group BIO-C: Roots filled with BIO-C Repair putty.
- Group Neo: Roots filled with NeoMTA putty.

Condensation of the plug materials according to the assigned groups was performed at a thickness of 3 mm in the apical area using pre-fitted endodontic pluggers, (Dentsply, Maillefer, Tulsa, USA). In case of overfilling, the excess material was removed by a sterile blade. A periapical radiograph was taken to ensure adequate apical plug density, placement, and thickness. All specimens were stored in an incubator at 37°C and 100% relative humidity for 1 week to allow complete MTA setting and mimic internal body temperature.

Micro-computed Tomography Analysis

A blinded investigator conducted the sample analysis. The teeth were scanned to measure total voids and gaps in cubic millimeters at 3 mm from the apex using a high-resolution desktop micro-CT scanner (SkyScan 1172, SkyScan, Bruker, Belgium) (Fig. 1). Simulated immature teeth from all groups were placed in a mold that held the teeth in a reproducible position during scanning. The micro-focus X-ray tube was set at 100 KV of acceleration voltage and 92 μA of beam current. Scanning was performed at a resolution of 9 μm, with a rotation step angle of 0.40° and an exposure time of approximately 1180 ms. Three-dimensional image reconstruction was conducted using NRecon software (SkyScan 1172). The canal space and repair material volumes were calculated using CTAn software V. 1.18.8 (SkyScan 1172). The exact num-

