UNIVERSIDADE ESTADUAL DE CAMPINAS
Faculdade de Odontologia de Piracicaba

MARIO LUIS ZUOLO

Avaliação do preparo de canais radiculares ovalados realizados com instrumentos mecanizados de diferentes cinemáticas. Análise por meio da microtomografia computadorizada

Evaluation of the preparation of oval shaped root canals performed with mecanic instruments with different kinematics. Analysis by means of computed micro tomography

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Tese apresentada à Faculdade de Odontologia de Piracicaba da Universidade Estadual de Campinas como parte dos requisitos exigidos para obtenção do título de Doutor em Clínica Odontológica, na área de Endodontia.

Thesis presented to the Piracicaba Dental School of the University of Campinas in partial fulfillment of the requirements for the degree of Doctor in Clinical Dentistry, in Endodontic Area.

Orientador: Prof. Dr. Alexandre Augusto Zaia

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RESUMO

Um dos principais objetivos do preparo químico-mecânico (PQM) durante o tratamento endodôntico é limpar e modelar o sistema de canais radiculares. Embora distintos, esses objetivos são alcançados simultaneamente durante o preparo do sistema de canais pelo uso de instrumentos e irrigantes. Este estudo avaliou a porcentagem de acúmulo de debris, áreas de canal não tocadas, dentina excisada e a frequência de microfraturas dentinárias após o preparo de canais com os sistemas BioRace, Reciproc, Self-Adjusting File (SAF) and TRUShape, por meio do uso de microtomografia computadorizada. Materiais e Métodos: Quarenta incisivos inferiores com canais únicos e ovalados anatomicamente pareados foram escaneados em um microtomógrafo de raios-X (SkyScan 1.173) com resolução de 14.25 μm e divididos em 4 grupos experimentais (n=10) de acordo com o sistema utilizado para o PQM: BioRace, Reciproc, SAF and TRUShape. Após o PQM os espécimes foram então escaneados novamente e os dados de registro em μCT pré e pós- PQM foram avaliados com relação : i) porcentagem de acúmulo de debris, ii) áreas de canal não tocadas, iii) quantidade de dentina excisada e iiii) frequência de microfraturas dentinárias. Após a verificação da não aderência à curva Gaussiana, os testes de Kruskal-Wallis e Mann-Whitney com correção de Bonferroni foram usados para comparar os sistemas de preparo de acordo com as variáveis descritas, com nível de significância de 5%. Resultados: As técnicas de preparo não influenciaram a porcentagem de acúmulo de debris, uma vez que nenhuma diferença estatisticamente significante foi observada entre os grupos ($P > .05$). O percentual de áreas do canal não tocadas foi significantemente mais alto para o sistema BioRace (32.38%), enquanto os sistemas Reciproc (18.95%) e SAF (16.08%) apresentaram os menores resultados ($P<.05$). O sistema TRUShape (19.20%) apresentou resultados intermediários, não sendo significativamente diferente dos sistemas BioRace, Reciproc ou SAF ($P>.05$). Quanto à remoção de dentina, o sistema Reciproc apresentou os maiores percentuais (4.18%), sendo significativamente diferente dos sistemas BioRace (2.21%) e SAF (2.56%) ($P<.05$). O sistema TRUShape (3.77%) novamente apresentou resultados intermediários, não sendo significativamente diferente dos sistemas BioRace, Reciproc ou SAF ($P>.05$). Todos os defeitos dentinários observados nas imagens de μCT pós-operatórias estavam presentes nas imagens correspondentes pré-operatórias, independentemente do grupo testado, demonstrando não haver correlação entre o PQM e a formação de defeitos. Conclusões: As técnicas de preparo avaliadas não influenciaram a porcentagem de debris acumulados e não induziram à formação de defeitos dentinários. O uso do sistema BioRace resulta em maior quantidade de paredes não tocadas, enquanto o sistema Reciproc produz o maior percentual de remoção de dentina. O sistema SAF resulta em maior percentual de paredes tocadas, porém em menor quantidade de dentina excisada. O sistema TRUShape apresenta resultados intermediários em relação às paredes não tocadas e remoção de dentina. Todos os sistemas testados deixaram paredes não tocadas após o preparo de canais ovalados.

Palavras-chave: Preparo de canais. Remoção de dentina. Área não tocada. Debris. Micro CT. Microfraturas. Defeitos dentinários.

ABSTRACT

Cleaning and shaping the root canals are one of the most important objectives of the endodontic treatment. These objectives are done simultaneously during root canal preparation using instruments and irrigants. This study evaluated the percentage of accumulated hard-tissue debris, untouched canal area, dentin removed and the frequency of dentinal micro-cracks after root canal preparation with the BioRace, Reciproc, Self-Adjusting File (SAF) and TRUShape systems through micro-computed tomographic analysis. Material and Methods: Forty anatomically matched mandibular incisors were scanned with a microtomograph XSkyScan 1.173 with 14.25 mm and assigned to four groups (n = 10), according to the preparation protocol: BioRace, Reciproc, Self-Adjusting File (SAF) and TRUShape systems. After instrumentation, the specimens were re-scanned and the registered pre- and postoperative datasets were examined to evaluate: i) the percentages of accumulated hard-tissue debris, ii) untouched canal areas, iii) quantity of dentine removed and iv) frequency of microcracks. After verification of non-adherence to the Gaussian curve the Kruskal-Wallis and Mann-Whitney U tests with Bonferroni correction were used to compare the variables in the groups with 5% significancy. Results: The preparation techniques did not affect the percentage of accumulated hard-tissue debris since no statiscal difference was observed among the groups (P>.05). The percentage of untouched canal areas was significantly higher for BioRace (32.38%) while the systems Reciproc (18.95%) and SAF (16.08%) presented the lowest results (*P* < .05). The TRUShape system (19.20%) presented intermediate results with no statiscally significant difference from the BioRace, Reciproc or SAF (P>.05). When evaluating dentin removal, the Reciproc system removed more dentine (4.18%) with statiscally significant difference from the BioRace (2.21%) and SAF (2.56%) systems (*P* < .05). The TRUShape (3.77%), system presented again an intermediate results with no significant difference compared to BioRace, Reciproc and SAF systems (P>.05). All dentinal defects observed in the postoperative datasets were already present in the corresponding preoperative images, independently from the tested groups, no statisticall test was necessary to compare the diferent systems. Conclusions: The preparation techniques evaluated did not influenced the percentage of accumulated hard-tissue debris and did not induced the creation of dentinal micro-cracks. The BioRace resulted in more untouched canal areas, and Reciproc produced the higher level of removed dentine. Although it touched more root canal walls, SAF removed less dentine, whereas TRUShape had intermediate results for these same parameters. All of the systems tested left untouched canal walls after the preparation of oval-shaped canals.

Keywords: Canal preparation. Dentin removal. Untouched canal areas. Debris. Micro CT. Micro-cracks. Dentinal defects.

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1 INTRODUÇÃO

A base da terapia endodôntica consiste em tratar dentes comprometidos por patologias pulpares e periapicais, para que o paciente possa recuperar sua estética e função naturais (Peters et al., 2004). Embora o sucesso do tratamento endodôntico dependa de múltiplas variáveis, é reconhecido que um dos fatores mais importantes é o preparo químico mecânico (PQM) do canal radicular, pois este está intimamente ligado com a limpeza, desinfecção e posterior obturação do sistema de canais radiculares (SCR), (Schilder, 1974).

O PQM do canal é influenciado negativamente pela anatomia muito variável dos canais radiculares (Nagy et al., 2003). Detalhes anatômicos, como curvaturas, achatamentos e irregularidades das paredes dos canais, posição espacial do forame, número de canais, dureza variável da dentina, entre outros, representam um desafio para os operadores, visto que os instrumentos endodônticos são manufaturados a partir de fragmentos de metal retos. O resultado é uma distribuição desigual das forças em áreas de contato e a tendência de o instrumento retificar o canal pode resultar em desvios e transporte do canal original, bem como as áreas não tocadas nas paredes radiculares (Roane et al., 1985; Wildey et al., 1992).

Vários instrumentos e procedimentos técnicos têm sido introduzidos com objetivo de contornar os erros de procedimento durante o PQM (Peters e Peters, 2006). Dentre eles, pode ser destacado a introdução de instrumentos fabricados com ligas de Níquel-Titânio (NiTi) e acionados por meio de motores elétricos. O desenvolvimento de sistemas de NiTi para o preparo de canais radiculares se baseia em mudanças no *design* do instrumento, no tratamento da liga NiTi e na cinemática de uso, resultando em avanços no campo da instrumentação de canais (Hülsmann et al., 2005)

Com a evolução das ligas de NiTi foram lançados no mercado vários sistemas que diferem em conicidade, tipo e tamanho da ponta, secção transversal, ângulo de corte e área de escape. As propriedades mecânicas e o comportamento dos instrumentos variam de acordo com a composição química da liga metálica e características de produção, bem como do seu modo de uso durante a instrumentação dos canais (Peters e Peters, 2006).

Dentre os vários instrumentos rotatórios disponíveis para o preparo de canais, o sistema BioRace (FKG Dentaire, La Chaux-de-Fonds, Switzerland) pode ser citado. A sequência BioRace foi especialmente desenvolvida para promover preparo de canais com uso de poucos instrumentos de uso sequencial. O sistema apresenta as seguintes características: a) ponta de segurança não ativa, b) secção transversal triangular sem guia radial, c) ângulos helicoidais variáveis para evitar rosqueamento durante o uso e d) acabamento eletroquímico de superfície. O conjunto básico é composto por 5 instrumentos BRO - 25/08, BR1 - 15/05, BR2 - 25/04, BR3 - 25/06, BR4 - 35/04 e BR5 - 40/04. Os instrumentos BioRace utilizam movimento rotatório contínuo em micromotor elétrico com a velocidade recomendada entre 500-600 rpm com 1Ncm de torque. Existem ainda limas complementares BR4C - 35/02, BR5C - 40/02, BR6 - 50/04 e BR7 - 60/02 (BioRace / FKG *website*).

O sistema Self-Adjusting File (SAF) (ReDent-Nova, Ra'anana, Israel) é um exemplo de instrumento modificado que foi desenhado com objetivo de se adaptar às características anatômicas de cada canal a ser preparado. SAF é um instrumento oco e flexível composto por fios entrelaçados compressíveis que promovem o corte de dentina por abrasão com movimento de vai e vem (Metzger et al., 2010a). Esses instrumentos modificados têm a habilidade de se adaptar às paredes dos canais de forma tridimensional e são usados em conjunção com uma bomba peristáltica que fornece irrigação contínua durante todo o preparo, por isso a solução irrigante é constantemente agitada pela vibração do próprio instrumento (Metzger et al., 2010b). O sistema é composto por apenas 2 instrumentos: SAF 1.5 mm, indicado para canais com diâmetro apical inicial, correspondente a limas ISO 20-35 e SAF 2.0 mm para canais mais amplos com diâmetro inicial apical ISO 35-60. Os instrumentos são fabricados em Niti e foram desenhados para serem utilizados com motor elétrico EndoStation™, contra ângulo de redução RDT3 e bomba peristáltica VATEA (*website* ReDentNova).

O conceito de preparo de canais com instrumento único tem chamado a atenção de inúmeros clínicos e pesquisadores. Dentre os sistemas disponíveis, o Reciproc (VDW, Munich, German) utiliza o princípio do movimento rotatório alternado, isto é, o instrumento é movimentado em uma direção de corte, e depois é solto girando na direção oposta. Os valores de rotação no sentido anti-horário e horário são diferentes e permitem o avanço dos instrumentos com pouca pressão apical. O movimento, assim denominado, recíproco reduz o estresse torsional sobre o instrumento, pois reverte periodicamente a rotação deste, diminuindo dessa forma o risco de fratura (Yared, 2011; Kim et al., 2012). O instrumento Reciproc (VDW, Munich, German) tem secção transversal em forma de S, ponta inativa e é confeccionado com a liga M-Wire. São oferecidos em 3 tamanhos: R 25 (ponta 0,25 mm e conicidade 0,8 mm – 25/0.8), R40 (40/0.6) e R50 (50/0.5). Cumpre ressaltar que essa é a conicidade nos primeiros 3 mm dos instrumentos.

