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Patrícia Eliana Fontana

A INFLUÊNCIA DA ESPESSURA DA FÉRULA NA RESISTÊNCIA À FRATURA DE DENTES RESTAURADOS COM DIFERENTES PINOS INTRARRADICULARES

Santa Maria, RS
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Dissertação apresentada ao Curso de Mestrado do Programa de Pós-Graduação em Ciências Odontológicas, Área de Concentração em Odontologia, ênfase em **Prótese Dentária**, da Universidade Federal de Santa Maria (UFSM, RS), como requisito parcial para obtenção do grau de **Mestre em Ciências Odontológicas**.

Orientador: Prof. Dr. Osvaldo Bazzan Kaizer

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RESUMO

A INFLUÊNCIA DA ESPESSURA DA FÉRULA NA RESISTÊNCIA À FRATURA DE DENTES RESTAURADOS COM DIFERENTES PINOS INTRARRADICULARES

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A manutenção da estrutura coronária remanescente é fundamental para o prognóstico do tratamento restaurador, e o efeito férula é um fator de extrema importância, o qual influencia o resultado clínico de dentes com tratamento endodôntico. O impacto da espessura da férula na resistência à fratura dos dentes tratados endodonticamente segue controverso, visto que não há estudos até o momento. O objetivo deste estudo foi investigar a influência da espessura da férula na resistência à fratura após ciclagem mecânica, e o padrão de falha de dentes tratados com diferentes pinos intracanais submetidos ao teste de resistência à fratura. Cento e vinte dentes incisivos bovinos foram randomizados em seis grupos, baseados no pino intrarradicular utilizado (pino de fibra de vidro ou núcleo metálico fundido), e na presença e espessura da férula (sem férula, presença de uma férula de 0,5 mm de espessura, e de 1 mm de espessura, permanecendo inalterada uma altura de 2 mm). As coroas metálicas e os pinos intrarradiculares foram cimentados adesivamente. As amostras foram submetidas à ciclagem mecânica (37°C, 45°, 130 N, 2.2 Hz, e 2 x 10^6 pulsos). Após, elas foram submetidas ao teste de resistência à fratura numa velocidade de 0,5 mm\min, e a uma inclinação de 45º, até que a falha ocorresse. As falhas foram classificadas em favoráveis ou desfavoráveis. Os dados da resistência à fratura foram analisados com os testes ANOVA 2-fatores e Tukey. O teste de Mann-Whitney e o teste Qui-Quadrado foram usados para analisar o padrão de falha. De todos os espécimes, 96,7% sobreviveram à ciclagem mecânica. O grupo restaurado com núcleo metálico fundido e com uma férula de 1 mm de espessura (CPC1) apresentou uma maior resistência à fratura do que o grupo restaurado com núcleo metálico fundido sem férula (CPC, p=0.001). Além disso, a variação na espessura da férula esteve associada com diferentes padrões de falha. Assim, a espessura da férula deve ser considerada ao escolher diferentes pinos intrarradiculares, buscando uma menor ocorrência de falhas desfavoráveis.

Palavras-chave: Efeito férula. Núcleo metálico fundido. Pino de fibra de vidro.

ABSTRACT

THE INFLUENCE OF FERRULE THICKNESS ON RESISTANCE TO FRACTURE OF RESTORED TEETH WITH DIFFERENT INTRACANAL POSTS

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ADVISOR: Osvaldo Bazzan Kaizer

The maintenance of the remaining coronary structure is fundamental for the prognosis of restorative treatment, and the ferrule effect is an extremely important factor, which influences the clinical outcome of teeth with endodontic treatment. The impact of ferrule thickness on fracture resistance of endodontically treated teeth remains controversial, as there are no studies to date. The objective of this study was to investigate the influence of ferrule thickness on fracture resistance after mechanical cycling and failure pattern of teeth restored with different intraradicular posts subjected to the fracture load test. One hundred and twenty bovine incisor teeth were randomized into six study groups, based on the intraradicular post used (fiber post or cast post and core) and the presence and thickness of the ferrule (without ferrule, presence of 0.5 mm or 1 mm thick ferrule, keeping unaltered 2 mm in ferrule height). Full metal crowns and the root posts were adhesively cemented. The samples were subjected to mechanical cycling (37°C, 45°, 130 N, 2.2 Hz, and 2 x 10^6 pulses). Afterwards, they were subjected to the fracture load test at a speed of 0.5 mm/min and a 45° slope until failure occurred. The failures were classified as favorable and unfavorable. The fracture resistance data were analyzed with 2-factor ANOVA and Tukey's test. The Mann-Whitney test and Chi-square test were used to analyze the pattern of failure. Of all the specimens, 96.7% survived the mechanical cycling. The group with cast post and core and 1 mm ferrule thickness (CPC1) presented a greater resistance to fracture that the group with cast post and core but without ferrule (CPC, p=0.001). Furthermore, varying ferrule thickness were associated with different failure patterns. Thus, ferrule thickness should be considered when choosing different intraradicular posts, looking for the less occurrence of unfavorable failures.

Keywords: Cast post and core. Ferrule effect. Glass fiber post.

SUMÁRIO

1 INTRODUÇÃO

A restauração de dentes com tratamento endodôntico continua sendo um desafio para os clínicos (ZHANG et al., 2015; JULOSKI et al., 2012; PEREIRA et al., 2006), tendo em vista que esses procedimentos (tratamento endodôntico e restauração) enfraquecem a estrutura dental e ocasionam mudanças nas propriedades mecânicas da dentina. Essas mudanças são causadas devido à perda da vitalidade pulpar durante a abertura coronária, a instrumentação endodôntica e a obtenção do espaço para o pino (BURKE et al., 1992; MORGANO et al., 2004; TANG et al., 2010; RODRIGUES et al., 2010; SCHWARTZ; ROBBINS, 2004; SOARES et al., 2007).

Esses procedimentos podem contribuir para a vulnerabilidade dos dentes tratados endodonticamente e reduzir a sua resistência à fratura (PEROZ et al., 2005). Segundo Tang et al. (2010), os dentes com tratamento endodôntico são mais suscetíveis à fratura do que dentes com vitalidade pulpar. O prognóstico a longo prazo dos dentes tratados endodonticamente é influenciado por vários fatores, tais como: a posição do dente no arco dentário, a relação oclusal, a presença de contatos proximais, o tipo de restauração final, o comprimento e espessura do pino e a quantidade de remanescente coronário preservado (CAPLAN et al., 2002; AQUILINO et al., 2002; NAUMANN et al., 2005a, b).

