Interfacial adaptation and presence of gaps of NeoMTA Plus, BioRoot RCS and MTA in root-end cavities: a micro-CT study

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Abstract

Aim: This study aimed to use the micro-computed tomography to evaluate the interfacial adaptation and the presence of gaps of NeoMTA Plus, BioRoot RCS, and MTA in the root-end cavities. **Methodology:** Thirty standardized bovine roots measuring 15 mm in length were selected. Chemical-mechanical preparation was performed up to instrument #80 and obturation with the cold lateral compaction technique with cement based on zinc oxide and eugenol. The roots were kept at 37º C for seven days. Afterward, apicectomy of the apical 3mm and a root-end filling cavity was performed at 3mm depth. Micro-computed tomography (micro-CT) was performed to measure the volume of the retroactivity. The roots were divided by stratified randomization into three groups according to the retro-end filling material: NeoMTA Plus, BioRoot RCS, and MTA. A new micro-CT was performed to assess the presence of voids in the root-end filling material and between it and the canal wall. One-way ANOVA and Tukey tests were performed using the BioEstat 4.0 program. **Results:** There was no difference in the initial volume values of the root-end cavities ($P > 0.05$). After the insertion of root-end filling materials, the most significant volumes of voids were observed in the NeoMTA Plus group ($P < 0.05$), with no difference for the BioRoot RCS and MTA Angelus groups ($P > 0.05$). **Conclusion:** Micro-computed tomography showed that MTA and BioRoot RCS have better interfacial adaptation and presented fewer number of gaps than NeoMTA Plus when used as root-end filling materials.

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Running Title: Interfacial adaptation of different root-end fillings.

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Keywords: Endodontics. Apical surgery. Root-end filling material. Micro-computed tomography.

Research Highlights: Micro-computed tomography evaluation of different root-end fillings materials.

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Graphical Abstract

ABSTRACT

Aim: This study aimed to use the micro-computed tomography to evaluate the interfacial adaptation and the presence of gaps of NeoMTA Plus, BioRoot RCS, and MTA in the root-end cavities. **Methodology:** Thirty standardized bovine roots measuring 15 mm in length were selected. Chemical-mechanical preparation was performed up to instrument #80 and obturation with the cold lateral compaction technique with cement based on zinc oxide and eugenol. The roots were kept at 37º C for seven days. Afterward, apicectomy of the apical 3mm and a root-end filling cavity was performed at 3mm depth. Micro-computed tomography (micro-CT) was performed to measure the volume of the retroactivity. The roots were divided by stratified randomization into three groups according to the retro-end filling material: NeoMTA Plus, BioRoot RCS, and MTA. A new micro-CT was performed to assess the presence of voids in the root-end filling material and between it and the canal wall. One-way ANOVA and Tukey tests were performed using the BioEstat 4.0 program. **Results:** There was no difference in the initial volume values of the root-end cavities ($P > 0.05$). After the insertion of root-end filling materials, the most significant volumes of voids were observed in the NeoMTA Plus group ($P < 0.05$), with no difference for the BioRoot RCS and MTA Angelus groups ($P > 0.05$). **Conclusion:** Micro-computed tomography showed that MTA and BioRoot RCS have better interfacial adaptation and presented fewer number of gaps than NeoMTA Plus when used as root-end filling materials.

Keywords: Endodontics; Apical surgery; Root-end filling material; Micro-computed tomography.

INTRODUCTION

Apical surgery is indicated in cases where the conventional endodontic treatment has failed or in cases of impossibility of access to the root canal through the coronary (DEL FABBRO et al., 2016). The technique consists of the surgical removal of the pathological periradicular tissue, followed by resection of the root apex, preparation of a cavity in the apical portion of the root canal, and filling this space with a suitable root-end filling material to seal this region (GUTMANN; HARRISON,1991). This material aims to prevent the infiltration of bacteria and their products, allowing the reorganization of the periodontal ligament space. (JOHNSON,1999; KIM; KRATCHMAN, 2006)