Em D 16, os instrumentos apresentam conicidade: 1.05, 1,10 e 1,17 mm, respectivamente. Os instrumentos são oferecidos em *blisters* estéreis e devem ser descartados após uso único, evitando fratura e contaminação cruzada (VDW *website*). Yared (2011) preconiza que o preparo de canais com Reciproc pode ser realizado sem a necessidade de *glide path* e também não necessita de pré-alargamento cervical, dois conceitos amplamente difundidos e aceitos para instrumentação de canais com instrumentos rotatórios. O instrumento Reciproc, devido ao seu *design* e ao tipo de movimento, pode seguir a via de menor resistência, que é o canal radicular, sem alteração em sua anatomia original e ser utilizado também em movimento de pincelamento, promovendo o pré-alargamento do canal.

Recentemente um novo sistema de instrumentos foi introduzido no mercado, o TRUShape 3D Conforming Files system (Dentsply Tulsa Dental Specialties, Tulsa, OK). Esse novo sistema de limas de NiTi rotatórias tratadas termicamente consiste de um alargador de orifício, Orifice Modifier (20/.08) e 4 limas de conformação Conforming Files (20/.06v, 25/.06v, 30/.06v and 40/.06v) com secção transversal triangular e ponta inativa. A conicidade na porção apical do instrumento é de 0.06 mm, porém devido à sua cinemática especial em forma de varredura, a conicidade geral do instrumento é variável e, por conseguinte, é designada como .06v. De acordo com o fabricante, o *design* do instrumento e sua cinemática permitem que esses instrumentos contatem mais de 75% das paredes dos canais, porém com menos desvios e transporte dos canais e pouca remoção de estrutura dental (Tulsa *website*). Poucos estudos (Bortoluzzi et al., 2015; Peters et al., 2015) ainda foram publicados sobre esse novo sistema. Bortoluzzi et al. (2015), mostraram que o preparo de canais com TRUShape removeu significantemente mais bactérias em canais ovalados, quando comparado às limas Twisted-File (SybronEndo, Orange, CA), porém bactérias estavam presentes nos túbulos dentinários após instrumentação com os dois sistemas.

No entanto, o PQM de canais com formato ovalado ainda representa um desafio para os clínicos, pois nenhuma técnica de preparo tem promovido uma adequada limpeza e desinfecção dos canais, deixando áreas não tocadas nas paredes vestibular e lingual (Wu et al., 2003; Versiani et al., 2011; Versiani et al., 2013; Busquim et al., 2015 BR; De Deus et al., 2010; De Deus et al., 2011; Taha et al., 2010). Esses espaços intocados podem abrigar bactérias, biofilmes e detritos e servir como uma causa potencial de insucesso do tratamento endodôntico (Siqueira et al., 2010; Alves et al., 2011; Paque et al., 2011; De Deus et al., 2015).

Muitas metodologias foram propostas para avaliar as mudanças morfológicas na anatomia do canal após preparo endodôntico, como injeção de silicone (Davis et al., 1968), canais simulados em blocos de resina (Weine et al., 1975), cortes transversais em dentes extraídos (Bramante et al., 1987), análises histológicas (Walton et al., 1976), radiográficas (Southard et al., 1987) e métodos computadorizados (Berutti, 1993).

Apesar de serem extensamente utilizadas ao longo dos anos, essas metodologias apresentam limitações, sendo a principal delas a falta de um grupo controle adequado. A procura por metodologias menos invasivas e mais confiáveis levou à utilização da microtomografia computadorizada (µCT). Essa metodologia possibilita ao pesquisador uma avaliação completa e detalhada da anatomia dental, além disso, possibilita a comparação do mesmo canal radicular antes e depois da instrumentação, sendo cada canal seu próprio controle (Nielsen et al, 1995). O uso dessa tecnologia para avaliação de diferentes parâmetros geométricos e a direção de transporte antes e depois do preparo de canais têm sido cada vez mais utilizados e diferentes pesquisadores atestam sua precisão (Rhodes et al., 2000; Peters et al., 2000, 2001; Bergmans et al., 2001; You et al., 2011; Paqué et al., 2011).

Diante do exposto acima, o objetivo desta pesquisa foi avaliar com auxílio de microtomografia computadorizada (µCT) a qualidade do preparo mecânico de canais ovalados, comparando distintos parâmetros : i) porcentagem de acúmulo de debris, ii) áreas de canal não tocadas, iii) dentina excisada e iiii) frequência de microfraturas dentinárias, após o preparo de canais com os sistemas BioRace, Reciproc, Self-Adjusting File (SAF) and TRUShape.

2 ARTIGOS

2.1 Challenging the shaping ability of four root canal systems in oval-shaped canals

* Artigo submetido ao periódico *International Endodontic Journal* (Anexo 2)

Abstract

Aim To challenge the shaping ability of TRUShape and three other instrumentation systems in oval-shaped canals using micro-computed tomographic analysis.

Methodology Forty anatomically matched mandibular incisors were scanned and assigned to four groups (n = 10), according to the preparation protocol: BioRace, Reciproc, Self-Adjusting File (SAF) and TRUShape systems. After instrumentation, the specimens were re-scanned and the registered pre- and postoperative datasets were examined to evaluate the percentages of accumulated hard-tissue debris, untouched canal areas and dentine removed. Kruskal-Wallis and Mann-Whitney U tests with Bonferroni correction were used to compare the variables in the groups ($\alpha = 5\%$).

Results The preparation techniques did not affect the percentage of accumulated hard-tissue debris ($P = .126$). The percentage of untouched canal areas was significantly higher for BioRace (32.38%), and Reciproc (18.95%) and SAF (16.08%) presented the lowest results ($P < .05$). The Reciproc system removed significantly more dentine (4.18%) compared to the BioRace (2.21%) and SAF (2.56%) systems ($P < .05$). The TRUShape system presented intermediate results for both untouched canal areas (19.20%) and removed dentine (3.77%), with no significant difference compared to BioRace, Reciproc and SAF systems.

Conclusions The preparation techniques resulted in the same level of accumulated hard-tissue debris. Compared to the other tested systems, BioRace resulted in more untouched canal areas, and Reciproc produced the higher level of removed dentine. Although it touched more root canal walls, SAF removed less dentine, whereas TRUShape had intermediate results for these same parameters. None of the systems tested were able to provide optimal shaping ability in oval-shaped canals.

Keywords: Dentin removal. Hard-tissue debris. Micro-CT. Shaping ability. Untouched canal areas.

Introduction

The development of a new generation of nickel-titanium (NiTi) systems for canal preparation relies on changes in instrument design, alloy and kinematics, aiming to optimise the mechanical instrumentation of the root canals (Peters 2004, Hülsmann *et al*. 2005). Most of the available rotary and reciprocating systems have failed to improve debridement of oval-shaped canals (Versiani *et al*. 2013), leaving large areas of untouched canal wall (Peters *et al*. 2001, Versiani *et al*. 2013, De-Deus *et al*. 2015a) and accumulated hard-tissue debris in fins, isthmuses and irregularities within the root canal space (Paqué *et al*. 2009, De-Deus *et al*. 2015b, Versiani *et al*. 2016). Bacteria located in these areas have the potential to remain unaffected and might be responsible for persistent periapical inflammation (Versiani *et al*. 2016).

Recently, a novel heat-treated NiTi rotary system, the TRUShape 3D Conforming Files system (Dentsply Tulsa Dental Specialties, Tulsa, OK, USA) was introduced to the market. It is advertised by the manufacturer as a set of instruments that enables greater dentinal preservation than conventional files, while making contact with nearly 75% of the canal walls (Dentsply Tulsa Dental Specialties website), due to the triangular cross section, a noncutting tip, and a sweeping S-shape along its long axis, resulting in a 0.06 taper in the apical 2 mm and an increasing variable taper from this level denoted as a .06v taper. A recent study showed that root canal preparation with TRUShape instruments removed significantly more bacteria from oval-shaped root canals than the Twisted File rotary system (SybronEndo, Orange, CA, USA) (Bortoluzzi *et al*. 2015), however, to the best of our knowledge, no study has attempted to challenge the shaping ability of this novel system regarding the accumulation of hard-tissue debris, untouched root canal walls and the amount of dentine removed from oval-shaped root canals compared to other preparation systems.

The aim of this study was therefore to compare the percentages of accumulated hard-tissue debris, untouched canal areas and dentine removed after root canal preparation with the BioRace (FKG Dentaire, La-Chaux-de-Fonds, Switzerland), Reciproc (VDW, Munich, Germany), Self-Adjusting File (SAF; ReDent-Nova, Ra'anana, Israel) and TRUShape systems through micro-computed tomographic (micro-CT) analysis. The null hypothesis tested was that there would be no significant difference in shaping outcomes among these four preparation systems.

Materials and methods

Sample size estimation

Based on the results of a previous study (De-Deus *et al*. 2015b), an effect size of 0.9 was estimated and input, together with the parameter alpha-type error of 0.05 and power beta of 0.95, into a one-way ANOVA procedure (G*Power 3.1 for Macintosh; Heinrich Heine, Universität Düsseldorf, Dusseldorf, Germany). A sample size of 28 teeth (7 per group) was indicated as the minimum to reveal statistical significance among groups.

Sample selection and preparation

After local research ethics committee approval, 127 human mandibular incisors were obtained from a pool of teeth. Each tooth was radiographed in both buccolingual and mesiodistal directions. The inclusion criteria was only teeth presenting straight roots (< 5º) (Schneider 1971), a canal ratio of long to short diameter more than 2.5 at the 5 mm level from the root apex and an initial apical size equivalent to a size 10 K-file (Dentsply Maillefer, Ballaigues, Switzerland). As a result, 63 teeth were selected and scanned in a micro-CT device (SkyScan 1173; Bruker-microCT, Kontich, Belgium) operated at 70 kV and 114 mA, using a low resolution (70 µm) to obtain an outline of the root canals. The acquired projection images were reconstructed (NRecon v.1.6.10; Bruker-microCT) providing axial cross sections of their inner structure, and 40 mandibular incisors with similar canal configuration were selected and scanned again at an increased resolution (14.25 µm) with 360° rotation around the vertical axis, a rotation step of 0.5°, a camera exposure time of 7000 milliseconds and frame averaging 5, using a 1.0 mm-thick aluminium filter. Images of each specimen were reconstructed using standardised parameters for beam hardening (40%), ring artefact correction (10) and similar contrast limits. The volume of interest was selected to extend from the cemento-enamel junction to the apex of the root, resulting in the acquisition of 800-900 transverse cross-sections per tooth. The apexes of the teeth were then sealed with hot glue and embedded in polyvinyl siloxane to create a closed-end system (Susin *et al*. 2010).

After access cavity preparation, a glide path was created by scouting a stainless steel size 20 K-file (Dentsply Maillefer) up to the working length (WL), which was established by deducting 1 mm from the canal length. Canals were then matched to create ten groups of four based on morphological elements of the canal (volume, surface area and configuration), and 1 root from each group was randomly assigned to one of the four experimental groups (n = 10) according to the preparation protocol:

BioRace system. BR0 (25/.08), BR1 (15/.05), BR2 (25/.04) and BR3 (25/.06) NiTi rotary instruments were used at 500-600 rpm and 1 N.cm in a crown-down manner (VDW Silver motor; VDW) up to the WL, using a gentle in-and-out pecking motion. After three steady strokes, the file was removed from the canal and cleaned.

Reciproc system. An R25 instrument (25/.08) was moved in the apical direction using a slow in-and-out pecking motion of about 3 mm in amplitude with a light apical pressure in a reciprocating motion (‘RECIPROC ALL’) powered by an electric motor (VDW Silver) until the WL was reached. After three pecking motions, the instrument was removed from the canal and cleaned. The WL was reached in the third wave of instrumentation for all teeth.

SAF system. A 1.5 mm diameter SAF instrument was operated to the WL with an in-and-out motion using an RDT3 head (ReDent-Nova) adapted to a vibrating handpiece (GentlePower Lux 20LP; KaVo, Biberach, Germany). Continuous irrigation with 5.25% NaOCl was applied throughout the procedure at a flow rate of 5 mL/min using a special irrigation apparatus (VATEA; ReDent-Nova).

TRUShape system. Using an electric motor (VDW Silver) pre-set at 300 rpm and 3 N.cm, TRUShape instrument (20/.08) was used with a gentle 2-5 mm in-and-out motion to shape the middle third. TRUShape 20/.06v and 25/.06v instruments were then used with a further 2 to 3 mm amplitude towards the WL. Each tooth was shaped as two canals due to its larger buccal-lingual dimension, as recommended by the manufacturer.

