Reconstruction of endodontically treated anterior teeth

Anaïs Ramírez Sebastià

Dipòsit Legal: B 1789-2014

Universitat Internacional de Catalunya

Facultat d'Odontologia

Departament d'Endodoncia i Restauradora

Reconstruction of endodontically treated anterior teeth

PhD Thesis – with European Mention

Anaïs Ramírez Sebastià

Dr. Prof. Ivo Krejci

Dr. Miguel Roig Cayón

Barcelona, 2013

El genio se compone de un 2% de talento y un 98% de perseverante aplicación.

Ludwig van Beethoven

(Alemania 1770-1827)

Remerciements

Ce travail de thèse n'aurait pas pu être réalizé sans l'aide précieuse des personnes suivantes que je tiens à remercier très sincèrement;

Prof. Ivo Krejci, Professeur de la Division de cariologie et d'Endodontie à l'Université de Genève et directeur de ma thèse, pour son soutien et son encouragement tout au long de ce projet de recherche, pour sa grand disponibilité, ses conseils avisés et bienveillants, il a su me faire partager sa passion et son enthousiasme pour la recherche et la profession.

Madame Nicole Allenspach, Madame Marie Claude Reymond et Cyril Hall, laborantines de la Division de Cariologie et d'Endodontie, pour son soutien et son travail d'analyse au MEB d'un nombre illimité de répliques.

Dr. Tissiana Bortolotto, pour l'intérêt porté à mon travail et la pertinence des questions qui m'ont été posées lors de la soutenance.

Mes remerciements s'adressent à tout le Staff de la Division de Cariologie et d'Endodontie pour leur soutien moral, leur esprit de collégialité: Ladislav Gregor, Stefano Ardu, Tommy Rocca, Nicolas Rizzcala, Dorien Lefever, Ana Argente, Teresa Rodríguez, Ivonne Chaskelis, Cristina Vento, Ioana Onisor, Maria José Sandoval. J'espère de tout cœur que l'amitié qu'ils m'ont généreusement offerte tout au long de mon séjour à Genève restera à jamais durable.

Gràcies

Aquest treball tampoc es podria haver dut a terme sense l'ajuda del meu director a Barcelona, el Dr. Miguel Roig, una persona que m'ha ensenyat a veure que els començaments són sempre difícils però que amb molt d'esforç es pot aconseguir tot el que et proposes.

Durant el camí han aparegut molts entrebancs que han estat molt difícils de superar, la distancia, la familia i els amics són molt importants; tot aquest treball us el dedico a vosaltres, papa, mama, iaio, Edgar i xef Victor, moltíssimes gràcies per ser-hi i per ajudar-me en TOT.

No em puc oblidar de molta altra gent que ha estat present i m'ha ajudat d'alguna manera, a vosaltres, que ja sabeu qui sou, gràcies: Tiet, tieta, Isabel Campos, Maria Cavaller, Mariona Guix, Pau Sanz, Natàlia Puig, Ivet Comas, Marta Bartrès, Ekipo, Quim, Àngela, Tere, Anita, Miguel Maraví, Rosa Puigmal, Carme, Mari, Maria Güell, Anna Pons, Núria Azanza, Miriam Roncero, José Antonio González, Montse Mercadé, Fernando Durán-Sindreu, Eva Stöber, Miguel Teixidó, Gonzalo Gómez, Joan de Ribot, Marta Collell, i per suposat a tots els alumnes i professors del master d'endodoncia i estètica de la Universitat Internacional de Catalunya. En especial a tu Marta, gràcies per compartir amb mi aquest tram final. Et desitjo lo millor.

A tu, Javi. GRÀCIES. Gràcies per la paciència, per escoltar-me, pels teus ànims, per la comprensió i per les hores que t'he privat a canvi d'aquesta tesis.

INDEX

1. JUSTIFICATION

Despite the large number of *in-vitro* and *in-vivo* investigations, there is still no agreement regarding which material or technique can be considered ideal for the restoration of endodontically treated teeth (1, 2).

Endodontically treated teeth is a unique subset of teeth requiring restoration for several factors. These factors include a loss of structural integrity due to access preparation, which has a negative effect on the fracture resistance, and reduced protection due to a lack of neurosensory feedback mechanism, which is impaired following the removal of pulp tissue.

The primary cause of endodontic failure is inadequate restorative therapy; there has been an increased emphasis on failure caused by orthograde contamination resulting from salivary contamination through an open access preparation or a faulty margin (3).

As a general rule, most endodontically treated posterior teeth and all structurally damaged anterior teeth should be restored with a crown (4). However, the principles of minimal invasive dentistry are becoming more accepted among clinicians.

Recently, several papers have supported the use of direct restoration without posts (5-7). Regarding fracture strength and fracture patterns, Krejci et al. showed no significant differences between teeth restored with and without posts in posterior teeth (8). Moreover, some studies have highlighted that mechanical resistance to fracture of endodontically treated teeth could be affected by the presence of posts, thus increasing the risk of residual tooth structure damage (9-11). Because the maxillary lateral incisors and the mandibular incisors are smaller teeth, a post is commonly indicated before crown placement. In maxillary incisors and canine teeth, however, it is unclear how much structure is required in order to make a post placement feasible.

Three papers written for this thesis described the reconstruction of endodontically treated teeth. The aims of this thesis are to present the composition and structural alterations resulting from loss of pulp vitality and to provide different approaches to restorative adhesive procedures for anterior teeth.

2. INTRODUCTION

Restoration of endodontically treated teeth represents a challenge for the clinician (12) and is a topic that has been widely discussed and hotly debated in the literature (13-18). Authors have concluded that apical periodontal health significantly depends more on coronal restoration than the technical quality of the endodontic treatment (15). Clinical concepts are often based on empirical assumptions rather than scientific evidence. The clinician´s choice of approach is complicated by the wide range of restorative materials and techniques available and there is a lack of accepted clinical standards and consensus regarding the optimal method of non vital teeth restoration (19, 20).

Root canal treatment should not be considered complete until appropriate coronal restoration has been achieved (3, 21). Prognosis of endodontic treatment depends both on the treatment itself, and on sealing the canal and minimizing the leakage of oral fluids and bacteria into periradicular areas (15, 16). 60% of extracted endodontically treated teeth fail due to inadequate restoration (22). The success rate of endodontic treatment significantly increases with good quality coronal restoration. Therefore, the treatment decisions and strategies should be based on the available evidence; before making a treatment decision, the clinician should evaluate the quality of endodontic treatment, the periodontal support available, and the status of the remaining tooth structure (23).