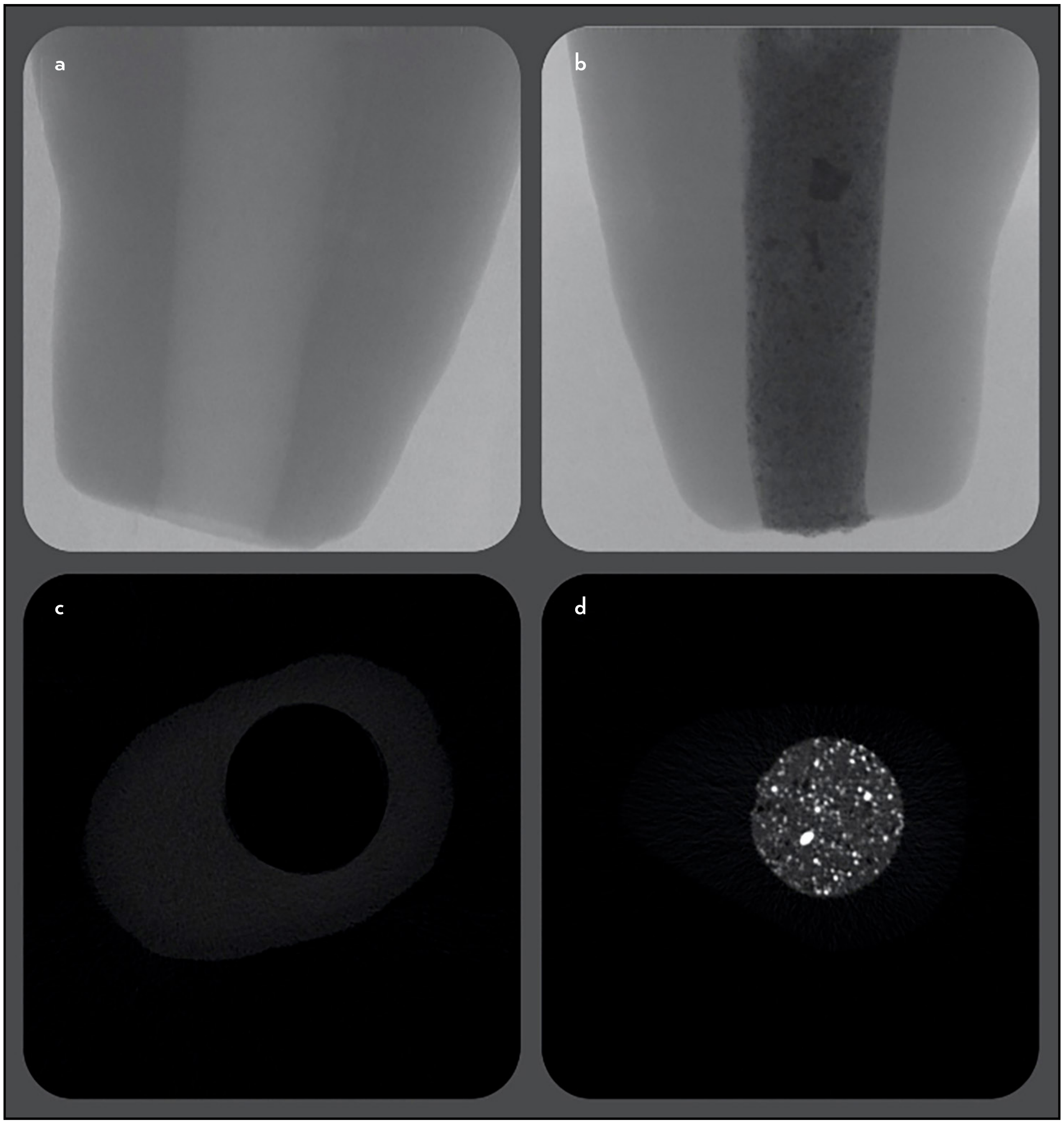

Figure 1. (a, c) Representative micro-CT slices for root canals before EndoSequence BC RRM FS obturation. (b, d) post-obturation after incubation at 37°C and 100% relative humidity for 1 week

CT: Computed tomography

ber of slices was taken for each root's pre- and post-obturation images. The voids were calculated as the percentage difference between the canal space volume and the repair material volume inside the canal space (12).

From the reconstructed images, the volumes of the prepared canals (C), root filling (F), and voids (V) were measured using the following equation:

Vx=C – Fx

where V1 and F1 represent the void and root filling volumes (mm3) before storage, and V2 and F2 represent the volumes after storage. The change in void volume after storage (V3) was calculated as follows:

V3=V2 – V1

The percentage of void volume change after storage (V%) was calculated as follows:

V%=(V3/V1) × 100

Statistical Analysis

Statistical analysis was performed using SPSS 16® (Statistical Package for the Social Sciences), GraphPad Prism, and Windows Excel, and the results were presented in two tables and one graph. Data normality was assessed using the Shapiro-Wilk and Kolmogorov-Smirnov tests, confirming that the data followed a normal distribution. Consequently, group comparisons were conducted using One Way ANOVA (Analysis of Variance) test and Tukey's post hoc test for multiple comparisons.

RESULTS

The minimum, maximum, mean, and standard deviation of canal volume at 3 mm, material volume at 3 mm, and percentage difference (voids %) for all groups are shown in Table 2 and Figure 2. Data collected from all tested groups indicated the presence of marginal gaps and/or internal voids following root-end filling (Fig. 3). A comparison between groups revealed no statistically significant differences in canal volume (mm^3) or material volume (mm^3), with P values