In all groups, the total preparation time was 4 min and included only active instrumentation. Irrigation was performed with a NaviTip needle (Ultradent Products Inc., South Jordan, UT, USA) using 25 mL of 5.25% NaOCl per tooth. At the end of the preparation, passive ultrasonic irrigation was performed for 20 s at 2 mm short of the WL using a size 15 K-file (Dentsply Maillefer). Canals were flushed with 3 mL of 17% EDTA for 5 min and 2 mL of bi-distilled water for 1 min. Aspiration of the irrigant solution was performed at the canal orifice with a SurgiTip (Ultradent Products Inc.)

attached to a high-speed suction pump. All preparation procedures were conducted by an experienced operator, after substantial training with all systems. Root canals were dried with absorbent paper points (Dentsply Maillefer) and the specimens submitted to a postoperative scan and reconstruction, applying the aforementioned parameters.

Micro-CT evaluation

The image stacks of the specimens after preparation were rendered and co-registered with their respective preoperative datasets using an affine algorithm of the 3D Slicer 4.5.0 software (available from http://www.slicer.org) (Fedorov *et al*. 2012). The quantification of accumulated hard-tissue debris was expressed as the percentage of the total canal system volume after preparation for each specimen, and undertaken as described elsewhere (De-Deus *et al*. 2014, De-Deus *et al*. 2015b, Neves *et al*. 2015). The volume of the dentine removed after preparation was calculated by subtracting pre- and postoperative segmented root dentine using morphological operations (Fiji v.1.47n; Madison, WI, USA). The area of untouched canal surface was determined by calculating the number of static voxels (voxels present in the same position on the canal surface before and after instrumentation). The untouched area was expressed as a percentage of the total number of voxels present on the canal surface (Paqué & Peters 2011), according to the formula:

$$\frac{number\ of\ static\ voxels\ \times\ 100}{total\ number\ of\ surface\ voxels}$$

Statistical analysis

The degree of homogeneity (baseline) of the groups regarding root canal volume (mm^3) and surface area (mm^2) was statistically compared using a one-way ANOVA test. Because normality assumptions of the percentages of accumulated hard-tissue debris, untouched canal area and dentine removed after root canal preparation could not be verified (Shapiro-Wilk test; $P < .05$), the results were expressed as medians and compared between groups by Kruskal-Wallis and Mann-Whitney U tests with Bonferroni correction (SPSS v.17; SPSS Inc., Chicago, IL, USA). Significance was set at $\alpha = 5\%$.

Results

Figure 1 shows representative images of the internal anatomy of four mandibular incisors before and after canal preparation with the tested systems.

The degree of homogeneity (baseline) of the groups regarding canal volume and surface area was confirmed ($P > .05$). There was no statistically significant difference in the mean and interquartile ranges (IQR) regarding the percentage of accumulated hard-tissue debris among TRUShape (0.00%, IQR 0.23), BioRace (0.00%, IQR 0.59), Reciproc (0.01%, IQR 0.49), or SAF (0.00%, IQR 0.17) groups ($P > .05$). A significantly higher percentage of untouched canal area was observed after preparation with the BioRace system (32.38%) compared to the Reciproc (18.95%) and SAF (16.08%) systems ($P < .05$). Reciproc removed significantly more dentine (4.18%) than BioRace (2.21%) and SAF (2.56%) ($P < .05$). The TRUShape system showed intermediate results regarding the untouched canal area (19.20%) and the amount of dentine removal (3.77%) with no significant difference compared to the other tested systems ($P > .05$) (Fig. 1). Figure 2 shows a boxplot representation of the median percentages and IQR of the parameters tested (untouched canal areas [a] and removed dentine [b]) after root canal preparation with the BioRace, Reciproc, SAF and TRUShape systems.

Discussion

The current investigation was designed to evaluate the percentages of accumulated hard-tissue debris, untouched canal areas and dentine removed after the preparation of oval-shaped canals of mandibular incisors with BioRace, Reciproc, SAF and TRUShape systems, using micro-CT analysis. Despite natural variations in the morphology of teeth, attempts were made to ensure comparability of the groups regarding root canal morphology. As oval-shaped canals present a challenge to the clinician (Peters 2004, De-Deus *et al*. 2010, Versiani *et al*. 2011), this type of canal configuration was selected. The specimens were balanced with respect to the canal anatomy, volume and surface area through micro-CT screening, enhancing the internal validity of the study and potentially eliminating significant anatomic biases that may confound the outcomes (Peters *et al*. 2001, Versiani *et al*. 2016).

Recently, 3-dimensional non-destructive imaging micro-CT technology has also been used for the quantitative evaluation of hard-tissue debris packed into recesses during canal preparation (Paqué *et al*. 2009, Paqué *et al*. 2011, Paqué *et al*. 2012, Robinson *et al*. 2013, De-Deus *et al*. 2014, De-Deus *et al*. 2015b, Neves *et al*. 2015, Versiani *et al*.

2016). Evidence from these studies indicates that dentine particles cut from the canal walls by endodontic instruments can be actively packed into the anatomical complexities of the canal system, becoming more resistant to removal. In the present study, accumulation of hard-tissue debris occurred regardless of system design and kinematics, in accordance with De-Deus *et al*. (2015b). On the other hand, the present findings disagree with other micro-CT studies, in which preparation with the SAF system resulted in less debris accumulation (Paqué *et al*. 2012), and with a reciprocating system that left significantly more debris within the root canals than a multi-file rotary system (Robinson *et al*. 2013). These contradictory results may be explained by differences in the methodological design. The oval-shaped canals of mandibular incisors were used here, and in those studies (Paqué *et al*. 2012, Robinson *et al*. 2013) a more complex preoperative root canal configuration (mesial canals of mandibular molars) was used. Passive ultrasonic irrigation was also used as a supplementary irrigation protocol in the present study. According to recent research, the activation of the irrigant solution with an oscillating ultrasonic tip after root canal preparation is more likely to remove hard-tissue debris from root canals with a single anatomy (Versiani *et al*. 2016), which may also help to explain the present results.

It is well established that untouched canal areas may be colonised by biofilms and serve as a potential cause of persistent infection, which may compromise the treatment outcome (Alves *et al*. 2011, Dietrich *et al*. 2012). In the current study, the percentage of untouched canal areas and dentine removed were significantly affected by the preparation protocols. Consequently, the null hypothesis tested was rejected. The median percentage of untouched canal walls ranged from 16.08% to 32.38% and none of the tested systems were able to completely debride the dentinal walls, which is in agreement with previous reports (Peters *et al*. 2001, Paqué & Peters 2011, Versiani *et al*. 2013, Bortoluzzi *et al*. 2015, De-Deus *et al*. 2015a). Amongst the tested systems, the SAF and Reciproc systems showed the lowest percentage of untouched canal area. As previously demonstrated (Metzger *et al*. 2010a, Paqué & Peters 2011, Versiani *et al*. 2011, Versiani *et al*. 2013), results from SAF system can be explained as due to its hollow NiTi lattice-like form, which adapts itself to the shape of the root canal, enabling a higher percentage of root canal walls to be touched. The back-and-forth grinding motion of the SAF instrument enables a circumferential removal of only a thin layer of dentine from most of the canal walls (Metzger *et al*. 2010b), which explains the lowest percentage of dentine removed by the SAF system in this study. On the other hand, the low percentage of untouched canal walls and high amount of removed dentine observed after canal preparation with the Reciproc system may be explained by the combination of its reciprocating kinematics, larger taper size (0.08 in the first 3 mm) and design (sharp cutting edges and smaller cross-sectional area), which effect its flexibility and increase its cutting efficiency in a brushing motion (Plotino *et al*. 2014). Similarly, the lower dimensions and cutting efficiency of BioRace instruments compared to Reciproc explain its higher percentage of untouched canal walls and lower amount of dentine removal (Lopes *et al*. 2010).

Root canal preparation with the TRUShape system showed intermediate median results regarding untouched canal areas and dentine removed. Peters *et al*. (2015) reported that TRUShape enables dentine preservation during root canal shaping, and Elnaghy *et al*. (2016) reported a mean percentage of dentine removed of about 2.77%, which contrasts with the 3.77% observed herein. The asymmetric cutting motion of the TRUShape files, which can reach a fluted diameter up to 0.80 mm, might be the basis on which to explain the lack of significance compared to the other groups studied here (Fig. 2).

Like other studies using the non-destructive micro-CT approach (Peters *et al*. 2001, Paqué *et al*. 2012, De-Deus *et al*. 2015a, De-Deus *et al*. 2015b, Versiani *et al*. 2016), the current results highlight the less than ideal ability of currently available preparation systems to prepare this type of root canal configuration. These findings emphasise the importance of irrigation and intracanal dressing procedures in an attempt to compensate for the suboptimal status of the mechanical debridement (Versiani *et al*. 2011, 2013).

Conclusions

Under the conditions of the present study, none of the tested systems were able to provide optimal shaping of oval-shaped canals. Root canal preparation with the BioRace, Reciproc, SAF and TRUShape systems resulted in similar amounts of accumulated hard-tissue debris. More untouched canal areas and dentine removed were observed after preparation with BioRace and Reciproc systems, respectively. SAF touched more root canal walls and removed the least dentine, and TRUShape had intermediate results for these same parameters.

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Figure 1: Representative 2D and 3D reconstructions of the anatomy of mandibular incisors from each experimental group, before and after root canal preparation. (a and b) Buccal and (c and d) lateral views of superimposed specimens before (green) and after (red) root canal preparation in each experimental group; (e) representative cross-sections of the superimposed root canals before (green) and after (red) preparation at the coronal (c), middle (m) and apical (a) thirds.

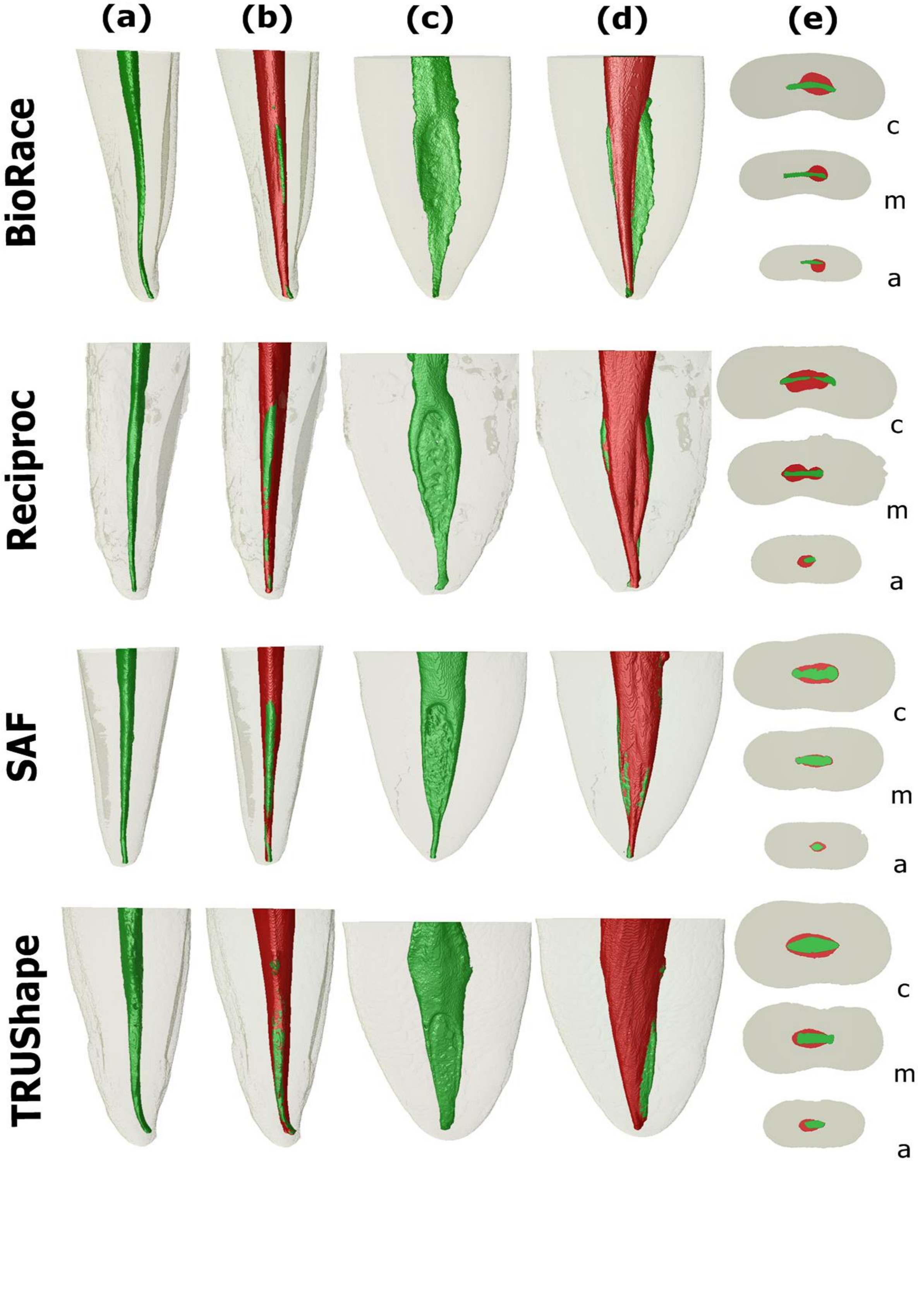
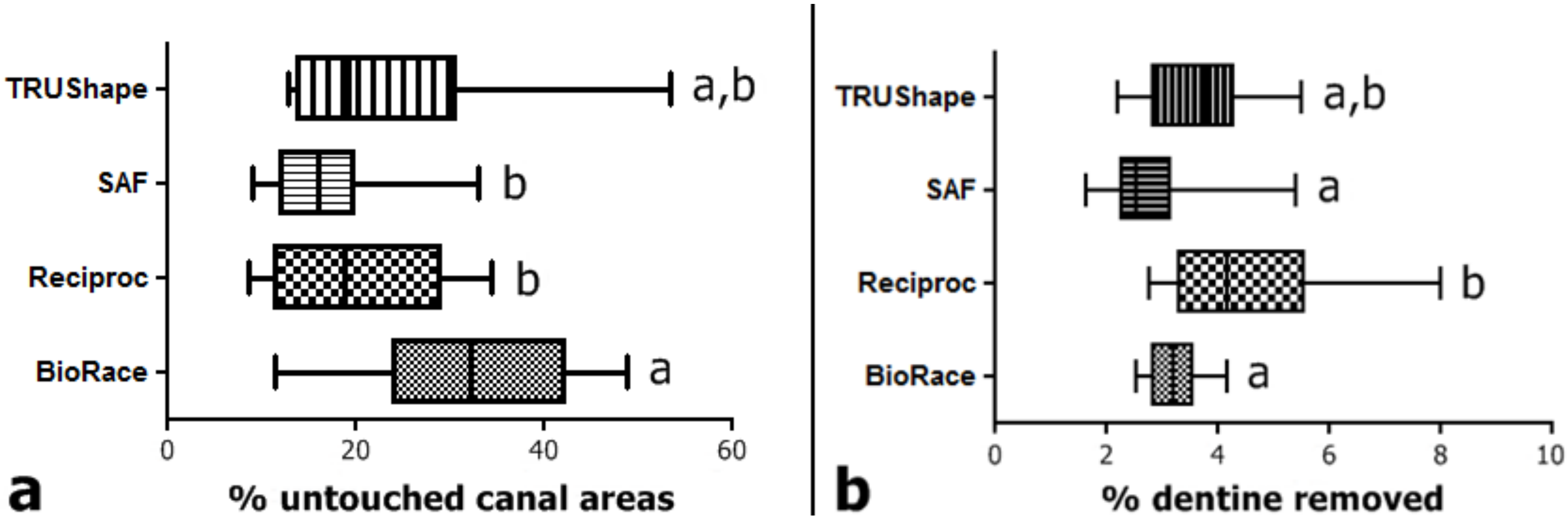