It is accepted that endodontically treated teeth are more likely to fracture, which cannot be explained by differences in biomechanical properties or moisture content of hard tissues, but by the structural defect generated during tooth preparation (19). In fact, tissue conservation is critical when treating a non vital tooth. Preserving intact structures and above all preserving and maintaining cervical tissue to create a ferrule effect are crucial for optimization of the biomechanical properties of the restored tooth (12, 13, 18).

Considering traditional principles of fixed prosthodontics, full-crown coverage would be recommended to strengthen the remaining tooth structure (4). At present, the protocol has changed due to improvements in adhesive material and techniques, thus paving the way for the post amalgam age (24). Macro retentive elements are no longer mandatory as long as enough surface area is available. Minimally invasive preparations with maximal tissue conservation are now considered the gold-standard for restoring the endodontically treated teeth (20). Based on the advantages of the adhesive restorations, indication for posts is remerging as a topic of debate and the post-insertion technique has become the exception rather than the rule (16, 20).

Biomechanical considerations

Several studies have proposed that the dentin in endodontically treated teeth is substantially different from dentin in vital teeth (25-27). It was thought that the dentin in endodontically treated teeth was more brittle because of water loss and loss of collagen cross-linking (25).

Sedgley and Messer tested the biomechanical properties of dentin of endodontically treated teeth and vital teeth of contralateral side and concluded that endodontically treated teeth are not more brittle (28). Loss of tissue is one of the most important changes in tooth biomechanics (29). Caries, cavity preparation, coronal access to the pulp, canal enlargement and chemomechanical preparation can disrupt tooth integrity· (20). Sodium hypochlorite, chelating agents and calcium hydroxide commonly used for canal irrigation and disinfection interact with root dentin, either with mineral content (chelating agents) or organic substrate (sodium hypochlorite) but no or only minor differences in micro hardness values were found between vital and non vital dentin of contralateral teeth after 0.2 to 10 years. Considerable differences exist which are attributed to root location and dentin microstructure (peritubular or intertubular) (19, 20).

Hence, after endodontic treatment the tooth does not become more brittle or weaken with respect to compressive or tensile strengths. No difference in collagen cross linkage was observed in vital and non vital teeth and there is no further evidence of chemical alteration due to the removal of pulp tissue (19).

The remaining amount of hard tissue is the major factor that influences the biomechanics (16). The loss of tooth structure during conservative access cavity preparation affects tooth stiffness by only 5% and the largest reduction results from the loss of marginal ridges; the actual literature reports 14% to 44% and 20% to 63% reduction in tooth stiffness following occlusal and mesio occlusal distal (MOD) cavity preparations, respectively. The maximum tooth fragility results from endodontic access preparation combined with an MOD preparation (19).

Fracture resistance of the endodontically treated teeth

Loss of the tooth structure from caries, trauma, or the two of them, makes endodontically treated teeth more susceptible to fracture (17, 30). Fracture resistance of a restored endodontically treated tooth decreases as the amount of dentin removed increases (31).

Loss of the tooth structure reduces the ability of the tooth to resist intraoral forces. The thickness of the dentinal wall at the root circumference is critical and there is a direct correlation between the root diameter and the ability of the tooth to resist lateral forces and avoid fracture (8, 31, 32).

The cavity depth, isthmus and configuration are highly critical factors that determining the reduction of tooth stiffness and risk of fracture. On the other hand, the ferrule effect increased tooth resistance to fracture; a minimal 1mm ferrule is considered necessary to stabilize the restored tooth (33-36).

Post concepts

The conventional and widespread belief among dentists is that all endodontically treated teeth are weaker or more brittle than vital teeth and therefore require aggressive reinforcement. This aggressive treatment has traditionally consisted of insertion of a metal post or dowel to strengthen the tooth followed by placement of a crown to protect it. Although some finite element analysis (FEM) studies indicate that a rigid post can strengthen the tooth in its cervical part, by way of totally cohesive interfaces (37), most studies suggest that posts have no strengthening effect (20, 38). Many authors even discourage the use of posts because the preparation of a post space and the placement can weaken the root and may lead to catastrophic root fracture. At present, a post is considered only as a retentive feature in well-selected situations (9, 12).

The need for a post placement depends on the dental group. For endodontically treated molars, the dental practitioner may take advantage of the anatomy; the large pulp chamber and canals provide adequate retention for a core build-up. Thanks to the anatomical features, molars do not require posts (17, 20). However, in a case of excessive loss of natural tooth structure, posts may be required and should be placed in the largest and straightest canal to avoid weakening the root during post placement and root perforation in curved canals.

The number of remaining cavity walls should be critically considered when placing posts (39). Based on several *in-vitro* studies, if all the axial walls remain intact and are thicker than 1 mm, there is no need to insert posts. In cases involving 1 or 2 cavity wall losses, a post is not required, as the remaining hard tissue provides enough surfaces for the use of other methods, in particular, for cores using adhesive systems (20). Posts are indicated in cases where only one cavity wall remains. In posterior teeth, both metal and non-metal posts are acceptable treatment options. In cases with a high degree of destruction where no cavity walls remain, the insertion of a post is necessary to retain core material. Ferrule effect has a great influence on resistance to fracture in decoronated teeth. Ferrule effect is defined as a 360º tissue collar of the crown surrounding the parallel walls of the dentin extending coronal to the shoulder of the preparation. This effect provides a greater crown resistance from the extension of dentinal tooth structure (33).

Bolhuis et al postulated that the ferrule effect is more important than the choice between a post and core, or a core reconstruction with adhesive fillings only (40).

After years of scientific research into posts, the indication for post placement is re-emerging as a topic of debate and a change of paradigm has occurred based on the advantages of adhesive restorations (16).

Today, posts do not seem to be mandatory for the restoration of a non vital tooth, unless there is evident insufficient core retention. When a post is needed to increase the stability of the foundation, resin fiber posts with physical properties close to natural dentin, adhesively luted appear to be the most suitable option (13, 41).

Prefabricated posts have become increasingly popular and can be classified as metal, ceramic and fiber posts, according to their structural composition. The combination of prefabricated posts with the composite resin cores has been associated with a decrease in catastrophic fractures when compared with the use of cast posts and cores (41, 42).

Metallic posts generate high stresses, often leading to non restorable root fractures (9, 43). In order to avoid these problems, metal-free posts with mechanical characteristics similar to those of dental tissues have been developed. Fiber-reinforced posts systems were subsequently introduced (9, 41).

Various recommendations have been proposed regarding post length. It was believed that given at least 4-5 mm of apical seal, together with the post placed in the more apical part of the canal, a higher retention of the restoration was obtained. Currently, thanks to the optimization of bonding mechanisms of current adhesive composite cements, guidelines on post length may need to be revised. Since fiber posts are bonded within the root canal, their length could be shortened (44-46).