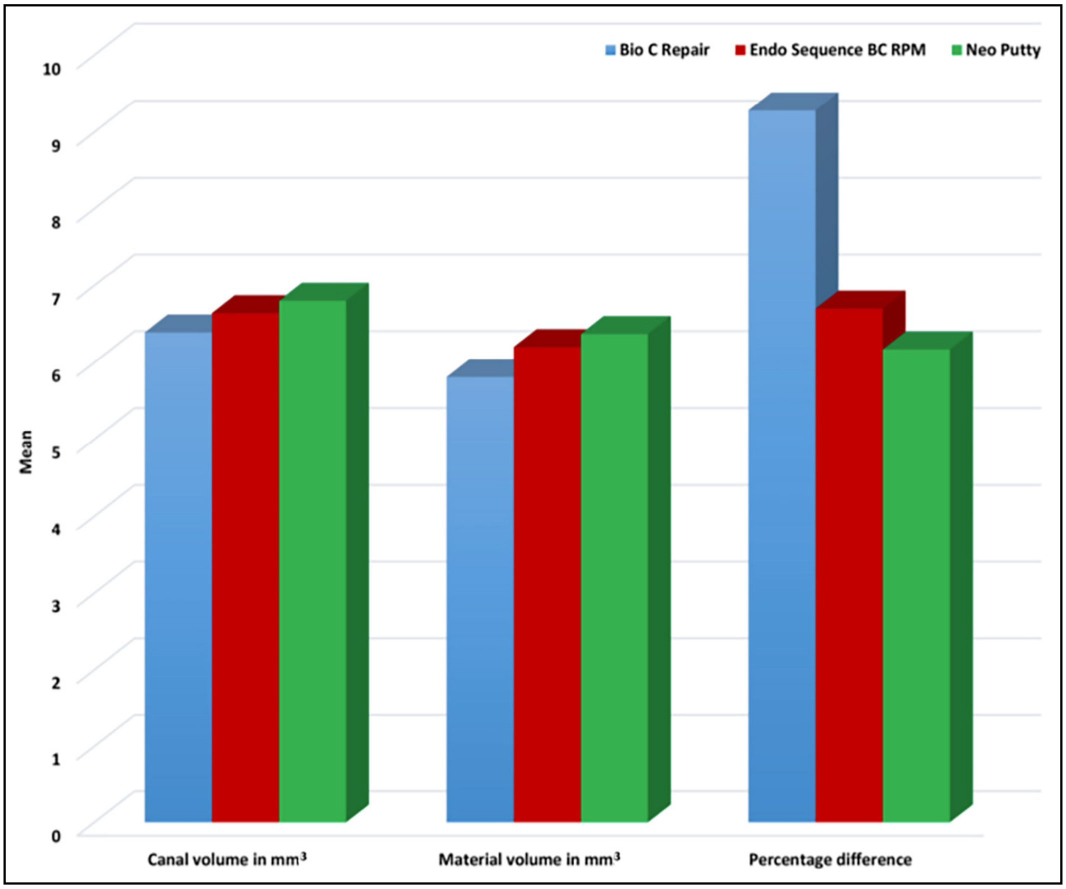

Figure 2. Bar chart representing canal volume at 3 mm, material volume at 3 mm, and percentage difference (voids %) in all groups

of 0.74 and 0.55, respectively (p>0.05). For the percentage difference (voids %), Bio-C Repair (9.28±3.27) and EndoSequence BC RRM (6.7±2.72) exhibited statistically insignificant differences. However, NeoMTA Putty demonstrated the lowest percentage difference (3.73±1.69), with a statistically significant difference compared to the Bio-C Repair and EndoSequence groups (p=0.003).

DISCUSSION

Pulp necrosis in young permanent teeth, often resulting from caries or trauma, halts root development, leaving the root short with thin dentin walls and a wide-open apex. The primary concern is the lack of an apical seat to support conventional obturation. The MTA-apical plug technique has been introduced to induce apical root-end closure and stim-

TABLE 2. Means and standard deviation of canal volume in mm^3, material volume in mm^3 and percentage difference (voids %) in all groups and comparison between them

	Min	Max	Mean	SD	p (One Way ANOVA test)
Canal volume in mm^3					
Bio-C Repair	4.01	7.61	6.39[a]	1.13	0.74 Ns
EndoSequence BC RRM	5.02	8.64	6.64[a]	1.04	
NeoMTA Putty	4.37	9.05	6.8[a]	1.37	
Material volume in mm^3					
Bio-C Repair	3.58	7.1	5.81[a]	1.13	0.55 Ns
EndoSequence BCRRM	4.66	8.33	6.2[a]	1.04	
NeoMTA Putty	4.08	8.74	6.37[a]	1.35	
Percentage difference (voids %)					
Bio-C Repair	2.33	13.43	9.28[a]	3.27	0.003*
EndoSequence BC RRM	2.64	11.57	6.7[a]	2.72	
NeoMTA Putty	1.21	6.55	3.73[b]	1.69	

Same lower case letters within each column indicates insignificant difference. *: Indicates significance. SD: Standard deviation, Min: Minimum, Max: Maximum, Ns: Non-significant difference as p>0.05, ANOVA: Analysis of variance