Figure 2: Representative boxplot with the medians (interquartile range) for the percentages of (a) untouched canal areas and (b) dentine removed by each root canal system. The different letters in each graph indicate statistical significance between groups (Mann-Whitney test with a Bonferroni correction; *P* < .05).



2.2 Micro-CT assessment of dentinal micro-cracks after root canal preparation with TRUShape and Self-Adjusting File systems

*Artigo aceito para publicação no periódico *Journal of Endodontics* (anexo 3)

Abstract

Introduction: The aim of the present study was to evaluate the percentage frequency of dentinal micro-cracks observed after root canal preparation with TRUShape and Self-Adjusting File (SAF) systems by means of micro-CT imaging analysis. A conventional full-sequence rotary system (BioRace) and a single-file reciprocation system (Reciproc) were used as reference techniques for comparison due to their known assertive cutting efficiency. **Methods:** Forty anatomically-matched mandibular incisors were selected, scanned at a resolution of 14.25 μm, and assigned to 4 experimental groups (n = 10), according to the preparation protocol: TRUShape, SAF, BioRace and Reciproc systems. After the experimental procedures, the specimens were scanned again and the registered pre- and postoperative cross-section images of the roots (n = 70,030) were screened to identify the presence of dentinal micro-cracks. **Results:** Overall, dentinal defects were observed in 28,790 cross-section images (41.11%). In the TRUShape, Self-Adjusting File, BioRace and Reciproc groups, dentinal micro-cracks were visualized in 56.47% (n = 9,842), 42.38% (n = 7,450), 32.90% (n = 5,826) and 32.77% (n = 5,672) of the slices, respectively. All dentinal defects observed in the postoperative datasets were already present in the corresponding preoperative images. **Conclusion:** None of the preparation systems induced the formation of new dentinal micro-cracks.

Keywords: dentinal defects, instrumentation, micro-cracks, micro-CT, root canal preparation.

Introduction

Vertical root fracture (VRF) is a clinical complication that may lead to tooth extraction (1) and have been described in either treated or non-endodontically treated teeth (2, 3). Over the last few years, several studies have reported a causal relationship between mechanical preparation of the root canal with nickel-titanium (NiTi) instruments and the formation of dentinal micro-cracks (4-8), which may potentially develop into VRF (9).

It has been speculated that the design and the hard-hitting cutting ability of the preparation systems are the main reasons associated with the development of dentinal defects, as they might generate damaging forces towards dentine (10). Recently, a novel heat-treated NiTi system named TRUShape 3D Conforming Files (Dentsply Tulsa Dental Specialties, Tulsa, OK) has been introduced onto the market, claiming to preserve more dentinal structure while providing an optimized canal debridement. The TRUShape system uses the same symmetric triangular cross-section, but displays a proprietary file design which resembles an S-shape configuration, providing an ability to flex within the canal, creating an envelope of motion kinematics (11-13). Another system, which is able to preserve more dentine, is the Self-Adjusting File (SAF; ReDent-Nova, Ra'anana, Israel). The SAF is a hollow file designed as a compressible cylinder composed of a thin NiTi lattice with an abrasive surface. It has the ability to adapt its shape to the root canal anatomy, applying a constant and delicate pressure on the canal walls, which might help to reduce the incidence of dentinal defects (4, 5). This system operates with a continuous flow of irrigant running through the instrument, allowing continuous replacement (8, 14, 15).

No studies have evaluated the incidence of dentinal micro-cracks resulting from the use of the claimed less aggressive cutting instruments (TRUShape and SAF systems) using micro-computed tomographic (micro-CT) imaging technology to date. Therefore, the aim of the present study was to evaluate the frequency of dentinal micro-cracks observed after root canal preparation with TRUShape and SAF systems through micro-CT imaging analysis. A conventional full-sequence rotary system (BioRace; FKG Dentaire, La-Chaux-de-Fonds, Switzerland) and a single-file reciprocation system (Reciproc; VDW, Munich, Germany) were used as reference techniques for comparison due to their known assertive cutting efficiency. The hypothesis tested was that there would be differences in the frequency of dentinal micro-cracks generation between the groups.

Material And Methods

Sample size estimation

Sample size was derived from the effect size of dentinal defects promoted by rotary and reciprocating systems by Bürklein et al. (16), in which the percentage sum of the sample with complete and incomplete dentinal defects varied from 18.3% to 51.6%. Chi-square test family and variance statistical test (G*Power 3.1 for Macintosh; Heinrich Heine, Universität Düsseldorf, Düsseldorf, Germany), with $\alpha = 0.05$ and $\beta = 0.95$, output 8 specimens as the minimum ideal size required for observing the same frequency of instruments-induced defects over dentine.

Sample selection and scanning

After approval of the local Ethics Committee, one hundred and twenty-seven straight mandibular incisors were obtained from a pool of teeth. The specimens were initially inspected with the aid of a stereomicroscope under 12X magnification. The exclusion criteria comprised teeth with pre-existing cracks or not patent to the canal length with a size 10 K-file (Dentsply Maillefer, Baillagues, Switzerland). As a result, 102 specimens were selected and scanned in a micro-CT device (SkyScan 1173; Bruker-microCT, Kontich, Belgium) operated at 70 kV and 114 mA, using a low resolution (70 µm). Then, forty mandibular incisors with a canal ratio of long to short diameter of more than 2.5 at 5-mm level from the root apex were selected and stored in 0.1% thymol solution at 5ºC. These specimens were scanned again at an increased resolution (14.25 µm) performed by 360° rotation around the vertical axis, rotation step of 0.5°, camera exposure time of 7000 milliseconds, and frame averaging of 5, using a 1.0-mm-thick aluminum filter. Images of each specimen were reconstructed (NRecon v.1.6.10, Bruker-microCT) providing axial cross-sections of their inner structure using standardized parameters for beam hardening (40%), ring artefact correction (10) and similar contrast limits. The volume of interest was selected to extend from the cementoenamel junction to the apex of the root, resulting in the acquisition of 800-900 transverse cross-sections per tooth.

Root canal preparation

The apexes were sealed with hot glue and embedded into polyvinyl siloxane to create a closed-end system (17). After access cavity preparation, a glide path was created by scouting a stainless steel size 20 K-file (Dentsply Maillefer) up to the working length (WL), which was established by deducting 1 mm from the canal length. Then, the specimens were randomly assigned to 4 experimental groups (n = 10), according to the following protocols:

TRUShape. Using an electric motor (VDW Silver; VDW) preset at 300 rpm and 3 Ncm, TRUShape instruments were used with a gentle in-and-out motion in the following sequence: 20/.08v (two thirds of the WL), 20/.06v (full WL) and 25/.06v (full WL). The instruments were advanced to the midroot in 2 to 5 mm and then in further 2 to 3 mm amplitudes toward the WL.

SAF. A 1.5-mm diameter SAF instrument was operated to the WL with an in-and-out motion using an RDT3 head (ReDent-Nova) adapted to a vibrating handpiece (GentlePower Lux 20LP; KaVo, Biberach, Germany). Continuous irrigation with 5.25% of NaOCl was applied throughout the procedure at a flow rate of 5 mL/min using a special irrigation apparatus (VATEA; ReDent-Nova).

BioRace. BR0 (25/.08), BR1 (15/.05), BR2 (25/.04) and BR3 (25/.06) NiTi rotary instruments (FKG) were used at 500-600 rpm and 1 Ncm in a crown-down manner (VDW Silver) up to the WL, using a gentle in-and-out pecking motion. After 3 steady strokes, the file was removed from the canal and cleaned.

Reciproc. R25 instrument (25/.08) was moved in the apical direction using a slow in-and-out pecking motion of about 3 mm in amplitude with a light apical pressure in a reciprocating motion (‘RECIPROC ALL’) powered by an electric motor (VDW Silver) until the WL was reached. After 3 pecking motions, the instrument was removed from the canal and cleaned. The WL was reached in the third wave of instrumentation for all teeth.

All experimental procedures were performed by an experienced operator after training with the systems. Irrigation was performed using a total of 40 mL of 5.25% NaOCl per tooth. Apical patency was confirmed with a size 10 K-file after each file use. After preparation, a postoperative micro-CT scan of each specimen was performed using the aforementioned parameters.

Dentinal micro-cracks evaluation

The pre- and postoperative image stacks of the specimens were co-registered using the affine algorithm of the 3D Slicer v.4.5.0 software (available from http://www.slicer.org) (18). Then, the cross-section images of the mandibular incisors were screened from the cementoenamel junction to the apex (n = 70,030) by 3 pre-calibrated examiners. Firstly, postoperative images were analyzed, and the cross-section number in which a dentinal micro-crack had been observed was recorded. Afterward, the preoperative corresponding cross-section image was also examined to verify the existence of the defect. To validate the screening process, image analyses were repeated twice at 2-week intervals; in the case of divergence, the images were examined together until an agreement was reached (19, 20). In this study, dentinal micro-cracks or dentinal defects were defined as all lines observed on the cross-section slice that extended either from the outer root surface into the dentine or from the root canal lumen to the dentine.

Results

Overall, dentinal defects were observed in 28,790 cross-section images (41.11%). In the TRUShape, SAF, BioRace and Reciproc groups, dentinal micro-cracks were visualized in 56.47% (n = 9,842), 42.38% (n = 7,450), 32.90% (n = 5,826) and 32.77% (n = 5,672) of the slices, respectively. All dentinal defects observed in the postoperative datasets were already present in the corresponding preoperative images (Figure 1), indicating that no new micro-cracks were observed after root canal preparation with the tested systems.

