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Measuring the tooth root canals' diameter, remnant dentin thickness, and the endodontic post-to-dentin distance by CBCT and microscopic analyses: an in vitro study

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Catarina José Dos Santos Machado Soares

Dissertação conducente ao Grau de Mestre em Medicina Dentária (Ciclo Integrado)

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Trabalho realizado sob a Orientação de Doutor Professor Júlio Souza e Co-orientador Dr. Valter Fernandes

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Resumo

O objetivo deste trabalho foi analisar o diâmetro dos canais radiculares dos dentes, a espessura restante da dentina, e a distância espigão-dentina após três tipos de preparação do canal radicular.

Trinta pré-molares humanos extraídos com ápice completamente formado foram armazenados em cloramina a 5% durante 7 dias e depois em água destilada a 4° C durante 7 dias. As coroas anatómicas foram inicialmente seccionadas, e todos os dentes foram tratados endodonticamente. Os grupos de espécimes foram divididos de acordo a cimentação e os diferentes tipos de espigões endodônticos, como se segue: A) ParaPost Fiber LuxTM (Coltène, Whaledent Inc, EUA); B) Rebilda GTTM (VOCO, Alemanha); C) Angelus ExactoTM (Angelus, Brasil). A tomografia computorizada de feixe cônico (CBCT) e análises convencionais de raios X foram realizadas antes e depois da cimentação endodôntica. Após a cimentação, as amostras foram embutidas em resina de poliéster autopolimerizante (Technovit 400TM; Kulzer GmbH, Alemanha) e depois seccionadas a 90 graus em relação ao plano da interface do espigão com o cimento. No início, os espécimes seccionados transversalmente foram inspeccionados por microscopia óptica (OM, Leica DM 2500 MTM, Leica Microsystems, Alemanha) com ampliações entre 10x e 500x. O programa de computador Image J (National Institutes of Health, EUA) foi utilizado para quantificar a percentagem de porosidade. Em seguida, as superfícies foram revestidas com filmes finos de AgPd para análises de microscopia eletrónica de varrimento (SEM) utilizando a unidade SEM (JSM-6010 LV, JEOL, Japão) acoplada à espectroscopia dispersiva de energia (EDS). A espessura e a microestrutura do cimento de matriz resinosa foi avaliada com uma alta resolução, variando de x1000 até x20000 em modo de eletrões secundários (SE) e retrodifundidos (BSE).

A variação da preparação do canal radicular fez com que ocorresse uma diminuição na espessura dos tecidos dentários remanescentes. As análises via CBCT e microscópicas também revelaram uma variação clara do cimento de matriz resinosa à volta de todos os espigões testados. Notou-se um aumento na espessura e no volume do cimento no terço coronal, uma vez que adaptação foi comprometida devido às variações anatómicas e à preparação do canal radicular. Defeitos tais como poros e fissuras micrométricas assim como zonas não preenchidas pelo cimento foram também detetados pela análise microscópica. As análises microscópicas revelaram ainda mais detalhes das fibras e defeitos do espigão na região de interface com a dentina intraradicular.

A preparação invasiva do canal radicular promove uma diminuição na espessura dos tecidos dentários remanescentes e pode aumentar os riscos de fractura radicular catastrófia. A espessura e volume do cimento varia ao longo dos espigões e aumentou desde o ápice do dente até ao terço coronal devido à falta de adaptação do espigão. O aumento de espessura do cimento revela um maior número de defeitos tais como poros e fissuras que são locais de concentração de tensões e início de fissuras como eventual risco de fratura catastrófica.

Palavras-chave: glass fiber-reinforced posts; endodontic posts; intraradicular; endodontics; root canal.

Abstract

The objective of this work was to measure the tooth root canals' diameter, remnant dentin thickness, and the endodontic post-to-dentin distance after three types of root canal preparation. Thirty extracted human premolars with completely formed apex were stored in 5% Chloramine for 7 days and then in distilled water at 4° C for 7 days. The anatomic crowns were initially sectioned, and all teeth were endodontically treated. Groups of specimens were divided according to the cementation with different endodontic post as follow: A) ParaPost Fiber Lux™ (Coltène, Whaledent Inc, USA); B) Rebilda GT™ (VOCO, Germany); C) Angelus Exacto™ (Angelus, Brazil). Cone beam computed tomography (CBCT) and conventional x-ray analyses were performed before and after the endodontic post cementation. After cementation, specimens were embedded in autopolymerizing polyether modified resin (Technovit 400™; Kulzer GmbH, Germany) and then cross-sectioned at 90 degrees relative to the plane of the GFRC post to resin-matrix cement interface. At first, cross-sectioned specimens were inspected by optical microscopy (OM, Leica DM 2500 M™, Leica Microsystems, Germany) at magnification ranging from x10 up to x500. Image J software (National Institutes of Health, USA) was used to quantify the porosity percentage. Then, surfaces were sputter coated with a AgPd thin layer for scanning electron microscopy (SEM) analyses by using SEM unit (JSM-6010 LV, JEOL, Japan) coupled to energy dispersive spectroscopy (EDS). The resin-matrix cement thickness and microstructure of the specimens was evaluated at high magnification ranging from x1000 up to x20000 under (SE) secondary and (BSE) backscattered electrons by using FEGSEM (400 FEG; Fei Quanta, USA).