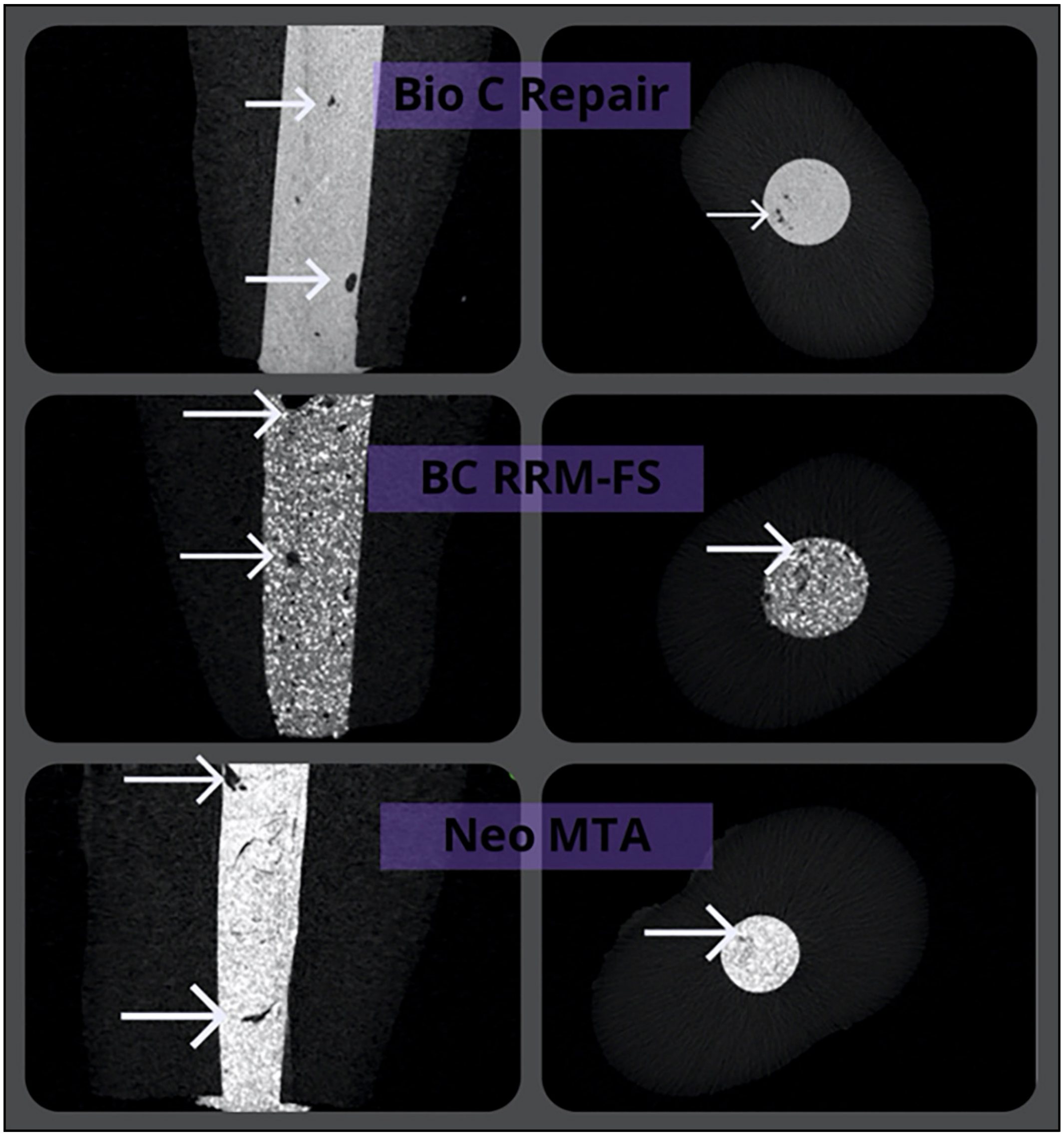

Figure 3. Reconstructed micro-CT image representing longitudinal and cross-sectional views of apical plug filling with Bio C Repair, EndoSequence BC RRM FS, and NeoMTA. The arrows refer to the internal voids and gaps. Each substance displayed distinct surface textures. In contrast to the other putties, EndoSequence BC RRM FS seems to be irregular in nature

CT: Computed tomography

ulate apical hard tissue formation (2). This technique reduces treatment duration and enhances biocompatibility, improving interaction with periapical tissue and promoting cell proliferation and differentiation (2, 13). The plug material must exhibit dimensional stability, adaptability, and retentive ability to effectively seal the canal and prevent the ingress of oral fluids and microorganisms. Recently, efforts have been made to develop ion-releasing endodontic materials with good marginal adaptation, dimensional stability, and ease of manipulation to overcome the limitations of existing materials (13). Manufacturers have aimed to meet these criteria with endodontic premixed bioceramic MTA putty forms.

