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Priscilla Cardoso Lazari

Influência do remanescente coronário e da técnica restauradora no desempenho mecânico de incisivos endodonticamente tratados e restaurados com coroas cerâmicas.

Influence of ferrule effect and restoration technique on the mechanical performance of endodontically treated incisor restored with ceramic crowns.

Piracicaba

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Tese apresentada à Faculdade de Odontologia de Piracicaba da Universidade Estadual de Campinas como parte dos requisitos exigidos para a obtenção do título de Doutora em Clínica Odontológica, área de concentração em Prótese Dental.

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Orientadora: Profa. Dra. Altair Antoninha Del Bel Cury

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RESUMO

A restauração de incisivos endodonticamente tratados (IET) e severamente comprometidos é um desafio para a odontologia restauradora devido a complexidade do tratamento e tradicionalmente é realizada utilizando pinos intraradiculares. A restauração com pinos demanda maior tempo e, portanto, custo e não está associado ao aumento da resistência mecânica do complexo raiz-restauração. O uso de pino também pode estar relacionado com um maior número de falhas catastróficas na raiz. O objetivo do estudo foi investigar o comportamento biomecânico dos IET com e sem remanescente coronário e com ou sem pino intraradicular restaurados com coroas cerâmicas cimentadas sobre núcleos resinosos. No primeiro estudo foram utilizadas quarenta e cinco raízes bovinas tratadas endodonticamente e divididas em 3 grupos: FPf (Controle – raiz com 2mm de remanescente coronário + pino de fibra de vidro + núcleo de resina composta); FNp (raiz com 2mm de remanescente coronário + núcleo de resina composta) e NfP (sem remanescente coronário + pino de fibra de vidro + núcleo de resina composta). Para o segundo estudo foram utilizadas sessenta raízes bovinas tratadas endodonticamente e sem remanescente coronário divididas em 4 grupos: NfPfB (pino de fibra de vidro + núcleo de resina composta bulk-fill), NfPfP (pino de fibra de vidro + núcleo de resina composta dual e reforçada por vidro), NfPt (pino de titânio + núcleo de resina composta) e NfPtB (pino de titânio + núcleo de resina composta bulk-fill). As raízes de ambos os estudos foram preparadas para receber coroas cerâmicas de dissilicato de lítio cimentadas com técnica adesiva utilizando cimento resinoso dual. Todas as amostras foram submetidas ao teste de fadiga acelerada. Cargas cíclicas isométricas foram aplicadas no terço incisal da coroa com angulo de 30° em relação ao longo eixo do dente. O carregamento (com frequência de 5 Hz) começou com carga de 100N (5.000 ciclos), seguidos por cargas de 200, 300, 400, 500, 600, 700, 800, 900 e 1000N ao máximo de 15.000 ciclos para cada carga específica. Os espécimes foram submetidos ao carregamento até a fratura ou no máximo 140.000 ciclos totais. Os grupos foram comparados utilizando a análise de sobrevivência Kaplan Meier (teste de log rank, $p \leqq 0{,}05$). Os espécimes foram classificados quanto ao modo de falha em: catastrófica, possivelmente reparável e reparável. Nenhuma amostra sobreviveu a todos os ciclos (140.000). As amostras dos grupos sem remanescente coronário apresentaram o fenômeno da “falha inicial”, que foi definida como uma falha precoce na face lingual entre a restauração e a raiz. Os grupos com remanescente coronário (FPf = 73.332 e FNp = 73.244 ciclos) diferiram significativamente do grupo sem remanescente coronário (50.121 ciclos; p=0,001). O uso do pino de fibra de vidro não influenciou a resistência à fadiga das amostras que apresentavam

2mm de remanescente coronário (FPF e FNp, p=0.884). Os grupos sem remanescente coronário apresentaram valores similares de sobrevivência (29.649 a 30.987 ciclos até a falha inicial) exceto pelo grupo NfPfB que apresentou os melhores resultados (39.761 ciclos) e foram estatisticamente melhores que os grupos restaurados com pinos de titânio. No entanto, o uso do pino intraradicular não foi suficiente para se obter o mesmo desempenho dos grupos com 2mm remanescente coronário (73.244 ciclos). Todas as amostras restauradas com pinos intraradiculares apresentaram fraturas catastróficas, enquanto o grupo restaurado apenas com o núcleo resinoso apresentou 50% de fraturas restauráveis ou possivelmente restauráveis. A presença do remanescente coronário com ou sem pino teve influência positiva sobre a resistência à fadiga dos IET. Dentre os grupos restaurados com pinos intraradiculares, o pino de fibra de vidro utilizado em conjunto com resina composta bulk-fill apresentou os melhores resultados. O uso do pino intraradicular foi prejudicial para o modo de falha dos IET independente da presença ou não do remanescente coronário.

Canal radicular; Técnica para retentor intraradicular; Restauração dentária permanente; Materiais - Fadiga.

ABSTRACT

The restoration of severely broken-down and endodontically-treated incisors (ETI) is a major challenge in daily practice and is commonly undertaken using various types of posts and composite resin buildups. Additional time, materials and risk involved in the placement of the post is not accompanied by an increase in mechanical resistance of the root-restoration complex. Use of a post was even correlated to a higher rate of unrestorable fractures. The aim of this study was to investigate the restoration of broken-down endodontically-treated incisors with and without ferrule using glass ceramic crowns bonded to composite resin core-buildups with or without post. Article number one used forty-five decoronated endodontically-treated bovine incisors divided in 3 groups: FP as control (2-mm ferrule, a glass-fiber post and nanohybrid composite resin buildup), FNp (with 2-mm ferrule and nanohybrid composite resin build-up) and NfP (without ferrule, glass fiber post and nanohybrid composite resin build-up). The second study used sixty decoronated endodontically-treated bovine incisors without ferrule divided in 4 groups: NfPfB (glass-fiber post and bulk-fill composite resin build-up), NfPfP (glass-fiber post and dual-cure glass glass reinforced composite resin build-up), NfPt (titanium post and nanohybrid composite resin build-up) and NfPtB (a titanium post bulk-fill composite resin build-up). All teeth were prepared to receive bonded lithium-disilicate ceramic crowns and were subjected to accelerated fatigue testing. Cyclic isometric loading was applied to the incisal edge at an angle of 30^{O}, a frequency of 5Hz, beginning with a load of 100 N (5000 cycles). A 100N load increase was applied each 15,000 cycles. Specimens were loaded until failure or to a maximum of 1,000N (140,000 cycles). Groups were compared using the Kaplan Meier survival analysis (Log rank test at $p \leqq 0.05$). Failure mode was classified in restorable, possibly restorable and catastrophic. None of the tested specimen withstood all 140,000 load cycles. Specimens without ferrule were affected by an initial failure phenomenon (wide gap at the lingual margin between the buildup/crown assembly and the root). There was a significant difference in mean survived cycles between the ferrule groups (73,332 and 73,244 cycles, respectively) and the no-ferrule groups (50,121 cycles; p=0.001). The use of a glass-fiber post was not significant in presence of the ferrule (p=0.884). The no-ferrule groups had similar survival rate (29,649 to 30,987 mean survived cycles until initial failure), except for the NfPfB that showed the highest result (39,761X cycles). However, none of the posts and buildup materials were able to match the performance of the ferrule group (73,244 cycles). In all groups with posts, 100% of failures were unrestorable (catastrophic). The no-post group had 50% of restorable and possibly restorable failures. The survival of broken-down nonvital incisors was improved by the presence of the ferrule but not by the glass-fiber reinforced post. Within the post-and-core groups, the combination of glass-fiber post and bulk-fill composite resin build-up presented better results when compared to the titanium posts. Posts were always detrimental to the failure mode.

Root canal; Post and core technique; Dental restoration, permanent; Materials - Fatigue

SUMÁRIO

INTRODUÇÃO

A restauração de incisivos endodonticamente tratados (IET) ainda é considerada um desafio para a Odontologia Restauradora. Após o tratamento endodôntico a arquitetura do dente é modificada devido à remoção do tecido cariado, do acesso e instrumentação do canal radicular (Dietschi et al., 2008). Dentes despolpados apresentam maior risco de fratura quando comparados a dentes vitais (Juloski et al, 2012; Torbjorner and Fransson, 2004) devido às tensões induzidas ao dente ser diretamente proporcional ao volume de estrutura dental remanescente (Egilmez et al., 2012). Por décadas, as opções restauradoras para dentes tratados endodonticamente têm sido objeto de estudos que buscam identificar meios que tornem o complexo restaurado mais resistente às cargas mastigatórias.

Sabe-se que o fator mais importante para a resistência dos IET é a presença do remanescente coronário (Juloski et al., 2012). O remanescente coronário ou “férula” é definido como uma parede de dentina coronária circundando em 360^0 a raiz do dente e dando configuração ao preparo da futura restauração. A altura de remanescente sugerida varia em torno de 1mm até 2mm (Sorensen and Engelman, 1990; Libman and Nicholls, 1995), sendo que a resistência do dente é proporcional à altura da férula (Isidor et al., 1999). A presença adequada do remanescente coronário diminui o impacto de outros fatores, tais como pinos e núcleos, agentes cimentantes e restauração, na resistência biomecânica do IET (Juloski et al., 2012) e pode melhorar o prognóstico da restauração (Naumann et al., 2006). Em situações clínicas onde não se permite obter uma circunferência completa de remanescente coronário, o remanescente incompleto é considerado uma opção mecanicamente melhor que a falta completa do remanescente coronário. A presença da férula também está associada à um maior número de fraturas reparáveis (Juloski et al., 2012).

Além disso, a quantidade de estrutura dental remanescente é um fator determinante na escolha da técnica restauradora (Schwartz and Robbins, 2004). Nas situações clínicas onde o dente apresenta considerável altura de remanescente coronário, os pinos pré-fabricados devem ser o material de escolha (Garbin et al., 2010; Heydecke and Peters, 2002). Idealmente, o material deve possuir propriedades físicas, tais como o módulo de elasticidade, resistência à compressão e expansão térmica, bem como a estética semelhante às da dentina (Cheung, 2005). Os pinos pré-fabricados são produzidos em diferentes materiais tais como: titânio, aço inoxidável, fibras (carbono e vidro) e zircônia. Eles são colados à estrutura dental utilizando cimentos resinosos e o núcleo de preenchimento é construído utilizando resina composta.

Dentre os pinos pré-fabricados, o pino de fibra de vidro parece ser o material de escolha. Além da alta qualidade estética, sua principal vantagem é ter propriedades mecânicas (módulo de elasticidade) muito semelhantes à dentina (Schwartz and Robbins, 2004; Plotino et al., 2007). Quando cimentado com cimento resinoso pode contribuir com uma melhor distribuição de tensões na raiz, resultando em um menor número de falhas (Schwartz and Robbins, 2004). No entanto, alguns trabalhos na literatura apontam a perda de retenção do pino como falhas frequentemente associadas aos pinos adesivos (Theodosopoulou and Chochlidakis, 2009; Rasimick et al., 2010; Sterzenbach et al., 2012).

A seleção e indicação dos pinos de fibra de vidro ainda não estão totalmente claras, principalmente quando se refere à dentes com remanescente coronário. É relatado que o preparo do canal para receber o pino intraradicular pode significantemente reduzir a resistência do dente (Dietschi et al., 2007). O uso de pino em dentes posteriores já foi comprovado como não tendo significativa importância na resistência à fratura, sendo substituídos somente pelo uso de núcleo de preenchimento resinoso (Magne et al., 2015; Massa et al., 2010). Outros estudos apresentam resultados promissores em dentes anteriores sem uso de pinos (Pereira et al., 2009; Lima et al., 2010), no entanto em ambos estudos, a metodologia usada (teste uniaxial de compressão) e material metálico para as coroas podem fornecer resultados não condizentes com a realidade clínica, sendo necessário novos trabalhos que avaliem as técnicas adesivas para dentes com remanescente coronário.

Como mencionado anteriormente, a quantidade de estrutura dental remanescente deve indicar a técnica restauradora do IET. Núcleos metálicos fundidos foram e ainda são utilizados por muito dentistas para promover retenção da coroa em restaurações de dentes severamente comprometidos. Esta técnica é recomendada quando não há estrutura coronária disponível para reter a coroa ou para adesão do material restaurador (Schwartz and Robbins, 2004). No entanto por causa do alto módulo de elasticidade da liga metálica quando comparado à dentina radicular, esse tipo de retentor está mais associado a fraturas catastróficas da raiz (Torbjörner and Fransson, 2003), além de envolver grande custo laboratorial e consumir maior tempo clínico (Heydecke and Peters, 2002).

Sabe-se que os retentores intraradiculares não contribuem com o aumento da resistência dos dentes tratados endodonticamente, atuando apenas em promover a retenção da coroa ao núcleo de preenchimento (Soares et al., 2007). Sob uma perspectiva biomimética, a substituição da estrutura dental por materiais metálicos não parece ser uma estratégia coerente, uma vez que as propriedades físicas e mecânicas das ligas são extremamente diferentes das propriedades do esmalte e dentina, o que leva à modificação dos padrões de distribuição de cargas no elemento dental (Martinez-Rus et al., 2011; Magne et al., 2010). Com o advento da Odontologia Adesiva, o aprimoramento dos materiais cimentantes e a crescente demanda por restaurações estéticas, tornou-se possível restaurar até mesmo os dentes sem remanescente coronário utilizando sistemas adesivos combinados com pinos pré-fabricados e núcleos resinosos.

Buscando aumentar a resistência das restaurações, as resinas compostas utilizadas para confecção do núcleo devem ser resistentes às forças mastigatórias (Scherrer and de Rijk, 1993). Resinas compostas fotopolimerizáveis apresentam diversas vantagens como: propriedades mecânicas aceitáveis, estabilidade de cor e podem ser adaptadas e esculpidas sob a técnica incremental (Vouvoudi and Sideridou, 2013; Ilie et al., 2013). Recentemente, introduziu-se no mercado odontológico as resinas compostas Bulk-Fill, que são capazes de serem fotopolimerizadas em camadas de até 5mm de espessura, acelerando a aplicação do material e diminuindo o tempo de atendimento clínico. Estudos afirmam que estas resinas compostas apresentam uma boa profundidade de polimerização, baixa contração de polimerização e são tão confiáveis quanto as resinas compostas nano-híbridas (Kemaloglu et al., 2015). Outra alternativa para a reconstrução dos IET é a combinação dos pinos pré-fabricados com materiais de polimerização dual, usados tanto para a cimentação de pinos quanto para a reconstrução do núcleo resinoso. Essa técnica diminui as interfaces entre dentina, pino e coroa podendo aumentar a longevidade da restauração (McLaren et al., 2009; Agrawal and Mala, 2014).

Especialmente em casos sem estrutura coronária remanescente para promover a retenção e resistência da restauração, a seleção dos materiais restauradores permanece um desafio, visto que não há um consenso na literatura sobre qual técnica seja mais eficaz, principalmente se tratando de restaurações adesivas.

Considerando que diferentes aspectos, tais como presença ou não do remanescente coronário e diferentes técnicas de restauração podem influenciar no comportamento biomecânico de incisivos endodonticamente tratados, o presente estudo, apresentado em dois capítulos, teve como objetivo avaliar a resistência à fadiga, carga à fratura e o modo de falha de incisivos endodonticamente tratados restaurados com coroas cerâmicas sob influência ou não do remanescente coronário e diferentes técnicas restauradoras.

ARTIGOS

Artigo 1: Ferrule-effect dominates over use of a fiber post when restoring endodontically-treated incisors with composite build-up and ceramic crown: an in-vitro study

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CLINICAL RELEVANCE

The use of a post for the restoration of nonvital incisors with ferrule is not relevant necessary. Additional time, materials and risk involved in the placement of the post do not provide an increase in mechanical resistance. The use of a post can even be correlated to unrestorable fractures.