The shape variation of the root canal preparation caused a decrease in the thickness of the remnant tooth tissues. CBCT and microscopic analyses also revealed a clear variation of resin-matrix cement around all the endodontic GFRC posts. An increase in thickness and volume of resin-matrix cement was noticed at the coronal third since the fitting was compromised due to anatomic variations and root canal preparation. Defects such micro-scale pores, cracks, and voids were also detected by OM and SEM analyses. Microscopic analyses revealed more details of the fibers and defects at the GFRC post to dentin interfaces.

The root canal preparation can promote a decrease in the thickness of the remnant tooth tissues that can increase the risks of clinical failures by fracture. The thickness and volume of resin-matrix cement varied around the endodontic posts. Additionally, that increased from the apex up to the coronal third due to the lack of fitting.

Key-words: glass fiber-reinforced posts; endodontic posts; intraradicular; endodontics; root canal.

Índice Geral

Introduction

Endodontic treatment is a clinical procedure in dentistry to treat teeth when pulp tissue has become irreversibly injured or necrotic due to caries or dental trauma(1–8). The extensive loss of coronal structure compromises the mechanical behavior of endodontically treated teeth, leading to an increased risk of catastrophic fracture. The excessive reduction of the root canal dentin thickness occurs due to caries, access to the canals, over-instrumentation, large tapered endodontic instruments, previous restoration with large-diameter posts, or internal root resorption (7,9,10). Such root canal damage can promote high risks of internal stress-induced fracture since strength is directly proportional to the volume of the remaining dental structure. Previous studies clearly show that a high volume of dentin provides a proper mechanical behavior of the remaining tooth structure(5,8,11,12). In this way, the ferrule effect is a required principle for restoration of endodontically treated teeth that have been submitted to extensive loss of tooth structure(4,7,11,13,14). The use of tooth root intracanal posts become an alternative to retain coronal restorations and to provide a proper distribution of stresses through the tooth tissues by the ferrule effect (1,2,4,6,9,10,15–18,18–20) However, several factors can be detrimental to the endodontically treated teeth such as the thickness of remnant tooth tissues, resin cement layer, and the materials' properties. A mismatch in mechanical properties among synthetic and natural materials can result in concentration of stresses at the interfaces and failures by fracture (1,2,4,6,9,10,15–18,18–20). Thus, the main factor that dictates the strength and long term survival of endodontically treated teeth is mainly related to the volume of remnant tooth tissues structure, selection of materials, cementation, and the integrity of the intracanal(3,4).

Several types of tooth root intracanal posts can be used for the restoration of endodontically treated teeth, such as cast metal posts, ceramic or composite standard-shaped posts, and ceramic or composite custom-made posts (1,1–3,10,13,15,16). Yttria stabilized tetragonal zirconia (3Y-TZP) can be used as standard or custom-made post, considering its high strength (3-point bending strength at ~1200 MPa) and fracture toughness (10-14 $MPa.m^{1/2}$) (17). ast metal and ceramic posts have been used for many years, although some clinical limitations have been related to the over-instrumentation and the mismatch in elastic modulus that increases the risks of catastrophic fractures of endodontically treated teeth (2). In the last years, glass fiber-reinforced composite (GFRC) posts became an alternative material to replace casting metal post systems because they reduced the risk of tooth fracture and less corrosion issues associated with metal posts. Commercially available GFRC posts are composed of glass fibers (60-80wt%) embedded in epoxy resin. Nowadays, GFRC have been the first choice materials considering the balanced elastic modulus (30-50 GPa) and adequate strength(3-point bending strength at around 433-677 MPa (15,16,18). In fact, those values of mechanical properties and the custom-made shape reduce the possibility of catastrophic fractures when an endodontically treated teeth are subjected to occlusal forces (19). Also, studies have shown that GFRC posts promote a restorable fracture pattern within a traumatic incident with a reliable prognosis(20,21). On the other hand, cast metal or 3Y-TZP posts can induce vertical fracture pattern and consequent unrepairable prognosis.

The most common failure of endodontically treated teeth restored with GFRC posts is the debonding from the resin-matrix cement (16,22). Additionally, fractures at the resin cement to dentin can also take place. Thus, the debonding and fractures can be associated with several factors related to materials, anatomic features, root canal shaping, remnant tooth tissues, and cementation (1,2,15,16,19,21–25). Anatomical and restorative design differences along the root canal cause a variation of distance between the post to the intracanal dentin surface. Such space is filled by the resin-matrix cement on cementation, resulting in regions with thick and thin layers of resin-matrix cement
(16,22). Thick layers of resin-matrix cements are prone to defects like macro- and micro-scale pores, cracks, and voids. In this way, the resin-matrix cement layer should be at micro-scale thickness, providing adequate retention and avoiding failures by crack propagation at those defects. According to previous studies, the highest bond strength values of GFRC posts to intracanal surfaces were recorded when an appropriate fitting promoted a resin cement layer thickness at 0.1-0.3 mm (12,16,22).

1.1 Purpose and hypothesis

Measure the tooth root canals' diameter, remnant dentin thickness, and the endodontic post-to-dentin distance after three types of root canal preparation. It was hypothesized that the dentin thickness decreases after invasive tooth root canal preparation and the post-to-dentin distance varies, considering anatomic and shaping factors.