Quando os dentes apresentam pouca estrutura coronária remanescente, é necessário um pino intrarradicular para auxiliar na retenção da restauração final (FREEDMAN et al., 2001; TROPE et al., 1985; SORENSEN; MARTINOFF, 1984; TRABERT; COONEY, 1984). O pino intrarradicular, além de auxiliar na retenção da coroa, distribui as tensões no interior da dentina radicular ao longo da raiz (ZOGHEIB et al., 2008).

Os núcleos metálicos fundidos são utilizados tradicionalmente na Odontologia e apresentam altas taxas de sobrevivência após 10 anos (GOMEZ-POLO et al., 2010). No entanto, eles vêm sendo gradativamente substituídos por outros tipos de pinos, devido a desvantagens como estética desfavorável, alto módulo de elasticidade em relação ao da dentina, fraturas radiculares denominadas desfavoráveis ou catastróficas (SCHWARTZ; ROBBINS, 2004, AKKAYAN; GULMEZ, 2002, FOKKINGA et al., 2004, ZICARI et al., 2013), além de poder ocasionar corrosão, dependendo da liga utilizada (FERRARI et al., 2000).

COELHO et al. (2009), através da análise de elementos finitos de raízes enfraquecidas restauradas com resina composta e pinos intrarradiculares mostraram que dentes tratados com pinos e núcleos de CuAl, de aço inoxidável, de dióxido de zircônia e de titânio induzem a maiores concentrações de tensão na superfície vestibular dos pinos do que na região lingual. Também, para todos os sistemas de pinos metálicos, a concentração de tensão foi observada no ápice do pino intrarradicular, o que pode ocasionar fraturas desfavoráveis (COELHO et al., 2009).

Em 1990, os pinos de fibra foram introduzidos na prática clínica como uma alternativa para os núcleos metálicos fundidos (FERRARI et al., 2012). Em comparação com esses últimos, os pinos de fibra proporcionaram uma melhoria na estética, maior biocompatibilidade, grande resistência à corrosão e maior facilidade de remoção do interior do canal radicular (MARTINEZ-INSUA et al., 1998; FERRARI et al., 2000; FERNANDES et al., 2003). Além disso, possuem módulo de elasticidade similar ao da dentina, o que pode levar à redução do risco de fraturas radiculares (TROPE et al., 1985; SORENSEN et al., 1984; SIRIMAI et al.,1999; DEUTSCH et al., 1983).

Os fatores que afetam o comportamento biomecânico de raízes tratadas são o tipo de pino e a presença de férula (SORENSEN; ENGELMAN, 1990; LIBMAN; NICHOLLS, 1995; ZHI-YUE; YU-XING, 2003; AKKAYAN et al., 2004; TAN et al., 2005; ICHIM et al., 2006; PEREIRA et al., 2006, 2009). A definição de férula é descrita como sendo resultado de paredes paralelas de dentina coronária a partir do término cervical da coroa, que proporcionam um efeito protetor através da redução de tensões intrarradiculares (STANKIEWICZ et al., 2008).

A manutenção da estrutura coronária remanescente é um fator fundamental para o bom prognóstico (FERRARI et al., 2012; SKUPIEN; LUZ; PEREIRA-CENCI, 2016), e o efeito férula é um fator de extrema importância, o qual influencia o resultado clínico de dentes com tratamento endodôntico. (WATANABE et al.,2012; SAMRAN et al., 2013).

A férula é mais relevante na resistência à fratura que o uso de pinos intrarradiculares (JULOSKI et al., 2012; FERRARI et al., 2012; JULOSKI ET AL., 2014). Na ausência do efeito férula, as forças de tensão são concentradas entre a interface do pino e do núcleo, o que leva a uma maior probabilidade de fratura do pino (MORGANO et al., 2004). Com a presença da férula, há uma redistribuição das tensões para outras regiões da superfície radicular e para o terço coronário da raiz (LONEY et al., 1990). Sorensen e Engelman (1990) relataram a importância da férula para aumentar a resistência à fratura dos dentes. No entanto, em outros estudos a presença da férula não influenciou na resistência de dentes tratados endodonticamente (GEGAUFF et al., 2000; CAGIDIACO et al., 2007; JULOSKI et al., 2014).

Alguns estudos avaliam o impacto do formato e da altura da férula na resistência à fratura dos dentes com tratamento endodôntico (SORENSEN; ENGELMAN, 1990; CHO et al., 2009; KUTESA-MUTEBI et al., 2004). Vários autores sugeriram que a altura mínima da férula deveria ser de 2mm para garantir adequada resistência (TRABERT et al., 1984), enquanto outros propuseram a altura de 1,5mm como sendo a mínima necessária para a sobrevivência em longo prazo de uma restauração (LIBMAN et al., 1995; DA SILVA et al., 2010).

Em algumas situações clínicas, não é possível a preparação de uma férula com altura uniforme em toda sua circunferência (TAN et al., 2005; DIKBAS et al., 2007; NAUMANN et al., 2006). No entanto, um dente com altura de férula não uniforme em toda sua circunferência ainda é preferível a um dente que não apresente nenhum remanescente coronal (TAN et al., 2005; DIKBAS et al., 2007).

Apesar de ser um assunto amplamente estudado, ainda há controvérsias e questões a serem definidas (SCHWARTZ et al., 2004; JULOSKI et al., 2012). Entre elas, há um fator ainda não relatado na literatura, que é a espessura mais adequada para uma férula e também se esta espessura influencia na resistência estrutural de dentes tratados endodonticamente, justificando plenamente o estudo.

O presente trabalho será apresentado em formato de artigo, intitulado **“Effect of ferrule thickness on fracture resistance of teeth restored with posts”** e visa avaliar a influência da espessura da férula na resistência à fratura de dentes restaurados com pinos de fibra de vidro ou núcleos metálicos fundidos, após ciclagem mecânica e teste de resistência à fratura.

2 ARTIGO - EFFECT OF FERRULE THICKNESS ON FRACTURE RESISTANCE OF TEETH RESTORED WITH POSTS

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EFFECT OF FERRULE THICKNESS ON FRACTURE RESISTANCE OF TEETH RESTORED WITH POSTS

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Short title: Ferrule thickness and fracture resistance of restored teeth

Clinical Relevance: When restoring a tooth without a ferrule, use of either a cast post and core or glass fiber post is associated with the same probability of unfavorable failures. With a 1 mm thick ferrule, the use of a glass fiber post may be the best clinical decision.