ABSTRACT

Objectives: The aim of this study was to investigate the restoration of broken-down endodontically-treated incisors with ferrule effect using glass ceramic crowns bonded to composite resin core-buildups with or without fiber post. A no-ferrule group with post was also included for comparison. **Materials and Methods:** Thirty decoronated endodontically-treated bovine incisors with a 2 mm ferrule were restored with a direct buildup using a nanohybrid direct composite resin (Miris 2 and Optibond FL) with or without a glass-fiber-reinforced post (GFR post). An additional group of 15 teeth without ferrule were restored with buildup and fiber post. All teeth were prepared to receive bonded glass ceramic crowns (e.max CAD luted with Variolink Esthetic DC) and were subjected to accelerated fatigue testing. Cyclic isometric loading was applied to the incisal edge at an angle of 30^{O}, a frequency of 5Hz, beginning with a load of 100 N (x 5000 cycles). A 100N load increase was applied each 15,000 cycles. Specimens were loaded until failure or to a maximum of 1,000N (x 140,000 cycles). Groups were compared using the Kaplan Meier survival analysis (Log rank test at p=0.05). **Results:** none of the tested specimen withstood all 140,000 load cycles. Specimens with posts but without ferrule were affected by an initial failure phenomenon (wide gap at the lingual margin between the buildup/crown assembly and the root). There was a significant difference in mean survived cycles between the ferrule groups (Fp=73,332X and FNp=73,244X) and the no-ferrule group (50,121X; p=0.001). The addition of a fiber post was not significant in presence of the ferrule (p=0.884). In both groups with posts, 100% of failures were unrestorable. The no-post group had 50% of restorable and possibly restorable failures. **Conclusions:** the survival of broken-down nonvital incisors was improved by the presence of the ferrule but not by the fiber-reinforced post. Fiber posts were always detrimental to the failure mode and were not able to compensate for the absence of ferrule.

INTRODUCTION

The restoration of severely broken-down and endodontically-treated incisors (ETI) is a major challenge in daily practice. Endodontically treated teeth have significantly different mechanical properties compared to vital teeth. The main modifications in the biomechanics of the tooth are attributable to the loss of tissue following caries lesion, fracture, or cavity preparation, including the access cavity before endodontic therapy.[1,2]

There is a general agreement that the ferrule is the most important mechanical factor[3–5] for the strength of ETI. The presence of an adequate ferrule decreases the impact of the post and core system, luting agents, and the final restoration on the performance of endodontically restored teeth.[3] Teeth prepared with a ferrule have a tendency to fail in a more favorable mode.[6] The amount of suggested ferrule vary between 1mm[7] to 1.5mm[8] up to 2mm.[3] The resistance seems to increase significantly with an increased ferrule height[9] and a better prognosis can be expected if the ferrule is circumferential.[10]

Traditionally, direct posts are used to retain adhesive core-buildups in ETI. Hence, studies about ETI typically compare different types of buildup methods that usually include posts. When deciding to use a direct post, glass fiber-reinforced posts (GFR post) seems to have many benefits (adhesion, tooth-like flexibility, esthetics etc.).[4,11,12] However, despite all the benefits of GFR posts, their selection and indication are still not fully understood. Earlier publications have reported loss of retention as a major mode of failure for glass fiber posts luted with resin cements.[13–15] In addition, the preparation of an access channel, canal enlargement during endodontic procedures, and use of specific chemicals as well as the post placement itself significantly reduce tooth strength.[2]

In posterior teeth, placement of a post has already proven not to significantly improve fracture resistance compared with composite resin core without extra retentive features.[16,17] Whenever a post is used, less restorable fractures are expected.[18,19] The uselessness of a post was even demonstrated on premolars[19] using restorative composite and a proven classic adhesive. Pereira et al.[20] demonstrated the importance of the ferrule on canines while Lima et al.[21] showed the uselessness of posts in incisors, however, both studies used a single load to failure experiment and metal crowns. Post insertion for teeth showing a minor substance loss should be critically reconsidered.[11] Thus, there is still a lack of scientific information about restoration of ETI with bonded ceramic crowns. Progresses in dentin bonding and the so-called biomimetic approach[22] have triggered new ways of restoring ETI using adhesive ceramic crowns and it has become more acceptable to restore ETI with extensive loss of coronal structure without a post.

Hence, the objective of the present study was to investigate the restoration of endodontically-treated incisors with ferrule using glass ceramic crowns bonded to composite resin core-buildups with or without a fiber post. A no-ferrule group with a fiber post was also included for comparison.

The null-hypotheses were that a) the use of a GFR post and b) the presence of ferrule would not influence the accelerated fatigue strength of ETI and that c) the presence of a GFR post would not affect the failure mode of the restored ETI tested in this in vitro study.

MATERIAL AND METHODS

Tooth preparation

Forty-five bovine incisors (n=15) with similar dimensions and pulp space were selected and stored in thymol-saturated solution (Thymol, Aqua Solutions Inc., Deer Park, Texas, USA). The sample size was determined by a pilot study, without performing a power analysis, following similar experimental designs of previous studies[18,19]. All teeth were decoronated, either up to 15mm (ferrule group) or 13mm (no-ferrule) from the apex and subsequently separated to three groups: FP= ferrule with GFR post and resin core build-up, FNp= ferrule and direct resin core build-up or NfP= no-ferrule with GFR post and resin core build-up (Figures 1 and 2).

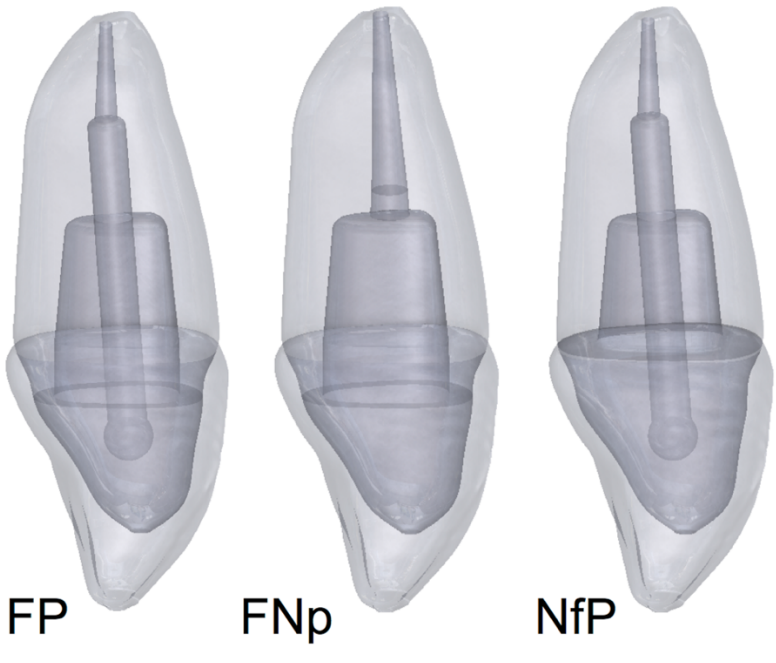

Figure 1: Schematic views of restored ETI. (A): Group FP, (B): FNp and (C): NfP.

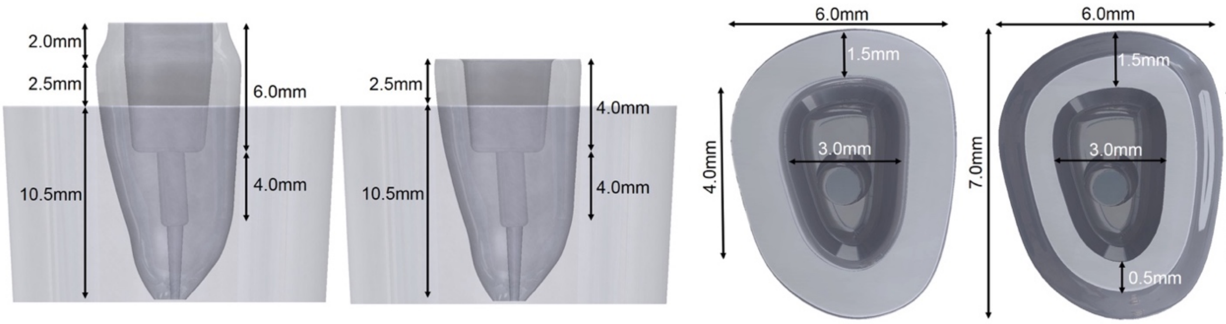

Figure 2: Schematic view of root dimensions before restoration.

The specimens were mounted in a special positioning device with acrylic resin (Palapress vario; Heraeus Kulzer, Armonk, NY, USA) embedding 11.5mm of the root. For the ferrule groups, the specimens were prepared with a tapered round-ended diamond bur (Brasseler, Savannah, GA, USA), creating a 2mm high / 1mm thick circular ferrule and a 0.8mm horizontal circular chamfer (cervical limit). Table 1 presents the identifications by brand and company, and also the qualitative composition information of materials used in the present study.

Table 1: Material application, brand name, composition and manufacturers of the materials used in the study.

APPLICATION	BRAND NAME	COMPOSITION	MANUFACTURER
ACRYLIC RESIN FOR TOOTH MOUNTING	Palapress Vario	*Powder*: methyl methacrylate copolymer. *Liquid*: methyl methacrylate, dimethacrylate.	Hereaus Kulzer, Wehrheim, Germany.
DUAL CURE SELF-ADHESIVE UNIVERSAL RESIN CEMENT FOR POST CEMENTATION	RelyX™ Unicem 2	*Base paste:*Methacrylate monomers containing or not phosphoric acid groups; Silanated fillers; Initiator components Stabilizers; Rheological additives *Catalyst paste:*Methacrylate monomers; Alkaline (basic) fillers; Silanated fillers; Initiator components; Stabilizers; Pigments; Rheological additives.	3M ESPE, Seefeld, Germany.
FIBER POST	Parapost® Fiber Lux™	60% glass fiber, 40% resin.	Coltene Whaledent, Altstatten, Switzerland.
GLASS IONOMER BARRIER	Vitrebond™ Plus	*Liquid:* resin modified polyalkenoic acid, HEMA (2-hydroxyethymethacrylate), water and initiators (including camphorquinone). *Paste:* HEMA, BIS-GMA, water, initiators and a radiopaque fluoroaluminosilicate glass (FAS glass).	3M ESPE, Seefeld, Germany
SILICATIZATION	Rocatec Soft™	High-purity 30 µm aluminium oxide, modified with silica (SiO2).	3M ESPE, Seefeld, Germany.
TOTAL-ETCH ADHESIVE SYSTEM	Optibond FL®	*Primer:* 2-hydroxyethyl methacrylate ethanol; 2-[2-(methacryloyloxy)ethoxycarbonyl]benzoic acid; glycerol phosphate dimethacrylate. *Adhesive:* 2-hydroxyethyl methacrylate; 3-trimethoxysilylpropyl methacrylate; 2-hydroxy-1,3-propanediyl bismethacrylate; alkali fluorosilicates(Na).	Kerr, Orange, USA.
COMPOSITE RESIN FOR CORE/BUILD-UP	Miris® 2	Methacrylate, barium glass, silanized, amorphous silica, hydrophobed.	Coltene Whaledent, Altstatten, Switzerland.
SILANIZATION	Monobond® Plus	Alcohol solution of silane methacrylate, phosphoric acid methacrylate and sulphide methacrylate.	Ivolcar Vivadent, Schaan, Liechtenstein.
SELF-ETCH ADHESIVE SYSTEM	Adhese® Universal	Phosphoric acid methacrylate; methacrylated carboxylic acid polymer; hydrophilic mono-functional methacrylate; hydrophilic / hydrophobic crosslinking dimethacrylate; hydrophobic crosslinking dimethacrylate.	Ivolcar Vivadent, Schaan, Liechtenstein.
RESIN CEMENT FOR RESTORATION LUTING	Variolink Esthetic® Dual Cure	Monomer matrix: urethane dimethacrylate, inorganic fillers (ytterbium trifluoride and spheroid mixed oxide). Initiators, stabilizers and pigments.	Ivolcar Vivadent, Schaan, Liechtenstein.
ACID FOR CERAMIC SURFACE TREATMENT	IPS Ceramic Etching Gel®	5% hydrofluoric acid	Ivolcar Vivadent, Schaan, Liechtenstein.
GLASS-CERAMIC FOR RESTORATION	IPS e.max® CAD	SiO_2; Li_2O; K_2O; P_2O_5; ZrO_2; ZnO; Al_2O_3; MgO; Colouring oxides.	Ivolcar Vivadent, Schaan, Liechtenstein.

Endodontic Treatment

Standard chemo-mechanical endodontic protocol with ideal irrigants ensued as was applicable in this case.[23,24] The canals were instrumented to at least a size 40/06 with K3XF rotary files (Sybron Endo) by crowning down and maintaining patency with a 10K file between rotaries. The canals were irrigated with 17% EDTA (Roydent, Johnson City, TN) for one minute followed by 5.25% NaOCl (Chlorox, Oakland, CA) for one minute as a final rinse.[25,26] The efficacy of irrigation was amplified by Endo Activator (Dentsply, Tulsa Dental Specialties) each with EDTA and NaOCl (Nair et al.). After the canals were dried with paper points, one coat of Thermaseal Plus (Dentsply, Tulsa Dental Specialities) was placed circumferentially around the lumen all the way to the working length with a 10k file. Then, 0.6 taper K3XF gutta percha cones (Sybron Endo) were coated with thermaseal plus and used for warm vertical obturation; the gutta percha was thermoplasticized with a 0.6 taper Buchanan heated plugger (Sybron Endo) and then down packed with stainless steel Buchanan hand pluggers (Sybron Endo).

Root canal and internal ferrule preparation

For post groups, gutta-percha was removed, 8mm deep into the pulp chamber from the cervical limit, with a Reamer pilot drill size no.3 (Ivoclar Vivadent, Schaan, Liechtenstein) using a handpiece at 1,000-2,000rpm. For all groups, a so-called “internal ferrule” was prepared in form of a box using a conical shape bur, 4mm deep from the cervical limit of the crown preparation.

Post groups preparation

The post spaces were prepared with ParaPost drills specifically designed for the ParaPost Fiber Lux (no 6, 1.5mm diameter; Coltene Whaledent, Altstatten, Switzerland) (Figure 3). Using a cutting disc, the apical portion of the posts was removed to obtain a length of 11mm (8mm below and 3 mm above the cervical limit of the crown preparation). Prior to the luting procedure, the posts were cleaned with alcohol and air-dried. The post space walls were lightly coated with cement (RelyX Unicem 2 Automix, 3M ESPE Seefeld, Germany) and the post was inserted. Cement excesses were cleaned, leaving 4mm of post height in cement. The cement system was light-cured for 40s (VALO Curing Light, Ultradent Products, Inc., South Jordan, UT, USA). After post cementation the exposed dentin walls and the post were sandblasted with 30µm silicated Al_2O_3 powder (Rocatec Soft, 3M ESPE, Seefeld, Germany). Silane (Ceramic Primer, 3M ESPE, Seefeld, Germany) was applied to the post head and air-dried. For denting bonding purpose, 35% phosphoric acid (Ultra-Etch, Ultradent, Utah, USA) was used for etching during 10s (dentin walls and post, rinsed and gently dried, followed by application of the adhesive system (Optibond FL Primer and Adhesive, Kerr, Orange, CA, USA) and light-curing for 40s (VALO Curing Light, Ultradent Products, Inc., South Jordan, UT, USA). All buildups were obtained with five to six 2-mm-thick increments of Miris 2, (Coltene Whaledent, Altstatten, Switzerland), each polymerized at 1,000 mW/cm2 (VALO Curing Light, Ultradent Products, Inc., South Jordan, UT, USA) for 40s. An air-blocking barrier (KY Jelly; Johnson & Johnson Inc., Montreal, QC, Canada) was used to cover the preparation surface, and additional polymerization was carried out for 10s per surface. A special care was taken to shape the Miris 2 buildup ideally in order to avoid any further corrections of the preparation surface and margins. All buildups were 11mm high (4mm internal and 7mm above cervical limit of the crown preparation).