Discussion

This *in vitro* study evaluated the incidence of dentinal micro-cracks after root canal preparation with TRUShape, SAF, BioRace and Reciproc systems. To the best of the authors' knowledge, this is the first study assessing the potential correlation between the use of TRUShape and SAF systems and dentinal micro-cracks using a non-destructive imaging method. All of the systems tested herein, which includes a wide range of dentinal cutting ability, did not create any new dentinal micro-cracks; this means that all dentinal micro-cracks appear not to be induced by the mechanical instrumentation of the root canals, regardless of the file design or its cutting efficiency. Therefore, the hypothesis tested was accepted.

The present results markedly contrast with several previous studies that have shown an association between mechanical canal preparation and the creation of dentinal micro-cracks (4, 5, 7, 21, 22). Hin *et al* (4) and Saha *et al* (22) showed that SAF caused cracks in 10% of the specimens. Liu and colleagues (5) observed the presence of a new defect in 5% of mandibular incisors prepared with Reciproc system, whereas Karataş *et al* (7) observed cracks in an increased rate of 11% after instrumentation with Reciproc system. Similarly, Saber & Schäfer (21) found the incidence of dentinal defects to be 26% in the group instrumented with Reciproc system. This discrepancy in the results may be explained by an essential difference in the analytical method used. The current body of evidence correlating mechanical preparation and the development of dentinal micro-cracks is mainly based on root sectioning methods and direct observation by some sort of optical microscopy (4, 5, 7, 21, 22). As previously stated (19, 20), these methods present a meaningful disadvantage related to its own destructive nature, which is probably the main cause of the reported outcomes. Although the control groups using non-prepared teeth in the sectioning studies seemed to validate the experimental design as no dentinal defects were detected, they do not take into consideration the potential damage to dentin produced by the interplay of the mechanical preparation, the chemical attack of the NaOCl-based irrigation and the sectioning procedures (10).

Recently, De-Deus *et al* (19, 20) reported that there was no causal relationship between canal preparation with rotary/reciprocating systems and micro-cracks formation, which is in accordance with the results presented in the current study. The similarities between these studies are related to the use of micro-CT imaging as an assessment tool. Micro-CT non-destructive technology provides the possibility to examine the dentinal tissue before any root canal procedure, which is indeed a very suitable and important feature. It also presents several advantages over the well-established root sectioning approach. While the latter allows the analysis of only a few slices per sample, which may result in a loss of information, the highly accurate micro-CT method permits the evaluation of hundreds of slices per tooth (19, 20). This explains the lower frequency of dentinal micro-cracks observed in the control groups of root-sectioning models, which usually investigate a few slices compared to micro-CT studies (19, 20). Besides, this method enables not only the visualization of pre-existing dentinal defects but also their precise location throughout the root, before and after root canal preparation, improving the internal validity of the experiment as each specimen acts as its own control. In addition, micro-CT technology admits overlapping further experiments on the same specimens, tracking the development of dentinal defects after root canal filling, canal retreatment, post-space preparation and post-removal procedures.

Conclusion

Under the conditions of the current study, it can be concluded that none of the preparation systems induced the formation of new dentinal micro-cracks.

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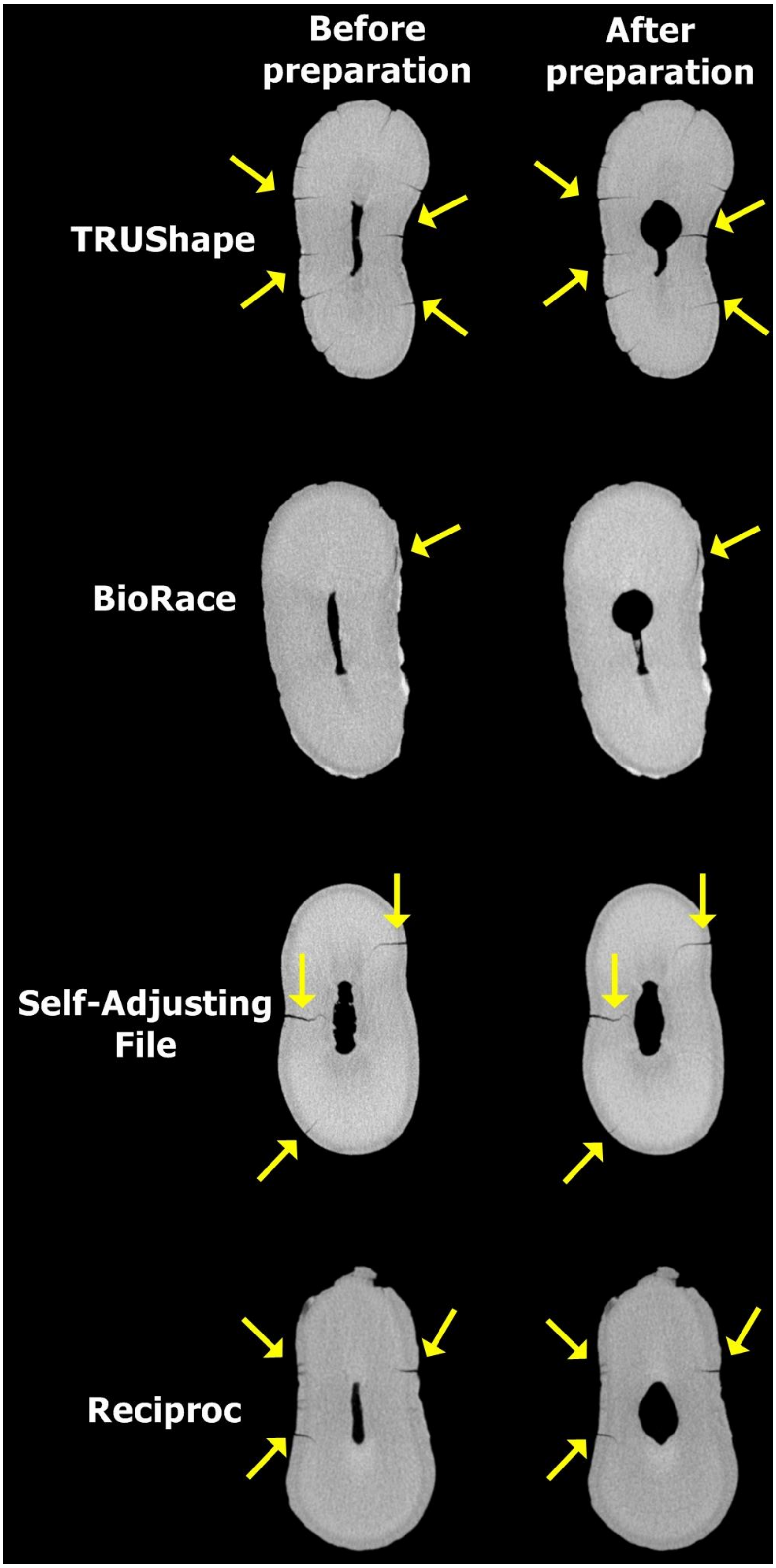
Figure 1. Representative cross-section images of 4 mandibular incisors showing the presence of dentinal micro-cracks (yellow arrows) before and after root canal preparation with TRUShape, BioRace, SAF and Reciproc systems.



3 DISCUSSÃO

3.1 Justificativa da pesquisa

O desenvolvimento de diversos novos instrumentos de NiTi e sua introdução no mercado têm como objetivo principal contornar os erros e limitações durante o preparo de canais e promover avanços nesse campo de conhecimento. Entretanto, mesmo essas novas tecnologias têm se mostrado insuficientes para o correto PQM de canais ovalados (Wu et al., 2003; Versiani et al., 2011; Versiani et al., 2013; Busquim et al., 2015; DeDeus et al., 2010; DeDeus et al., 2011; DeDeus et al., 2015; Taha et al., 2010). O PQM de canais ovalados tem se mostrado parcial, pois fica evidente nas pesquisas que há paredes não tocadas após a instrumentação e remoção incompleta de debris. Bactérias e biofilme bacteriano localizados em áreas não tocadas pelos instrumentos resultam em infecção intracanal persistente e podem influenciar negativamente o índice de sucesso do tratamento endodôntico. (Siqueira et al., 2010; Alves et al., 2011).

Nesse estudo foram selecionados incisivos inferiores com raízes retas e achatadas no sentido próximo proximal, apresentando canais com mais de 2,5 x de diâmetro no sentido vestíbulo lingual, quando comparados ao sentido mésio distal nos últimos 5 mm a partir do vértice radiográfico. Portanto, os dentes dessa amostra podem ser considerados como canais ovalados. (Wu et al., 2003; Versiani et al., 2011; Versiani et al., 2013)

A microtomografia computadorizada (μCT) tem sido amplamente utilizada para avaliação da qualidade do preparo de canais. Essa metodologia não invasiva possibilita a comparação do mesmo canal radicular antes e depois da instrumentação, de maneira tridimensional, permitindo o estudo de diferentes parâmetros anatômicos e geométricos, como por exemplo, a porcentagem de debris acumulados, variações de área e volume dos canais e presença de microfraturas. (Nielsen et al., 1995; DeDeus et al., 2014; DeDeus et al., 2015). Uma importante característica dessa metodologia explorada nesse estudo foi a possibilidade de utilização de espécimes pareados em termos de anatomia interna, volume e área do espaço intracanal. Esse processo de triagem para escolha de espécimes morfologicamente semelhantes e sua distribuição igualitária entre os grupos teve como objetivo melhorar a validade interna do estudo e eliminar o possível viés anatômico, que poderia exercer influência negativa nos resultados finais (Peters at al., 2001; De Deus, 2015).

Dentre os vários sistemas de limas rotatórias de NiTi lançados para a especialidade, o sistema TRUShape 3D Conforming Files system (Dentsply Tulsa Dental Specialties, Tulsa, OK) é um dos mais recentes. Segundo o fabricante, o *design* do instrumento aliado à sua cinemática de trabalho resulta em preparos de canais com menor incidência de desvios apicais, remove uma menor quantidade de dentina, embora contatando mais de 75% das paredes dos canais, sendo indicado especialmente para canais com geometrias irregulares. Poucos estudos até agora têm avaliado essas propriedades e comparado a performance desses novos instrumentos com outros disponíveis no mercado. (Peters et al., 2015; Bortoluzzi et al., 2015; Shen et al., 2016; Coelho et al., 2016). Portanto, um estudo avaliando a porcentagem de debris acumulados, áreas de canais não tocadas, dentina excisada e incidência de microfraturas, durante o preparo de canais ovalados, comparando esse novo instrumento TRUShape com os sistemas BioRace, Reciproc e SAF, parece estar justificado.

3.2 Debris acumulados

Vários estudos atestam que partículas de dentina excisadas por meio de instrumentos endodônticos durante o preparo de canais podem ficar impactadas nas irregularidades anatômicas das paredes do canal, tornando difícil sua remoção (Paqué et al., 2009; De Deus, 2015; De Deus, 2014; Paqué et al., 2012; Paqué et al., 2011; Robinson et al., 2013). Nesse estudo, o acúmulo de debris ocorreu nos quatro grupos estudados, independentemente do modo de atuação dos instrumentos, sem diferenças estatisticamente significantes entre os grupos. De Deus et al. (2015) também reportaram os mesmos resultados, quando comparando dois sistemas de lima única, WaveOne (Dentsply Maillefer, Baillaigues, Switzerland) e Reciproc (VDW, Munich, Germany) com um sistema de limas múltiplas, BioRaCe (FKG Dentaire, La-Chaux-de-Fonds, Switzerland).

Entretanto, outros estudos utilizando microtomografia reportaram resultados diferentes. Paqué et al. (2012) concluíram que canais preparados com o sistema SAF resultaram em menor acúmulo de debris, quando comparados ao sistema ProTaper Universal (Dentsply Maillefer, Ballaigues, Switzerland). Robinson et al. (2013) também reportaram que o sistema de lima única WaveOne deixou mais debris acumulados em paredes de dentina, quando comparado ao sistema de limas múltiplas Pro Taper Universal. Os resultados contraditórios desses estudos podem ser explicados por diferenças metodológicas. Este estudo utilizou canais ovalados em incisivos inferiores, enquanto os estudos mencionados utilizaram canais mesiais de molares inferiores. As diferenças anatômicas entre esses distintos grupos de dentes impedem, dessa forma, uma comparação direta de resultados.