Materials and Methods

2.1. Preparation of endodontically treated teeth

Thirty extracted human premolars (mean root length at 15 mm) with completely formed apex were selected considering root sizes and absence of caries, visible fracture lines, or cracks (Figure 2A). The teeth were selected according to the Schneider method (26) Teeth were stored in 5% Chloramine for 7 days and then in distilled water at 4° C for 7 days. The anatomic crowns were initially sectioned, and all teeth were endodontically treated. The working length was determined by using an endodontic file type K-flexofile ISO # 10 until it is visible through the apical foramen and then 1 mm was subtracted. Mechanic-assisted instrumentation was carried out using reciprocating friction instrumentation with # 25.08 primary files (25mm) (Wave One™, Dentsply-Maillefer, Switzerland) (Figure 2B). The canal was disinfected using 3% sodium hypochlorite solution (NaOCl) between each filing on which permeabilization procedure was performed with 10K file between every 3 reciprocating movements using a syringe with lateral irrigation needle (30G). The canals of the teeth were dried with calibrated paper cones (Dentsply-Maillefer, Switzerland). At last, the canals were filled using calibrated primary gutta percha cones (Dentsply Maillefer, Switzerland) plus single cone technique and vertical compaction with gutta-percha points and embedded within resin-matrix cement (AH-Plus™, Dentsply-Maillefer, Switzerland), as seen in Figure 2D and 2E. Gutta-percha was removed using reamers sizes 2, 3, 4 (Largo Peeso reamers™; Dentsply Intl, USA). A parallel-sided twist drill n° 6 (Parapost Black P-42™; Coltène/Whaledent Inc, USA) was used at low speed. No attempt to generate pressure on instruments against the intracanal dentin surfaces was made when using either Largo reamers or drills. Silicone stops (Dentsply Intl, USA) were placed on each drill to ensure that the canal shaping was achieved as previously determined lengths. The debris generated after each instrumentation were rinsed away with 2 mL of 3% NaOCl. After preparation, teeth root canals were thoroughly dried with paper points.

Fiber glass-reinforced composite (GFRC) posts (Fibio Fiberglass Post™ , Anthogyr, France) were passively placed in the tooth root canals on the cementation. On cementation, a non-enriched ParaBond primer™ (Coltène, Whaledent,USA) was applied to the channel using a fine microbrush at reciprocating friction movement for 30 s. The excess primer was removed using paper tips and a light air stream was applied for 2 s. A mixture of parabond

A & B adhesive™ (Coltène, Whaledent Inc, USA) was applied to the tooth root canal with a fine microbrush at reciprocating friction movement for 30 s. The excessive adhesive layer was removed using paper tips and a light air stream was applied for 2 s. At last, the resin-matrix cement material (ParaCore Automix™, Coltene Whaledent, USA) was applied directly into the intracanal space using a syringe tip. The GFRC post was also coated with the cement and then inserted into the tooth root canal on slight pressure. The excessive cement layer was removed and the cement was then light-cured using a light curing unit at 420-480nm wavelength (LY- A180, Anyang Zongyan Dental Material Co, Ltd, China) for 120 s. Specimens were then assembled with a self-curing acrylic resin (Ortho resin^{tm}; Dentsply, USA) in a short length of polyvinyl chloride mold. The dental inspector apparatus (Ney surveyor, Germany) was used to align the post space with the long axis of the tooth. To increase root retention in the acrylic resin block on push-out test, each root was scratched on the buccal and lingual surfaces with a tungsten carbide bur (27–30).

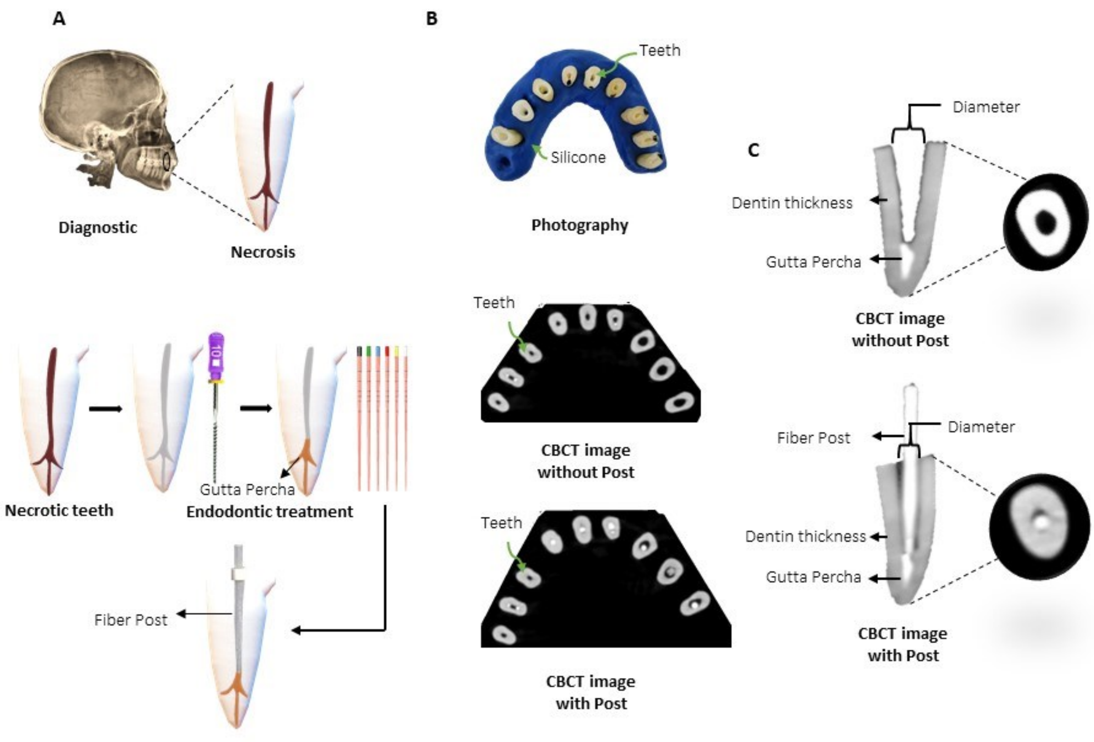

Figure 1. Schematics of the preparation of endodontically treated teeth and measurements.