ABSTRACT

Purpose: To investigate the influence of ferrule thickness on fracture resistance after mechanical cycling and failure pattern of teeth restored with different intracanal posts subjected to the fracture load test. **Methods:** One hundred and twenty bovine incisor teeth were randomized into six study groups, based on the intraradicular post used (glass fiber post or cast post and core) and the presence and thickness of the ferrule (without ferrule, presence of 0.5 mm or 1 mm thick ferrule, keeping unaltered 2 mm in ferrule height). Full metal crowns and the root posts were adhesively cemented. The samples were subjected to mechanical cycling (37°C, 45°, 130 N, 2.2 Hz, and 2 x 10^6 pulses). Afterwards, they were subjected to the fracture load test at a speed of 0.5 mm/min and a 45° slope until failure occurred. The failures were classified as favorable and unfavorable. The fracture resistance data were analyzed with 2-factor ANOVA and Tukey's test. The Mann-Whitney test and Chi-square test were used to analyze the pattern of failure. **Results:** Of all the specimens, 96.7% survived the mechanical cycling. The group with cast post and core and 1 mm ferrule thickness (CPC1) presented a greater resistance to fracture that the group with cast post and core but without ferrule (CPC, p=0.001). **Conclusions:** Greater ferrule thickness only increased fracture resistance when considered cast post and core. Furthermore, varying ferrule thickness were associated with different failure patterns. Thus, ferrule thickness should be considered when choosing different intracanal posts, looking for the less occurrence of unfavorable failures.

INTRODUCTION

The prognosis of endodontically treated teeth depends on several factors, such as adequate coronary reconstruction,[1,2] tooth position in the dental arch, type of final restoration, post length and thickness and the presence of a ferrule.[3,4] A ferrule is composed of parallel walls of dentin extending coronally from the crown's margin.[4-6] When the crown is formed around the remaining structures, intraradicular stress is reduced, generating the ferrule effect.[4,5,7,8]

Eraslan et al., (2009) confirmed using finite element analysis that the cervical region received higher stress, and that the cervical ferrule reduced these stress values.[9] In addition, its presence may reduce the incidence of fractures considered as unfavorable.[10-12]

Some studies have evaluated the impact of the configuration and height of the ferrule on the fracture resistance of teeth.[7,13] Several authors have suggested that the minimum height of the ferrule required to provide adequate fracture resistance is 2 mm,[14-18] while others have proposed a height of 1.5 mm as the minimum required for long-term survival of a restoration.[19,20]

The importance of the ferrule for increasing the resistance of endodontically treated teeth has been reported in several studies.[6,21,22] However, some studies reported that the presence of a ferrule did not influence the resistance of teeth to fracture.[10,13,23,24] Although this is a widely studied topic and has great clinical relevance, there is still no report in the literature about the effect of the remaining coronal thickness on the mechanical behavior of endodontically treated teeth.

From this point of view, the remaining coronal thickness might influence the stress distribution on the tooth/post/crown, consequently affecting its fracture resistance and the mode of fracture. Thus, the objective of this research was to evaluate the influence of the remaining coronal thickness (i.e. different ferrule patterns) on the resistance to fracture and failure pattern of endodontically restored teeth (using glass fiber post or cast post and core). The null hypothesis was that the ferrule thickness would not influence the fracture resistance, nor the probability of unfavorable failures of endodontically treated teeth with different intracanal posts after mechanical cycling and fracture load test.

METHODS AND MATERIALS

Selection of specimens

One hundred and twenty bovine incisor teeth were selected and analyzed for possible fractures, cracks, and fissures, with the aid of a loupe (4x magnifying, EyeMag Pro S, Carl Zeiss, Gottingen, Germany). Afterwards, the selected teeth were randomized through the random.org website[25] into six groups (n=20 each) based on the post type (glass fiber post or cast post and core), the presence of ferrule, and its thickness, according to Table 1.

Thereafter, the coronary portion of each tooth was sectioned at a distance of 16 mm (in the absence of a ferrule) or 18 mm (in the presence of a 2 mm high ferrule, with different thickness) from the root apex. All the procedures were performed by two trained researchers.

In order to avoid differences in tooth size among groups, the teeth were measured with the aid of digital calipers (Starrett 727, Starrett, Itu, São Paulo, Brazil), at the mesio-distal and vestibular-lingual distances and the measures were tabulated. The data were verified to be normally distributed. Subsequently, a one-way ANOVA was performed in order to verify if there were differences between the vestibulo-lingual and mesio-distal dimensions of the groups. It was shown that there was no statistically significant difference ($\alpha<0.5$) in the dimension of the teeth between the groups.

Periodontal ligament confection and endodontic treatment

To simulate the periodontal ligament, the protocol described by Soares et al. (2005)[26] was used, where the roots were coated with a 0.3 mm thick (measured by digital calipers - Starrett 727, São Paulo, Brazil) layer of wax (Lysanda, São Paulo, Brazil), which was liquefied in a container with a standard temperature of 70ºC. The specimens were embedded in polyvinyl chloride cylinders (height of 20 mm and diameter of 25 mm) with self-cured acrylic resin (VIPI Flash, VIPI, Pirassununga, São Paulo, Brazil). Afterwards, the teeth were removed from the acrylic resin and the wax was removed, creating a space corresponding to the periodontal ligament, which was reproduced using an elastomeric material (Impregum F-3M-ESPE, Seefeld, Germany). Then, the impression material was manipulated as recommended by the manufacturer and inserted inside the artificial alveolus. Each tooth was immediately placed into its respective alveolus and the excess material was removed.

Afterward, the root was prepared using the staggered technique, using second-series endodontic files (Dentsply-Maillefer, Ballaigues, Switzerland) and no. 3, 4, 5 Gates-Glidden burs (Dentsply-Maillefer, Ballaigues, Switzerland). The specimens were filled with AH plus sealer (Dentsply-Maillefer, Ballaigues, Switzerland) and gutta-percha cones (Dentsply-Maillefer, Ballaigues, Switzerland). The cold lateral condensation technique was used with accessory FM cones (Dentsply Maillefer, Ballaigues, Switzerland). The compaction force of the material was 2 kg, which was measured using a digital scale. After root treatment, the specimens were stored for 24 hours at 37°C.

Preparation for post and preparation of ferrule

The post space (cementation length) was prepared in 12 mm, for the groups without ferrule (CPC, GFP), and 14 mm, for the groups with ferrule (GFP0.5, GFP1, CPC0.5, CPC1). For the GFP, GFP0.5, and GFP1 groups, the preparation was initially performed with the aid of no. 4 Largo burs (Dentsply Maillefer, Ballaigues, Switzerland) and then finished with standardized drills of the Whitepost DC # 2 fiberglass post system (FGM, Joinville, Santa Catarina, Brazil). For the CPC, CPC0.5, and CPC1 groups, the post space was prepared using no. 3, 4, 5 Largo burs (Dentsply Maillefer, Ballaigues, Switzerland). The GFP0.5, GFP1, CPC0.5, and CPC1 groups were manually prepared with diamond bur # 3216 (KG Sorensen, Barueri, Brazil) using a high-speed hand piece (Extra Torque 605C; Kavo do Brasil, Joinville, Brazil) with water spray cooling, leaving the ferrules with the thickness corresponding to each group. The preparation margin was chamfered at least 1 mm wide. For this, the thickness to be ground with a diamond bur was marked with graphite with the aid of a digital caliper (Starrett 727, Starrett, Itu, Brazil).