A root-end filling material choice that has adequate biological and physical-chemical characteristics is essential for a successful apical surgery (DEL FABBRO et al., 2016). The material's resistance to displacement and sealing capacity is included among the physical-chemical characteristics. The first material based on calcium silicate was developed in the 1990s to be used as a root-end filling material, called Mineral Trioxide Aggregate. (MTA) (LEE; MONSEF; TORABINEJAD, 1993) and marketed as ProRoot MTA (Tulsa Dental Products, Tulsa, OK, EUA) in gray coloring. Adding a bismuth oxide radiopacifier is the differential component of this product for Portland cement (FUNTEAS; WALLACE; FOCHTMAN, 2003). MTA has hydraulic properties, sealing ability, bioactivity, and biocompatibility (CAMILLERI, 2015a; PRATI; GANDOLFI, 2014).

MTA can be found on the market in gray and white colors. It began to be produced in Brazil in 2001 by Angelus company (MTA Angelus; Angelus Produtos Odontológicos, Londrina, Brasil) in gray and, in 2004, in white (SARZEDA et al.,2019). The sandy consistency makes handling the material and its application challenging. MTA also presents a lengthy setting time and can lead to coronal and gingival darkening (BORTOLUZZI et al.,2007; SARZEDA et al.,2019). However, recent studies suggest that some physical and chemical characteristics should be improved (SHETTY; HIREMATH; YELI, 2017; Ber, Hatton, Stewart, 2007).

New calcium silicate-based materials have been developed and commercialized to improve the characteristics of MTA. These materials have been called ”bioceramic cement” or ”MTA-like” due to their composition similar to MTA (CAMILLERI, 2015a; COOMARASWAMY; LUMLEY; HOFMANN, 2007).

BioRoot RCS (Septodont, Saint- Mouer-Dis-Fosses, France) is a powder (tricalcium silicate, zirconia oxide, povidone) and a liquid (hydrated calcium chloride, polycarboxylate, and purified water). According to the manufacturer, this cement was developed to combine high biocompatibility with better physical properties such as ease of handling, resistance to compression, and better biological. As root-end filling material, 1.5 scoops of powder must be mixed with five liquid drops. Even when manipulated in a denser thickness, it has good biological properties and little cytotoxicity (BONAFÉ, 2021; ALSUBAIT et al.,2018). BioRoot RCS has zirconium oxide as a radiopacifier, which is not correlated with changes in the color of the dental crown (SIBONI et al., 2017). BioRoot RCS can also induce hard tissue formation due to its alkaline pH and high release of calcium ions (SIBONI et al., 2017; SFEIR et al., 2021; DONNERMEYER et al., 2018). A systematic review of in vitro studies showed (Donnermeyer et al., 2018) high biocompatibility, low cytotoxicity, and satisfactory clinical performance.

NeoMTA Plus (Avalon Biomed Inc. Bradenton, FL, USA) is an evolution of MTA Plus (Avalon Biomed Inc. Bradenton, FL, USA). The primary difference is that NeoMTA Plus features tantalum oxide as a radiopacifying agent, while MTA Plus presents bismuth oxide. NeoMTA Plus is formed by mixing powder and liquid. The powder contains tricalcium silicate, dicalcium silicate, tantalum oxide, calcium aluminate, and calcium sulfate. A water-based gel forms the liquid with thinner water-soluble agents and polymers, which provides better handling of the cement (EID et al., 2014; MCMICHAEL; PRIMUS; OPPERMAN, 2016).

Small powder particles also improve handling (Camilleri, Formosa, and Damidot, 2013). Neo MTA Plus also stimulates hard tissue deposition (CAMILLERI, 2015a). It is a biocompatible material with low cytotoxicity (PINHEIRO et al., 2018; QUINTANA et al., 2018).

This study aims to evaluate, using micro-CT, the number of empty spaces (i.g. voids and gaps) of NeoMTA Plus, BioRoot RCS, and MTA (Angelus, Londrina, Brazil) in root-end cavities of bovine teeth.

MATERIAL AND METHODS

Sample size

The sample calculation was based on a previous study (Keleş et al., 2018) for the micro-computed tomography analysis. ANOVA test was used, and the minimum difference between treatment means was 30, standard error 20, three number of treatments, power of 80%, and significance level of 5%.