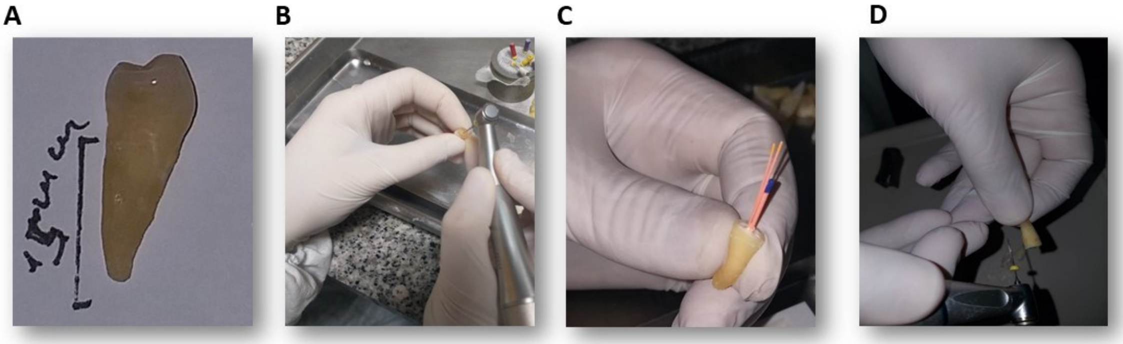

Figure 2. (A) View of the first premolar selected for root canal preparation. (B) Mechanic-assisted instrumentation on reciprocating friction instrumentation with Wave One™ primary # 25.08 files, 25mm (Dentsply-Maillefer, Switzerland). (C) Tooth toot canals filled with cement and guttas perchas on obturation. (D) Preparation for cementation was initiated by enlarging the root canals with Largo Peeso Reamers™ (Dentsply, USA).

2.2. X-ray and CBCT analyses

Periapical X-ray images of tooth roots were acquired by using a Corix 70 Plus KVP X-ray™ (CORAMEX S.A, Mexico). X-ray analyses were performed at 70 kVp and 8 mA for 53" on triangular scanning technique (31).

Cone Beam computed tomography (CBCT) was performed to measure the tooth root canals' diameter, remnant dentin thickness, and the endodontic post-to-dentin distance. The CBCT unit KaVo OP 3D™ (KAVO, Germany) used in this study operates in various configurations, expanding from panoramic-only through cephalometric and three-dimensional capabilities to accomplish three-in-one configuration. The CBCT focal spot was at 0.5 mm, IEC 336 (IEC 60336/2005) while the tube voltage and the tube current were set at 60-95 kV and 3.2–16 mA, respectively. Image voxel size ranged from 80 up to 400 µm and the scanning was performed for 27-45 s. A fast scan time was provided by the complementary metal-oxide semiconductor (CMOS) X-ray detectors. The image volume sizes (H x Ø) were 5x5, 6x9, 9x11, 9x14 cm. Different resolution levels could be evaluated such as: low dose technology scan, standard resolution scan, high resolution scan, and endo resolution scan. CBCT was coupled to the Blue Sky Plan 4™ software program (BlueSkyBio, USA). Two hundred and seventy-five axial cross-sectioned CBCT images were acquired for each tooth root specimen. Cross-sections were evaluated at each tooth root third: coronal, cervical, and apex. Tooth root canal diameter was measured prior to the placement of the endodontic post. Then, the endodontic post-to-dentin distance was measured at mesial, distal, buccal and lingual regions. Navigation and evaluation of the anatomical details was supported by the Blue Sky Plan software as previously reported in literature (32,33).

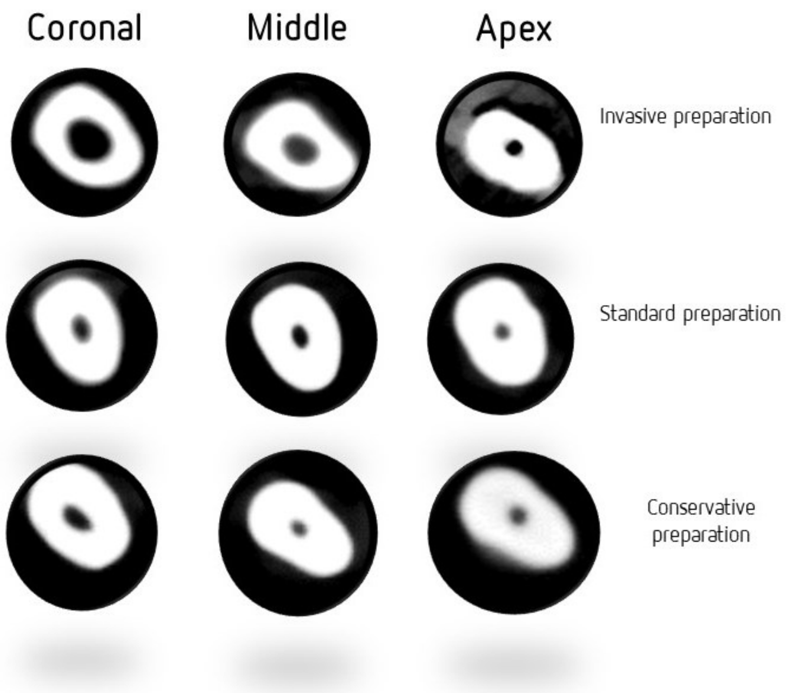

Figure 3. CBCT images of the post to dentin distance at mesial, distal, vestibular and lingual regions (invasive, standard and conservative preparations).