Figure 3: Post insertion and build-up.

<u>No post groups preparation</u>

After internal ferrule preparation, a 1-mm-thick GI barrier (Vitrebond Plus, 3M-ESPE, ST.Paul MN) was placed first, followed by sandblasting (Rocatec Soft), acid etching of all exposed dentin (Ultra-Etch), and application of the adhesive system (Optibond FL Primer and Adhesive). The same buildup technique and materials were used as for the two post groups.

Design and manufacturing of restorations

All bonded ceramic crowns were fabricated using the Cerec 3 CAD/CAM system (Sirona Dental Systems GmbH, Bensheim, Germany). Digital impression of the prepared teeth was performed with Cerec Blue Cam, using a contrast powder (IPS Contrast Spray Chairside, Ivoclar Vivadent, Schaan, Liechtenstein). The specimens were fitted with a crown of standardized thickness and anatomy with 11mm inciso-cervical length and 9mm mesio-distal width. All crowns were milled in lithium disilicate ceramic (IPS e.max CAD, Ivoclar Vivadent, Schaan, Liechtenstein) using the “crown mode" with the sprue located at the lingual surface. After milling, lithium disilicate restorations were glazed, crystalized and fired according to the manufacturer’s protocol (Programat CS, Ivoclar Vivadent, Schaan, Liechtenstein) using IPS Object Fix Putty and IPS e.max CAD Crystall/Glaze Spray (Ivoclar Vivadent, Schaan, Liechtenstein). The steps of digital design as well as the final restoration are presented in figures 4-6.

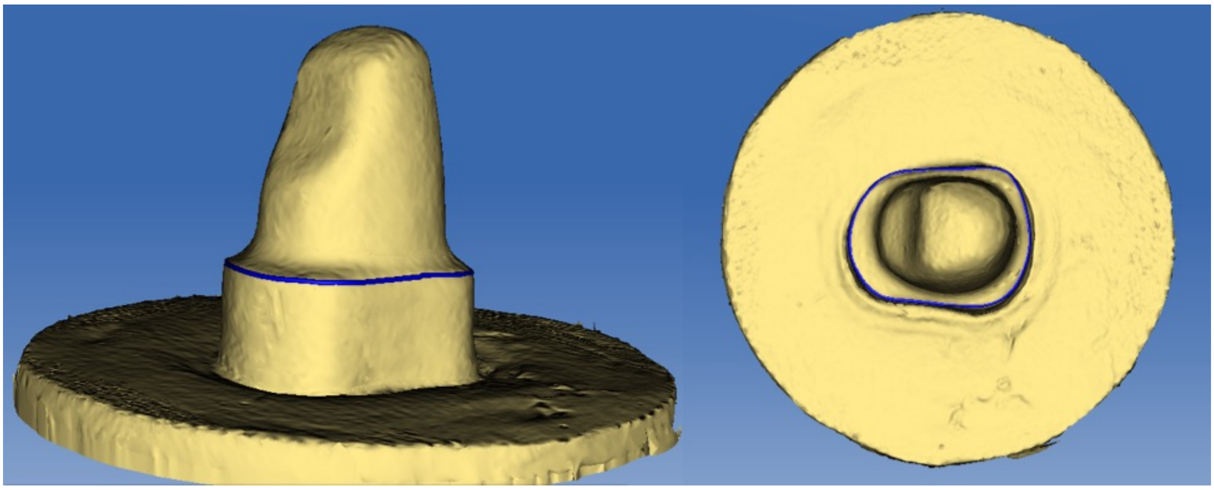

Figure 4: CAD data set of preparation with preparation line.

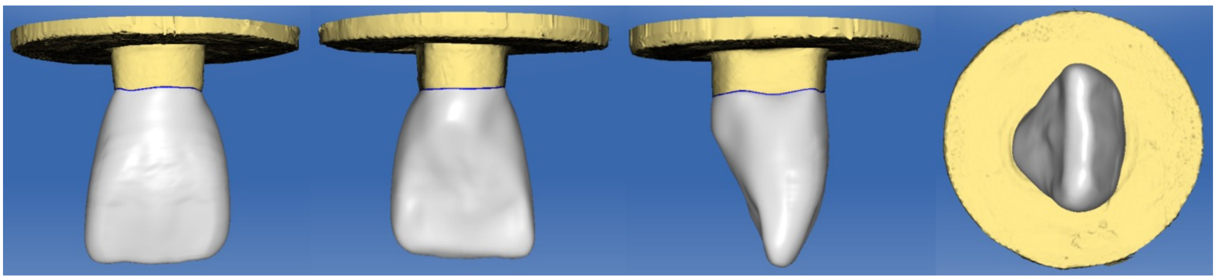

Figure 5: Standardization of crown-design using the Cerec software. All crowns had 11mm high and 9mm in mesial-distal width.

Figure 6: Final assembly after cementation.

<u>Adhesive luting of the crowns</u>

The dual-cure resin cement Variolink Esthetic DC (Ivoclar Vivadent, Schaan, Liechtenstein) was used. Before luting, each restoration was fitted on its respective tooth to check its marginal adaptation. All crowns were cleaned in ultrasonic bath in distilled water followed by etching with 5% hydrofluoric acid (IPS ceramic etching gel, Ivoclar Vivadent, Schaan, Liechtenstein) for 20s and post-etching cleaning again for 1 minute in distilled water in ultrasonic bath. Silane (Monobond Plus, Ivoclar Vivadent, Schaan, Liechtenstein) was applied with a microbrush and heat-dried at 100°C for five minutes in a mini-oven (D.I.-500, Coltene, Altstatten, Switzerland).

The tooth preparation and buildups were sandblasted with 30μm silicated Al_2O_3 powder (Rocatec Soft, 3M ESPE, Seefeld, Germany) and coated with Adhese Universal (Ivoclar Vivadent). Variolink Esthetic was then applied to the fitting surface of the crown and seated on the tooth with approximately 500g of pressure. Cement excesses were removed and followed by light polymerization for 3 times 20s on each surface (buccal and lingual) with a LED light (VALO Curing Light). Air-blocking barrier (KY Jelly; Johnson & Johnson Inc., Montreal, QC, Canada) and additional polymerization was carried out for 10s per surface. The margins were finished with hand instruments (scalpel and scaler). The samples were stored in distilled water at room temperature (24°C) for a minimum of 24h following adhesive restoration placement and then subjected to accelerated fatigue testing.

Accelerated fatigue test

Masticatory forces were simulated in an artificial mouth using closed-loop servo-hydraulics (Acumen III; MTS Systems, Eden Prairie, MN, USA). The chewing cycle was simulated by an isometric contraction (load control) applied through a flat composite resin antagonist (Z100; 3M ESPE, Seefeld, Germany). The force was applied at a palatal angle of 30º with the flat surface contacting 3/4 of the incisal edge (figure 7). The load chamber was filled with distilled water to submerge the sample during testing. Cyclic load was applied at a frequency of 5Hz, starting with a load of 100N (warm-up of 5,000 cycles), followed by stages of 200, 300, 400, 500, 600, 700N, 800N, 900N and 1000N a maximum of 15,000 cycles each force. Samples were loaded until fracture or to a maximum of 140,000 cycles.

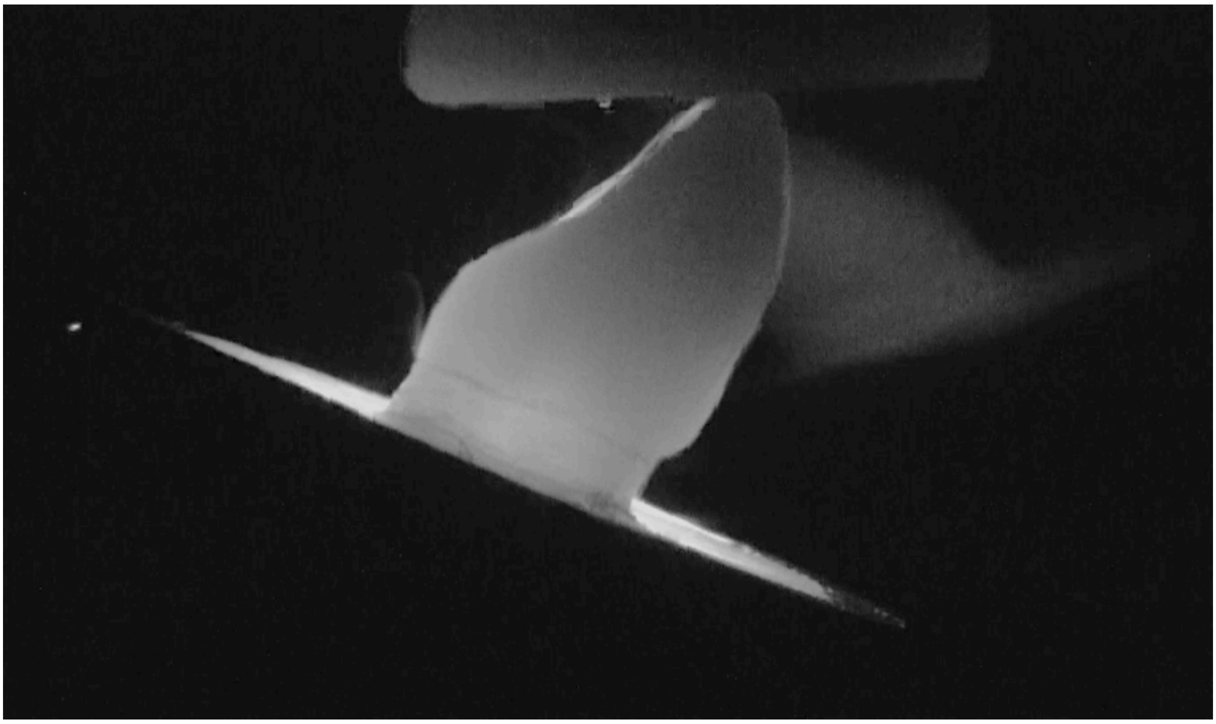

Figure 7: Specimen in load chamber. Cyclic isometric loading was applied to the incisal edge at an angle of 30^{O}.

Analysis

All the fatigue testes were monitored using a macro video camera and recorded continuously in order to determine the crack propagation mode (initial gap, root fracture and final fracture). The number of endured cycles, load to failure and failure mode of each specimen were recorded. After the test, each sample was evaluated by transillumination (Microlux; Addent, Danbury, CT) and optical microscope (Leica MZ 125; Leica Mycrosystems, Wetzlar, Germany) at 10:1 magnification. A visual distinction was made among three fracture modes, considering the reparability of the tooth: catastrophic, that is, root fracture that would require tooth extraction; possibly reparable, that is, cohesive/adhesive failure with fragment and minor damage, chip or crack, of underlying tooth structure; or reparable fracture, that is, cohesive or adhesive failure of restoration only.

The fatigue resistance of the groups was compared using the Kaplan Meier survival table (for cycles). At each time interval (defined by each load step), the number of specimens starting the interval intact and the number of specimens fracturing during the interval were counted, allowing the calculation of survival probability at each interval. Post hoc Log Rank test was used to analyze the influence of the ferrule, post system and core build-up material on the fracture resistance of the ETI on a significance level of 0.05 (corrected for multiple comparisons when indicated).

Additionally, the fracture load and number of cycles at which the specimen failed was compared using one-way analysis of variance (ANOVA) followed by Tukey test at a significance level of 0.05. For all statistical analyses, the level of significance was set at 95%. The data were analyzed with statistical software (SPSS 23, SPSS Inc, Chicago, IL).

RESULTS

None of the specimen withstood all 140,000 load-cycles. As all specimen fractured, the mean fracture load/cycles could be calculated (Figure 8 and 9). During cyclic-loading, initial failures were detected in 81% (12/15) of specimens of no-ferrule group, 14% (2/15) and 7% (1/15) for ferrule with post and ferrule without post, respectively. The initial failure phenomenon can be described as the opening of a wide gap between the buildup/crown assembly and the root. The gap was always located at the lingual margin. Because clinical detection of such initial failures appears to be questionable, the analysis of survival was both conducted for the "final failure" (NfP[f]) as well as considering the "initial failure" (NfP[i]). The initial failure (i) values were recorded by reviewing the motion picture (high definition macro mode) of the entire test for each specimen. Initial failure was easily detected by a significant high pitch noise and simultaneous opening of a wide gap with emission of debris and air bubbles. The final failure (f) values were obtained by the testing machine when the sample completely fractured, causing the test to stop by activating the predetermined trigger parameters (axial displacement and axial acceleration).

The life table survival graphs for all groups are displayed in figure 9. The Log-rank test showed significantly higher survival of groups with ferrule compared to group without ferrule (p<0.001). No difference could be found between groups with ferrule (p= 0.488). Also when considering the initial failure, the Log-rank test showed the same results, that is a significantly higher survival of ferrule group compared to no-ferrule group (p=<0.001) and no statistical difference between ferrule groups (p=0.508).

One-way ANOVA and Tukey test revealed that the mean fracture load for the FP group (620.00 ± 137.32N; p=0.984) showed no statistical difference when compared with FNp group (633.33 ± 111.2697N; p=0.984). Ferrule groups were significantly higher than NfP group (380.00 ± 77.4596N [i], 480.00 ± 67.6123N [f]) considering the initial and final failure (p<0.001). The same results were found when the number of survived cycles was statistically compared (FP group to FNp group: p=1.000; FP group to NfP group: p<0.01; FNp group to NfP group: p<0.01). Figure 8 shows the mean values of fracture loads and survived cycles and their standard deviations, respectively.

<u>Failure mode analysis</u>

Groups with fiber post showed 100% of catastrophic failures, while the no-post group presented 50% of non-catastrophic failure. Possible fractures of the roots were made visible by trans-illumination in order to classify the specimen correctly (Figure 10). Figure 11 provides the number of specimen and percentage of each specific fracture mode for each group.

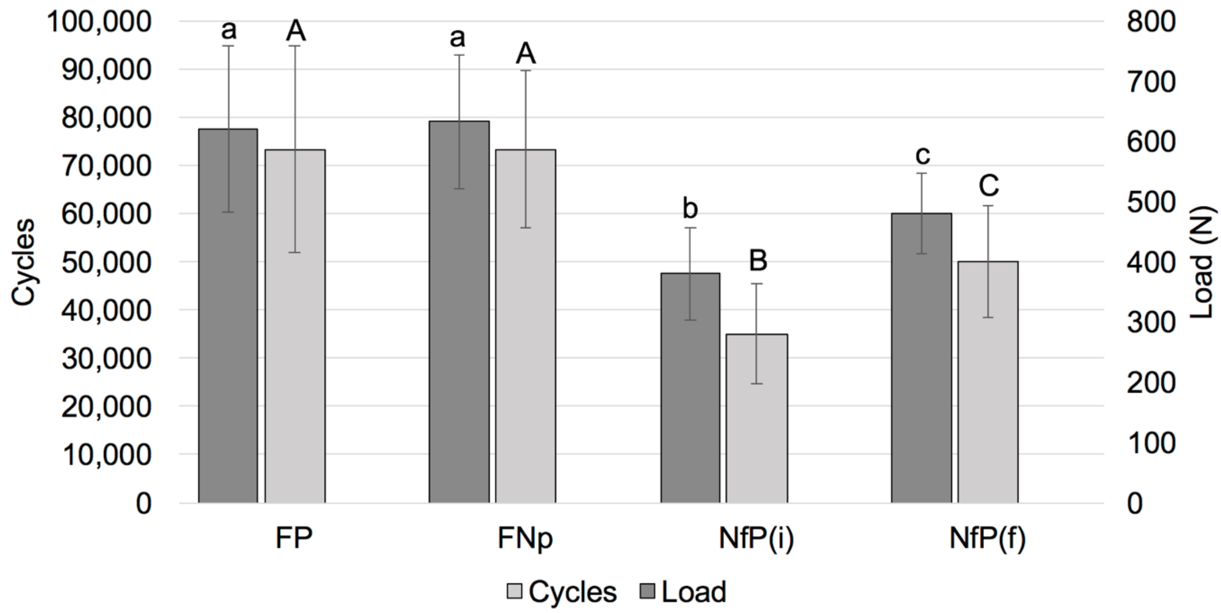

Figure 8: Mean fracture loads (dark gray) and average number of survived load cycles (light grey) and their standard deviations, respectively.