In an *in-vitro* study, Zicari et al concluded that short posts may yield higher fracture resistance than long posts could, due to a less invasive build-up approach (42). Moreover, the fracture patterns associated with shorter posts appeared to be more favorable because they allow re-intervention and preservation of the tooth (45, 47).

Cusp Coverage

The quality of the restoration directly influences the prognosis of the long term success of the tooth (18, 22).

Aquilino et al., comparing the survival relationship between the root canal treated posterior teeth with and without crown placement, concluded that coronal coverage with full cast crown reduced the risk of tooth fracture. They also reported that endodontically treated teeth with crowns had a survival rate six times greater than those without crowns (48).

Conversely, Mannocci et al. evaluated endodontically treated premolars that had been restored (both with and without complete coverage) by either a post or direct composite resin restorations and reported similar success rates for the two (49).

Adhesively placed restorations with total cuspal coverage (overlays) have been proposed as an alternative to the more traditional and invasive full-coverage crown (50). Compared to bonded restorations, full-crown restorations require more sacrifice of hard tissue, subgingival margins and are associated with more gingival inflammation and secondary caries.

The use of adhesive cuspal coverage restorations (overlays instead of crowns) is recommended to reduce the risk of fracture and increase the coronal mechanical resistance in endodontically treated teeth.

In-vitro experiments have shown that there is no difference in retention, marginal adaptation and fracture resistance between a vital tooth configuration and a non vital covered with an onlay restoration, paving the way for conservative partial crown coverage for endodontically treated teeth (8, 20).

With the advent of adhesive dentistry it is feasible to restore posterior teeth with extensive coronal destruction by means of onlay and/or overlay restorations, and more recently, with endocrowns without the use of radicular posts while using the entire extension of the pulp chamber as a retentive source (20, 51).

Endocrowns

The endocrown is a restorative option for endodontically treated posterior teeth with extensive loss of coronal structure and it represents an interesting and conservative alternative to full-coverage crowns (52, 53). This restorative approach provides adequate function and esthetics, as well as biomechanical integrity of structurally compromised posterior non vital teeth. The advantages of the endocrown over the conventional crown are: improved mechanical performance, lower costs, and less chair-time. Moreover, the marginal restoration is positioned supragingivally and prevents interferences with periodontal tissues (52).

The nomenclature endocrown was first described by Blind and Mormann in 1999 as adhesive endodontic crowns and was characterized as total porcelain crowns fixed to devital posterior teeth. These crowns would be anchored to the internal portion of the pulp chamber and on the cavity margins, obtaining macromechanical retention provided by the pulpal walls and microretention would be attained with adhesive cementation. This method is indicated in cases in which there is excessive loss of hard crown tissue with limited interproximal space, making traditional rehabilitation with post and crown unfeasible (52, 54, 55).

In-vitro studies have shown a high success rate of endocrowns (20, 51, 57), which clinical studies had already corroborated (13, 56). Endocrowns have exhibited statistically significant higher resistance to fracture. Otto reported a survival rate of 100% after 12 to 16 months' placement (58).

Composite vs. Ceramic

Whether ceramic or composite resin is better as a restorative material for adhesive restorations warrants further investigation (50, 59-61). In spite of the advantages of all-ceramic restorations, including aesthetic appearance, biocompatibility and durability, these materials have some drawbacks such us the potential for catastrophic fracture and abrasive wear of the opposing natural teeth (60). Ceramic is a brittle material that cannot absorb a large amount of deformation energy and shows only moderate resistance to localized shear and tensile stresses (50).

Manhart et al revealed significantly enhanced anatomical shape and integrity of the ceramic restorations compared to those composite resins (62). However, the higher cost and technique sensitivity explain why clinicians restrict their use to specific clinical situations, hence a growing interest in composite inlays/onlays. Composite resin overlays can also be fabricated using CAD/CAM (computer-aided design/computer-assisted manufacturing) technology and offer a considerable time advantage by being produced chairside (50).

Advances in adhesive dentistry and technologic developments with computer-aided design/computer-assisted manufacturing (CAD-CAM) technologies have resulted in new systems for dental restoration. Various machinable materials are used currently with CAD/CAM systems to fabricate restorations at the chairside. The CEREC 3 CAD/CAM system was introduced more than 15 years ago and it is the only system that can be used in both clinical practice and the laboratory (57).

In a *in-vitro* study, Magne el al. assessed and compared the fatigue resistance of composite resin (Paradigm MZ100, 3M ESPE) and ceramic posterior occlusal veneers (IPS Empress CAD, Ivoclar Vivadent and IPS e.max CAD, Ivoclar Vivadent). The authors concluded that CAD/CAM composite resins had significantly higher fracture resistance when compared to ceramic. Despite the simulation of loads of a higher magnitude than is usually encountered in clinical situations, there were no catastrophic failures, but only cracks limited to the restoration material (63). This constitutes a demonstration of the "biomimetic" approach of the restoration and underlying tissue.

Although the composite resin restorations are expected to wear more than ceramic, they also tend to preserve more of the antagonist, yet this differential wear requires additional investigation (63).

3. OBJECTIVES

OBJECTIVES:

1. Evaluate the quality of marginal adaptation of crowns made of composite and ceramics on devitalized anterior teeth before and after a thermomechanical fatigue test.

2. Evaluate the influence of restorative material, composite or ceramic, on fracture strength, on devitalized anterior teeth before and after a thermomechanical fatigue test.

3. Evaluate the fracture strength between endocrowns for anterior teeth, 5mm glass fiber post and 10mm glass fiber post retained crowns made of ceramic and composite.

4. Evaluate the mode of fracture between endocrowns for anterior teeth, 5mm glass fiber post and 10mm glass fiber post retained crowns made of ceramic and composite.

OBJETIVOS:

1. Evaluar la calidad de la adaptación marginal de las coronas de composite y cerámica en dientes anteriores endodonciados antes y después de ser fatigados termomecánicamente.

2. Evaluar la influencia del material de restauración, composite y cerámica, en la resistencia a la fractura de dientes anteriores endodonciados antes y después de ser fatigados termomecánicamente.

3. Evaluar la resistencia a la fractura entre dientes anteriores endodonciados y restaurados con coronas de composite y cerámica, endocoronas, poste corto de 5mm y poste largo de 10mm.

4. Evaluar el modo de fractura entre dientes anteriores endodonciados y restaurados con coronas de composite y ceramic, endocoronas, poste corto de 5mm y poste largo.

4. HYPOTHESES

The null hypotheses (HN) were:

1. (NH_0) There will be no differences on marginal adaptation between ceramic and composite crowns.