2.3. Microstructural analyses

Randomly endodontically treated teeth specimens were embedded in autopolymerizing polyether modified resin (Technovit 400™; Kulzer GmbH, Germany) and then cross-sectioned at 90 degrees relative to the plane of the GFRC post to resin-matric cement interface. Surfaces were wet ground down to 2400 Mesh using SiC abrasive papers and then polished with 1µm Al_2O_3 particles. Then, surfaces were ultrasonically cleaned in isopropyl alcohol for 10 min and then in distilled water for 10 min (4,7,11).

At first, cross-sectioned specimens were inspected by optical microscopy at magnification ranging from x10 up to x500. Microstructural analyses were performed using an optical microscope (Leica DM 2500 M™; Leica Microsystems, Germany) connected to a computer for image processing, using Leica Application Suite™ software (Leica Microsystems, Germany). A number of six micrographs were acquired at x500 magnification, for each specimen ($n = 18$). The software Adobe Photoshop™ (Adobe Systems Software, Ireland) was used to analyze black and white images, with the black regions representing the pores and the white regions representing the bulk material. Image J™ software (National Institutes of Health, USA) was used to quantify the porosity percentage of the cross-sections. Then, surfaces were sputter coated with a AgPd thin layer for scanning electron microscopy (SEM) analyses by using SEM unit JSM-6010 LV™ (JEOL, Japan) coupled to energy dispersive spectroscopy (EDS). The resin-matrix cement thickness and microstructure of the specimens was evaluated at high magnification ranging from x1000 up to x20000 under (SE) secondary and (BSE) backscattered electrons (33–35).

3. Results

The mean values and standard deviation values recorded for tooth remnant thickness are shown in Figure 4.

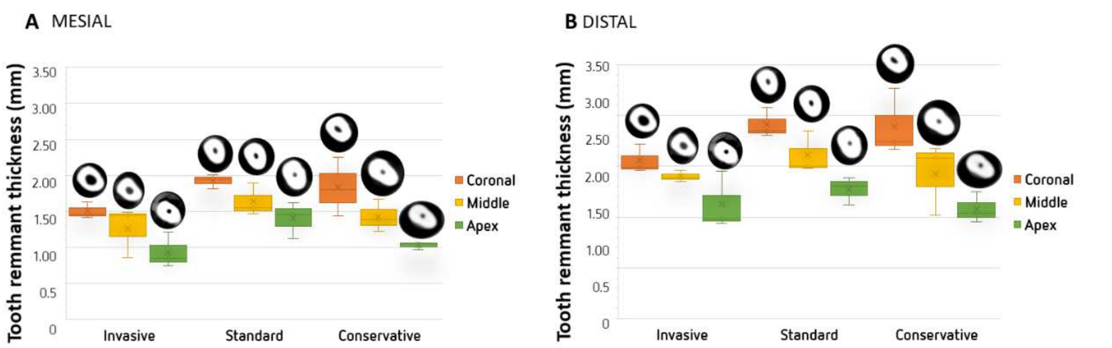

Figure 4. Thickness values of the remnant tooth structure at (A) mesial and (B) distal after invasive, standard, conservative preparation.

On mesial and distal regions, invasive preparation revealed the lowest values of remnant tooth tissues in the three thirds (coronal, middle, and apex) as well as in the different graphs performed compared to the standard preparation and very conservative preparation. At mesial side, the mean values of remaining tooth thickness at the coronal third were recorded at 1.63 mm and 1.49 and 1.21 mm at middle and apical thirds, respectively (Figure 4A). At the distal level, the mean values of remaining tooth thickness were recorded at 1.72, 1.46, and 1.45 mm, at coronal, middle, and apical thirds, respectively (Figure 4B). Thus, thickness of the remnant tooth tissues decreased from the coronal to the apex third region.

Specimens on conservative preparation did not show significant differences when compared to the standard preparation. However, specimens on conservative preparation revealed larger remnant tooth tissues at the mesial and distal regions. At mesial side, the mean values of remaining tooth thickness were recorded at 2.01, 1.89 , and 1.62 mm, at coronal, middle, and apical thirds, respectively (Figure 4A). At the distal side, the mean values of remaining tooth thickness were recorded at 2.08, 1.85, and 1.31 mm, at coronal, middle, and apical thirds, respectively (Figure 4B). As expected, thickness of the remnant tooth tissues also decreased from the coronal to the apex third region.

The mean values and standard deviation values recorded for diameter measurement of tooth root canals after endodontic shaping procedures are shown in Figure 5.