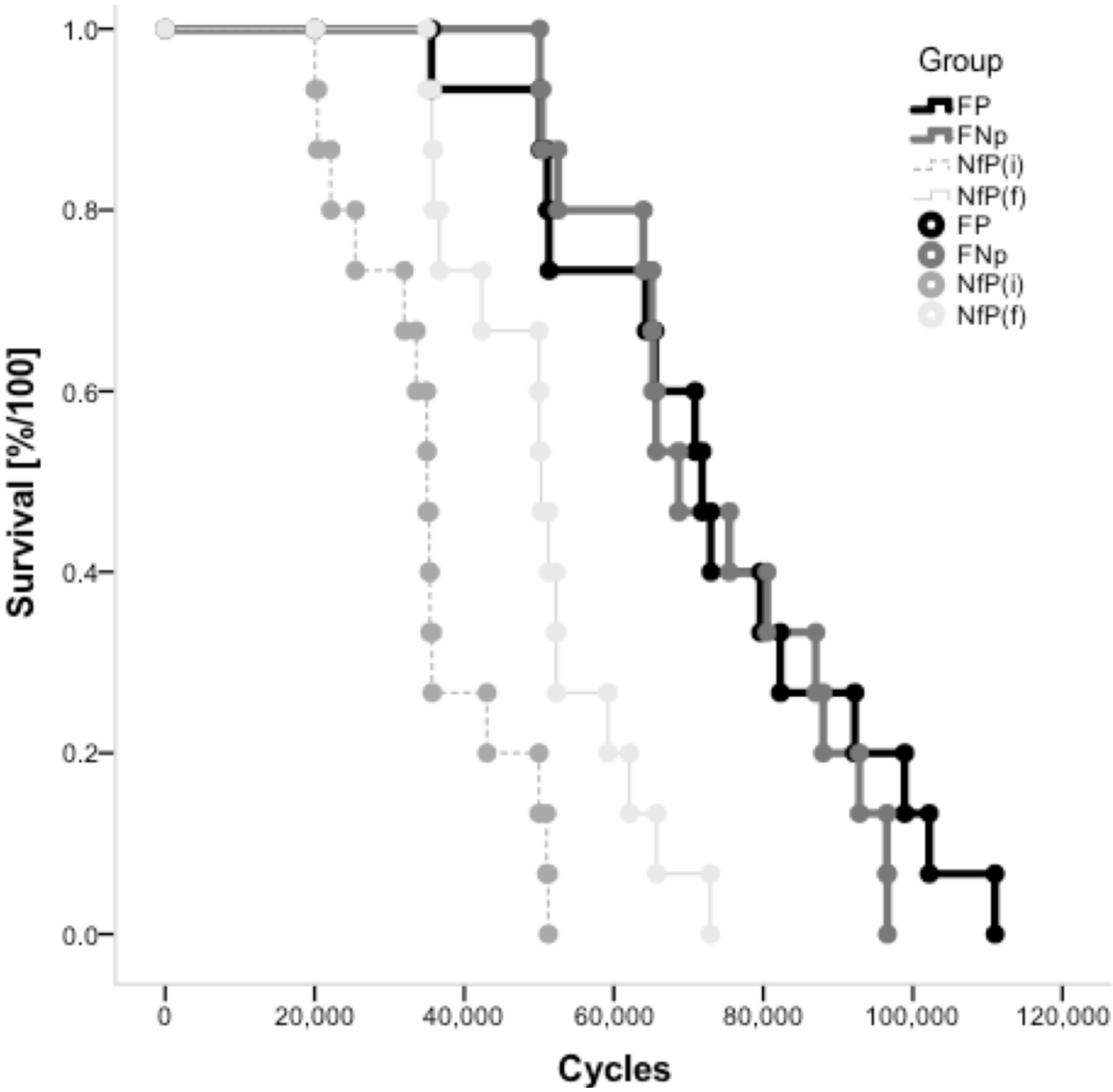

Figure 9: Kaplan-Meyer survival graphs for groups FFp, FNp, and NfFp. For better comparison, the survival graph of group NfFp was divided in initial failure and final failure.

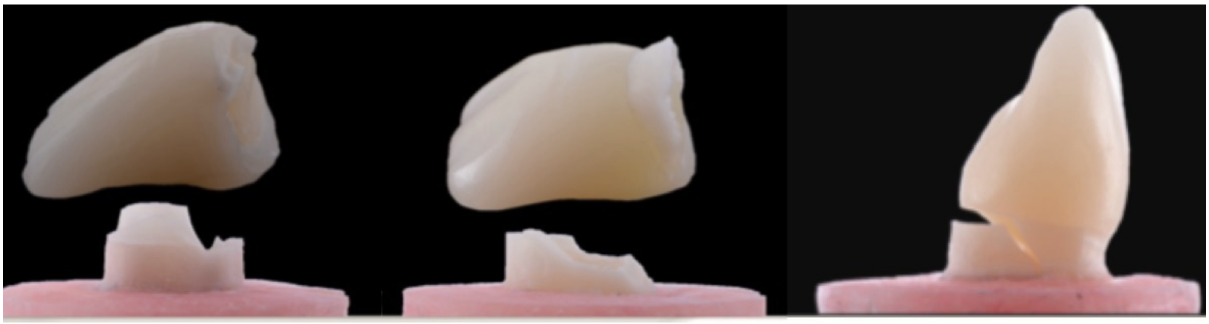

Figure 10: All specimens were analyzed and classified in one of the three failure modes: "catastrophic" (tooth/root fracture that would require tooth extraction), "possibly reparable" (cohesive/adhesive failure with fragment and minor damage, chip or crack, of underlying tooth structure) or "reparable" fracture (cohesive or cohesive/adhesive fracture of restoration only).

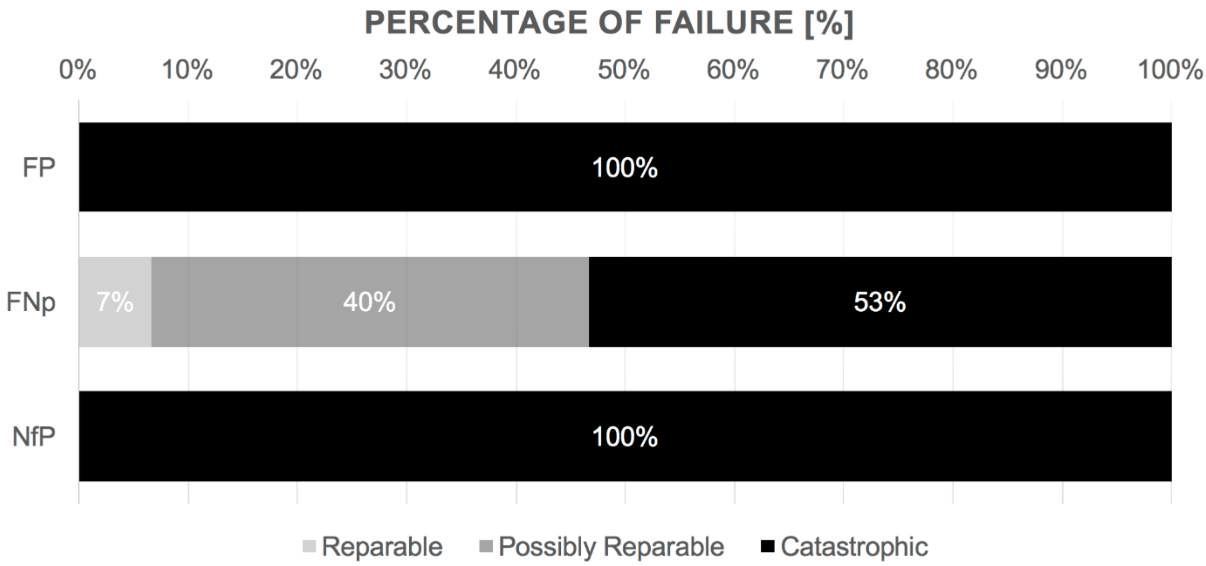

Figure 11: Percentage of specimens per group for each fracture mode.

DISCUSSION

This study evaluated the effect of ferrule on the adhesive rehabilitation of endodontically-treated incisor with glass ceramic crowns. A core-buildup made with composite resin was compared with and without the use of a fiber-reinforced post system and a no-ferrule group with fiber post was added for comparison. The first null-hypothesis, was accepted because there was no significant difference on fracture loads and survival rates when comparing ferrule groups with or without glass fiber posts. The second null-hypothesis was rejected since the presence of the ferrule increased the fatigue resistance of the ETI. Since the no-post group (FNp) presented 50% of non-catastrophic failures compared to 100% of catastrophic failure in both groups with post (FP and NfP), the third null hypothesis was also rejected.

Bovine teeth were used because of lack of availability and large natural anatomic variations of extracted human teeth (age, size, and shape). Using standardized specimens is of paramount importance and allows minimizing confounding variables and gaining sensitivity in testing. Bovine dentin is often used for in vitro tests, and is generally considered similar to human dentin in composition and geometric root configuration.[27,28] Because of the high standardization level that can be obtained using bovine roots and CAD/CAM technology, several confounding variables were avoided. However, the slight variations in internal dimensions (after internal ferrule preparation) of the root and the cementation process have still to be considered as a possible limitation of this experiment.

All reviewed articles used single-rooted human or bovine teeth and constant load was applied at an angle to the long axis until fracture of the specimen occurred. Maximum loads that teeth could withstand and fracture patterns were analyzed and compared. However, the clinical significance of results obtained from in vitro static testing has been questioned[29] because a monostatic load does not represent the clinical situation in which repetitive mechanical loading and thermal changes are inherent. Therefore, in order to acquire more clinically relevant data with regards to the ferrule effect, the accelerate fatigue test was performed. This test consists in a stepped load protocol, using a closed-loop servohydrolic system which allows a physiological representation of mastication.[30] This stepped load protocol is a compromise between the conventional load-to-failure protocol and the time-consuming low-load fatigue test.

The cyclic loads were phased, increasing the load in 100N-steps up to 1,000 N at a frequency of 5Hz. A flat composite resin surface was used as an antagonist instead of stainless steel, as suggested in other similar fatigue studies[30,31] in order to prevent localized and intense point loads and unrealistic surface damage. Healthy humans exhibit maximal isometric bite forces in the incisor region ranging between 243N (women) and 287N (men).[32] Even higher forces may be encountered in bruxism, trauma (high extrinsic loads), or intrinsicmasticatory accidents (under chewing loads but delivered to small area due to a hard foreign body like a stone or seed, for example). It is difficult, however, to draw direct correlations between the load range applied in this study and its significance *in vivo*. Due to the application of far higher forces in this study, it can be expected that an accelerated life cycle of the restored tooth may have been simulated.

In view of the present results, the use and effect of glass-fiber posts can be questioned. No significant difference could be observed between groups FP and FNp. These findings are in accordance with a previous study,[21] in which a fiber-post insertion did not increase the fracture resistance of severely broken-down endodontically-incisors with ferrule. The results of this investigation confirm the general consensus that the presence of ferrule (reminiscent coronal dentin) is the most important factor and increases the resistance of the tooth.[33]

The combination of coronal dentin, shock-absorbing properties of the core buildup and the use of a 3-steps etch-and-rinse adhesive appear to be the major advantages of this approach. It seems to more closely mimic the structure and biomechanical behavior of a natural tooth, in contrast to the concepts of post-and-core buildups in which a post is actually located at the position of the mechanically-functionless pulp. Coronal dentin (ferrule) increases the intrinsic resistance of the core. Optimized approaches in bonding procedure such as immediate dentin sealing and high strength of the nano-hybrid composite resin may have increased the assembly strength within the ferrule groups regardless of the presence of the post. All elements (crown, buildup, and tooth) have to form a cohesive assembly requiring a capable adhesive system and cement, which ideally mimics the properties of the dentin-enamel junction.

An initial failure phenomenon was observed essentially associated to the presence of a post without ferrule. A sudden failure of the adhesion at the lingual margin could be easily observed thanks to the high-definition video. It was immediately accompanied by the opening of a wide gap starting at the margin between the buildup/crown assembly and the root, intensifying and well preceding total failure. Such phenomenon was also observed in others studies on endodontically-treated molars restored with fiber posts.[16] From a clinical perspective, this type of failure is extremely critical because it is impossible to detect, can initiate bacterial contamination of the root-canal system, often referred to as “coronal leakage” or “coronal microleakage,” and can be a potential cause of periodontic and endodontic failures.[34] In addition, recurrent caries or fractured restorations may lead to recolonization of the root-canal system.[35] Schwartz and Robbins concluded in their literature review that there are some questions about the flexibility of the glass fiber post, suggesting that flexible post allows too much movement of the core, resulting in increased microleakage under the crown. A reasonable explanation for the lack of initial failure on the FP group is the fact that the ferrule itself was responsible for increasing the resistance of the assembly and changing the bending behavior of the tooth/restoration. The absence of initial failure phenomenon in the ferrule groups is a significant advantage because patient would more rapidly consult in case of complication.

Fiber posts are popular because of their elastic modulus similar to that of dentin,[36] which should improve the stress distribution within the root[37,38] and reduce the risk of vertical root fractures.[39] However, in view of the results in the present study, the use of a glass-fiber post should be questioned. In addition, the use of the fiber post was not able to compensate the absence of ferrule. A further problem with fiber posts was revealed with the rate of catastrophic failures (100% in FP and NfP compared to 53% FNp). This result is in accordance with Zicari et al,[40] stating that teeth restored with longer glass-fiber posts showed more not-repairable failures.

Base on this preliminary study there are several clinically-relevant elements that can be drawn. Avoiding placement of a post significantly facilitates clinical procedures without interfering with longevity, as far as the right materials are selected. Anterior teeth with at least 2mm of ferrule may be restored conservatively with a bonded restoration using a restorative composite resin as a core build-up, which should increase the chances for a restorable failure without decreasing the resistance of the restored tooth. The amount of ferrule that is available to the clinician can vary substantially. The present data suggests that the operator should use the available tissue to provide ferrule whenever possible. There is still a lack of data regarding the best treatment option in the absence of ferrule. Before opting for crown lengthening or even extraction, the clinician should consider obtaining more coronal tooth structure through orthodontic extrusion, when possible. However, further research will determine whether newer restoration designs, such as endocrowns or new materials such as fiber-reinforced composites may be able to compensate for the absence of ferrule and prevent more invasive surgical interventions.

CONCLUSION

Within the limitations of this in-vitro study, it can be concluded, when restoring endodontically-treated incisors with ferrule, that:

1. Insertion of a fiber-reinforced post does not enhance the load bearing capacity and survival of all-ceramic crowns.

2. In presence of GFR post, catastrophic failure of the specimen was often preceded by the cyclic opening of a wide gap at the margin between the buildup/crown assembly and the root (initial failure). This significantly affected the survival rate.

3. The least amount of unrestorable failures was found with direct core-buildups from light curing composite without a fiber-reinforced post.

4. The absence of ferrule was not compensated by the use of a fiber post.

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Artigo 2: Effect of post type and build-up material on adhesive restoration of endodontically treated incisors without ferrule

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ABSTRACT

Statement of problem: It is commonly believed that the use of posts will improve the performance of broken-down endodontically-treated incisors without ferrule. Clinicians have the choice to combine various composite resin buildup materials with fiber or metal posts with very different elastic moduli.