This study is the first to compare three popular premixed bioceramic materials that contain radiopacifiers other than bismuth oxide: Bio-C Repair, which uses zirconium oxide as its radiopacifying agent, and both EndoSequence BC RRM and NeoMTA Putty, which utilize tantalum oxide. By evaluating these three materials, this novel study aims to provide valuable insights into their relative performance and properties, enhancing our understanding of their applications in endodontics.

Many studies have utilized stereoscopes to investigate the apical seal values of biomaterials (4, 8, 10, 14). However, stereoscopic examination is limited to surface analysis and cannot provide internal views of samples without compromising their integrity. In contrast, micro-CT offers a reliable, non-destructive, and rapid imaging method that overcomes many drawbacks of other techniques. Micro-CT provides high-resolution 3D imaging, revealing tissue organization within topographic sections and allowing for comprehensive analysis of internal structures. This technology can detect voids and gaps at the cement-canal wall interface and within the material itself (12).

Due to these advantages, numerous studies have adopted micro-CT as a dependable testing method for evaluating endodontic materials and procedures (10, 12, 15, 16).

To ensure standardization, all teeth in this study were radiographically examined to confirm they had a single canal (Type I Vertucci). The same pesso size was used for preparation to ensure consistent internal dimensions. The canal volume was evaluated before restoring the apical seal and after preparation to calculate volumetric changes precisely. The material volume of the putties was calculated post-operatively and subtracted from the canal volume. A single trained operator filled all samples from the occlusal access, simulating the apical plug technique used in young permanent teeth. The material thickness in the plug was 3 mm, which multiple researchers have shown to provide optimal sealing ability and prevent apical leakage compared to 1 mm and 2 mm thicknesses (2, 4).

Density and porosity are crucial factors influencing the effectiveness of endodontic treatments. Higher porosity, characterized by larger pore diameters, increases leakage, facilitating the ingress and transmission of microorganisms and compromising the three-dimensional seal (17). Porosity is an inherent tricalcium silicate cement property originating from gaps between non-hydrated cement particles. During hydration, these spaces initially become saturated with water. As the hydration reaction progresses, the resulting products gradually fill these gaps, reducing overall porosity. This process is essential for improving the material's sealing ability and, consequently, the treatment outcome (18).

The micro-CT analysis in this study revealed that all tested premixed bioceramic MTA putties developed defects after setting. The volumetric changes after material setting, represented by the percentage difference (voids %), ranged from 3.73% to 9.28% of the total material volume. The null hypothesis was rejected due to significant differences between the materials. NeoMTA Putty demonstrated the lowest percentage difference (voids %) compared to EndoSequence BC RRM and Bio-C Repair groups (Table 2). This finding indicates that NeoMTA Putty exhibited superior dimensional stability among the tested materials.

These results are in accordance with Delikan and Aksu (4) who compared the sealing ability of several bioceramic materials using methylene blue dye penetration observed under a stereomicroscope. Their study found that NeoMTA and Biodentine demonstrated superior sealing compared to EndoSequence BC RRM. The authors suggested that applying a bioceramic sealer to the canal before placing EndoSequence BC RRM Fast Set putty could significantly enhance its adaptation and sealing properties.

The micro-CT analysis revealed varying volumetric changes among the tested bioceramic materials, with Bio-C Repair exhibiting the highest volumetric percentage change, followed by EndoSequence BC RRM and NeoMTA Putty (Table 2 and Fig. 2). These differences may be attributed to the distinct consistencies of each material. Bio-C Repair has a smooth and creamy texture, while EndoSequence BC RRM features a compact and dense consistency similar to Cavit (16). In contrast, NeoMTA is characterized by a tacky consistency specified by the manufacturer, which is moderate, neither excessively creamy nor thick. This unique consistency may contribute to NeoMTA's lower volumetric change. These findings align with the authors' observations and clinical expertise, suggesting that material consistency significantly influences dimensional stability and sealing ability.