Outra diferença importante que pode justificar os resultados contraditórios é que, neste estudo, utilizou-se irrigação ultrassônica passiva ao final do protocolo de preparo, tal procedimento pode ter facilitado a remoção de debris como demonstrado em outros trabalhos (Lee et al., 2004; Gutarts, 2005). Além disso, chama a atenção o pequeno volume de solução irrigante utilizada por Robinson (et al., 2013) em sua pesquisa, um a dois ml a cada troca de instrumento, enquanto neste estudo utilizou-se um volume total de 25 ml de NaOCl, seguido de irrigação ultrassônica passiva por 20 segundos e depois 3 ml de EDTA por 5 minutos e como irrigação final de 2 ml de água bidestilada.

3.3 Áreas de canal não tocadas / Quantidade de dentina excisada

Está bem estabelecido na literatura que áreas de canais que não foram tocadas durante o preparo químico mecânico podem servir de abrigo para colonização bacteriana e contribuir para a persistência da infecção endodôntica. (Alves et al., 2011; Dietrich et al., 2012). Nesse estudo todos os grupos exibiram áreas de canal não tocadas, indicando que nenhum sistema estudado foi capaz de promover uma limpeza completa das paredes dentinárias, o que está de acordo com outros estudos previamente publicados (Versiani et al., 2013; De Deus, 2015; Bortoluzzi et al., 2015; Siqueira et al., 2010; Paqué e Peters, 2011).

Entre os sistemas testados, os grupos SAF e Reciproc foram os que exibiram uma porcentagem mais baixa de paredes não tocadas, 16.08% e 18.95%, respectivamente, quando comparados aos grupos BioRace (32.38%), com diferença estatisticamente significante. O sistema TRUShape (19.20%) apresentou resultados intermediários, não sendo significantemente diferente dos sistemas BioRace, SAF e Reciproc

O sistema Reciproc removeu mais dentina (4.18%) em comparação com os outros sistemas avaliados, sendo significativamente diferente dos sistemas BioRace (2.21%) e SAF (2.56%) ($P<.05$). O sistema TRUShape (3.77%) novamente apresentou resultados intermediários, não sendo significativamente diferente dos sistemas BioRace, Reciproc ou SAF ($P>.05$).

Como demonstrado em outros estudos (Paque e Peters, 2011; Versiani et al., 2011; Versiani et al., 2013; Metzger, 2010), os resultados superiores com o sistema SAF podem ser explicados por causa do *design* do instrumento constituído por uma trama de metal oca, que tem a capacidade de se adaptar às paredes do canal. Além disso, sua cinemática que utiliza movimentos de raspagem no sentido vai e vem pode facilitar o corte de dentina circunferencial mesmo em canais mais irregulares (Metzger, 2010a).

Com respeito ao sistema Reciproc, a baixa porcentagem de paredes não tocadas e uma maior quantidade de dentina removida observada após o preparo de canais pode ser explicada pela cinemática do instrumento que corta dentina com movimentos alternados reciprocantes e pelo *design* do instrumento que apresenta duas características distintas: a) grande conicidade (0.08 mm) nos 3 mm finais do instrumento, e b) arestas com ângulos agudos de corte e pequena área de secção transversal em forma de S. Essas características de *design* influenciam na flexibilidade do instrumento e aumentam sua eficiência de corte, quando utilizadas em movimentos de pincelamento contra as paredes dos canais (Plotino et al., 2014).

Da mesma maneira, as pequenas dimensões e a menor capacidade de corte dos instrumentos Biorace, quando comparados aos do sistema Reciproc, podem explicar os resultados desse estudo, que apontam diferenças entre os dois grupos, em que o grupo BioRace deixou uma maior porcentagem de paredes não tocadas e removeu uma menor quantidade de dentina após a instrumentação (Lopes et al., 2010).

Preparos de canais com o sistema TRUShape apresentaram resultados intermediários com respeito a paredes não tocadas e remoção de dentina sem diferenças estatiscamente significante, quando comparados aos outros grupos. Em estudo recente, Peters (et al., 2015) preparando canais mesiais de molares inferiores reportaram que o uso do instrumento TRUShape promoveu boa conservação de dentina e ausência de transporte do canal principal. Elnaghy et al. (2016) reportaram uma porcentagem de 2,77% de dentina removida durante o preparo de canais radiculares curvos, porém comparações com esse estudo não podem ser feitas devido às diferenças na metodologia empregada.

3.4 Frequência de microfraturas dentinárias

Os resultados desta pesquisa estão em marcante contraste com inúmeros artigos, que têm demonstrado uma associação positiva entre o preparo mecanizado de canais e o aparecimento de microfraturas dentinárias (Hin et al., 2013; Liu et al., 2013; Karatas et al., 2016; Saber e Schafer, 2016; Saha et al., 2016) Neste estudo, as mesmas microfraturas observadas após a instrumentação dos canais já haviam sido previamente detectadas nas tomadas de micro Ct pré-operatórias, portanto, nenhuma nova microfratura foi induzida após o preparo de canais com os sistemas testados.

As discrepâncias entre os estudos de Hin (et al., 2013) e Saha (et al., 2016), que apontam um aumento na incidência de microfraturas na casa de 10% nos casos de uso da SAF, dos estudos de Liu et al. 2013, Karatas (et al., 2016), Saber e Schafer (2016), que relatam um aumento entre 5% a 26% na incidência de microfratura após uso de limas Reciproc, e os resultados dessa pesquisa podem ser explicados pelo tipo de metodologia utilizada. Nos estudos citados acima, a correlação positiva entre preparo mecanizado e aparecimento de microfraturas está baseada em metodologias que empregam o corte de raízes e a observação com diversos tipos de microscópios ópticos. Esses métodos empregados têm como principal desvantagem seu caráter destrutivo durante o processo de corte dos dentes, o que também pode influenciar no aparecimento de microfraturas (De Deus, 2014; De Deus, 2015).

Os resultados deste trabalho estão em concordância com os de De Deus et al. (2014) e De Deus et al. (2015), que não observaram uma relação de causa e efeito entre preparos mecanizados rotatórios ou reciprocantes e o aparecimento de microfraturas. A similaridade de resultados entre os estudos está relacionada ao uso de microtomografia para análise dos espécimes. Essa tecnologia permite a avaliação tridimensional dos espécimes antes e depois do preparo dos canais, utilizando uma metodologia não invasiva, sem necessidade de cortes de dentes. Além disso, a tecnologia de micro Ct permite a avaliação de centenas de cortes por dente. Neste estudo foram analisados entre 800-900 cortes transversais de cada dente tratado. De maneira geral, defeitos dentinários foram observados em 28.790 imagens transversais, o que corresponde a 41,11% da amostra. Não houve diferença entre os grupos TRUShape, SAF, BioRace e Reciproc, onde microfraturas foram observadas em 56.47% (n = 9,842), 42.38% (n = 7,450), 32.90% (n = 5,826) e 32.77% (n = 5,672) dos cortes respectivamente. Todos os defeitos dentinários observados nas imagens pós-operatórias já estavam presentes nas imagens pré-operatórias correspondentes.

4 CONCLUSÕES

De acordo com a metodologia utilizada neste estudo, pode-se concluir que:

1) As técnicas de preparo avaliadas não influenciaram a porcentagem de debris acumulados.
2) Todos os sistemas testados deixaram paredes não tocadas após o preparo de canais ovalados. O uso do sistema BioRace resulta em maior quantidade de paredes não tocadas, enquanto o sistema Reciproc produz o maior percentual de remoção de dentina. O sistema SAF resulta em maior percentual de paredes tocadas, porém em menor quantidade de dentina excisada. O sistema TRUShape apresenta resultados intermediários em relação às paredes não tocadas e remoção de dentina.
3) Nenhum sistema testado induziu a formação de microfraturas dentinárias.

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ANEXOS

ANEXO 1: COMITÊ DE ÉTICA

COMITÊ DE ÉTICA EM PESQUISA
FACULDADE DE ODONTOLOGIA DE PIRACICABA
UNIVERSIDADE ESTADUAL DE CAMPINAS

CERTIFICADO

O Comitê de Ética em Pesquisa da FOP-UNICAMP certifica que o projeto de pesquisa **"Avaliação do preparo de canais radiculares curvos realizados com instrumentos rotatórios e reciprocantes. Análise por meio da microtomografia computadorizada "**, protocolo nº 114/2014, dos pesquisadores Mario Luis Zuolo e Alexandre Augusto Zaia, satisfaz as exigências do Conselho Nacional de Saúde - Ministério da Saúde para as pesquisas em seres humanos e foi aprovado por este comitê em 26/03/2015.

The Ethics Committee in Research of the Piracicaba Dental School - University of Campinas, certify that the project **"Evaluation of the shaping ability of reciprocating and rotary instrumentation in curved root canals assessed by microcomputed tomography"**, register number 114/2014, of Mario Luis Zuolo and Alexandre Augusto Zaia, comply with the recommendations of the National Health Council - Ministry of Health of Brazil for research in human subjects and therefore was approved by this committee on Mar 26, 2015.

Prof. Dr. Jacks Jorge Junior
Secretário
CEP/FOP/UNICAMP

Prof. Dr. Felippe Bevilacqua Prado
Coordenador
CEP/FOP/UNICAMP

Nota: O título do protocolo aparece como fornecido pelos pesquisadores, sem qualquer edição
Notice: The title of the project appears as provided by the authors, without editing

ANEXO 2: SUBMISSÃO PARA INTERNATIONAL ENDODONTIC JOURNAL

International Endodontic Journal

International Endodontic Journal
The Official Journal of the British Endodontic Society and the European Society of Endodontology

Challenging the shaping ability of four root canal systems in oval-shaped canals

Journal:	*International Endodontic Journal*
Manuscript ID	IEJ-16-00768
Manuscript Type:	Original Scientific Article
Keywords:	dentine removal, hard-tissue debris, micro-CT, shaping ability, untouched canal areas

ANEXO 3: APROVAÇÃO PARA PUBLICAÇÃO NO JOURNAL OF ENDODONTICS

From: THE JOURNAL OF ENDODONTICS
<support@elsevier.com>
Date: 2016-11-15 10:03 GMT-03:00
Subject: Acceptance of JOE Manuscript
To: endogus@gmail.com, itrossi@gmail.com

Ref.: Ms. No. JOE 16-909R1
Micro-CT assessment of dentinal micro-cracks after root canal preparation with TRUShape and Self-Adjusting File systems

Dear Dr. De-Deus,

I am pleased to inform you that your manuscript has now been accepted for publication in Journal of Endodontics.

You will soon be contacted by our publisher to review the galley proofs.

When your paper is published on ScienceDirect, you want to make sure it gets the attention it deserves. To help you get your message across, Elsevier has developed a new, free service called AudioSlides: brief,webcast-style presentations that are shown (publicly available) next to your published article. This format gives you the opportunity to explain your research in your own words and attract interest. You will receive an invitation email to create an AudioSlides presentation shortly.

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[2]

Thank you for submitting this manuscript. I look forward to seeing it published soon.