2. (NH_1) There will be no influence of restorative material, i.e composite or ceramic, on fracture strength.

3. (NH_2) There will be no differences on fracture strength of teeth restored with endocrowns, short and long post.

4. (NH_4) There will be no differences on fracture patterns of teeth restored with endocrowns, short and long post.

The alternative hypothesis (AH) were:

1. (AH_0) There will be differences on marginal adaptation between ceramic and composite crowns.

2. (AH_1) There will be influence of restorative material, i.e composite or ceramic, on fracture strength.

3. (AH_2) There will be differences on fracture strength of teeth restored with endocrowns, short and long post.

4. (AH_3) There will be differences on fracture patterns of teeth restored with endocrowns, short and long post.

HIPÓTESIS

Las hipótesis nulas fueron:

1. (NH_0) No habrá diferencias en cuanto a la adaptación marginal entre las coronas de cerámica y las coronas de composite.

2. (NH_1) No habrá influencia alguna en cuanto a la resistencia a la fractura entre composite y cerámica.

3. (NH_2) No habrá diferencias en cuanto a la resistencia a la fractura entre los dientes restaurados con endocoronas, con poste corto y con poste largo.

4. (NH_4) No habrá diferencias en los modos de fracturas entre los dientes restaurados con endocoronas, con poste corto y con poste largo.

Las hipótesis alternativas fueron:

1. (AH0) Sí habrá diferencias en cuanto a la adaptación marginal entre las coronas de cerámica y las coronas de composite.

2. (AH1) Sí habrá inflencia en cuanto a la resistencia ala fractura entre composite y cerámica.

3. (AH2) Sí habrá diferencias en cuanto a la resistencia a la fractura entre los dientes restaurados con endocoronas, con poste corto y con poste largo.

4. (AH3) Sí habrá diferencias en los modos de fracturas entre los dientes restaurados con endocoronas, con poste corto y con poste largo.

5. PUBLISHED PAPERS

PUBLISHED PAPER 1

Adhesive restoration of anterior endodontically treated teeth: influence of post length on fracture strength

Anaïs Ramírez[1, 3], Tissiana Bortolotto[3], Maria Cattani-Lorente[4], Lluis Giner[2], Miguel Roig[1], Ivo Krejci[3]

[1]*Department of Endodontic and Restorative Dentistry, School of Dentistry, Universitat Internacional de Catalunya, Spain.*
[2]*Head of Research, School of Dentistry, Universitat Internacional de Catalunya, Spain.*
[3]*Division of Cariology and Endodontology, School of Dentistry, University of Geneva, Switzerland.*
[4]*Division of Biomaterials, School of Dentistry, University of Geneva, Switzerland.*

Clinical Oral Investigations 2013, April 20.

Impact Factor: 2.364 (2011 JCR Science Edition) (1st Quartil)

Clin Oral Invest
DOI 10.1007/s00784-013-0978-3

ORIGINAL ARTICLE

Adhesive restoration of anterior endodontically treated teeth: influence of post length on fracture strength

Anaïs Ramírez-Sebastià · Tissiana Bortolotto · Maria Cattani-Lorente · Lluis Giner · Miguel Roig · Ivo Krejci

Received: 31 May 2012 /Accepted: 4 April 2013

Abstract

Objectives This study aims to evaluate the fracture resistance of endodontically treated anterior teeth restored with crowns made of composite or ceramic and retained without the use of a post (endocrowns) or with posts of 5 mm (short) and 10 mm in length (long).

Material and methods Forty-eight intact maxillary incisors were selected for the study. After endodontic treatment, the crowns were sectioned 2 mm coronally to the cementoenamel junction provided with a ferrule of 2 mm. The roots were randomly divided into six groups (n=8) according to the post length and type of coronary restoration. The crowns were fabricated with the chairside economical restoration of esthetic ceramics system. Group 1 was restored with a 10-mm glass fiber post, composite core, and a full-coverage ceramic crown (LPCer); group 2, with a 5-mm glass fiber post, composite core, and a full-coverage ceramic crown (SPCer); group 3, with a 10-mm glass fiber post, composite core, and a full-coverage composite crown (LPCpr); group 4, with a 5-mm glass fiber post, composite core, and a full-coverage composite crown (SPCpr); and groups 5 (EndoCer) and 6 (EndoCpr) were restored with ceramic and composite endocrowns, respectively. The teeth were then thermomechanically loaded in a chewing machine. After fatigue, the specimens were loaded to fracture. Data were analyzed with ANOVA and chi-square test. Mode of failure was defined as repairable or non-repairable.

Results Presence of post, post length, and crown material had no significant effect on the fracture resistance. Groups restored with endocrowns presented a higher number of repairable fractures in respect to the other groups.

Conclusions Presence of a post had no effect on the restorations' fracture strength.

Clinical relevance Although this in vitro study has some limitations in respect to its clinical relevance, the restoration of largely destroyed anterior teeth with the use of an endocrown or a short glass fiber post might have advantages over a large glass fiber post.

Keywords Anterior teeth · Endodontically treated teeth · Fracture strength · Post length

A. Ramírez-Sebastià (✉) · M. Roig
Department of Endodontic and Restorative Dentistry, School of Dentistry, Universitat Internacional de Catalunya, Sant Cugat del Vallès, Barcelona, Spain
e-mail: annaisramses@csc.uic.es

L. Giner
Division of Biomaterials, School of Dentistry, Universitat Internacional de Catalunya, Sant Cugat del Vallès, Barcelona, Spain

T. Bortolotto · I. Krejci
Division of Cariology and Endodontology, School of Dentistry, University of Geneva, Geneva, Switzerland

M. Cattani-Lorente
Division of Biomaterials, School of Dentistry, University of Geneva, Geneva, Switzerland

Published online: 20 April 2013

Introduction

Restoration of endodontically treated teeth (ETT) is compromised primarily because of coronal destruction that results in an increased risk of tooth fracture during function. Before the introduction of adhesion technology in dentistry, the coronal restoration of ETT has been mainly performed with metallic and macromechanically retained posts. In the past, a post length equal to three fourths of the root canal length or at least equal to the crown length was recommended [1, 2]. Metallic posts generated high stresses, often leading to non-restorable root fractures [3]. In order to avoid these problems, metal-free posts with mechanical characteristics similar to those of dental tissues have been developed. Subsequently, fiber-reinforced post systems were introduced [4, 5]. At present, restoration of posterior ETT with a direct composite without placing any post has been proposed by several authors [6–8]. Moreover, a recent study might show that in largely compromised premolars, no significant differences existed between teeth restored with and without posts [6]. These authors argued that the results were due to the use of an adhesive restorative design.