Sample selection, root canal preparation, and obturation

Thirty bovine mandibular incisors were used. The inclusion criteria were teeth with one canal, straight and with complete root formation, without calcifications, and anatomical diameter equivalent to a #45 K file (Dentsply Sirona, Ballaigues, Switzerland). A double-sided diamond disc (KG Sorensen, Cotia, São Paulo, Brazil) transversally sectioned the roots and standardized their length at 15mm. The working length was determined to be 1mm shorter than the roots. The chemo-mechanical preparation was performed sequentially up to a #80 K File. During all preparation, the canals were irrigated with 10 ml of 2.5% sodium hypochlorite (NaOCl) (Farmácia Marcela, Porto Alegre, RS, Brazil). Next, canals were irrigated with 1 mL of 17% EDTA (Farmácia Marcela) for 3 minutes, followed by 5 mL of 2.5% NaOCl for 60 seconds and 2 mL of saline solution (Farmácia Marcela) and dried with absorbent paper cones #80 (Endopoints Ltda., Paraíba do

Sul, RJ, Brazil). With the cold lateral compaction technique, the canals were filled with a #80 main and accessory gutta-percha cones and zinc oxide-eugenol-based sealer (Endofill, Dentsply). Excess filling material was removed with a heated plugger, and vertical compaction was performed. The cervical portion of the roots was sealed with temporary restorative material (Cavit; 3M, Sumaré, São Paulo, Brazil) and kept in 100% humidity at 37oC.

After seven days, apicoectomy of the apical 3 mm roots was performed at an angle of 90º with the long axis using an ultrasonic tip (Bladesonic; Helse Ultrasonics, Santa Rosa de Viterbo, SP, Brazil). Root-end cavities were prepared with 3mm depth using an ultrasonic tip P1 (Helse Ultrasonic). After preparation, the root-end cavities were irrigated with 2 mL of saline solution and dried with paper points.

Computerized microtomography for allocation in the experimental groups

Scanning was performed with a microtomograph (Shimadzu inspexio SMX-090CT Plus, Kiyamachi-Nijo, Kyoto, Japan). The settings were 70 kV X-ray tube voltage, 800 mA anode current, and 0.019mm/pix voxel size. The scan with 1024x1024 pixels originated in 4800 slices, obtained with acquisition intervals of 1° over 360° of rotation, and the average scan time ranged from 45 to 60 minutes. All samples were digitized after preparation of the root-end cavities for volume measurement and allocation into experimental groups by stratified randomization.

Figure 1 shows a sequence of micro-CT images using the CTAn software. The set of images was exported in. DICOM file format for analysis in the CTAn software (CT-Analyser Version 1.13 Bruker micro-CT Konitch Belgium). The volume of the root-end cavity was measured from the most apical layer until the filling material (i.g. gutta percha endodontic sealer) became visible in the axial sections. Then, the regions of interest (ROI) corresponding to the areas to be considered in the volume calculation were determined.

NeoMTA Plus and MTA were handled according to the manufacturers' instructions. BioRoot RCS was prepared with a powder/liquid ratio of 1.5 spoons for five liquid drops. The root-end cavities filling was performed with a micro applicator. Samples were stored in a humid environment at 37°C for seven days to ensure the complete materials' setting.

Evaluation of marginal adaptation by micro-CT

After seven days of filling the root-end cavities, the samples were scanned again to measure the volumes of empty spaces at the cement/dentin wall interface and inside the cement. The measurement method and parameters used were performed as described above.

Statistical Analysis

The Shapiro-Wilk test was used to verify data distribution. As normal distribution was observed, one-way ANOVA and Tukey's post-hoc tests were used with a significance of 5%.