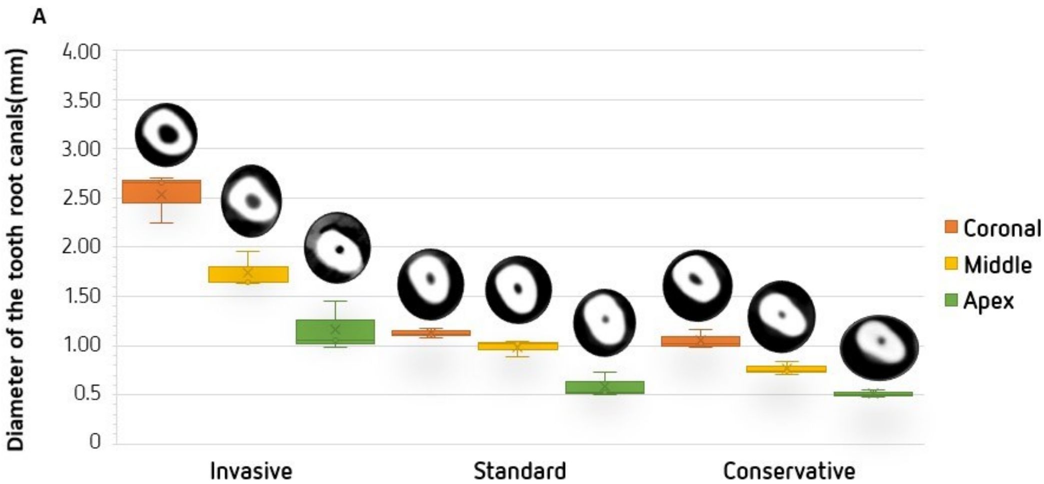

Figure 5. Diameter measurement of the tooth root canals after endodontic shaping procedures (A) after invasive, standard, conservative preparation.

The invasive preparation provided the largest measurements of tooth root canal diameter. The diameter measurement mean values of tooth root canals after endodontic shaping procedures were recorded at 2.07, 1.91 , and 1.45 mm, at coronal, middle, and apical thirds, respectively (Figure 5). Specimens on conservative preparation revealed the smallest mean values of tooth root canal diameter. The diameter measurement mean values of tooth root canals after endodontic shaping procedures were recorded at 1.16, 0.74, and 0.55 mm, for coronal, middle, and apical thirds, respectively (Figure 5).

The mean values and standard deviation values recorded on the post to intracanal dentin distance measurement are shown in Figure 6.

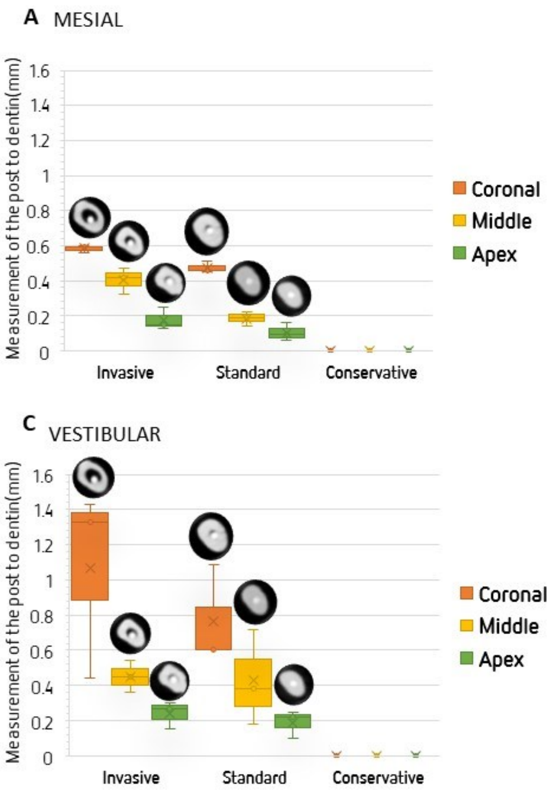

Figure 6. Measurement of the post to intracanal dentin distance at (A) mesial, (B) distal, (C) buccal, and (D) lingual regions after after invasive, standard, conservative preparation.

As seen in Figure 6, the invasive preparation resulted in the largest distance measurements from the post to the tooth root canal surfaces in the different sections (coronal, middle and apex) at mesial, distal, and vestibular. However, specimens on standard preparation showed slightly higher values than that recorded for specimens from invasive preparation at the lingual anatomic side.

At the mesial side of specimens from invasive preparation, the distance mean values from the post to the intracanal dentin surfaces were recorded at 0.59, 0.42, and 0.13 mm, at coronal, middle, and apical thirds, respectively (Figure 6A). At the distal side, the mean values were recorded at 0.45 , 0.36 , and 0.7 mm, at coronal, middle, and apical thirds, respectively (Figure 6B). At the buccal side, the distance mean values from the post to the intracanal dentin surfaces were recorded at 1.43, 0.54, and 0.27mm, respectively, at coronal, middle, and apical thirds, respectively (Figure 6C). Finally, standard preparation revealed slightly higher values than that recorded for the invasive preparation at the lingual side. On the standard preparation, the distance mean values from the post to the intracanal dentin surfaces were recorded at 0.86, 0.59 and 0.25 mm, at coronal, middle, and apical thirds, respectively (Figure 6D).