The fracture resistance of ETT has been reported to be mainly dependent on the amount of the remaining tooth structure, the amount of adhesive surface, and the quality of adhesion [7]. The role of a post in the retention of the core material is particularly relevant for posterior teeth where masticatory loads are essentially compressive. On the other hand, as upper incisors are loaded transversally, the influence of post length on the tooth's flexural behavior is an important issue to be considered in order to reduce tooth fracture [8].

Recent studies have demonstrated that shortening the post length has no negative influence on fracture resistance and may be used in anterior teeth without compromising the apical seal [9–13]. This is because in modern conservative dentistry, the retention of restorations is mainly based on adhesion; therefore, the use of macroretentive elements could be no longer required [14]. While the insertion of radicular posts may often become obsolete in posterior teeth [6], little or no information on anterior teeth has been reported in the literature.

An endocrown is a restorative option for ETT. It consists of a full or compact crown that extends a post into the pulp chamber and/or pulp canals as one unit [15]. It is interesting to note that, to the author's knowledge, this type of crowns on anterior teeth has been evaluated to test how forces are transmitted along the tooth through the finite element analysis (FEA) [16]. No in vitro studies on adhesive restoration of anterior endodontically treated teeth have been tested to analyze fracture strength and mode of failure.

Innovative computer-assisted design/computer-assisted manufacturing (CAD/CAM) technologies have introduced new systems for dental restorations. CAD/CAM system has the advantage of being the only chairside system available. In addition, its efficacy has been proven in both in vitro and in vivo studies [17–20].

The purpose of the present study was to evaluate the fracture strength and mode of failures between a new model called endocrowns for anterior teeth, a 5-mm glass fiber post and a 10-mm glass fiber post retained crowns made out of ceramic and composite.

The null hypotheses tested were that (1) there would be no effect of post length on fracture strength of devital anterior teeth; (2) there would be no influence of restorative material, i.e., composite or ceramic, on fracture strength; and (3) there would be no difference on fracture patterns of teeth restored with the different groups.

Material and methods

Forty-eight sound upper central human incisors stored in 0.1 % thymol solution for 1 month following extraction were randomly divided in to six experimental groups (Table 1). Bucco-palatal and mesio-distal dimensions and root lengths of all teeth selected were measured using digital calipers. The inclusion criteria were that teeth had to be free of carious lesions with complete and straight roots, as well as no visible fracture lines in the root.

Endodontic treatment

Before endodontic treatment, the root was sealed using a filled light-curing adhesive (OptiBond FL, KerrHawe Neos, Orange, CA, USA). The pulp chamber of each tooth was opened following a standardized procedure, and working length was determined visually by placing a size no. 10 K-file (Dentsply Maillefer, Ballaigues, Switzerland) at the apical foramen. Root canals were instrumented using stainless steel K-files nos. 10, 15, and 20 (Dentsply Maillefer) followed by rotary Ni-Ti instruments (ProTaper U®, Dentsply Maillefer) according to the manufacturer's instructions. All canals were prepared up to the F5 rotary file, and instruments were discarded after four canal preparations or if instrument deformation was visible. Root canals were irrigated between each of the instrumentation with 1 ml of sodium hypochlorite at a concentration of 4.2 %. The roots were filled using the warm

Table 1 Description of the experimental groups

Group	Description	Abbreviation
1	10-mm glass fiber post (long)/composite core/ceramic crown	LPCer
2	5-mm glass fiber post (short)/composite core/ceramic crown	SPCer
3	10-mm glass fiber pots (long)/composite core/composite crown	LPCpr
4	5-mm glass fiber post (short)/composite core/composite crown	SPCpr
5	Ceramic endocrown	EndoCer
6	Composite endocrown	EndoCpr

vertical condensation technique (SystemB and Guta-percha Extruder, Elements Obturation UnitTM, Analytic Endodontics, Sybron Endo, USA), using calibrated gutta-percha (Autofit®, Analytic Endodontics) and an endodontic sealer (AHplus, Dentsply Maillefer). Then the access cavity was sealed with a light-cured resin reinforced glass ionomer restorative (Fuji II® LC, GC America Inc., Alsip, IL). After a setting period of 48 h, each tooth was fixed on a custom-made metallic holder (Provac FL, Balzers, Liechtenstein) with a self-curing acrylic resin (Technovit 4071, Heraeus Kulzer GmbH, Wehrheim, Germany).

Root preparation, post selection and luting procedure

The crown of each tooth was sectioned 2 mm above the cementoenamel junction. Gutta-percha was removed with a Reamer size no. 3 (Ivoclar Vivadent, Schaan, Liechtenstein) using a handpiece at 800–1,220 rpm. Dowel spaces were prepared with calibrated diamond rotary cutting instruments specifically designed for the post system used. Endocrown preparation was limited to removal of the pulp chamber, excessively retentive areas, and alignment of the pulpal walls. The canal was deepened for 5 mm (3 mm seated in the root).

The groups were divided according to their post lengths. In groups 1 (LPCer) and 3 (LPCpr), 10 mm of glass fiber posts (FRC Postec Plus, size 3, Ivoclar Vivadent) were used (7 mm seated in the root); gutta-percha was removed, leaving 4 mm of root filling to preserve the apical seal. In groups 2 (SPCer) and 4 (SPCpr), 5 mm of glass fiber posts (FRC Postec Plus, size 3, Ivoclar Vivadent) were used (3 mm seated in the root). Translucent glass fiber posts with a standardized size (FRC Postec Plus, size 3, Ivoclar Vivadent) were selected to be placed in each root canal. In group 5 (EndoCer) and group 6 (EndoCpr), coronal gutta-percha was also removed with a Reamer size no. 3 at the same level as that of groups 2 and 4. Endocrowns were directly prepared with the CAD/CAM system. The canalar and core portions were considered as a one-component machined from a ceramic and a prepolymerised composite block (Paradigm MZ100, 3M ESPE, Seefeld, Germany/IPS Empress CAD, Ivoclar Vivadent).

Table 2 show the composition of adhesive system and restorative materials used.