Production and cementing of posts and crowns

The standards of the cast post and core were obtained by molding the root canals with chemically activated acrylic resin Bosworth Trim Plus (Bosworth Company, Illinois, USA). After the roots were isolated with hydrosoluble insulation (K-Y gel, Johnson & Johnson, São José dos Campos, Brazil), the acrylic resin was applied in the canal with the aid of a fine brush (Postcel # 0, Dencril, Pirassununga, Brasil) and a prefabricated plastic post (Pinjet, Ângelus, Londrina, Brazil). For the preparation of the coronary part of the core, acetic matrices were used.

These matrices were obtained through a standard specimen, on which the metal core was prepared in acrylic resin and molded with addition silicone (Elite Double 8, Zhermack, Badia Polesine, Italy), obtaining a gypsum pattern (Durone, Dentsply-Maillefer, Ballaigues, Switzerland). Afterwards, the standardized matrices were made in a plasticizer, using acetate plates and plaster models. This procedure was performed for each group due to the different thickness of the ferrule. The acetate matrices were filled with red acrylic resin and positioned on the teeth. Afterward, they were removed and their excesses finished with tungsten cutters.

Resin patterns were handed over to a commercial laboratory for the casting. Next, the cast posts and cores were evaluated for adaptation and, prior to cementation, received surface treatment by air-abrasion with aluminum oxide particles (110 µm, pressure 2.8 bars, 10 mm distance and 15 seconds) (Blue, São José do Rio Preto, Brazil).

For the glass fiber post groups, 7 mm of the coronary portion of the post was maintained and its surface cleaned with alcohol at 70%. Next, a silane coupling agent (Prosil, FGM) was applied to each post, and the solvent was allowed to evaporate for 5 minutes.

All the root posts were cemented using the same procedures: the root canal and the coronary portion were prepared using 37% phosphoric acid (Condac 37, FGM), and the adhesive Ambar (FGM) was applied according to the manufacturer's guidelines. Finally, the posts were cemented with dual resin cement (Allcem, FGM), which was manipulated as recommended by manufacturer.

The cores (for glass fiber post samples) were made with a composite resin (Opallis, FGM). For the core standardization, an acetic matrix (identical to that used for the CPC groups) was used. The matrix was filled with increments of composite resin and adapted over the coronary portion of the post. Afterward, the matrices were sectioned and the composite resin was photo-activated (1200 mW/cm^2, Radiical, SDI, Victoria, Australia) on each side of the tooth for 10 seconds.

For all groups, metallic full-crowns (Ni-Cr alloy, Wirona light, Bego, Goldschlagerei, Germany) were prepared with standard shape and dimensions, according to the anatomy of a superior canine. After that, the crowns were evaluated and air-abraded with aluminum oxide (110 µm, pressure: 2.8 bars, 10 mm distance and 15 seconds)

Before the cementation of the crowns, they were cleaned with absolute alcohol. The dentin and core (composite and metal) surfaces was etched by 37% phosphoric acid for 15 s, followed by rinsing with air-water spray and drying with absorbent paper, and the adhesive

Ambar (FGM, Joinville, Santa Catarina, Brazil) was applied according to the manufacturer's guidelines. The total metal crowns were cemented with dual resin cement (Allcem, FGM|), which was mixed for 10 seconds and applied inside each crown. Next, a 5 kg load was applied on each metal crown by means of a static press during cementation. Excess cement was removed after 3 minutes and photo-activation was carried out (1200 mW/cm^2, Radiical, SDI) on each side of the tooth for 10 seconds. The samples were stored for 24 hours before testing.

Mechanical cycling

The specimens were subjected to mechanical cycling in fatigue equipment (Erios ER 3000, São Paulo, Brazil) with the following protocol: 2.2 Hz frequency, load pulses from 0 N to 130 N, immersion in water at ± 37°C temperature, piston at a 45° angle with respect to the long axis of the root and 2 mm from the lingual incisal edge, and 2 million pulses on the crown. Thus, in this trial, approximately 2 years of clinical service was simulated, since according to Wiskott et al. (1995),[27] 1 million cycles correspond to one year of service.

Fracture load test

To perform the fracture load test, a universal test machine (DL 2000, Emic, São José dos Pinhais, Brazil) was used. The specimens were subjected to the fracture load test, positioned on a fixed metal device and aligned at a 45° angle with respect to the long axis of the tooth. The cylindrical metallic tip (diameter 0.8 mm) attached to the load cell (1000 kN) was applied to the lingual load (2 mm from the lingual incisal edge) at a speed of 0.5 mm/min until failure occurred. This was defined as the failure threshold, a point at which the force reached a maximum value by root fracture, post-curvature, and core and post displacement.

Failure analysis

The roots were stained superficially with hydrographic pens (Blue overhead marker, Faber-Castell, São Carlos, Brazil). The excess ink was then removed with cotton and 70% alcohol and the specimens were visualized with a stereomicroscope at 10x magnification (Stereomicroscope Discovery V20; Carl Zeiss, Germany). The failures were classified as favorable and unfavorable. The fractures were considered favorable when they were located above the limit of the inlaid acrylic resin (3 mm), which simulated the bone tissue. Fractures located below this limit (3 mm) were considered unfavorable.

Data analysis

Using the Shapiro Wilk test, the fracture load data were analyzed for their distribution, while their homogeneity was analyzed using the Levene test. They were found to have a homogeneous and normal distribution ($\alpha>0.5$). Then, the fracture load data were submitted to two-way ANOVA and Tukey tests ($p<0.5$). The Mann-Whitney test was performed to analyze the association between fracture load and pattern of failure. In addition, the Chi-square test was used to analyze the association between the different patterns of failure and the different groups.

RESULTS

Mechanical cycling

It was found that 96.7% of the specimens survived mechanical cycling. In the GFP group, two failures occurred, one of which was favorable, presenting a crack in the vestibular region and a detachment of the crown from the lingual region; and another was unfavorable, with cracks in the proximal and lingual regions, besides displacement of the crown from the lingual one. The GFP0.5 group presented an unfavorable failure with cracks in the proximal region and displacement of the crown from the lingual region. In the CPC0.5 group, only an adhesive failure was observed in the lingual region. In the CPC, GFP1, and CPC1 groups, there were no failures during cycling. (see Table 2).