Objectives: The aim of this study was to investigate the restoration of broken-down endodontically-treated incisors without ferrule using glass ceramic crowns bonded to various composite resin core-buildups and two types of posts.

Materials and Methods: Sixty decoronated endodontically-treated bovine incisors without ferrule were divided in 4 groups and restored with various posts and buildups. NfpfB= no-ferrule (Nf) with glass-fiber post (Pf) and bulk-fill resin core build-up (B); NfPfP= no-ferrule (Nf) with glass-fiber post (Pf) and dual-polymerization composite resin core build-up (P); NfPt= no-ferrule (Nf) with titanium post (Pt) and resin core build-up; and NfPtB= no-ferrule (Nf) with titanium post (Pt) and bulk-fill resin core build-up (B). Previously published data from the same authors about the ferrule effect (glass-fiber post (Pf) and composite resin core build-up with and without ferrule, FPf and NfPf, respectively) using the same experimental setup were included for comparison. All teeth were prepared to receive bonded ceramic crowns (IPS e.max CAD luted with Variolink Esthetic DC) and were subjected to accelerated fatigue testing. Cyclic isometric loading was applied to the incisal edge at an angle of 30^{O}, a frequency of 5Hz, beginning with a load of 100 N (x 5000 cycles). A 100N load increase was applied each 15,000 cycles. Specimens were loaded until failure or to a maximum of 1,000N (x 140,000 cycles). Groups were compared using the Kaplan Meier survival analysis (Log rank test at p=.05 and pairwise post hoc comparisons).

Results: none of the tested specimen withstood all 140,000 load cycles. All specimens without ferrule were affected by an initial failure phenomenon (wide gap at the lingual margin between the buildup/crown assembly and the root). NfPfP, NfPt and NfPtB had similar survival (29,649 to 30,987 mean survived cycles until initial failure). NfPfB outperformed NfPt and NfPtB. None of the posts and buildup materials were able to match the performance of the ferrule group, FPf (72,667X cycles). In all groups, 100% of failures were unrestorable.

Conclusions: the survival of broken-down nonvital incisors without ferrule and restored with posts was slightly improved by the use of a fiber post with a bulk-fill composite resin buildup. However, none of the post-and-core technique was able to compensate for the absence of ferrule. Posts are always detrimental to the failure mode.

CLINICAL IMPLICATIONS

The two different of posts (titanium vs. fiber) and buildup composite resin (bulkfill vs. composite resin) displayed similar performance and were not able to compensate for the absence of ferrule. The presence of a post, either metal or fiber-based, generated 100% of catastrophic and unrestorable failures (oblique and vertical root fracture). An initial failure phenomenon (wide gap at the lingual margin between the buildup/crown assembly and the root) was observed. Clinically, this silent and undetectable failure could lead to leakage between the restoration and the tooth.

INTRODUCTION

The restoration of endodontically treated incisors (ETI) is still a controversial topic. Due to the biomechanical alterations related to endodontic procedures, the fracture strength of the root-post-core assembly is very important to maintain the mechanical stability of the restoration.[1]

A ferrule effect is considered to be crucial for the optimal biomechanical behavior of ETI [2–5] and currently a minimum ferrule of 1 mm is considered necessary to stabilize the restored tooth. However, ETIs do not always offer enough tooth structure to generate a ferrule effect. It is therefore fitting to investigate other elements (e.g., the use of a post as well as the buildup material itself) that could compensate for the absence of a ferrule.

Cast post-and-cores have been widely used for many years and are still used by some clinicians. Generally, they are recommended when there is minimal or no coronal tooth structure available for antirotational features or bonding.[6] However, the traditional cast post-and-core technique is more time consuming and frequently involves higher laboratory and material costs.[7] Furthermore, because of the high elastic modulus of the material, this approach is associated with catastrophic types of failure.[8]

The decision of how to restore ETIs has become increasingly difficult because of the large number of restorative materials and treatment options. Nowadays, enhanced adhesive procedures are possible through the use of adhesive luting systems in combinations with prefabricated posts and direct buildups. As for prefabricated posts, these are either metallic posts such as stainless steel, titanium alloy and noble metal posts, or non-metallic posts such as zirconia, carbon fiber or glass fiber reinforced posts. The effect of the post and core materials on the fracture strength of ETI has been investigated in several in vitro studies and conflicting results have been reported.[9–13] Prefabricated posts seem to demonstrate less resistance than cast post-and-core, but present more favorable failure pattern, ensuring the repair of the restoration.[7,14]

Post materials with physical properties close to those of natural dentin [14] are considered the best current approach for restoring ETIs. Glass fiber posts have an elastic modulus close to that of dentin[15] and seemed to be associated with more favorable failure modes (fracture located within the core or post) when compared to metal posts (fractures predominantly located within the root).[16,17] In a 4-year clinical evaluation, the success rate of cast posts-and-cores (cemented approach) was 84% compared to 95% when using glass-fiber-reinforced posts and resin cores (adhesive approach); root fractures and crown displacements were observed only in the cast post-and-core group.[18] Inserting posts with an adhesive luting system seems to result in greater retention, less microleakage, and higher resistance against root fracture.[19]

Associated or not with pre-fabricated posts, core buildups are used to replace a large volume of lost tooth structure and must be resistant to the masticatory forces. It was demonstrated that the performance of all-ceramic crowns is influenced by the mechanical properties of the core buildup[20] and if correctly designed, the core can enhance the performance of the crowns.[21] Composite resins, either light or dual-cured, are commonly used as materials for direct buildups. Light-cure buildup materials have several advantages over dual-cure materials. They can be bonded, layered, and shaped to ideally form and present optimal mechanical properties and color stability.[22,23] More recently, bulk-fill composite resins have and can be applied in 4–5-mm thicknesses, without the need of incremental technique but cured in one step only. This accelerates the application of the material and reduces the chairside time. The manufacturers of bulk fill resin composites claim that materials have greater depth of cure and lower polymerization induced shrinkage stress than conventional composites resin. Recent study showed that bulk-fill composites can be used reliably as well as nano-hybrid composites.[24]

Another alternative for core build-up is the 2-in-1 material that is used to cement the post and build the core with the same dual cure material. The manufacturer claims that the “monoblock bond interface” between dentin, post and crown would produce a restoration with long term survival and very high strength. However, there are few study comparing this method with the traditional ones.[12,25]

In order to increase the knowledge database about materials or combination of materials to restore ETIs without ferrule, the objective of the present study was to investigate the use of glass ceramic crowns bonded to different composite resin core-buildups with glass fiber posts or titanium posts. The null hypotheses were that (1) no significant difference would be found in accelerated fatigue resistance and (2) there would be no difference of failure mode among the restorative techniques.

MATERIAL AND METHODS

Tooth preparation

Sixty bovine incisors with similar dimensions and pulp space were selected and stored in thymol-saturated solution (Thymol, Aqua Solutions Inc.). All teeth were decoronated, either up to 13mm from the apex and subsequently separated to four groups: NfpfB= no-ferrule(Nf) with glass-fiber post (Pf) and bulk-fill resin core build-up (B); NfPfP= no-ferrule (Nf) with glass-fiber post (Pf) and dual-cure composite core build-up; NfPt= no-ferrule (Nf) with titanium post (Pt) and resin core build-up; and NfPtB= no-ferrule (Nf) with titanium post (Pt) and bulk-fill resin core build-up (B) (Fig. 1). The specimens were mounted with acrylic resin (Palapress vario; Heraeus Kulzer) embedding 10.5mm of the root. The properties of the three core buildup composite resin materials are presented in Table I.

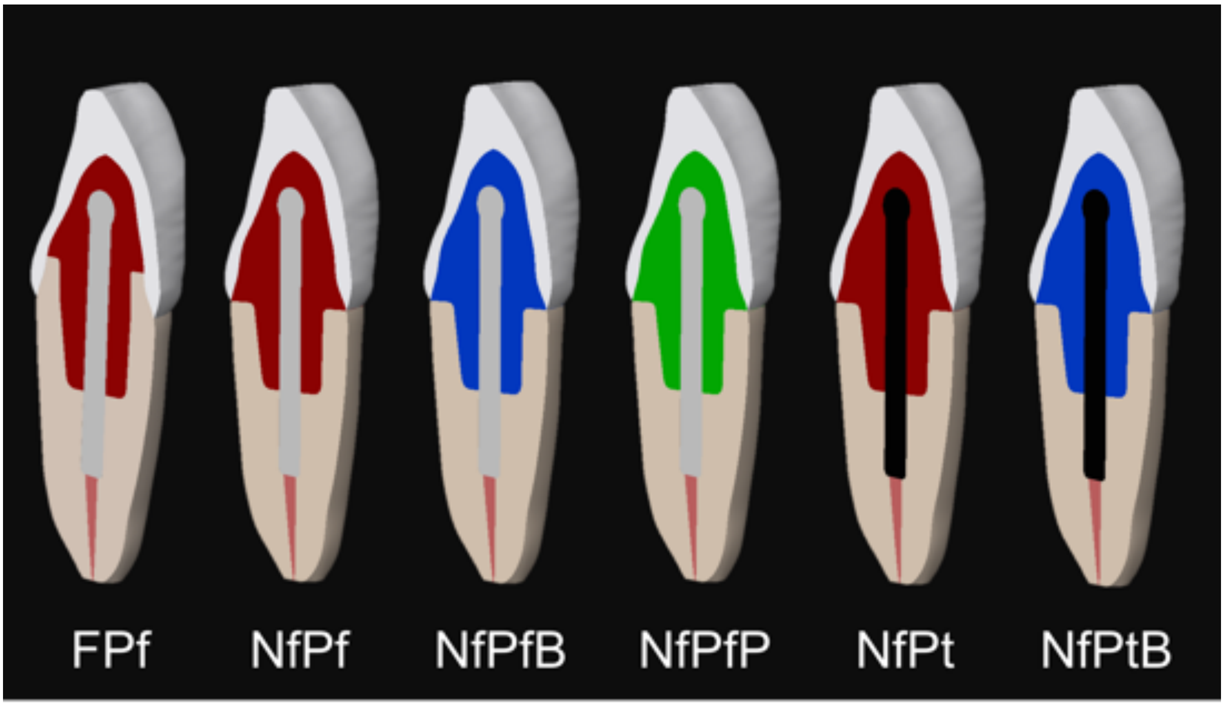


Fig. 1. Schematic views of restored ETI with posts (previous groups included).

Table 1: Overview of Properties of Material Used for Core Buildups Parameter

Parameter	Miris 2	Tetric Evoceram BulkFill	Paracore
	light-cured, nano-hybrid composite.	light-cured, nano-hybrid composite.	dual-cured, glass-reinforced composite
Matrix	Methacrylate	Dimethacrylate	Methacrylate
Matrix (weight%)	n.i.	19.7	n.i.
Filler	Silanized barium glass, amorphous silica hydrophobed.	Barium glass, Ytterbium trifluoride, Mixed oxide	Fluoride, Barium glass, Amorphous silica
Filler content (weight%)	80.0	62.5	74
Prepolymers (weight%)	n.i.	17.0	n.i.
Flexural strength (MPa)	120	120	120
E-Modulus (MPa)	13,000	10,000	n.i.
Compressive strength (MPa)	n.i.	n.i.	280
Vickers hardness (MPa)	n.i.	620	n.i.
Water absorption 7 days (mg/mm^{3})	n.i.	21.1	18

*n.i.: material property not informed by the manufacturer.

Endodontic Treatment

Standard chemo-mechanical endodontic protocol with ideal irrigants ensued as was applicable in this case [26,27]. The canals were instrumented to at least a size 40/06 with K3XF rotary files (Sybron Endo) by crowning down and maintaining patency with a 10K file between rotaries. The canals were irrigated with 17% EDTA (Roydent) for one minute followed by 5.25% NaOCl (Chlorox) for one minute as a final rinse [2829]. The efficacy of irrigation was amplified by Endo Activator (Dentsply) with EDTA and NaOCl. After the canals were dried with paper points, one coat of Thermaseal Plus (Dentsply) was placed circumferentially around the lumen all the way to the working length with a 10k file. 0.6 taper K3XF gutta percha cones (Sybron Endo) were then coated with thermaseal plus and used for warm vertical obturation; the gutta percha was thermoplasticized with a 0.6 taper Buchanan heated plugger (Sybron Endo) and then down packed with stainless steel Buchanan hand pluggers (Sybron Endo).

Root canal and internal ferrule preparation

Gutta-percha was removed, 8mm deep into the pulp chamber from the cervical limit, with a Reamer pilot drill size no.3 (Ivoclar Vivadent) using a handpiece at 1,000-2,000rpm. For all groups, a so-called "internal ferrule" was prepared in form of a box using a conical shape bur, 4mm deep from the cervical limit, 3mm wide and 4mm buccal-lingually in order to simulate a broken down root.

Post preparation

The post spaces were prepared with ParaPost drills specifically designed for either ParaPost Fiber Lux or ParaPostHX (n^o6, 1.5mm diameter; Coltene). Using a cutting disc, the apical portion of the posts was removed to obtain a length of 11mm (8mm below and 3 mm above the cervical limit). Prior to the luting procedure, the posts were cleaned with alcohol and air-dried.

Core-buildup with light-cure composite resin: groups NfPfB, NfPt and NfPtB.

The post space walls were lightly coated with cement (RelyX Unicem 2 Automix, 3M ESPE) and the post (either fiber or titanium) was inserted. Cement excesses were cleaned, leaving 4mm of post height in cement. The cement system was light-cured for 40s (VALO Curing Light, Ultradent Products). After post cementation, the exposed dentin walls and the post were sandblasted with 27µm silicated Al2O3 powder (CoJet, 3M ESPE). Silane (Ceramic Primer, 3M ESPE) was applied to the post head and air-dried. For denting bonding purpose, 35% phosphoric acid (Ultra-Etch, Ultradent) was used for etching (10s in dentin walls and post), rinsed (20s) and gently dried, followed by application of the adhesive system (Optibond FL Primer and Adhesive, Kerr) and light-curing for 40s. The buildups were made either with composite resin (Miris 2, Coltene Whaledent) or bulk-fill composite resin (Tetric EvoCeram Bulk Fill, Ivoclar Vivadent). In order to build a 11mm high core (4mm below cervical limit and 7 above cervical limit), for Miris 2, 5 increments were used and polymerized at 1,000 mW/cm^2 (VALO Curing Light) for 40s (first two increments) and 20s (next 3 increments) each, while for Tetric EvoCeram Bulk Fill, only two increments (internal box below cervical limit and core above cervical limit) were light-cured for 20s each. An air-blocking barrier (KY Jelly; Johnson & Johnson Inc.) was used to cover the preparation surface, and additional polymerization was carried out for 10s per surface (buccal and lingual). A special care was taken to shape the buildups ideally in order to avoid any further corrections of the preparation surface and margins.

Core-buildup with dual-cure composite resin: group NfPfP:

The non-rinse conditioner and mixed adhesive components (ParaBond NRC and Adhesive A and B, respectively; Coltene Whaledent) were applied in two subsequent steps into the post space walls and cervical dentin (internal ferrule preparation) using a micro brush disposable applicator, rubbing for 30s each step. The excess was removed from the root canal using paper points and gentle air dried for 2s. ParaCore dual-cure glass reinforced composite resin was then dispensed directly from the syringe into the prepared root canal and the post was inserted using gentle pressure and light-cured for 20s. The build-up was added and shaped ideally in order to avoid any further correction and light-cured for 40s. An air-blocking barrier (KY Jelly; Johnson & Johnson Inc.) was used to cover the preparation surface, and additional polymerization was carried out for 10s per surface (buccal and lingual).