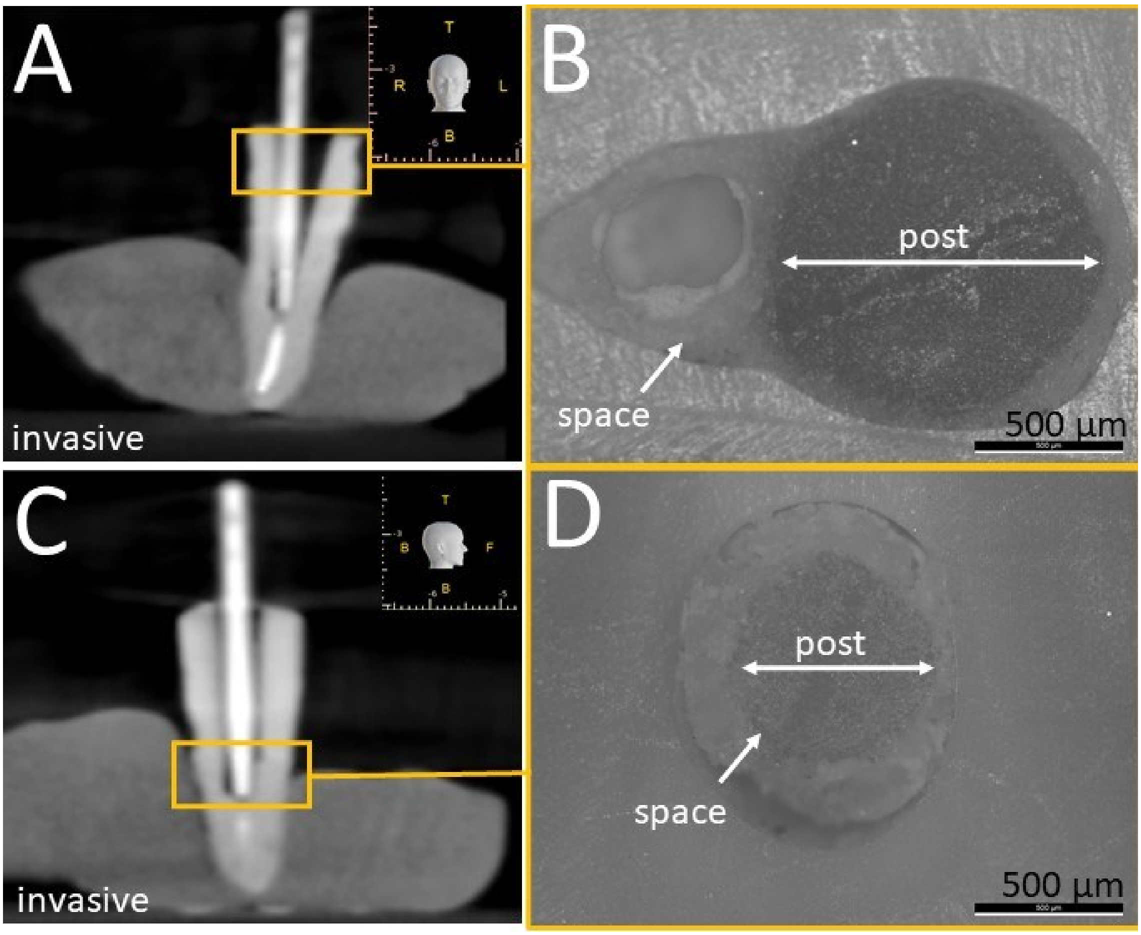

Figure 7. CBCT and microstructural analyses of the post to dentin distance on invasive preparation. (A,C) CBCT images of a sagittal view of the tooth with a post prior to cementation: (A) coronal and (C) apical third zoom view. (B) Optical microscopy of a horizontal cross-section of the post to dentin interface in the (B) coronal and (D) apical third after cementation.

As seen in Figure 7A and B, the invasive tooth preparation promoted a larger destruction of tooth root inner tissues as noticeable by the space from the post to the intracanal dentin surfaces. That was filled by the resin-matrix cement as seen in the microscopic analyses (Figure 7B). In Figure 7C, the post was fitted in the apex third region that decrease the cement layer as seen by the optical microscopy analysis (Figure 7D). The distance from the post to the remaining dentin was much more uniformly than at the coronal level.

Discussion

In this study, the tooth root canal's diameter, remnant dentin thickness, and the endodontic post-to-dentin distance were measured by CBCT and traditional X-ray analyses. Teeth root canals were prepared by invasive, standard, or conservative endodontic procedures and then inspected by CBCT and traditional X-ray analyses. Then, a second set of analyses was performed after placement of GFRC posts. Also, GFRC posts were cemented and cross-sectioned for microscopic analyses. The results of the present study revealed similar thickness values of remnant dentin between conservative and standard canal shaping. Also, the distance of GFRC post to dentin varied considering the anatomic features. The coronal third showed the highest post to dentin distance that provided the highest values of resin cement layer thickness. Thus, the present results support the hypothesis that dentin thickness decreases after invasive tooth root canal preparation and the post-to-dentin distance varies considering anatomic and shaping factors.

Regarding the thickness of remaining dentin on the mesial and distal side, invasive preparation resulted in less remaining dentin compared to the other two tooth root canal shaping. The thin thickness of tooth root tissues promotes a high risk of failures by catastrophic fracture under occlusal loading. A root fracture is a critical type of failure in endodontically treated teeth. Additionally, other several complications can occur during endodontic preparation such as perforations, canal transportation, protrusion, zipper formation, and instrument fracture(34–36). Micro- and macro-scale cracks can appear in the dentin and enamel tissues on reciprocating friction movements over the endodontic treatment (34,36,37)(. Cracks are spots of stress concentration leading to the catastrophic fracture from crack propagation (34,36). Vertical oriented cracks are the worst type of defects to induce fracture in endodontically treated teeth (34). The rotary and reciprocal NiTi endodontic files cause a significant increase in the percentage of microcrack formation when compared to the handheld NiTi file (34,38,39). A study reported that ProTaper Universal™ and WaveOne™ systems showed significant improvements on the basic geometric parameters (area, perimeter, roundness, major diameter, minor diameter, volume, surface area, structure model index) in comparison with the Reciproc™ and SAF™ systems(40). However, all systems performed similarly regarding the amount of worn dentin surfaces when the brushing motion was applied. Neither technique was capable of completely preparing the oval-shaped root canals (40).