Fracture Load

The mean values and standard deviation of the fracture loads (N) are shown in the Table 3. The Tukey test showed a significant difference between the groups CPC and CPC1 ($p=0.001$). The other groups did not have significant differences between themselves.

Failure analysis

Table 2 shows the failures that occurred during the test of fracture load and mechanical cycling, in addition to the location where these occurred. Fifty-eight per cent (58%) of the fractures were unfavorable, while 42% were favorable. After the fracture load test, the surface that presented the most cracks in the root thirds was the distal one, followed by the mesial one. Furthermore, displacement of the lingual portion of the crown occurred in 82% of the specimens.

The Mann-Whitney test (Table 4) showed that the type of failure pattern was associated with fracture resistance ($p<0.008$). The higher the fracture resistance, the greater the occurrence of failure considered unfavorable. The pattern of failure obtained in the groups was analyzed using the Chi-square test. (Table 5).

DISCUSSION

The null hypothesis that the ferrule thickness would not influence the fracture resistance, nor the probability of unfavorable failures of endodontically treated teeth with different intracanal posts after mechanical cycling and fracture load test was rejected. To our knowledge, there are no reports on ferrule thickness and fracture resistance of restored teeth; hence, this discussion is based only on studies assessing the height and presence of the ferrule, and/or the amount of coronary remnant.

Table 3 shows that, numerically, the greater the thickness of the ferrule, the greater the mean fracture resistance of the restorer assembly (root, post, core and crown). However, only the CPC and CPC1 groups presented significant difference in the fracture resistance test. Several studies have shown that the greater the remaining coronal height, the greater the fracture load on endodontically treated teeth restored with intracanal posts. [28-30] This can be explained by the better distribution of stresses in the root canal that occurs in the presence of a ferrule, and which increases with its height. [9]

Similar findings were reported in another study, i.e. the presence of a 2 mm high ferrule increased the fracture resistance of endodontically treated teeth restored with cast post and core or glass fiber post.[28-30] On the other hand, Silva et al., (2010) found lower fracture resistance values in teeth with a 2 mm high ferrule restored with cast post and core, compared to teeth restored with glass fiber post.[20]

Fiber post is less rigid than cast post and core, thus presenting a modulus of elasticity similar to that of dentin; it allows for better distribution of stresses within the root canal and commonly has been associated with favorable failures.[21,31,32] These findings are in agreement with the results presented in Table 4, which found that favorable failures were associated with a lower fracture resistance.

When analyzing the restored specimens with cast post and core, it was observed that, when ferrule thickness reached 0.5 mm, the number of unfavorable failures also increased (Table 5). This may have been caused by increases in fracture resistance with a thicker ferrule. This corroborates the findings of Stankiewicz et al., (2002), i.e. the higher the height of the ferrule, the greater the resistance to fracture.[4] However, when analyzing the specimens restored with glass fiber posts, there was no difference in the number of unfavorable failures between the groups with different thicknesses of ferrule (Table 5).

The Chi-square test, using the proportions of failure pattern in each group, was performed to determine which association between post type and ferrule thickness would generate more favorable fractures. When the specimen has no ferrule (GFP and CPC groups), both the posts types could be used, because there was no statistically significant difference between their failures patterns. However, a specimen having a 0.5 mm thick ferrule and restored using cast post and core (more favorable failures) would be more suitable compared to that restored with a glass fiber post ($p<0.00$). On the other hand, with a 1 mm thick ferrule, glass fiber post would be more suitable than cast post and core ($p <0.009$).

In addition, the mechanical cycling of the specimens was performed by simulating an aging condition close to the real-life situation. Applying 2 million cycles approximately simulated 2 years of clinical service.[27] It was found that 96.7% of the specimens did not fracture after mechanical cycling. It is difficult to compare these results with those of other studies due to the great variability of factors that occurs in the fatigue resistance test as well as variations in humidity, load direction, and temperature.[32]

The failures obtained in the present study are consequences of a series of forces/loads supported by the restoring assembly that promote successive events of failure until the ultimate fracture. Biomechanical studies demonstrated that restored teeth subjected to oblique loads support tensile tensions (lingual surface) and compression (buccal surface).[33, 34] These tensions are maximal in the external portions (lingual and vestibular) and minimal in the center of the restorative set (root canal). The presence of the ferrule effect on a restored tooth with post alters the arrangement of the forces acting on the restored tooth.[35] A tooth with a cervical ferrule presents a coronary displacement of the fulcrum line decreasing the effect of flexion (bending moment) on the specimen (Figure 1).

Finally, the fracture load test does not correspond to what occurs in natural oral environment.[32, 36] Studies evaluating the fracture load of endodontically treated teeth restored with posts and tested *in vitro* present higher values of fracture than occurs *in vivo*, consequently a large standard deviation (Table 2). [32, 36] We tried to attenuate this limitation by using a large number of specimens for each group and standardizing the root size. However, other factors, such as, loading direction, pH alterations, humidity, and temperature are not possible to simulate in *in vitro* tests. Therefore, new *in vitro* research should be conducted in order to evaluate the influence of ferrule thickness on fatigue resistance of endodontically treated teeth, evaluating their survival and failure pattern under isometric cyclic loading.

CONCLUSIONS

- Greater ferrule thickness only statistically increased fracture resistance when considered cast post and core.
- Greater fracture resistance was associated with more unfavorable failures and varying ferrule thickness were associated with different failure patterns.

Conflict of Interest

The authors claim no conflict of interest.