With kind regards,

Ken Hargreaves
Editor
Journal of Endodontics

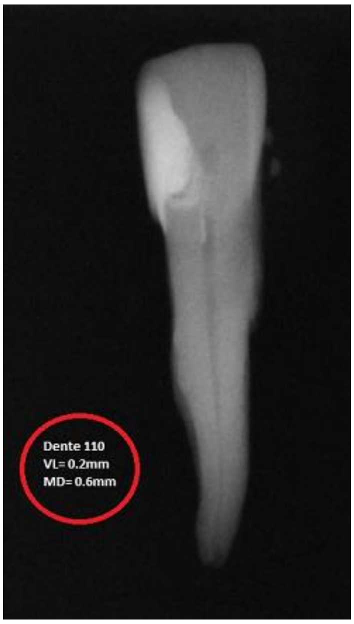
ANEXO 4: MATERIAIS E METODOS

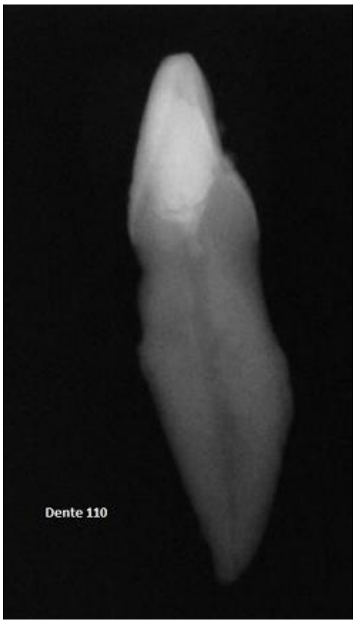
Estimação do tamanho da amostra

Baseado em estudo prévio (De-Deus *et al*. 2015b) uma amostra composta por 28 dentes (7 por grupo) foi indicado como minima para revelar diferenças estatisticamente significantes entre os grupos (tamanho de efeito de 0,9 foi estimado e computado juntamente com o parâmetro de erro tipo alfa de 0,05 e potência beta de 0,95, utilizando ANOVA) com auxilio do software específico (G*Power 3.1 for Macintosh; Heinrich Heine, Universität Düsseldorf, Dusseldorf, Germany)

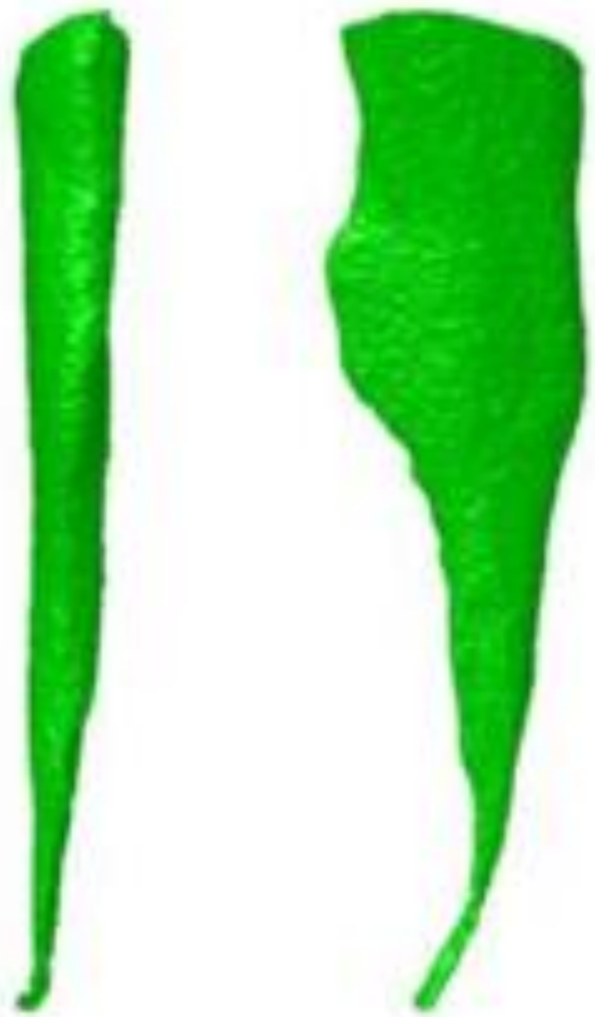
Seleção dos espécimes e preparo

Após aprovação do conselho de ética, 127 incisivos mandibulares humanos foram selecionados de uma amostra de dentes extaidos . Cada dente foi radiografado nos sentidos mésio-distal (MD) e vestibulo-lingual (VL). O critério de inclusão inicial foi: dentes com raizes retas e canais únicos (< 5º) (Schneider 1971), mais de 2.5 mm de diferença entre os sentidos MD e VL a partir de 5 mm antes do apice e após acesso endodontico um diametro apical mínimo equivalente a uma lima 10 tipo – K.





Como resultado 63 dentes foram selecionados e escaneados no micro-CT (SkyScan 1173; Bruker-microCT, Kontich, Belgium) usando baixa resolução (70 kV 114 mA, 70 µm) para obter um contorno dos canais radiculares. As imagens obtidas foram reconstruidas (NRecon v.1.6.10; Bruker-microCT) proporcionando secções transversais axiais da estrutura interna dental.



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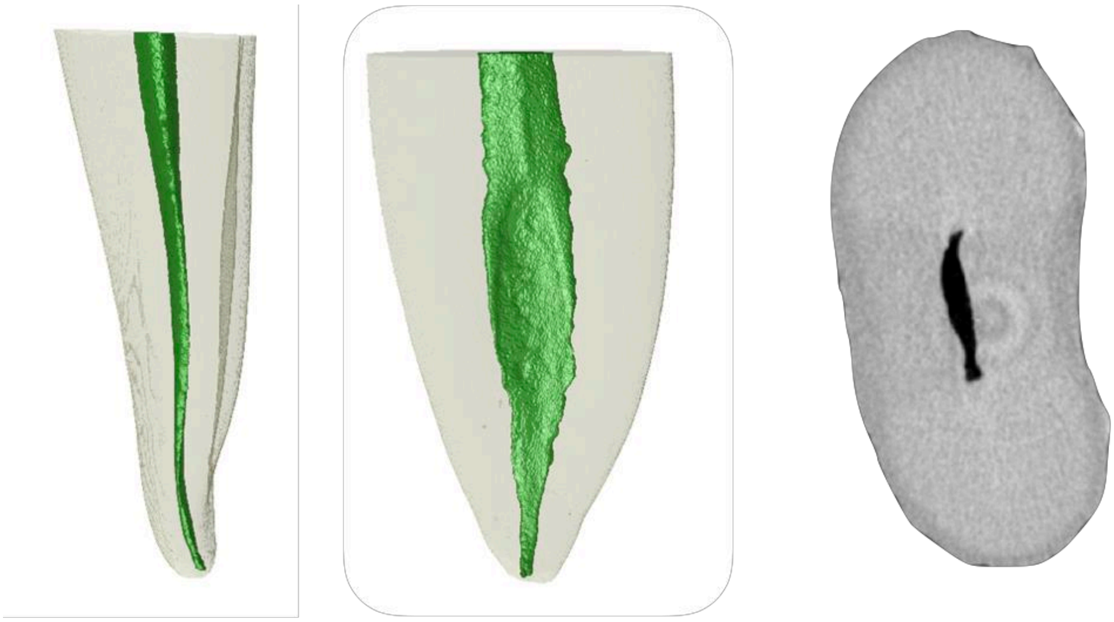
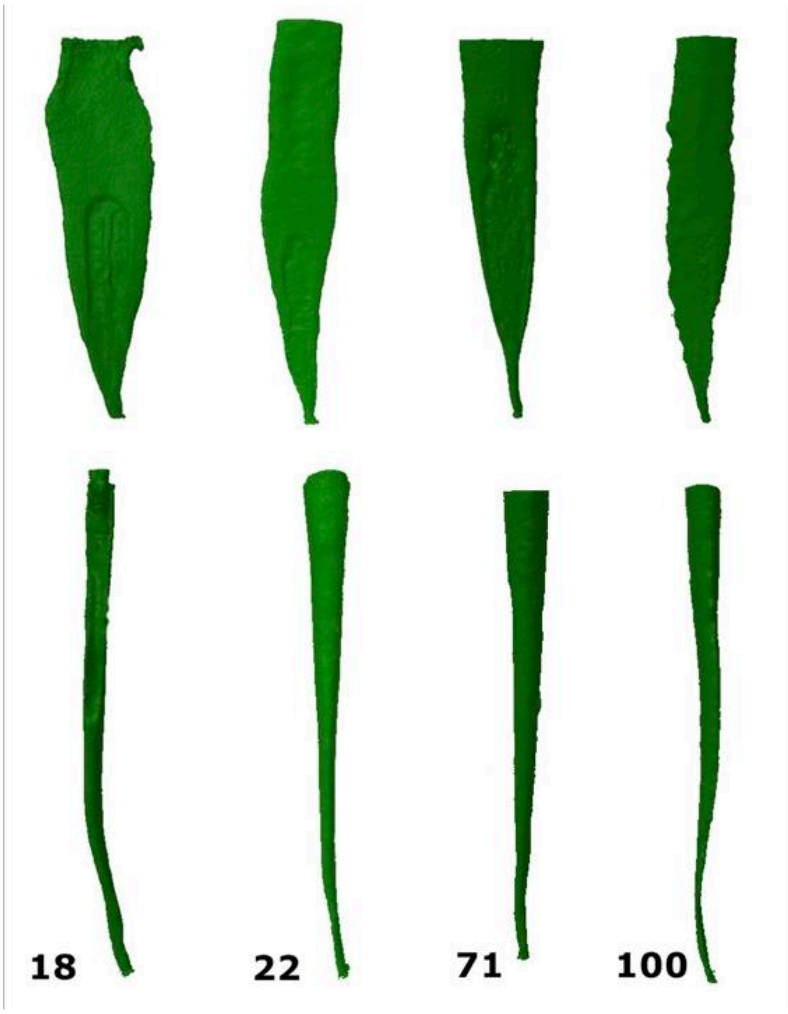
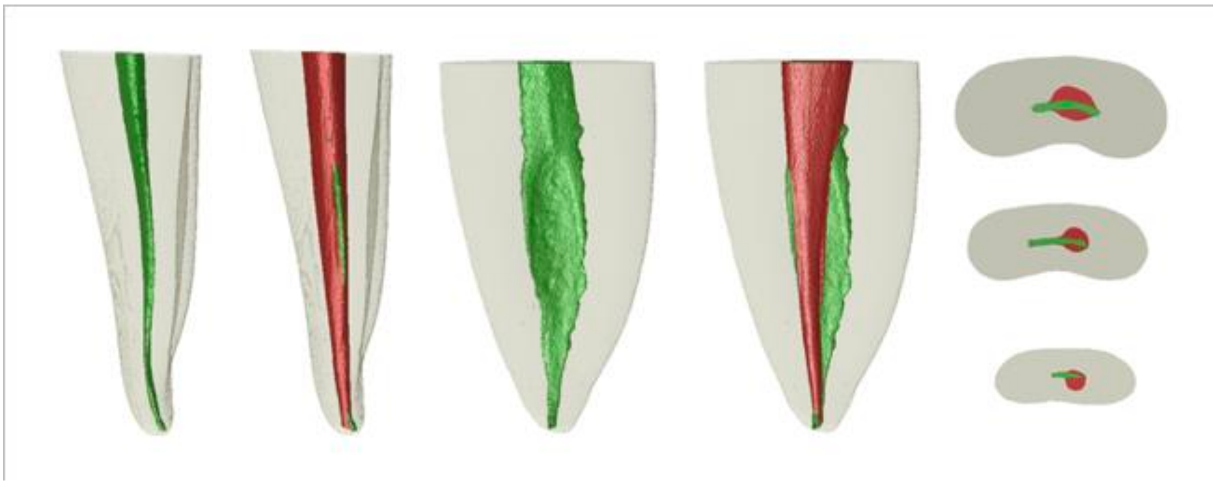
Depois disso foram selecionados 40 incisivos mandibulares com canais de configurações similares. Esses dentes foram então novamente escaneados nas mesmas condições anteriores agora utilizando alta resolução (14.25 µm com rotação de 360° 0.5°/, 7000 milisegundos utilizando filtro de aluminio 1.0 mm). As imagens de cada espécime foram reconstruídas usando parâmetros padronizados: 40% feixe duro, correção de artefato anelar e limites de contraste semelhantes. Os volumes de interesse foram selecionados desde a extensão do limite cemento - esmalte até a porção apical, resultando na aquisição de 800-900 secções trasversais por dente .



Os apices dos dentes foram então selados com cola e embebidos em silano polivinílico criando dessa forma um sistema fechado (Susin *et al*. 2010). Foi feito então em cada dente glide path com limas manuais tipo K até que uma lima 20 tipo K pudesse alacançar o comprimento de trabalho (CT) estabelecido a 1 mm aquém do comprimento do canal. Os especimes foram então pareados em quadruplicata tendo como base as caracteristicas morfologicas do canal (volume, área e configuração) e divididos aleatoriamente em 4 grupos experimentais de 10 dentes (n = 10). Cada grupo foi então preparado utilizando os sistemas : BioRace (FKG Dentaire, La-Chaux-de-Fonds, Switzerland), Reciproc (VDW, Munich, Germany), Self-Adjusting File (SAF; ReDent-Nova, Ra'anana, Israel) e TRUShape 3D Conforming Files system (Dentsply Tulsa Dental Specialties, Tulsa, OK, USA), segundo as recomendações de cada fabricante .