At coronal level, the conservative preparation showed similar values of remnant tooth root tissues when compared to the standard procedure, although the conservative approach promoted more remaining tooth root on a high number of anatomical sites, as seen in Figure 4. Regarding the remaining root thickness on the distal side of the tooth, the standard preparation showed higher mean values n at the coronal and the apical level when compared with the invasive approach. Invasive preparation remains the most destructive preparation method considering remaining tooth root thickness (Figure 4- B). In comparison with the present results, previous findings have reported that an adequate selection of instruments and techniques can prevent excessive intracanal dentin damage leading to an enhanced stress distribution through the tooth tissues (34,36,41–43). The stress magnitude must not exceed the strength of the tooth tissues. A study emphasized the difficult instrumentation aspects in larger root canals when compared to small and even complex systems (44). The complexity of the root canal system induces challenges for fulfilling the disinfection and shaping goals of tooth root canal treatment. Such anatomic features reveals clinical limitations since tapered instruments for apical preparation might weaken the tooth root structure at the mesiodistal surfaces (40,45).

The invasive preparation promoted the largest tooth root canal diameter values at the coronal, middle, and apex thirds. However, the standard preparation only promoted a larger tooth root canal diameter than that recorded for conservative preparation at the middle and the apical thirds (Figure 5). On the tooth root canal filling, heating of thermoplastic gutta-percha increases plastic deformation and fitting to the spaces within root canal system with oval configuration . On the cooling of the gutta-percha, shrinkage occurs and results in macro- and micro-scale voids and gaps along the root canal filling. A recent study also proposed that the use of alternative sealing materials to gutta-percha would be beneficial to prevent microleakage when the size of the apex is larger than ISO #50 (45–47). Even though increasing the GFRC post diameter can improve the mechanical behavior, a variation of the resin-matrix cement can occur and therefore risks of fracture would depend on the thickness and number of defects.

Considering the mesial site, standard preparation of tooth root canals provided shorter distances from the post to the intracanal dentin surfaces compared to the invasive one (Figure 6-A). In the distal view, the standard preparation showed higher mean values on the distance from the post to the remaining intracanal dentin in the coronal measurement of the tooth although revealed much lower values at the apical and middle thirds (Figure 6-B). On the buccal side, the invasive preparation at all different thirds revealed high values of distance from the post to the remaining intracanal dentin when compared to the standard preparation. However, there were no statistical differences in the invasive preparation at the apical and middle third of the tooth (Figure 6-C). Burs with the same diameter of standard GFRC posts often allow a good fit of the posts in the tooth root canals although unfortunately shaping and anatomical discrepancies cause variations in the thickness of resin-matrix cement as seen in Figure 7. Therefore, the resin-matrix cement layer tends become thick in clinical situations of misfit of the post to the intracanal space (41)Thick layers of resin-matrix cement are susceptible to the presence of defects such as macro- to nano-scale voids, pores, or cracks (41). Also, the polymerization shrinkage stresses become higher in thick resin-matrix cement layers (41). In this way, failures related to thick resin-matrix cement layer can occur in the oral environment such as fracture at the GFRC post to dentin interface, microleakage, and progressive degradation that can further compromise the post-endodontic adhesive interface (48,49). On the other hand, the literature has reported controversial results on the influence of resin-matrix cement thickness on the adhesion of standard and custom-made endodontic posts to tooth root canal (41). Several studies have suggested that a thick layer of cement may induce displacement of GFRC posts (22,41,50–52) although other studies (53,54) have shown that the bond strength was not influenced by increasing the thickness of the resin-matrix cement layer. Self-adhesive resin-matrix cements have been recently suggested for the cementation of GFRC posts and indirect restorations (41,55) .Such recommendation is based on the fact that self-adhesive cements are not as delicate as conventional resin-matrix cements, which require the previous use of bonding systems(41) .Nevertheless, the use of self-adhesive resin-matrix cement is limited in enclosed spaces, and when the lack of direct visualization and monitoring of adhesive procedures may make the bond strength less reliable in the root dentin(41). A study showed the occurrence of a strong correlation between thick resin-matrix cement thickness and low bond strength values (41). It should be highlighted that clinicians should seek improved cementation techniques providing the lowest resin-matrix cement thickness when around GFRC posts. Furthermore, custom-made procedures involving GFRC posts and resin-matrix composites are strategic approaches to promote an adequate fitting of GFRC posts to different tooth intracanal shape (40,48).

Conclusions

Within the limitations of this *in vitro* study, the following conclusions can be drawn:

- A conservative tooth root canal preparation provides adequate volume of remnant dentin and enamel tissues for further restoration. Also, a conservative approach can promote a proper fitting of the endodontic post to the intracanal dentin;
- The invasive tooth root canal preparation promotes a severe destruction of the tooth root tissues that increases the risks of catastrophic fractures from the propagation of cracks. Also, the fitting of the endodontic post is compromised that increases the occurrence of macro-scale spaces from the post to the intracanal dentin surfaces mainly at the coronal third;
- Macro-scale spaces are filled by resin-matrix cements on cementation although thick cement layers increase the possibility of defects (i.e., cracks and pores) and stress concentration leading to catastrophic fractures;
- Further studies should assess the percentage of defects in different thickness of resin-matrix cements. Additionally, the use of self-adhesive resin cement and flowable resin-matrix composites can be compared considering the application of bonding systems.

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