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FIGURES

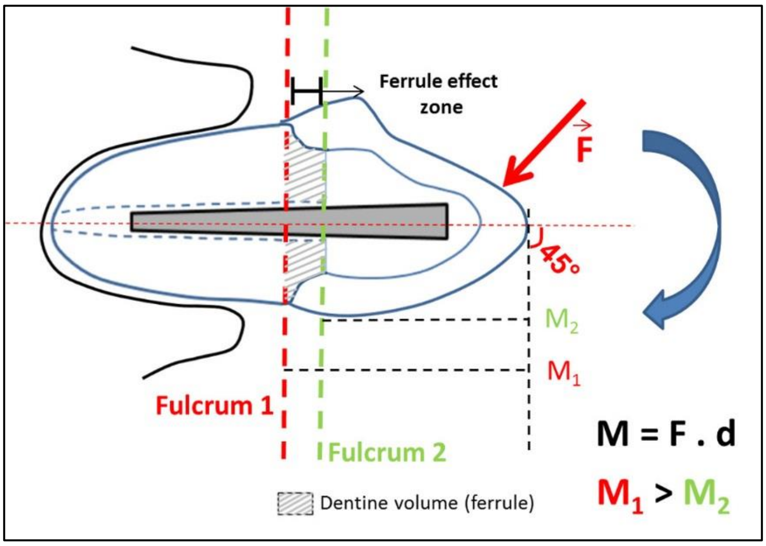

Figure 1. Schematic representation of a restored tooth with a post subjected to an oblique force. $\vec{F}$: force exerted on the specimen (45°); Fulcrum 1: fulcrum formed when there is no ferrule present in the specimen (GFP and CPC groups); Fulcrum 2: fulcrum formed when there is presence of ferrule in the specimen (groups GFP0.5, GFP1, CPC0.5 and CPC1). M: bending moment (measured by multiplying the force applied by the distance between the point of application of the load and the fulcrum line); F: applied force; D: distance from the point of application of the load to the fulcrum line; M1: bending moment referring to the fulcrum 1; M2: bending moment relative to fulcrum 2; Dentine volume: volume of coronary remaining present in specimens with the presence of ferrule. In specimens without ferrule, the fulcrum line is formed more cervically and farther from the point of application of the load (Fulcrum 1) relative to a tooth with ferrule. In specimens with ferrule, the fulcrum line, it is formed more coronally and closer to the point of application of the load (Fulcrum 2). As in specimens without ferrule, the distance from the point of application of the load to the fulcrum line is larger, the bending moment in these specimens is larger (M1> M2). In addition to the specimens with ferrule having a lower bending moment, the remaining cervical dentin volume is larger in comparison to the specimens without ferrule, so the ferrule protects the restorative post / core / crown assembly.

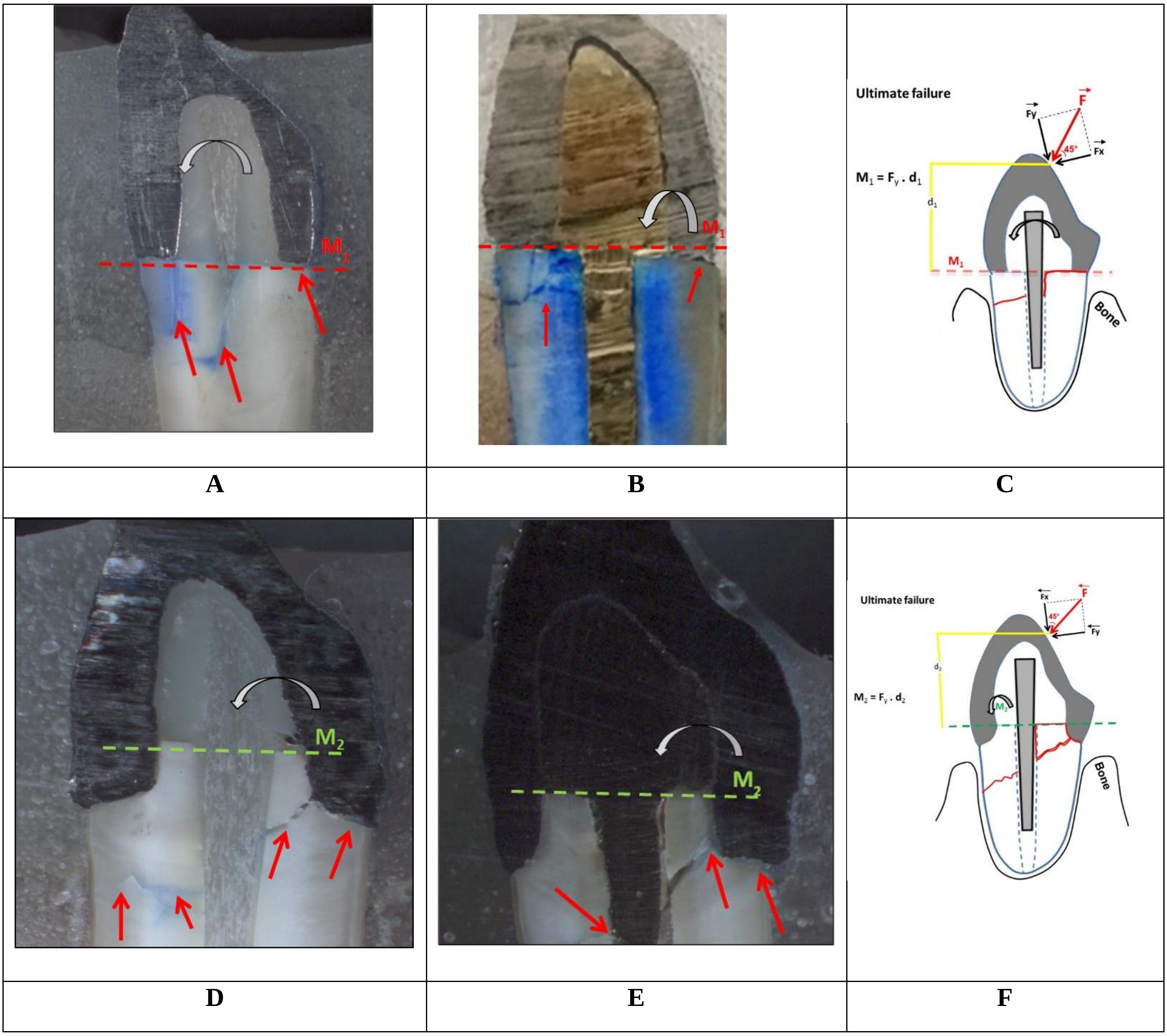

Figure 2. A. Specimen of the post-fiber group without ferrule. B. Specimen of the group with cast post and core without ferrule. C: schematic drawing of the ultimate fracture without ferrule specimens ($\vec{F}$: force exerted on the specimen (45 °), $\vec{Fy}$: vertical component of F, $\vec{Fx}$: horizontal component of $\vec{F}$, d1: distance from the point of application of the load to the specimen M1: bending moment of the specimen without ferrule – red line). D: Specimen of group GFP1. F: Specimen of group CPC1. The non-ferrule specimens showed an adhesive failure between the crown and the root on the lingual surface (consequence of the maximum tensile stress), following a split crack into the root canal and ending with cracks in the acrylic support (Figure 2A & 2B). In contrast, the specimens with ferrule had mostly adhesive failure followed by a crack from the prosthetic shoulder into the root and ending with cracks in the acrylic support (Figure 2D & 2E). F: final failure of the specimens with ferrule (red line) (M2: bending moment

of the specimen with ferrule; d2: distance from the point of application of the load to the fulcrum line)