RESULTS

There was no difference in the initial volume values of the root-end cavities ($P > 0.05$). After the insertion of root-end filling materials, the most significant volumes of empty spaces were observed in the NeoMTA Plus group ($P < 0.05$), with no difference for the BioRoot RCS and MTA Angelus groups ($P > 0.05$). In descending order, the average percentage of empty spaces for the experimental groups was 19.9% for NeoMTA Plus, 6.3% for MTA Angelus, and 4.9% for BioRoot RCS. Table 1 presents the volumes of the root-end cavities before filling with the root-end filling materials, the volume of filling material in the root-end cavities, and the percentage of empty spaces. In contrast, Figure 2 presents the 3D reconstruction of a sample of each experimental group. In red are empty spaces inside the root-end filling material and at the dentin-material interface.

DISCUSSION

Endodontic treatment failures can be caused by microorganisms able to survive in the apical root canal system or outside the apical foramen. Bacteria can form an organized structure in a biofilm around the root. Conventional treatment cannot remove this persistent infection due to its external localization (PURICELLI et al., 2014).

Thus, if the endodontic retreatment by the conventional endodontic treatment is unsuccessful, endodontic periapical surgery is considered the last option before tooth extraction (SERRANO GIMENEZ M; TORRES; ESCODA 2015). This procedure has a success rate between 69% and 93% (PINTO et al., 2020). The European Society of Endodontology defines *periapical surgery success* as the absence of pain, swelling, or other symptoms, satisfactory healing of soft tissues, and radiological evidence of repair of apical periodontitis, including restoration of the periodontal ligament. Occasionally, a radiolucent area such as a "scar" should be followed up to 4 years. (ESE, 2006).

Endodontic periapical surgery consists of two stages. The first is root preparation, which can be performed with drills or ultrasonic instruments, and root-end filling. Root preparation aims to remove the apical portion of the root contaminated with resistant microorganisms, and the second step aims to seal the apex of the remaining canal (LI H et al., 2021) to promote the elimination of apical periodontitis and prevent new contamination (HARGREAVES K; BERMAN L, 2015)

Among the factors that influence the prognosis of endodontic surgery are smoking, location, shape of the tooth, absence or presence of dentinal defects, interproximal bone level, and filling material used (PINTO D et al., 2020). Knowing that the quality of the root canal filling material influences the success of surgical endodontic treatment, it is expected that an ideal root filling material is biocompatible, has dimensional stability, resistance to resorption is bactericidal and bacteriostatic, easy to handle, and an excellent sealing capacity (CHONG; FORD, 2005; PINTO et al., 2020; DEL FABBRO et al., 2016).

This study analyzed the presence of empty spaces (quantifying the volume and percentages of cavities filled with the root-end filling material) both inside the root-end filling material and at the interface between dentin and cement through computerized microtomography, providing a three-dimensional volumetric analysis. It also allows viewing the relationship between the root-end filling material interface with the dentin and filling material interface without sample destruction (GANDOLFI et al., 2013; ZASLANSKY et al., 2011; CAMILLERI et al., 2012)

The results showed that all materials tested (MTA Angelus, NeoMTA Plus, BioRoot RCS) failed after the set period. Empty spaces were present at the cement-dentin interface and in the center of the root-end filling material, as in figure 1. There was a statistical difference between NeoMTA Plus and MTA and BioRoot RCS ($p<0.05$) concerning the number of empty spaces, rejecting the null hypothesis. (Table 1). The flaws in the root-end filling material may allow the reinfection of the apex with residual bacteria from inside the canal, which may migrate to the periodontal ligament due to its flaws. (CAMILLERI et al., 2013). Although MTA and BioRoot RCS have different chemical compositions, setting time and particle size (CAMILLERI, 2015b) (DIMITROVA et al., 2015) and MTA has poor handling properties (SHETTY; HIREMATH; YELI, 2017), while the manipulation and insertion of BioRoot RCS in the root-end cavities was much easier than that of MTA, no statistical differences were found in the percentage of empty spaces of these materials after filling the root-end cavities. The distribution of samples through stratified randomization and the performance of micro-CT to measure the volume of root-end cavities made in bovine teeth ensured the comparability of the groups, which could also be one of the reasons for the absence of statistically significant differences between the materials. In addition, MTA is composed of hydrophilic powder particles that absorb water during powder hydration, causing the expansion of the material during the setting process, providing better interfacial adaptation than MTA Plus (SHETTY; HIREMATH; YELI, 2017) demonstrating good marginal adaptation in the dentin walls (KÜÇÜKKAYA; PARASHOS, 2018). NeoMTA Plus is a calcium silicate-based cement with adequate radiopacity according to ISO Standard 6876:2012 (root canal sealing materials), finer powder particles than MTA, prolonged setting time, and high-water release capacity. Calcium and hydroxyl ions (SIBONI et al., 2017) resulted in greater solubility and mass loss during time than MTA Angelus (QUINTANA et al., 2019; GANDOLFI et al., 2014), and this is directly associated with the voids found in the NeoMTA Plus group. During the setting process, the material was in a humid environment, in contact with cotton rolls moistened with water. Materials containing calcium silicate immersed in deionized water present more voids than materials in contact with biological-type saline solutions (GANDOLFI et al., 2011). Thus, when in contact with body fluids, calcium and hydroxyl ions from the materials combine with phosphate from the periapical fluids, precipitating a superficial layer of calcium phosphate to fill the empty spaces opened at the adaptation interface between the root-end filling material and dentin. (SIBONI et al. 2017)