Em todos os grupos o tempo total de preparo e irrigação foi de 4 minutos. A irrigação foi realizada utilizando agulha NaviTip (Ultradent Products Inc., South Jordan, UT, USA) e 25 mL of 5.25% NaOCl por dente. Após o final do preparo, irrigação ultrasonica passiva foi realizada com insertos de limas # 15 tipo K , por 20 segundos a 2 mm co CT. Os canais foram então irrigados com 3 mL de 17% EDTA por 5 min. seguidos por irrigação final utilizando 2 mL de agua bi-destilada por 1 min. Aspiração da soluções irrigantes foi feita com a ponta SurgiTip (Ultradent Products Inc.) no orificio de entrada dos canais. Todos os preparos foram realizados por operador experiente treinado com todos os sistemas . Os canais foram então secos com pontas de papel (Dentsply Maillefer). Os espécimes foram então submetidos a escaneamento pós operatório e reconstruções seguindo os parametros já mencionados



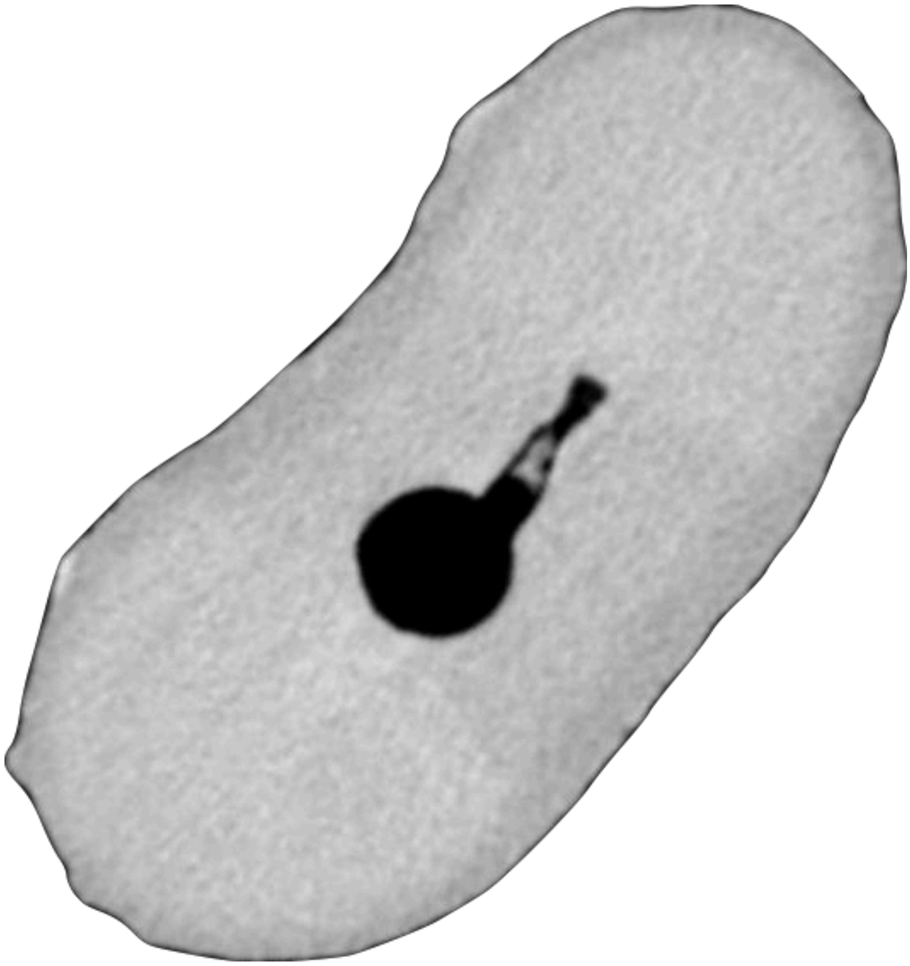
Avaliação com micro CT

As secções de imagem dos espécimes após a preparação foram processadas e co-registadas com os respectivos conjuntos de dados pré-operatórios utilizando um algoritmo afim de software específico 3D Slicer 4.5.0 software (http://www.slicer.org) (Fedorov *et al*. 2012). Quatro variáveis foram então avaliadas:

i) porcentagem de acúmulo de debris, ii) áreas de canal não tocadas, iii) quantidade de dentina excisada e iv) frequência de microfraturas dentinárias

porcentagem de acúmulo de debris:

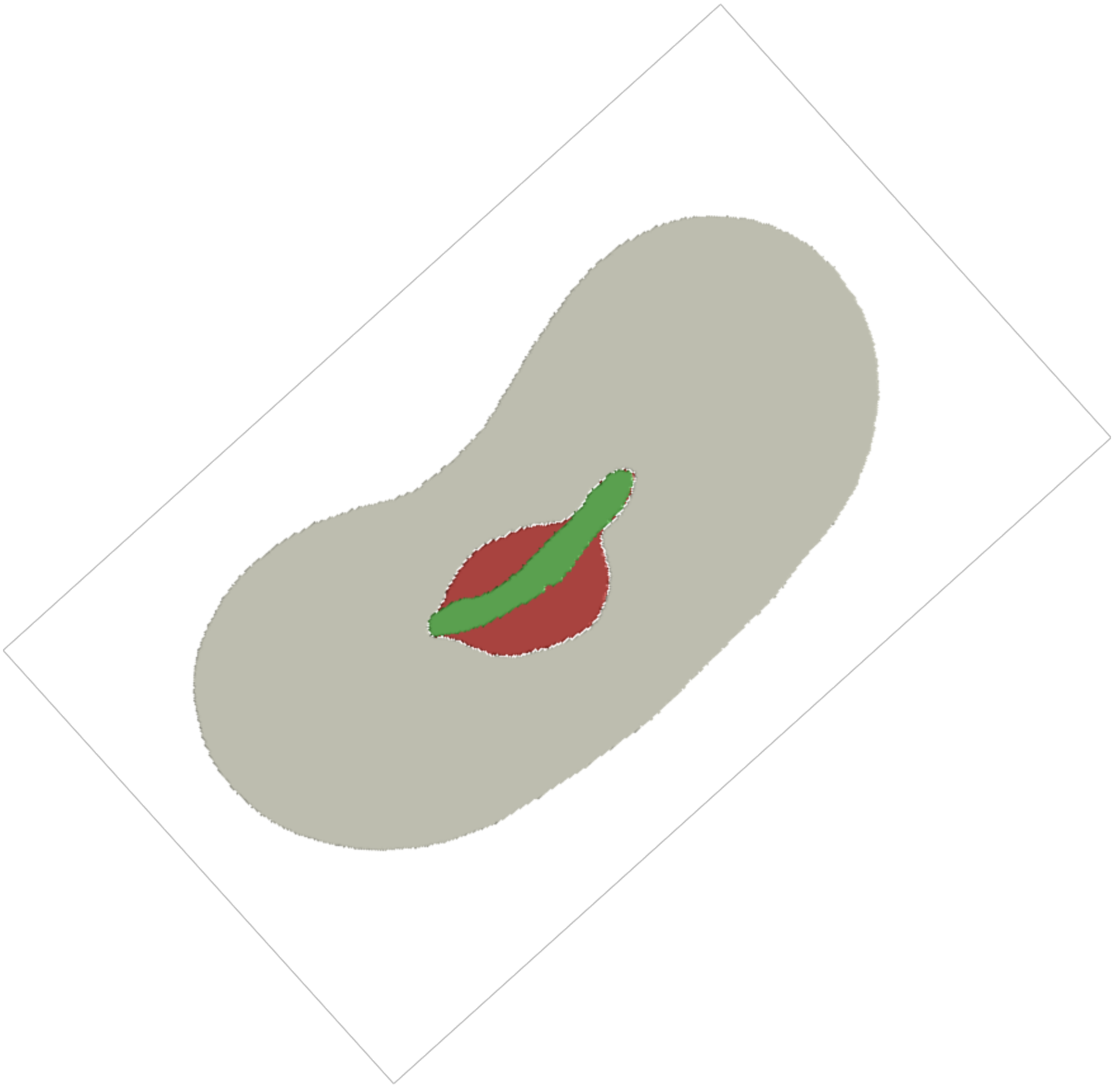
A quantificação do acumulo de debris foi expresso como % do volume total do canal segundo (De-Deus *et al*. 2014, De-Deus *et al*. 2015b, Neves *et al*. 2015).



i) áreas de canal não tocadas

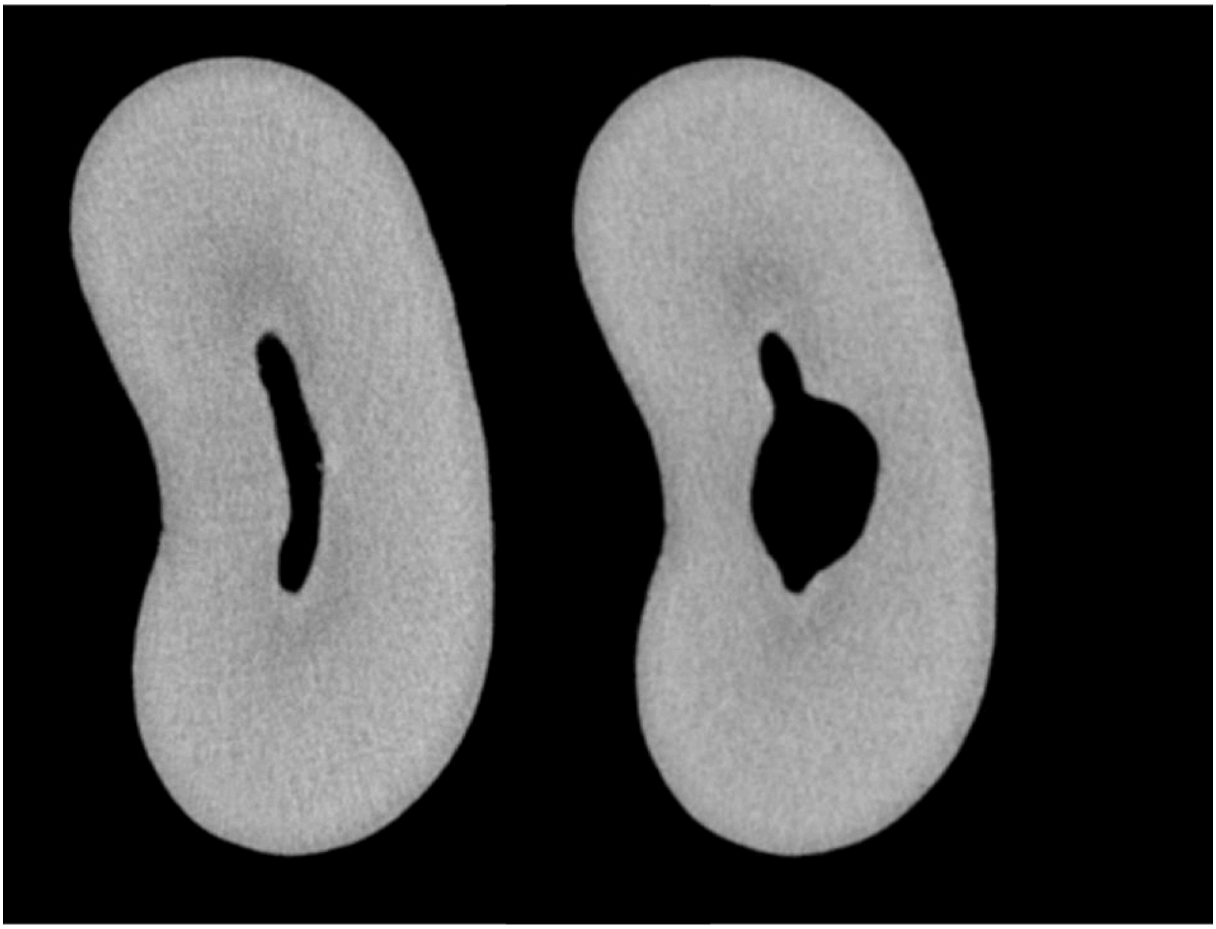
A area de canal não tocada foi determinda calculando o número de voxeis estáticos (voxeis presentes na mesma posição na superfície do canal antes e após a instrumentação). A area de canal não tocada foi expressa como % do numero total de voxeis presentes na superfície do canal (Paqué & Peters 2011), segundo a formula :

$$\frac{\textit{número de voxeis estáticos} \times 100}{\textit{número total de voxeis de superfície}}$$



iii) quantidade de dentina excisada

O volume de dentina removida após o preparo foi calculada subtraindo segmentos pre e pós operatórios da mesma secção transversal utilizando software específico de operações morfologicas (Fiji v.1.47n; Madison, WI, USA) e expresso como % de dentina excisada



iv) frequência de microfraturas dentinárias

Inicialmente secções pós operatórias foram examinadas por 3 operadores (n = 70,030). As secções que apresentavam microfraturas dentinarias foram anotadas. Depois disso as secções pré operatórias correspondentes foram verificadas para observar se essas fraturas já estavam presentes ou não. Para validação do processo todas as imagens foram novamente analisadas por duas vezes com intervalos de duas semanas. Em caso de divergência, as imagens foram então analisadas conjuntamente até que um consenso fosse estabelecido.