Each post was tried in the root canal and sectioned at the adequate length with a diamond bur. Prior to the luting procedure, the fiber post surface was cleaned with etching gel (K-etchant gel, Kuraray, Japan) for 15 s, rinsed, and air-dried. Silicatization was performed with a 27-μm silicated Al_2O_3 powder (CoeJet, 3 M ESPE, Seefeld, Germany), and silane (Clearfil Ceramic Primer, Kuraray, Japan) was then applied on the surface of the posts for 60 s. Then, the bonding system (Clearfil DC Bond, Kuraray, Japan) was applied on the post and air-dried for 30 s. All materials used in root canals were applied using superfine-sized microbrushes (Microbrush® International, Wisconsin, USA). The following bonding protocol was adopted, strictly following the manufacturer's instructions: 37 % phosphoric acid (K-Etchant Gel) was applied to the canal wall surfaces for 15 s and rinsed thoroughly with water for at least 15 s. Excess water was removed from the canal with mild air pressure and paper points (Dentsply Maillefer). The surface was not overdried in order to avoid dentine desiccation. The adhesive system (Clearfil DC Bond, Kuraray, Japan) was dispensed onto a disposable microbrush and immediately rubbed on all root canal surfaces for at least 20 s. The solvent was removed by blowing air gently from a dental syringe for at least 5 s. The posts were then luted with a dual-cured resin cement (Clearfil Esthetic Cement, Kuraray), according to the manufacturer's instructions. The luting cement was applied to the post and to the post space with a superfine-sized microbrush. The posts were seated into the root canals and stabilized, and the cement excess was removed with paper points. Both the adhesive system and resin cement were simultaneously light-cured for 60 s (Demi LED, Kerr Corp. Middleton, WI, USA) directly in contact with the post. In order to ensure an appropriate light intensity, the emitted light was measured before each exposure with the digital radiometer of the light unit.

Core preparation

After luting the posts, the core was prepared with the same adhesive system (Clearfil DC Bond, Kuraray), following the same application technique described above. The core was built up by using a dual-cured core material (Clearfil Photo Core, Kuraray) light-cured for 40 s. Transparent matrices (Hawe Striproll, KerrHawe, Bioggio, Switzerland) were used to confine the restorative material. The core preparation was finished with diamonds burs (Advanced Preparation Set for Cerec Anterior Restorations, Intensiv, Lugano, Switzerland). Dimensions of the test specimen mounted in a resin block are shown in Fig. 1. All crown margins were located in the dentin with a ferrule effect of 2 mm. The anatomical shape was prepared following the chairside economical restoration of esthetic ceramics (CEREC) approach, and the minimum thicknesses recommended for anterior crowns were considered.

Crown design and milling

The prepared abutments were scanned with a camera (CEREC 3D, software V2.40 R1800, Sirona, Bensheim, Germany). In group 5 (EndoCer) and group 6 (EndoCpr), ceramic and composite endocrowns were directly prepared with the CAD/CAM system. After the crown preparation, the surface was uniformly

Table 2 Summary of products used

Material	Product name (manufacturer)	Composition (main constituents)	Application mode	Batch numbers
Fiber post	FRC Postec Plus (Ivoclar Vivadent, Schaan, Liechtenstein)	Glass fibers (70 vol %), dimethacrylate resin matrix (21 vol %), ytterbium fluoride (9 vol %)		35052
Ceramic blocks	IPS Empress CAD (Ivoclar Vivadent)	Components: SiO_2. Additional contents: Al_2O_3, K_2O, Na_2O, CaO, and other oxide pigments		57343
Composite blocks	MZ100 (3M ESPE, Germany)	Conventional hybrid composite resin, bisphenol A diglycidylether dimethacrylate (bis-GMA), triethylene glycol dimethacrylate (TEGDMA), and ultrafine zirconia silica ceramic particles as filler. Particles have spherical shape and average size 0.6 mm.		20071221
Dual-cure resin-based cement system	Clearfil Esthetic Cement (Kuraray)	*Clearfil ceramic primer*: 3-MPS, 10-MDP, ethanol; *Paste A*: Bis-phenol A diglycidylmethacrylate, TEGDMA, methacrylate monomers, silanated glass filler, colloidal silica. *Paste B*: Bis-phenol A diglycidylmethacrylate, TEGDMA, methacrylate monomers, silanated glass filler, silanated silica, colloidal silica, benzoyl peroxide; CQ: pigments	Apply primer on ceramic and air-dry. Mix equal quantities of pastes A and B. Apply and light cure for 40 s.	13ABA
Adhesive system	Clearfil DC Bond (Kuraray)	K-Etchant Gel Liquid A: HEMA, MDP, bis-GMA, DL-camphorquinone, benzoyl peroxide, colloidal silica. Liquid B: water, ethanol	Etch for 15 s; rinse with water spray and gently dry with air and paper points; mix liquid A and B (1:1); apply with a brush; gently air-dry for 2–3 s.	41119
Buildup	Clearfil Photo Core (Kuraray)	Silanated silica, silanated barium, glass, CQ, bisphenol A diglycidylmethacrylate	Apply on the tooth; light cure for 40 s.	2295BA

10-MDP 10-methacryloxydecyl dihydrogen phosphate, *3-MPS* 3-methacryloxypropyltrimethoxysilane, *TEGDMA* triethyleneglycol-dimethacrylate, *CQ* camphorquinone

covered with an antireflecting powder (Vita Cerec Powder, Vita Zahnfabrik, Bad Säckingen, Germany), and a digital impression was procured with the 3D camera. The digital design and milling of the crowns were performed with the CEREC software. The composite and ceramic crowns were milled from prefabricated blocks (Paradigm MZ100, 3M ESPE, Seefeld, Germany and IPS Empress CAD, Ivoclar Vivadent) with a cylinder pointed bur and a step bur 10. All restorations were milled in Endo mode, and a new set of milling burs was used for each group even though this was not requested by the software.

Tooth/core preparation for the luting procedure

The bonding agent (Clearfil DC Bond, Kuraray) was applied following the manufacturer's instructions: 15 s of dentin etching with 37.5 % phosphoric acid, abundant rinsing, air-drying for 5 s, and application of adhesive agent with a light brushing motion for 20 s. The composite core was treated with airborne particle abrasion with 27 μm of silicatized Al_2O_3 powder (CoeJet, 3M ESPE, Seefeld, Germany). The surface was then rinsed with water for 20 s and air-dried. A silane (Clearfil Ceramic Primer, Kuraray) was applied on the surface and air-dried after an exposure time of 60 s. One coat of adhesive resin (Clearfil DC Bond, Kuraray) was then applied on the surface and left unpolymerized until the application of the luting material.