Design and manufacturing of restorations

All bonded ceramic crowns were fabricated using the Cerec 3 CAD/CAM system (Sirona Dental Systems GmbH). Digital impression of the prepared teeth was performed with Cerec Blue Cam, using a contrast powder (IPS Contrast Spray Chairside, Ivoclar Vivadent). The specimens were fitted with a crown of standardized thickness and anatomy with 11mm inciso-cervical length and 9mm mesio-distal width. All crowns were milled in lithium disilicate ceramic (IPS e.max CAD, Ivoclar Vivadent) using the “crown mode" with the sprue located at the lingual surface. After milling, lithium disilicate restorations were glazed, crystalized and fired according to the manufacturer's protocol (Programat CS, Ivoclar Vivadent) using IPS Object Fix Putty and IPS e.max CAD Crystall/Glaze Spray (Ivoclar Vivadent).

Adhesive luting of the crowns

The dual-cure resin cement Variolink Esthetic (Ivoclar Vivadent) was used. Before luting, each restoration was fitted on its respective tooth to check its marginal adaptation. All crowns were cleaned in ultrasonic bath in distilled water followed by etching with 5% hydrofluoric acid (IPS ceramic etching gel, Ivoclar Vivadent) for 20s and post-etching cleaning again for 1 minute in distilled water in ultrasonic bath. Silane (Monobond Plus, Ivoclar Vivadent) was applied with a microbrush and heat-dried at 100°C for five minutes (D.I.-500, Coltene).

The tooth preparation and buildups were sandblasted with 27µm silicated Al2O3 powder (CoJet, 3M ESPE) and coated with Adhese Universal (Ivoclar Vivadent). Variolink Esthetic was then applied to the fitting surface of the crown and then seated on the tooth with approximately 500g of pressure. Cement excesses were removed and followed by light polymerization for 3 times 20s on each surface (buccal and lingual) with a 1,000 mW/cm^2 LED light. Air-blocking barrier (KY Jelly) and additional polymerization was carried out for 10s per surface. The margins were finished with hand instruments (scalpel and scaler). The samples were stored in distilled water at room temperature (24°C) for a minimum of 24h after adhesive restoration luting and then subjected to accelerated fatigue testing.

Accelerate fatigue test

Masticatory forces were simulated using closed-loop artificial mouth electro-dynamic machine (Acumen III; MTS Systems). The chewing cycle was simulated by an isometric contraction (load control) applied through a flat composite resin antagonist (Z100; 3M ESPE). The force was applied at a palatal angle of 30º with the flat surface contacting 3/4 of the incisal edge (Fig. 2). The load chamber was filled with distilled water to submerge the sample during testing. Cyclic load was applied at a frequency of 5Hz, starting with a load of 100N (warm-up of 5,000 cycles), followed by stages of 200, 300, 400, 500, 600, 700N, 800N, 900N and 1000N a maximum of 15,000 cycles each. Samples were loaded until fracture or to a maximum of 140,000 cycles.

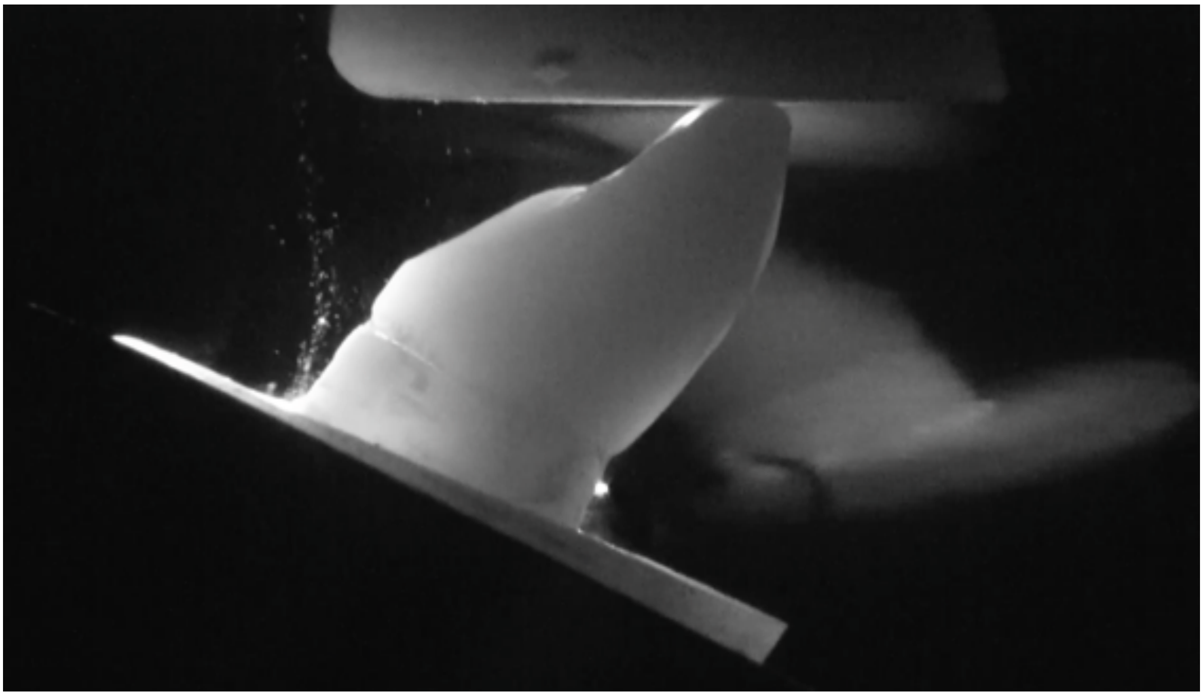


Fig. 2. Cyclic isometric loading was applied to the incisal edge at an angle of 30^{O}. Initial failure as a wide lingual gap between the crown margin and tooth.

Analysis

All the fatigue testes were monitored using a macro video camera and recorded continuously in order to determine the crack propagation mode (Initial gap, root fracture and final failure) (Fig. 3). The number of endured cycles, load to failure and failure mode of each specimen were recorded. After the test, each sample was evaluated by transillumination (Microlux; Addent) and optical microscope (Leica MZ 125; Leica Mycrosystems) at 10:1 magnification. A visual distinction was made among three fracture modes, considering the reparability of the tooth: catastrophic, that is, root fracture that would require tooth extraction; possibly reparable, that is, cohesive/adhesive failure with fragment and minor damage, chip or crack, of underlying tooth structure; or reparable fracture, that is, cohesive or adhesive failure of restoration only.

Fig. 3. Specimen in load chamber. Macro-camera and transillumination light was used to identify the crack propagation mode.

The fatigue resistance of the groups was compared using the Kaplan Meier survival table (for cycles). At each time interval (defined by each load step), the number of specimens starting the interval intact and the number of specimens fracturing during the interval were counted, allowing the calculation of survival probability at each interval. Pos hoc Log Rank test was used for analyze the influence of the ferrule, post system and core build-up material on the fracture resistance of the ETI on a significance level of 0.05 (corrected for multiple comparisons when indicated).

The fracture load step at which the specimen failed was compared using one-way analysis of variance (ANOVA) followed by Tukey test at a significance level of 0.05. For all statistical analyses, the level of significance was set at 95%. The data were analyzed with statistical software (SPSS 23, SPSS Inc, Chicago, IL).

Additional data from a previous study[5] about the same post preparations, design buildups and crowns by the same authors in strictly identical experimental conditions were combined to the present data for additional computation and comparison. The previous study included two groups with a glass-fiber post and the same light-curing composite core-buildup (Miris 2): FPf (2 mm ferrule) and NfPf (no ferrule).

RESULTS

Because none of the specimen withstood all 140,000 load-cycles, the mean fracture load could be calculated. Previous results about failure mode, fatigue resistance and fracture load were combined with the new data and are presented in Figures 4, 5 and 6. The complete failure of the specimens was possibly preceded by an initial failure in form of a cyclic opening of a wide gap at the margin between the core-buildup/crown assembly and the root (Video 1).

This initial failure phenomenon was detected in 14% of specimens in group FPf, 81% in NfPf, 86% in NfPfB, 87% in NfPfP, 93% in NfPt, and 100% in NfPtB. The initial gap was always located at the the lingual margin of the crown (Fig. 2). Because of clinical detection of such failures appears to be questionable, the analysis of survival was conducted for both the ‘‘final failure’’ and the ‘‘initial failure’’.

The life table survival graphs for initial failure are displayed in Figure 4. The log-rank test showed a significantly higher survival rate of the group with ferrule (p=0.000). The no-ferrule group NfPfB presents a better survival rate when compared with NfPt (p=0.046) and NfPtB (p=0.013) (Table 2). The average number of survived cycles for initial and final failure are presented in Figure 5.

The one-way ANOVA revealed a statistical difference between initial and final failures ($p<0.05$) for the samples without ferrule (initial failure always happened before final failure). The mean fracture load for initial failures ranged from 340N (NfPfP) to 400N (NfPfB), and from 480N (NfPf) to 526N (NfPfP and NfPtB) for final failure (Fig. 6).

Failure mode analysis showed 100% of catastrophic failures (crack vertically propagated in the cervical and middle portions of the root) (Fig. 7).

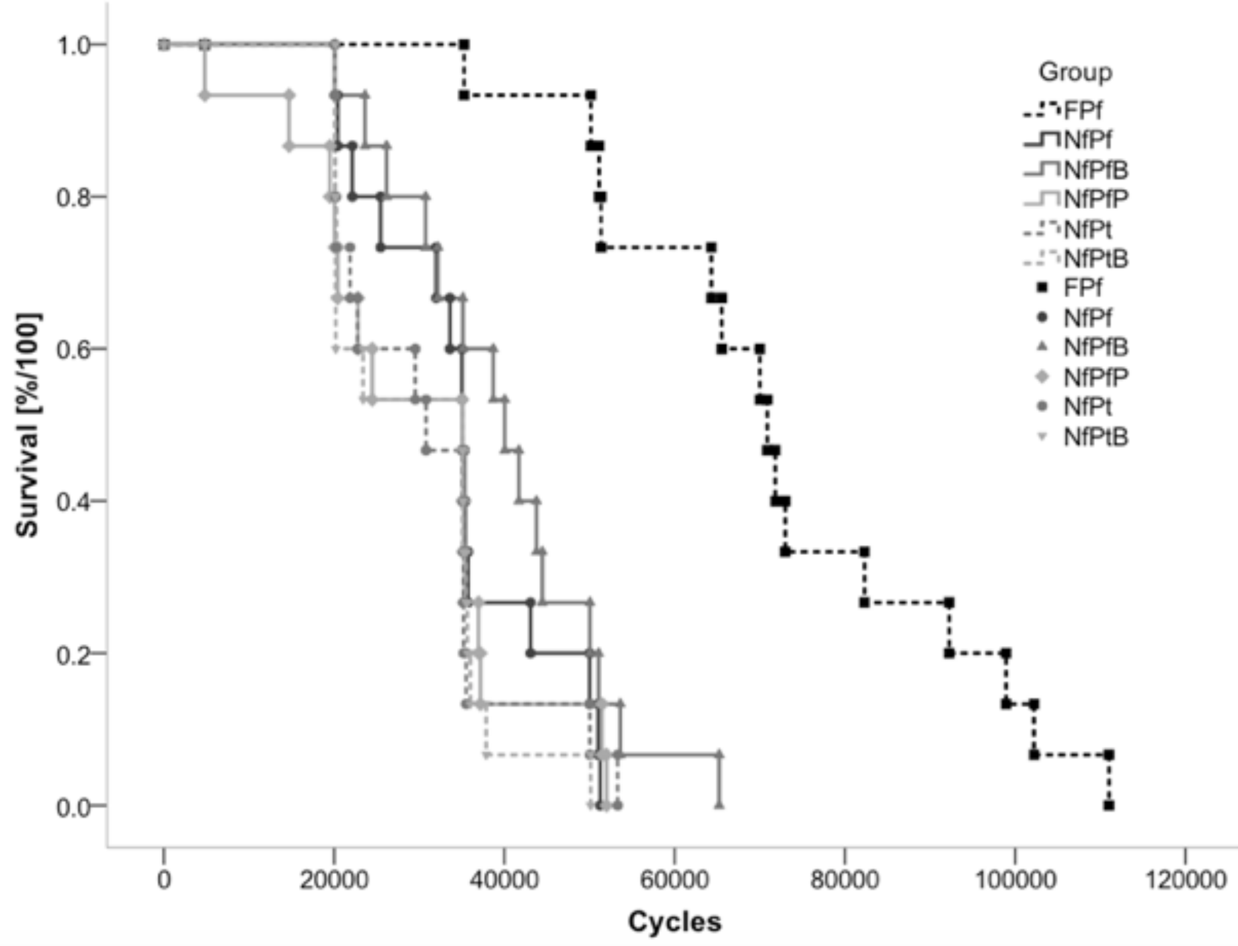


Fig. 4. Kaplan-Meyer survival graphs. For better comparison, the survival graph of group FPf and NfPf from a previous study was added.

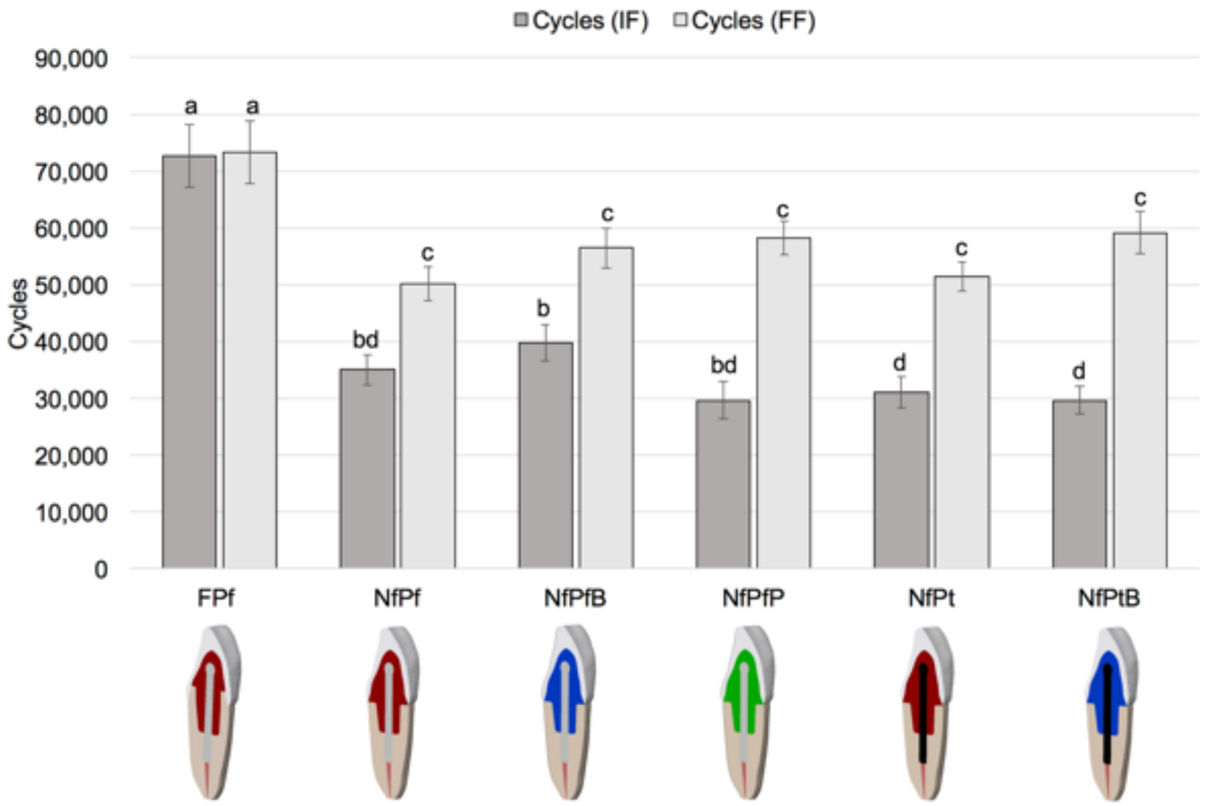


Fig. 5. Average number of cycles for initial (dark grey) or final fracture (light grey).