Multiple studies have suggested that NeoMTA Putty and EndoSequence BC RRM have a higher calcium-to-phosphorus (Ca/P) ratio than hydroxyapatite (19–21). This indicates that the precipitate formed by these materials likely consists of a mixture of hydroxyapatite and calcium carbonate (in the form of calcite or aragonite). The presence of this mixture is associated with increased crystallinity and mineral maturity. This unique composition may explain why these materials demonstrate superior sealing ability compared to Bio-C Repair. The enhanced crystalline structure and mineral maturity could contribute to a more effective and durable seal at the root canal interface (19–21).

The disparities observed in this study may be attributed to several factors, particularly the diverse composition of calcium silicate-based materials. The choice of radiopacifying agent is crucial, as it can significantly influence these materials' biological and physical properties. Traditional MTA powder contains bismuth oxide, which provides radiopacity and actively participates in cement hydration. In contrast, NeoMTA and EndoSequence BC RRM utilize tantalum oxide, while Bio-C Repair incorporates zirconium oxide as radiopacifiers. These variations in radiopacifying agents may affect the hydration reaction, potentially leading to differences in clinical performance, setting time, and sealing ability among the tested materials (21, 22).

The particle size of cement plays a crucial role in its setting reactions, biological and physical properties, and ability to penetrate dentinal tubules (23–25). Smaller particles enhance tubule penetration and absorb water more quickly due to their increased surface-to-volume ratio (26). For instance, Bio-C Repair and NeoMTA Putty have particle sizes ranging from 1 to 3 µm, with an average of 2 µm, while EndoSequence BC RRM Putty contains nanosphere particles with a maximum diameter of 1×10^{-3} µm. These tiny particles enable the material to effectively penetrate dentinal tubules and interact with dentin fluid, resulting in strong mechanical bonds and improved sealing properties (27). However, this particle size difference may not significantly impact the current study's findings, as Lo Giudice et al. (28) reported that apical dentinal tubules have an average diameter of 1.73 µm (range: 3.033±2.43 µm), which closely aligns with the average particle size of the tested bioceramic putties, suggesting comparable penetration capabilities in the apical region.

All experimental groups in this study exhibited marginal gaps and/or internal voids after root-end filling, potentially impacting cement stability. As materials contract, their sealing ability may be compromised, potentially allowing for infectious processes. However, limited voids within the material may offer unexpected benefits. These small spaces can serve as sheltered areas for healing tissue, promoting periapical revascularization. These voids act as scaffolds, facilitating improved integration between the material and surrounding periapical tissues. This suggests that while complete void elimination may not be achievable or even desirable, controlling void size and distribution could be crucial for optimizing the balance between sealing ability and tissue integration (29).

Our findings align with previous research (4, 16, 29), confirming that premixed bioceramic materials demonstrate superior sealing properties compared to conventional MTA. The continuous advancement of dental materials is essential for enhancing clinical outcomes in dentistry. The introduction of these improved materials into clinical practice opens up new treatment possibilities that were previously unattainable, potentially revolutionizing endodontic procedures and improving patient care.

To address the limitations of this study, further research is recommended to investigate the hydration reaction of ready-to-use premixed bioceramic putties. Additionally, clinical trials are necessary to validate the findings obtained from *in vitro* experiments. It is essential to acknowledge that while *in vitro* models provide valuable insights, they offer a simplified representation of clinical reality. Future studies should aim to bridge the gap between laboratory findings and clinical applications, providing a more comprehensive understanding of these materials' performance in real-world scenarios.

CONCLUSION

NeoMTA Putty exhibited superior dimensional stability compared to EndoSequence BC RRM and Bio-C Repair. Specifically, NeoMTA Putty showed the least volumetric changes after setting, indicating better preservation of its initial shape and volume. This enhanced dimensional stability of NeoMTA Putty may contribute to improved long-term sealing ability and reduced risk of microleakage in clinical applications.

Disclosures

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Ethics Committee Approval: The study was approved by the Al-Azhar University, Faculty of Dental Medicine for Girls Research Ethics Committee (no: REC-PD-23-07, date: 12/04/2023).

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