Crown preparation for the luting procedure

In the leucite-reinforced glass–ceramic groups (groups 1, 2, and 5), the internal surfaces of the crowns were etched with hydrofluoric acid (Vita Ceramic Etch, Vita Zahnfabrik, Bad Säckingen, Germany) for 60 s. Then a silane (Clearfil Ceramic Primer, Kuraray) was applied and blow-dried after an exposure time of 60 s. Lastly, the bonding agent (Clearfil DC Bond, Kuraray) was applied, and excesses were blown out. In the micro-hybrid composite groups (groups 3, 4, and 6), the

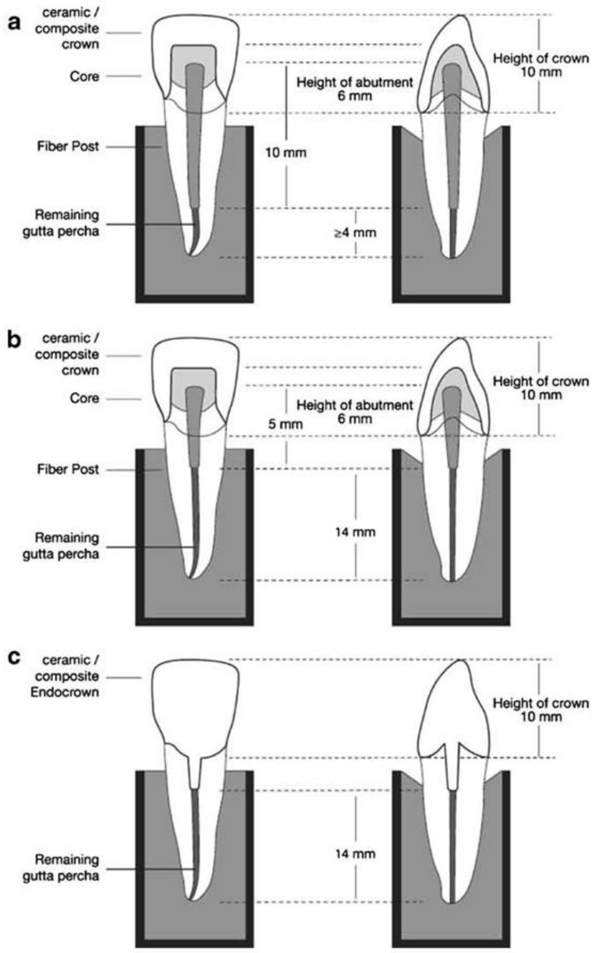

Fig. 1 Schematic drawing of a test specimen mounted in a resin block. The dimensions of the tooth preparations, the post-and-core, and the crown are shown for each group restored with large post (**a**), short post (**b**), and endocrown (**c**)

internal surfaces of the crowns were treated with 27 µm of silicatized Al_2O_3 powder (CoeJet, 3M ESPE, Seefeld, Germany). Then the surface was rinsed with water for 20 s and air-dried. A silane (Clearfil Ceramic Primer, Kuraray) was applied and blow-dried after an exposure time of 60 s. Lastly, the bonding agent (Clearfil DC Bond, Kuraray) was applied, and excesses were blown out. The crowns from all groups were adhesively luted with a dual-cured luting cement (Clearfil Esthetic Cement, Kuraray) and cured with the same light-curing device as mentioned above. All margins were then finished and polished under ×10 magnification with abrasive disks (Soft-Lex XT, 3M ESPE) and intermittent water spray.

Fatigue test

The restored teeth were loaded on the palatal surface at an angle of 45° with respect to the longitudinal axis of the root (Fig. 2). A computer-controlled chewing machine with 600,000 mechanical cycles at 49 N and 1,500 thermal cycles between 5 and 55 °C was used to test fatigue [20].

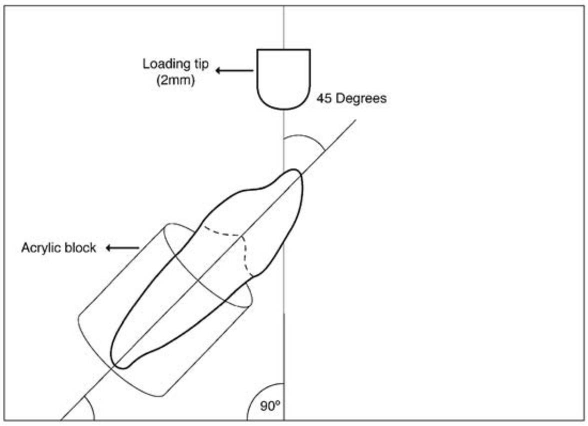

Fig. 2 Schematic drawing of test specimens subjected to load at 45° in a universal testing machine. Pressure from the rod tip was applied at a crosshead speed of 1 mm/min (3 mm below the incisal edge) on the palatal surface of the crown

Fracture test

After the fatigue test, all groups were subjected to a fracture strength evaluation in a universal testing machine (Instron, model 1114, Instron Corp, High Wycombe, Great Britain). Each specimen was placed in a fixing device, and a controlled load was applied using a stainless steel rod at a 45° with respect to the longitudinal axis of the root. Pressure on the tip was applied 3 mm below the incisal edge on the palatal surface of the crown at a crosshead speed of 1 mm/min. The specimens were loaded until fracture, and the maximum breaking loads were recorded in Newtons (N). The modes of fractures were determined and classified as repairable or non-repairable/catastrophic. Fractures in the incisal third of root, core fracture, and dislodging of post or crowns were deemed repairable, and fractures below were deemed catastrophic.

Statistical analysis

Data were analyzed with statistical Statgraphics Plus 5.1. Fracture strength data were assessed using a multifactorial ANOVA test. Mode to fracture was submitted to chi-square test. The level of confidence was set to 95 % in the two tests.

Results

The results of fracture strength test on loaded specimens are presented in Table 3. All specimens survived the fatigue test, and no loss of retention or pretest fracture was observed.

The influence of the two crown materials (composite vs. ceramic) and the type of post (short, large, and endocrown) on fracture strength was not significant (P=0.778). However, when considering the absolute values, the highest score of fracture strength was attained by the groups restored with endocrowns (552.4±54.4). Endocrowns also showed the maximum load to fracture (662.5 N).

Analysis of fracture patterns observed after the fracture strength test offered interesting information. The numbers of specimens from each group with both reparable and non-reparable fractures are detailed in Table 4. A significantly higher number of non-reparable fractures were observed in groups in which a 10-mm-long post was used (4 reparable vs. 12 non-reparable). With endocrowns and groups restored with the 5-mm-long posts, reparable fractures were observed in 19 specimens, whereas only 13 specimens presented non-reparable fractures (P=0.0246). Figure 3 shows representative pictures of two specimens restored with endocrowns and 10-mm posts after the fracture strength test. The groups restored using long posts had catastrophic failures or fractures that could not be repaired intraorally, and therefore, tooth extraction would be necessary. This was not the case in the group restored with endocrowns.