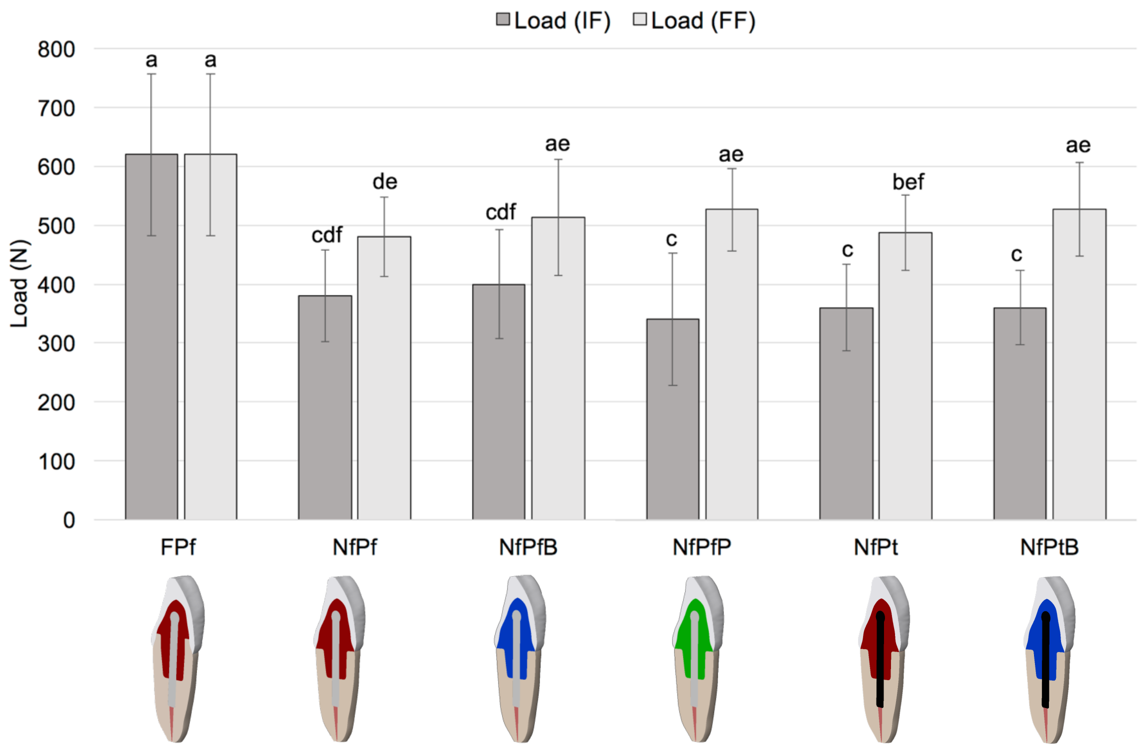


Fig. 6. Mean fracture loads for initial (dark grey) or final fracture (light grey).

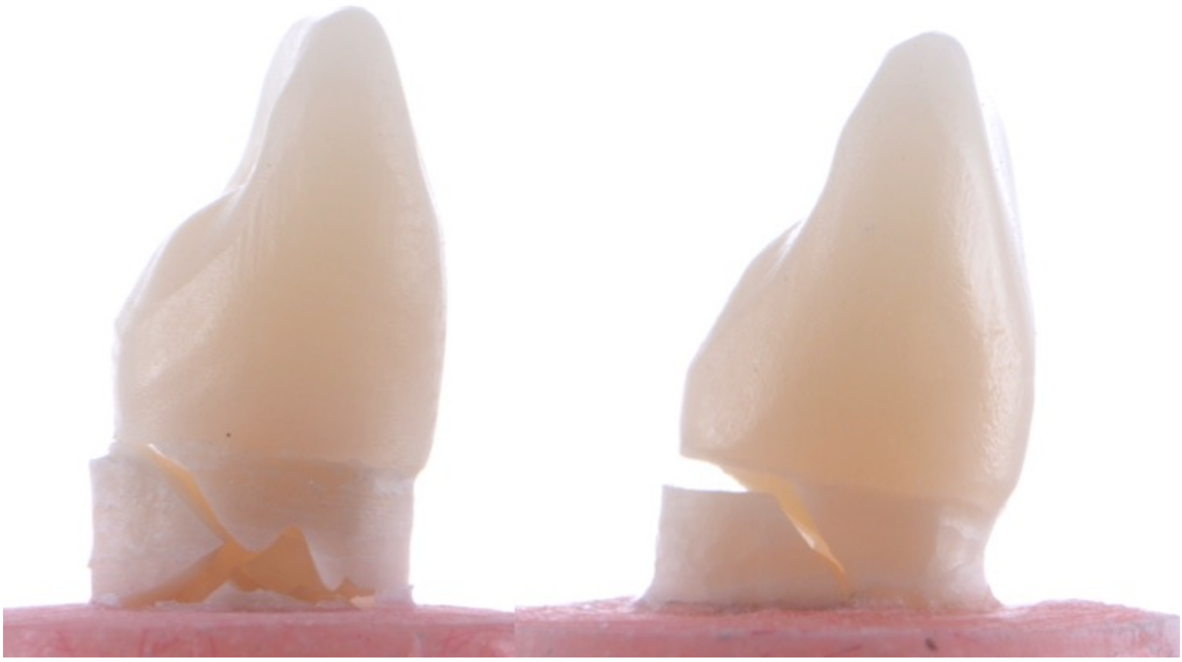
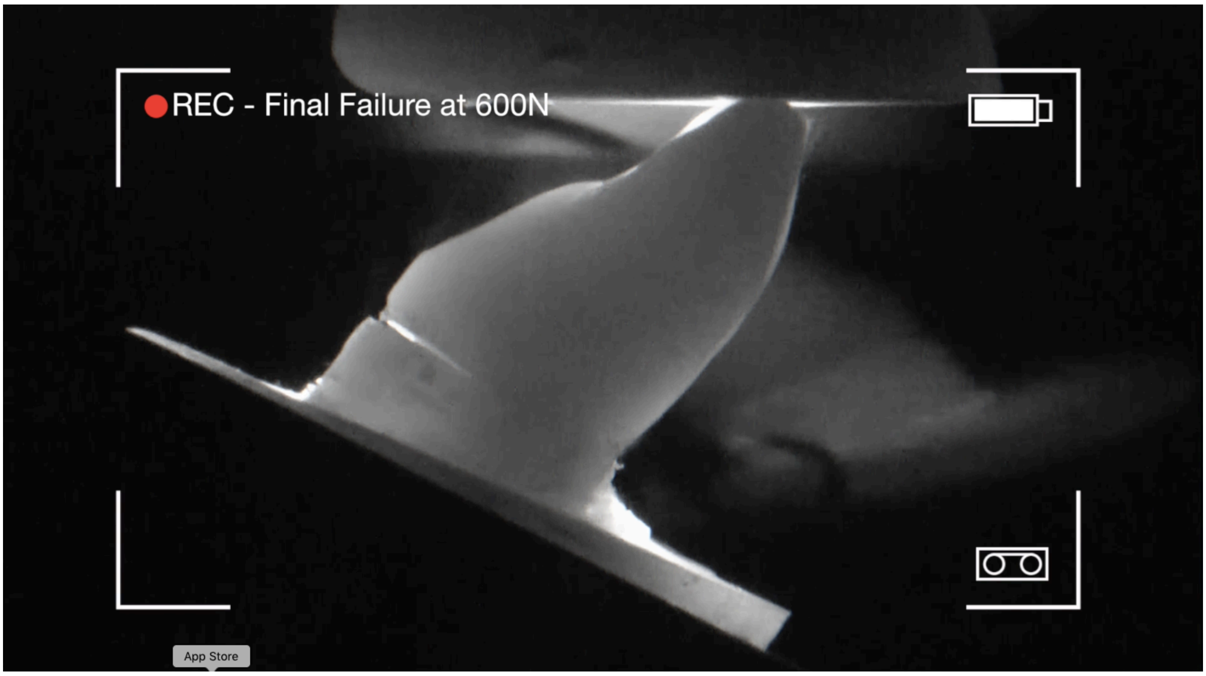


Fig. 7. All specimens were classified in "catastrophic" (tooth/root fracture that would require tooth extraction).



Video 1: The occurrence of preliminary failure (cyclic opening of a wide gap at the lingual margin) at 400N and the complete failure (machine detects alterations and stop the test) at 600N.

Table 2: p-Values of Pairwise Comparisons

		FPf	**NfPf**	**NfPfB**	**NfPfP**	**NfPt**
		Sig.	Sig.	Sig.	Sig.	Sig.
Log Rank (Mantel-Cox)	**FPf**					
	NfPf	**0.000***				
	NfPfB	**0.000***	0.202			
	NfPfP	**0.000***	0.919	0.069		
	NfPt	**0.000***	0.520	0.046*	0.994	
	NfPtB	**0.000***	0.258	**0.013***	0.643	0.992

* Significant difference at the 0.005 level of significance

DISCUSSION

It is generally agreed that the successful treatment of endodontically treated teeth depends the amount of structure left after preparation. A worst-case scenario (broken-down no-ferule condition) was considered in the present study to determine the fatigue strength of different materials. In view of the statistical analysis, the first null hypothesis can be rejected. The fatigue resistance of ETI was slightly improved by the use of a fiber post with a bulk-fill composite resin core-buildup compared to the titanium post groups and regular composite resin core-buildup. The second null hypothesis was accepted; the failure mode was similar across materials (100% catastrophic failure after fatigue test).

The experimental protocol of this study is based on original study by Fennis et al[30] that represent a stepped fatigue loading procedure. Some specific elements, however, were designed to adapt to the load configuration of an incisor and prevent local damage at the load point. A flat composite resin surface was used as an antagonist instead of stainless steel, as suggested in other similar fatigue studies.[31,32] The flexibility and wear of the antagonist allowed a more realistic simulation of anterior tooth contact through a wear facet included in the incisal edge of the restoration. The large and uniform contact surface prevented localized and intense load points, which could exceed the compressive limit of the restorative materials and generate surface damage and powder-like debris by crushing (Hertzian cone-cracks).[33]

The stepped fatigue loading protocol represents a reasonable balance between the simple load-to-failure test and more sophisticated and time-consuming fatigue tests. In the load-to-failure test, the specimen is forced to fail under displacement control of the load apparatus, providing useful data under extreme conditions but limited clinical relevance. The present study design covers a wide range of clinically relevant situations. The first part of the test lies inside the range of realistic bite forces in the anterior region, ranging between 243N (women) and 287N (men).[34] The second part comprises the range of loads that may be encountered in bruxism, trauma (high extrinsic loads), or intrinsic masticatory accidents (under chewing loads but delivered to small area due to a hard foreign body like a stone or seed, for example).

Even though in vitro studies only partially mimic clinical reality, their chief advantage over clinical studies is the possibility to decrease confounding variables in a more controlled process. Bovine teeth can be used as a substitute to human teeth, not only because they are available in large number but also because they allow the selection of specimens with minimal anatomic variations (age, size, and shape). Bovine dentin is generally considered similar to human dentin in composition and geometric root configuration.[35,36] Combined with CAD/CAM restorations, several confounding variables could be avoided, such as the dental technologist skills and mechanical properties (absence of hand-made defects) as well as other steps involved in the fabrication process. The CAD/CAM system is also characterized by its ability to control the restoration thickness and anatomy. It also allowed the standardization of the internal fit of the crowns as well as external dimensions.

Due to the presence of the post, the final failure (corresponding to the end of fatigue test by the machine) was typically preceded by initial failure (cyclic opening of a wide gap at the lingual margin) (Video 1). It was decided not to interrupt the fatigue test when initial failure happened but instead allow the specimen to be fatigued until complete failure (machine detects alterations and stop the test). Every cycle was continuously recorded using a macro camera during the entire fatigue test. Thus, it was possible to identify the crack propagation mode and chronology. Some may interpret the post's elastic behavior as a disadvantage due to the cyclic bending between the crown and core-buildup can induce micro-cracks in the core material or in the resin cement, leading to failure of the restoration.[37] Initial failure of the crown–tooth interface at the crown margin has been assumed to be the earliest sign of failure in post–core-restored tooth and depends on the adhesive strength of the crown-tooth interface.[38,39] It is possible that, clinically, a restoration that has experienced initial failures could remain in place, apparently intact, for some time.[39] As it progresses silently, this interfacial failure at the crown margin may prolong into the tooth, leading to core fracture and subsequently tooth fracture. Thus, the adhesive failure between the post-core unit and the remaining tooth structure could lead to the vertical root fracture.[38]

The occurrence of preliminary failure is clinically silent and undetectable and allows leakage between the restoration and tooth that may extend down the prepared post space.[39] Leakage, given enough time, could progress, facilitating bacterial infiltration and possibly causing secondary decay, jeopardizing the integrity of the root canal seal. Few studies in the literature describe the initial failure phenomenon in ETI.[12,38,39] Single-load to failure studies are unable to provide such insight, reason for which accelerated fatigue tests are more clinically relevant.

Recently, a variety of materials have been developed to enhance the mechanical properties of structurally weakened teeth. There are different material options for direct composite resin build-ups that can increase the resistance of the ETI. Bulk-fill and so-called "glass-reinforced" composite resins are two present-day materials, which are claimed to have low shrinkage and tooth-strengthening effects. In our study, the combination of fiber post and bulk-fill composite resin increased the number of cycles required to cause initial failure of the restoration compared to the titanium posts groups. The bulk-filling technique was used to decrease the layering defects of composite resin. Akkayan and Gulmes[16] reported similar results, as titanium posts groups presented lower resistance to fracture loads and more catastrophic failures when compared to fiber posts. However, the results of this study somewhat differ from those who reported that when no coronal tooth structure is left, the pre-fabricated metal posts show higher fracture strength than the fiber post.[13,17] Although the bulk-fill resin composite had higher fatigue resistance when associated to a fiber post compared to a titanium post in the present study, the results were not significantly different from others fiber posts groups ($p>0.05$).

In a previous study by the same authors in strictly identical conditions, a ferrule group was used to verify the ferrule influence on the fatigue resistance of the ETI. The previous results were used in the current study in order to investigate if the use of different post and core build-ups could compensate for the absence of a ferrule. The results clearly revealed the superior performance of FPf group (see Fig. 4) showing the insertion of post did not increase the fracture resistance enough to compensate the absence of ferrule. This results confirm that the presence of the ferrule always improves the biomechanical behavior on ETI.[2,3,11]

Additionally to the fracture resistance, success of a restored ETI has to be considered in view of possibility for re-treatment and preservation of the underlying tooth structure when failure happens. One of the main issues has been the risk of catastrophic root fractures. With the use of rigid posts, stress is transmitted internally and concentrates towards the apical level, thus increasing the risk of vertical root fracture.[40] Several studies reported that rigid cast post-and-cores and prefabricated metallic or zirconia posts, increase the risk of non-repairable root fractures.[4,14,41] Opposing results are reported when using fiber post, the elastic modulus of which is similar to that of dentin.[15] This should improve the stress distribution within the root[42,43] and reduce the risk of vertical root fractures.[4] Fracture strength studies reported tooth fractures to be "favorable" when restored with fiber posts; when fiber post restored tooth failed the root remained intact at lower fracture strength values.[16,17,44] However, the present study presented 100% of catastrophic failures regardless the material of the pre-fabricated post. This result is in accordance with some recent studies that reported catastrophic failures when using fiber post.[3,21,45] Naumann et al.[46] reported that the load capability and fracture patterns of endodontically treated teeth do not depend on the rigidity of the post material. This is somewhat confirmed in the present study.