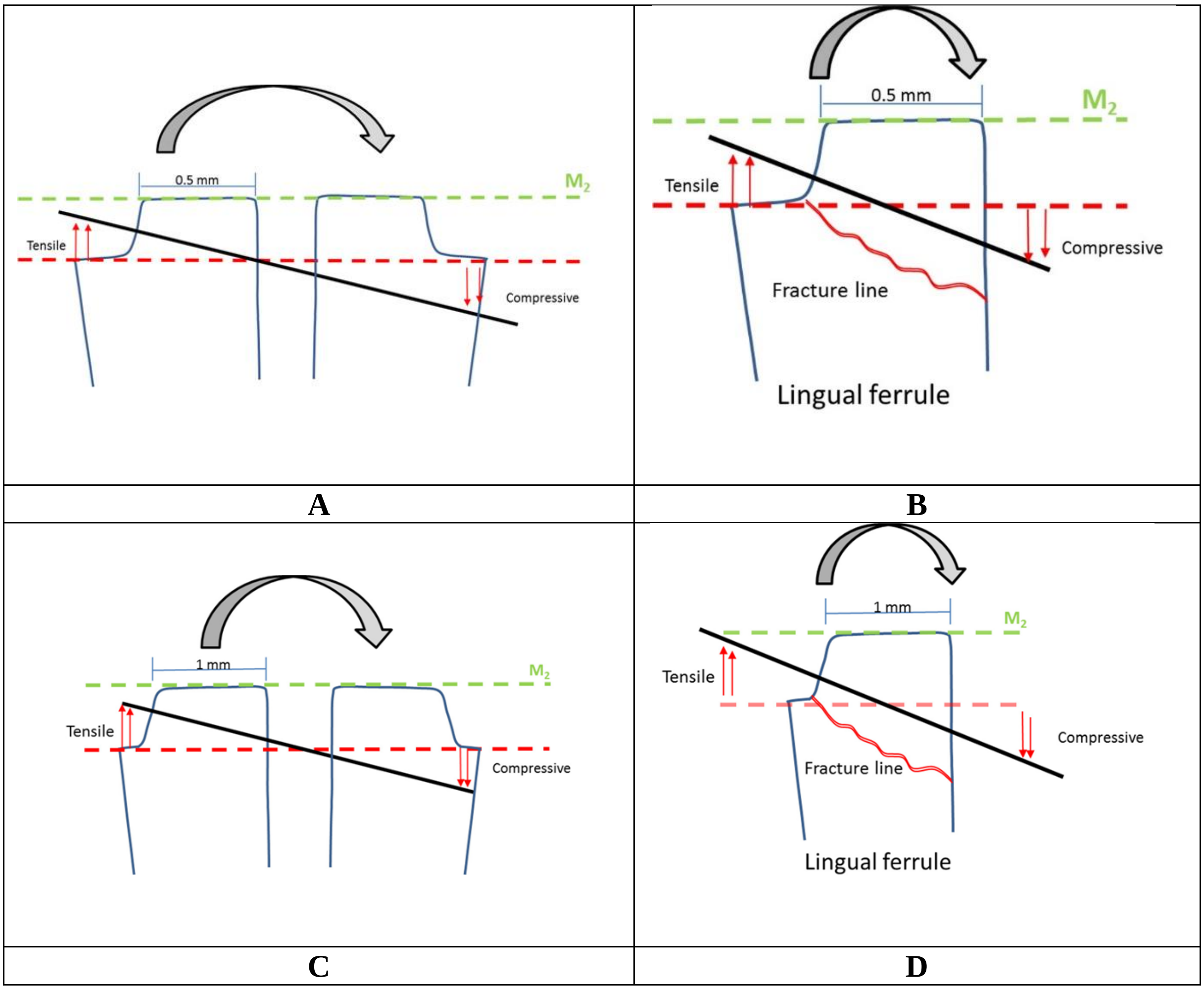

Figure 3. Schematic representation of tensile and compression stresses acting on the cervical portion of the specimens with ferrule. A / B: specimens with a thickness of 0.5 mm and C / D: thickness 1 mm. Figures B and D represent only the lingual ferrule. It is possible to observe that due to the tensile and compression stresses form a lever arm that caused the crack starting on the prosthetic shoulder until the root canal. As the specimens with a 1 mm ferrule thickness had a larger remaining structure, the values of fracture resistance presented were also higher.

TABLES

Table 1- Study design

Group	Description of groups	Groups
Glass Fiber Post	No ferrule	GFP
	Ferrule with a height of 2 mm and a thickness of 0.5 mm.	GFP0.5
	Ferrule with a height of 2 mm and a thickness of 1 mm.	GFP1
Cast post and core	No ferrule	CPC
	Ferrule with a height of 2 mm and a thickness of 0.5 mm.	CPC0.5
	Ferrule with a height of 2 mm and a thickness of 1 mm.	CPC1

Table 2 - Qualitative evaluation of failures after mechanical cycle and fracture loading.

			STUDY GROUPS (n / n%)						
			GFP	**GFP0.5**	**GFP1**	**CPC**	**CPC0.5**	**CPC1**	**TOTAL**
FAILURES AFTER FRACTURE LOAD	Pattern of Failure	Favorable	9(45%)	4(20%)	12(60%)	16(80%)	5(25%)	4(20%)	50(42%)
		Unfavorable	11(55%)	16(80%)	8(40%)	4(20%)	15(75%)	16(80%)	70(58%)
	Failure Place	Crown Displacement (lingual)	17	15	19	14	16	17	98
		Mesial crack	11	16	15	10	15	16	83
		Buccal crack	8	3	10	9	8	15	53
		Distal crack	13	16	16	6	16	18	85
		Lingual crack	1	-	-	1	-	3	5
		Fracture in the post	-	-	-		-	1	1
		Crown, core, post pull out	2	1	-	5	3	3	14
FAILURES DURING MECHANICAL CYCLING	Failure mode	Mesiodistal	10	16	15	6	11	16	
		Buccolingual	-	-	-	-	-	1	
	Pattern of Failure	Favorable	1	-	-	-	1	-	2
		Unfavorable	1	1	-	-	-	-	2
	Failure Place	Crown Displacement (lingual)	2	1	-	-	-	-	3
		Mesial crack	1	1	-	-	-	-	3
		Buccal crack	1	-	-	-	-	-	1
		Distal crack	1	1	-	-	-	-	2
		Lingual crack	1	-	-	-	-	-	1
		Fracture in the post	-	-	-	-	-	-	-
		Crown, core, post pull out	-	-	-	-	1	-	1

Table 3 - Mean (± standard deviation) of the results of fracture load (N) and Tukey's test.