It is also necessary to describe that other factor, such as viscosity, could influence the presence of empty spaces within the root-end filling materials analyzed. The lower the viscosity, the greater the penetration of the materials into the dentinal tubules and the prepared surface, and the better interfacial adaptation of the root-end filling material (KÜÇÜKKAYA; PARASHOS, 2018). The conditions of the cavity surfaces also influence interfacial adaptation. Although ultrasound works under irrigation, debris remains after preparation requiring additional irrigation, and when not performed, may leave debris inside the cavity (KÜÇÜKKAYA; PARASHOS, 2018).

CONCLUSION

Micro-computed tomography showed that MTA and BioRoot RCS have better interfacial adaptation and presented fewer number of gaps than NeoMTA Plus when used as root-end filling materials.

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FIGURES

Figure 1: - Analysis of specimens on micro-CT using CTAn software. **1A:** blue arrow indicating the interface between filling and retrofilling material, indicating the most coronal layer selected. Orange arrow indicating the most apical layer of the retrocavities; **2B:** Coronal layer selected in axial section.**2C:** Most apical layer of the retrocavity in axial section.

Figure 2 - 3D reconstructions of experimental groups. A- NeoMTA Plus; B- BioRoot; C-MTA Angelus. In red, the empty spaces in the retrofilling material and at the dentin-material interface are represented.

TABLES

Table 1: Materials, respective distributions in the experimental groups and composition.

Material (Manufacturer)	Number of samples per group	Composition
MTA Angelus (Angelus soluções odontológicas, londrina, Paraná, Brasil)	Group 1 (10)	Powder: Tricalcium silicate, dicalcium silicate, tricalcium aluminate, calcium oxide, bismuth oxide; Liquid: Distilled water
BioRoot RCS (Septodont, Saint- Mouer-Dis-Fosses, France)	Group 2 (10)	Powder: Tricalcium Silicate, Zirconia Oxide, Povidone Liquid: Hydrated Calcium Chloride, Polycarboxylate and Purified Water)
NeoMTA Plus (Avalon Biomed Inc., Bradenton, FL, EUA)	Group 3 (10)	Powder: Tricalcium Silicate, Tantalite, Dicalcium Silicate, Calcium Sulfate, Silica; Liquid/Gel: water

Table 2 – Mean and standard deviation (mm^3) of retrocavity volumes before filling with retrofilling materials, volume of filling material in retrocavities and percentage of empty spaces.

	Before (mm^3)	After (mm^3)	Empty spaces (%)
Material NeoMTA Plus	Mean ± SD 2,65 ± 0,40	Mean ± SD 2,16 ± 0,71	% 19,9 % B
BioRoot RCS	2,10 ± 0,09	1,97 ± 0,52	4,9 % A
MTA Angelus	2,17 ± 0,26	1,81 ± 0,46	6,3 % A

Different letters in the column indicate significant differences after one-way ANOVA and Tukey's post hoc test ($P < 0{,}05$).