Further research should explore alternatives to post and core restoration (possibly a no-post approach) in order to obtain and more resistant and non-destructive outcomes. Even though fiber post presents optimized elastic modulus compared to titanium post or cast post-and-core, the vertical catastrophic failures were not prevented. Optimized approaches to restore the broken-down no-ferule root in order compensate the absence of ferule is still a major need in modern dentistry.

CONCLUSION

Within the limitations of this in vitro study, the following can be concluded when restoring endodontically treated incisors without ferrule:

1. The most favorable combination of post and build-up materials to increase the fatigue strength could be observed when using a bulk-fill composite resin core build-up and fiber post.
2. The insertion of a post was not sufficient to compensate for the absence of ferrule.
3. The failure of no-ferrule specimens were always preceded by the cyclic opening of a wide gap at the lingual margin between the buildup/crown assembly and the root (initial failure). This significantly affected the survival rate.
4. Posts are always detrimental to the failure mode.

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DISCUSSÃO

Com o avanço da Odontologia Adesiva, e o progresso da Odontologia Minimamente Invasiva, as técnicas restauradoras vêm sendo discutidas e aprimoradas com o objetivo de utilizar materiais com propriedades mecânicas e características que mais se assemelham às estruturas dentárias. É de suma importância compreender e avaliar estas novas técnicas para que haja uma correta indicação do tratamento. Este estudo teve como objetivo avaliar o comportamento mecânico de raízes endodonticamente tratadas com ou sem remanescente coronário e restauradas com diferentes técnicas.

O primeiro artigo avaliou a influência do pino de fibra de vidro na resistência a fadiga de incisivos endodonticamente tratados com 2mm de remanescente coronário. O trabalho também utilizou, como controle negativo, um grupo sem remanescente coronário e restaurado com pino de fibra de vidro. Foi realizado o teste de fadiga acelerada e avaliada a resistência à fadiga, carga à fratura e modo de falha das amostras. Os dados obtidos no primeiro estudo também foram utilizados no segundo estudo, que avaliou diferentes técnicas restauradoras utilizando pinos intraradiculares para dentes endodonticamente tratados sem remanescente coronário. Os resultados mostraram que o efeito do remanescente coronário foi superior ao efeito do pino intraradicular. A inserção do pino nos dentes sem remanescente coronário não foi suficiente para compensar a ausência do remanescente coronário e aumentar a resistência dos IET. A presença do pino também se mostrou ineficaz quando comparado os dois grupos com 2mm de remanescente coronário. Os grupos sem remanescente coronário restaurados com pinos intraradiculares apresentaram resultados semelhantes, exceto pelo grupo restaurado com pino de fibra de vidro e resina composta bulk-fill, que apresentou resultados significantemente melhores que os grupos restaurados com pino de titânio (independente da resina composta utilizada). A presença do pino intraradicular se mostrou prejudicial ao modo de falha, visto que todas as amostras restauradas com pino apresentaram 100% de falhas catastróficas, enquanto o grupo sem pino intraradicular e com remanescente coronário apresentou 50% de fraturas restauráveis. Baseados nos achados dos estudos, sugere-se que o uso dos pinos intraradiculares devem ser questionados e cuidadosamente avaliados nos casos que apresentam remanescente coronário. A preservação da estrutura dentária é o fator de maior importância na resistência do dente endodonticamente tratado.

Os dois artigos apresentam a mesma metodologia e utilizam dentes bovinos em substituição ao dente humano. Os dentes bovinos apresentavam condições padronizadas como tamanho, idade, tempo de extração, tempo de armazenamento. Devido à dificuldade de se obter grande quantidade de dentes humanos com dimensões similares, os dentes bovinos tornaram-se opções confiáveis devido a similaridade na composição e geometria com a dentina humana (Reis et al., 2004; Fonseca et al., 2008). Em função de cárie, fratura, reabsorção interna, remoção de pinos e núcleos, do acesso para o tratamento endodôntico ou causas idiopáticas, surgem casos em que a raiz se torna extremamente fragilizada e, consequentemente, com uma espessura da parede de dentina muito fina. Dessa maneira, para simular essa condição real, as raízes foram preparadas realizando um desgaste interno padronizado *"internal ferrule",* deixando paredes da dentina radicular remanescente com 1,5 mm de espessura até uma profundidade de 4,0 mm. As raízes então foram restauradas com coroas de dissilicato de lítio através do sistema CEREC 3. Com o uso do sistema CAD/CAM algumas variáveis como habilidade do técnico em prótese e alguns passos envolvidos no processo de fabricação da coroa puderam ser evitadas. O ligamento periodontal não foi simulado porque os materiais geralmente utilizados para esta finalidade (elastômeros e silicones), mostram uma acelerada degradação, pois não resistem às cargas aplicadas pela metodologia de fadiga acelerada, causando um excessivo deslocamento da raiz e o desequilíbrio do sistema.

O teste de resistência à fadiga utilizado no estudo permitiu uma representação fisiológica da mastigação através do uso de uma maquina de ensaio elétrica. Através desta máquina foi possível estabelecer um protocolo de carga acelerada. Existem vários métodos e formas de análise de fadiga descritos na literatura. Tradicionalmente, a análise de sobrevivência envolve a aplicação de uma carga baixa por um grande número de ciclos e depois é necessário a aplicação de elevada carga (single-load-to-failure) para que haja a fratura da amostra. A fadiga acelerada representa uma análise de resistência à fratura entre os testes "single-load-to-failure" e o teste de fadiga cíclica. Desta forma, o modo de falha e a análise de sobrevivência podem ser melhor entendidos em um espaço de tempo menor (Bonfante et al., 2009). Apesar de não ser possível fazer uma correlação clínica direta entre o presente protocolo de carregamento e um suposto tempo de função mastigatória clínica, a fadiga acelerada apresenta-se como uma técnica sofisticada e adequada para se obter a resistência mecânica de matérias e técnicas restauradoras (Fennis et al., 2004). O uso de antagonista resinoso com uma faceta de desgaste incisal permitiu uma análise mais realista sem que ocorresse desgaste do material restaurador da coroa (Magne and Knezevic, 2009b; Magne and Knezevic, 2009a).

O uso de da macro-câmera de filmagem e luz transiluminada durante a realização dos testes foi outro fator crucial para os resultados do presente estudo. Foram através dos dados da filmagem que observou-se a formação da falha inicial nos grupos sem remanescente coronário, que até então havia sido relatada em poucos trabalhos na literatura (Kishen, 2006; Freeman et al., 1998; Fan et al., 1995; Libman and Nicholls, 1995). A falha inicial é considerada como o primeiro sinal da falha da restauração e depende a resistência adesiva da interface dente-cimento-coroa (Kishen, 2006; Freeman et al., 1998). A falha foi correlacionada ao uso de pinos intraradiculares e ao comportamento elástico dos pinos (independente se este era fibra de vidro ou titânio), que proporcionou a abertura cíclica da falha sem causar a fratura total da restauração. A ocorrência da falha inicial pode ter induzido micro-falhas no material do núcleo e cimento resinoso causando a posterior falha total da restauração (Sidoli et al., 1997). É possível que clinicamente a coroa total possa permanecer intacta por um longo período de tempo (Freeman et al., 1998), mesmo depois de apresentar a falha inicial. Por ter progressão silenciosa pode causar micro-infiltração, facilitando a colonização bacteriana e podendo causar cáries secundárias ou contaminar o canal radicular (Freeman et al., 1998; McLaren et al., 2009; Kishen, 2006). Estudos utilizando testes como "single-load-to-failure" e fadiga cíclica são incapazes de promover tais falhas, visto que no primeiro caso as amostras são fraturadas em uma única aplicação da carga, enquanto no teste de fadiga cíclica a carga aplicada não é suficiente para causar a falha inicial, já que geralmente é realizada com aplicação de 50N por 1.000.000 de ciclos. No presente estudo as falhas iniciais foram detectáveis somente após a aplicação de 200N de força.

Quanto ao uso de pinos intraradiculares, existem algumas controvérsias na literatura. Formato, tamanho, diâmetro, material, agentes cimentantes são alguns dos fatores que podem influenciar a performance biomecânica do dente. Há indicações na literatura de que pinos paralelos são mais retentivos do que cônicos, e não necessitam de maior desgaste da estrutura dentária (Goracci and Ferrari, 2011). Enquanto núcleo metálicos fundidos devem ser tão longos quanto possível, pinos de fibra de vidro parecem não ser tão sensíveis quando se trata de comprimento, podendo variá-lo sem alterar sua biomecânica (Hsu et al., 2009). Diferenças entre o diâmetro do pino de fibra de vidro e o preparo do conduto radicular podem influenciar na camada de cimento ou na tensão gerada no pino, sem alterar as tensões na raiz (Lazari et al., 2013). Outro fator controverso é o material de fabricação do pino. No presente, estudo optou-se pelo uso de pinos pré-fabricados de fibra de vidro e titânio por serem as escolhas mais frequentes entre os pinos diretos. Estudos na literatura reportam que pinos metálicos pré-fabricados apresentam maior número de falhas catastróficas quando comparados aos pinos de fibra de vidro (Dietschi et al., 2008; Dietschi et al., 2007; Santos-Filho et al., 2014), fato não comprovado por este estudo, sendo que os pinos de fibra de vidro apresentaram o mesmo número de falhas catastróficas do que os pinos metálicos. A similaridade entre as propriedades mecânicas da fibra de vidro e dentina deveria atuar como um fator de melhor distribuição de tensões (Mezzomo et al., 2011; Watanabe et al., 2012) e diminuir o risco de fraturas da raiz (Santos-Filho et al., 2014). No entanto, este estudo apresentou 100% de fraturas catastróficas quando associadas aos pinos intraradiculares, independente do tipo de material do pino utilizado. Baseado nos achados deste estudo, podemos concluir que a propriedade mecânica do material do pino (módulo de elasticidade) usado na restauração não afetou o modo de fratura das amostras.

Há relatos na literatura que a falha adesiva é o problema mais frequente dos pinos de fibra de vidro (Goracci and Ferrari, 2011). No presente estudo foram utilizadas somente técnicas adesivas auto-condicionantes para cimentar os pinos intraradiculares. A simplificação é uma vantagem da técnica e não foram observadas falhas adesivas na cimentação dos pinos. A combinação dos pinos pré-fabricados e núcleos de preenchimento com resina composta é mais simples e prática, pois a resina composta é facilmente colocada no local desejado, polimerizada em curto espaço de tempo, permitindo o preparo imediato para a coroa na mesma sessão. A incorporação de resinas compostas bulk-fill e reforçadas por vidro favorecem ainda mais a praticidade da técnica e ainda evitam falhas na restauração por diminuir o número de interfaces entre os incrementos e entre as estruturas, como é o caso das resinas compostas reforçadas por vidro que atuam como agente cimentante do pino e reconstrutor no núcleo.

No estudo em geral podemos concluir que o remanescente coronário foi o fator de maior impacto na resistência dos incisivos endodonticamente tratados. Em dentes sem remanescente coronário, a extrusão ortodôntica deve ser considerada para se obter uma dentina coronária adicional. Se nenhum método para obtenção do remanescente coronário for possível, evidências deste estudo sugerem um desfecho deficiente, visto que além da existência das falhas iniciais, a presença do pino intraradicular foi responsável por falhas catastróficas na raiz.

Embora existam diversos estudos na literatura que avaliam as restaurações em incisivos endodonticamente tratados, fica evidente a necessidade de novos estudos para permitir o aprimoramento das técnicas restauradoras avaliadas. Para os estudos futuros sugere-se analisar outros materiais para a confecção de núcleos de preenchimento, assim como outros procedimentos alternativos não destrutivos (restaurações sem pinos intraradiculares) no intuito de se obter restaurações mais resistentes e com menor número de falhas catastróficas.

CONCLUSÃO

Dentro das limitações do estudo pode-se concluir que:

1- A presença de 2mm de remanescente coronário aumentou a resistência dos incisivos endodonticamente tratados.
2- A inserção de pino de fibra de vidro não tem influência na resistência à fadiga de incisivos com remanescente coronário.
3- A ausência de remanescente coronário não é compensada pelo uso dos pinos intraradiculares.
4- Pinos intraradiculares estão associados com maior número de fraturas catastróficas sempre precedidas pela ocorrência da falha inicial.
5- A utilização de pinos de fibra de vidro apresenta melhores resultados que os pinos de titânio se combinados com resinas compostas Bulk-Fill.

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ANEXOS

Anexo 1: Declaração de ex-bolsista CAPES - PDSE

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Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - CAPES
Setor Bancário Norte, Quadra 2, Bloco L, Lote 06
CEP 70040-020 - Brasília, DF

Processo: 99999.009625/2014-03

Origem:	CAPES
Data do Envio:	17/02/2016 10:00:23

Mensagem da CAPES

Prezado (a) Senhor (a),
PRISCILLA CARDOSO LAZARI
RUA PADRE MOISES DE MIRANDA, NÚMERO 592
CENTRO
Reginópolis - São Paulo
Brasil
17.190-000

17 de Fevereiro de 2016

Processo: PDSE 99999.009625/2014-03

DECLARAÇÃO DE EX-BOLSISTA

Prezado(a) Ex-bolsista,

Declaramos, para os devidos fins, que o(a) interessado(a) foi bolsista da Capes e realizou Doutorado Sanduíche no exterior, conforme os dados abaixo:

PERÍODO DA BOLSA:01/2015 a 31/12/2015

INSTITUIÇÃO DE ENSINO: UNIVERSITY OF SOUTHERN CALIFORNIA

PAÍS: Estados Unidos

Atenciosamente,

Adi Balbinot Junior
Coordenador (a) Geral de Acompanhamento e Monitoramento de Resultados
Esta assinatura independe de reconhecimento de firma, por se tratar de documento público
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Anexo 2: Confirmação de submissão do Artigo 1 na revista Operative Dentistry

☆ **editor@jopdent.org** 9December, 2016 00:13

To: Pascal Magne Cc: Priscilla Lazari, Marco Aurélio Carvalho, Jide Johnson, Profª Altair, aoc1981@fop.unicamp.br Details

December 7, 2016

Dear Pascal Magne,

The referees' comments regarding your manuscript, "Ferrule-effect dominates over use of a fiber post when restoring endodontically-treated incisors: an in-vitro study", have been received. On the basis of these reviews I am pleased to inform you that your paper is accepted for publication in Operative Dentistry. We will begin our initial editing of the paper within one month of this email. The authors will be asked to proof the copy (text) first, and will have a chance to edit the final typeset version before it is published online early. The paper will be first published electronically on our online journal site at www.jopdentonline.org and then assigned to a specific issue in the Journal as determined by the Editor (usually within 6-8 months from acceptance). Online only and print publications will all be assigned to an issue. The DOI will not change once an issue citation is finalized.

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10 units of CDE to:
Dr. Magne
and to the 1st author (if Different).

and

2 units of CDE to:
Pascal Magne
Priscilla Lazari
Marco Carvalho
Taoheed Johnson
Altair Del Bel Cury

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Thank you for considering Operative Dentistry for publication of this excellent manuscript.

Sincerely yours,

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Operative Dentistry

Anexo3: Confirmação de submissão do Artigo 2 na revista Journal of Prosthetic Dentistry

From: <JPD@augusta.edu>
Date: 1 November 2016 7:44:29 PM GMT-2
To: <lazari.pcl@gmail.com>
Subject: Your recent submission to JPD

Dear Dr. Priscilla Lazari ,

You have been listed as a Co-Author of the following submission:

Journal: The Journal of Prosthetic Dentistry
Corresponding Author: Pascal Magne
Co-Authors: PRISCILLA CARDOSO LAZARI, DDS; Marco A Carvalho , DDS, MS, PhD; Altair A Del Bel Cury, DDS, MS, PhD;
Title: Post type and buildup material have limited effect on the survival of endodontically treated incisors without ferrule

If you did not co-author this submission, please contact the Corresponding Author of this submission at magne@usc.edu;pmagne66@gmail.com; do not follow the link below.

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