	Thickness of ferrule		
Post	Without ferrule	0.5 mm	1 mm
Glass fiber post	348.02 ± 214.19 aA	447.71 ± 273.38 aA	474.30 ± 219.67 aA
Cast post and core	339.04 ± 153.78 aA	469.02 ± 340.03 aAB	575.72 ± 214.34 aB

Upper case letters compare the thickness of ferrule (lines). Similar upper case letters indicate absence of difference between groups ($p<0.05$).
Lower case letters compare the glass fiber post and cast post and core (column). Similar lower case letters indicate absence of difference between groups ($p<0.05$).

Table 4 - Association between pattern of failure and fracture resistance (Mean-SD). Mann-Whitney test.

Pattern of failure	**Mean (SD)**	**Frequency**	**Sig.**
Favorable	354.99 (164.54)	50	p<0.0008
Unfavorable	504.66 (283.09)	70	
Total	442.30 (251.21)	120	

Table 5 – Association between groups and pattern of failures. Chi-square test.

Groups	Pattern of Failures	
	Favorable	Unfavorable
GFP [Aa]	45%	55%
GFP0.5 [Ab]	20%	80%
GFP1 [Ad]	60%	40%
CPC [Ba]	80%	20%
CPC0.5 [Cc]	25%	75%
CPC1 [Ce]	20%	80%

* Upper case letters compare groups with the same intracanal post, but different ferrule thickness. Similar upper case letters indicate absence of difference between groups ($p<0.05$).
* Lower case letters compare groups with the same ferrule thickness, but different intracanal post. Similar lower case letters indicate absence of difference between groups ($p<0.05$).

3 CONCLUSÃO

O presente trabalho analisou o impacto da espessura da férula na resistência à fratura de dentes tratados com diferentes pinos intrarradiculares. Evidenciou-se que o aumento da espessura da férula apenas aumentou a resistência à fratura ao comparar grupos restaurados com núcleo metálico fundido sem férula e com 1 mm de espessura de férula. Além disso, para ambos os grupos, o aumento da resistência à fratura esteve associado a maior ocorrência de falhas desfavoráveis.

Também, ao restaurar dentes com tratamento endodôntico sem férula, houve a mesma ocorrência de falhas desfavoráveis independentemente do tipo de pino utilizado. Entretanto, havendo uma férula de 0,5 mm de espessura, a utilização de núcleo metálico fundido apresentou menos falhas desfavoráveis. Por outro lado, quando o dente apresentou 1 mm de espessura de férula, ocorreram menos falhas desfavoráveis com os pinos de fibra de vidro. Demonstrou-se significância estatística nessas relações. Assim, ao se buscar uma redução na ocorrência de falhas desfavoráveis, a escolha entre o tipo de pino intrarradicular utilizado pode ser orientada pela espessura de férula presente.

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ANEXO A – NORMAS PARA A PUBLICAÇÃO NO PERIÓDICO OPERATIVE DENTISTRY

Authors Guide for publication on Operative Dentistry:

Manuscript submission General Requirements

Operative Dentistry requires electronic submission of all manuscripts. All submissions must be sent to Operative Dentistry using the Allen Track upload site. A mandatory and nonrefundable $25.00 fee is required at submission. Your manuscript will only be considered officially submitted after it has been approved through our initial quality control check, and any quality problems have been resolved. You will have 6 days from when you start the process to submit and approve the manuscript. After the 6 day limit, if you have not finished the submission, your submission may be removed from the server. You are still able to submit the manuscript, but you must start from the beginning. Be prepared to submit the following manuscript files in your upload:

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• An acknowledgement, disclaimer and/or recognition of support (if applicable) must in a separate file and uploaded as supplemental material.

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• All other manuscript types use this template, with the appropriate changes as listed below.

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• Acknowledgement of receipt is sent automatically upon acceptance through quality control. This may take up to 7 days. If you do not receive such an acknowledgement, please check your author homepage at http://jopdent.allentrack.net if the paper does not appear there please resend your paper.

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All Manuscripts

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NOTE: Corresponding authors MUST update their profile if their e-mail or postal address changes. If we cannot contact authors within seven days, their manuscript will be removed from our publication queue.

AUTHOR INFORMATION must include:

• full name of all authors

• complete mailing address for each author

• valid email address for each author

• degrees (e.g. DDS, DMD, PhD)

• affiliation (e.g. Department of Dental Materials, School of Dentistry, University of Michigan)

MENTION OF COMMERCIAL PRODUCTS/EQUIPMENT must include:

• full name of product

• full name of manufacturer

• city, state and country of manufacturer

MANUSCRIPTS must be provided as Word for Windows files. Files with the .doc and .docx extensions are accepted.

TABLES may be submitted as either Word (.doc and .docx) or Excel (.xls and .xlsx) files. All tables must be legible, with fonts being no smaller than 7 points. Tables have the following size limitations: In profile view a table must be no larger than 7 x 9 inches; landscape tables should be no wider than 7 inches. It is the Editor's preference that tables not need to be rotated in order to be printed, as it interrupts the reader's flow.

ILLUSTRATIONS, GRAPHS AND FIGURES must be provided as TIFF or high resolution JPEG files with the following parameters:

• line art (and tables that are submitted as a graphic) must be sized with the short edge being no shorter than 5 inches. It should have a minimum resolution of 600 dpi and a maximum resolution of 17 Current as of: 1200 dpi. This means the shortest side should be no smaller than 3000 pixels.

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CLINICAL TECHNIQUE/CASE STUDY MANUSCRIPTS must include as part of the narrative:

• a running (short) title

• purpose

• description of technique

• list of materials used

• potential problems

• summary of advantages and disadvantages

• references (see below)

LITERATURE AND BOOK REVIEW MANUSCRIPTS must include as part of the narrative:

• a running (short) title

• a clinical relevance statement based on the conclusions of the review

• conclusions based on the literature review…without this, the review is just an exercise and will not be published

• references (see below). References must be numbered (superscripted numbers) consecutively as they appear in the text and, where applicable, they should appear after punctuation. The reference list should be arranged in numeric sequence at the end of the manuscript and should include:

1. Author(s) last name(s) and initial (ALL AUTHORS must be listed) followed by the date of publication in parentheses.

2. Full article title.

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4. Abstracts should be avoided when possible but, if used, must include the above plus the abstract number and page number.

5. Book chapters must include chapter title, book title in italics, editors' names (if appropriate), name of publisher and publishing address.

6. Websites may be used as references, but must include the date (day, month and year) accessed for the information.

7. Papers in the course of publication should only be entered in the references if they have been accepted for publication by a journal and then given in the standard manner with "In press" following the journal name.

8. DO NOT include unpublished data or personal communications in the reference list. Cite such references parenthetically in the text and include a date.

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Reference Style Guide

• Journal article-two authors: Evans DB & Neme AM (1999) Shear bond strength of composite resin and amalgam adhesive systems to dentin American Journal of Dentistry 12(1) 19-25.

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