Table 3 Results of fracture strength for post type and crown material. Mean and SD expressed in Newtons. Minimum and maximum loading forces registered for each group. Note that no significant differences between post type (short post, endocrown, and long post) and crown material, i.e., composite and ceramic, were observed (P=0.778)

Type of restoration	Mean±SD	Minimum	Maximum
SP	470.9±55.2	359.2	582.6
Endocrown	552.4±54.4	442.3	662.5
LP	432.6±55.3	320.6	544.6
Ceramic	483.1±46.2	389.6	576.6
Composite	487.5±42.4	401.7	573.4

Table 4 Statistical analysis of mode of fracture (reparable or unreparable). A significantly higher number of non-reparable fractures were observed in groups in which long post was used (4 reparable vs. 12 non-reparable). With endocrowns and short post, reparable fractures were observed in 19 specimens, whereas only 13 specimens presented non-reparable fractures

Group	Number of specimens with repairable fractures	Number of specimens with non-repairable fractures
LP	4 (2 fractures on incisal third of the root)	12
SP + Endo C	19 (2 fractures on incisal third of the root)	13

Discussion

The purpose of this in vitro study was to evaluate the fracture strength and failure types of endodontically treated anterior teeth restored with endocrowns and short-post and long-post retained crowns. The fracture strength evaluation was performed on previously fatigued specimens. The fatigue test was carried out with thermomechanical loading in a chewing machine that tries to closely simulate the clinical situation [21, 22]. The chewing force was applied to the specimens at 45° to the tooth long axis, in accordance with publications about fatigue testing followed by fracture strength test of anterior teeth [5]. The artificial chewing cycle (duration, force profile, and frequency) was designed to correspond as closely as possible to physiological conditions [23 25].

All specimens survived the fatigue test, and no loss of retention or pretest fracture was observed; no fracture of the root, post and core and no loss of crown occurred during the fatigue test, and all teeth could be used to fracture strength test.

In the present study, no artificial periodontium was placed around the abutment roots; the silicone is not standardizable and varies between 300 and 700 μm, which leads to uncontrolled and unstandardized mobility of the abutment teeth. In the clinical situation, increased mobility is only present in teeth that are severely periodontally compromised with a loss of attachment of six or more millimeters [26].

Several studies evaluated the mechanical resistance of endodontically treated teeth, in particular, of upper incisors [27 32]. Most of these studies included specimens with

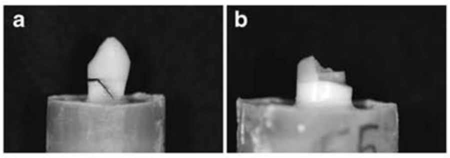

Fig. 3 Detail of fracture pattern (reparable or non-reparable) observed in teeth restored with long posts (**a**) or with endocrowns (**b**) after the fracture strength test. Fractures in the incisal third of root, core fracture, and dislodging of post or crowns were deemed reparable (**b**), and fractures below were deemed catastrophic and, thus, non-reparable (**a**)

different types of posts. It has been suggested that posts with a high elastic modulus such as metallic ones could improve the bending resistance of restored teeth by opposing their stiffness to the bending stresses arising from function [33]. However, a post with a high elastic modulus could be more prone to cause unrestorable fractures. This is why the use of posts with lower elastic modulus such as glass fiber ones have been proposed by several authors [34 36]. The advantage of glass fiber posts is that they are able to improve the bending resistance and that failures, if they occur, are more easily restorable. In addition, they have a modulus of elasticity similar to dentin. When they are submitted to loading, they can better absorb the forces concentrated along the root, thus reducing the probability of fracture [37, 38].

When the FEA was used, a favorable performance of endocrown restorations was observed [16, 39, 40]; however, this type of study evaluates how forces are transmitted along the tooth and depends on the computer-generated model. The models used in this type of study deviate from reality in several aspects and compare the stress distribution patterns of a sound tooth with teeth restored with different material configurations. This computer evaluation needs further laboratory and clinical research to prove its efficacy.

The modulus of elasticity is approximately 65.4 GPa for IPS Empress CAD and 16 GPa for MZ100 blocks, whereas the flexural strength is 160 MPa (ISO 6812) for IPS Empress CAD blocks [41] and ranges between 140 and 150 MPa for MZ100 [42]. These similar values of flexural strength may have influenced the results of this study, as will be further discussed in this section.

No significant differences could be detected between the composite and ceramic restorations either (Table 3). The similar values of flexural strength between ceramic and composite and the ferrule effect provided by 2 mm of dentin may account for the present findings. The importance of preserving a minimum amount (2 mm) of coronal dentin height after preparation on the fracture resistance and prevention of root fracture on ETT has been reported in various studies [43, 44]. It has been reported that when the ferrule effect is present, stresses are redistributed in the outer surface regions of the coronal third of the root, thus a possible fracture in this area can be repairable. When the ferrule is absent, occlusal forces must be supported by a post that may fracture, and a vertical root fracture may occur. Fatigue studies have clearly demonstrated the importance of tissue conservation and the presence of a ferrule effect to optimize tooth biomechanical behavior [10, 35, 45]. In the present study, each tooth was prepared with a severe loss of coronal tooth structure preserving 2 mm of ferrule effect; the area of load application has also been widely described as one of the paramount factors to achieve reliable laboratory results [33, 46, 47]. The position of loading site seems to influence the results on failure mode, particularly in relation to the position of the post. It is important to know that anterior teeth are responsible for tearing and functional guidance [47]. It has been well documented that fracture resistance of teeth depends on the angle of applied load, since axial forces are less detrimental than oblique forces [27]. As a consequence, the restored anterior teeth were loaded on the palatal surface at an angle of 45° with respect to the longitudinal axis of the root.

The findings of our study indicate that restorations may be possible without the use of a post. This is an advantage because more tooth substance is preserved, and the clinical procedure may be easier to achieve. Ferrule lowers the impact of the post and core system, luting agents, and the final restoration on the performance of ETT [48].

According to the results of this investigation, the two first null hypotheses stating that the post length has no effect on the fracture strength of devital anterior teeth, and that there is no influence of the restorative material, i.e., composite or ceramic, on the fracture strength have to be accepted. Recent studies have demonstrated that shortening the post length on the posterior teeth has no negative influence on fracture resistance and may be used without compromising the apical seal [9–12]. No differences were detected in the fracture strength scores of specimens restored either with an endocrown, a short post (5 mm), or a long post (10 mm). Based on our findings, the increase in post length did not increase the fracture resistance. This would mean that shorter posts might be used in anterior teeth. Contrary to our findings, significantly higher values of fracture resistance have been recently observed in groups restored with 10-mm-long glass fiber posts with respect to shorter post lengths [49]. However, their material and methods were different; metallic crowns were cemented with phosphate-based cement. Because non-adhesive anterior restorations were used to restore these teeth, it is reasonable to have better results with a long post, as these restorations are macromechanically retained. In addition, most studies used non-fatigued specimens; therefore, extrapolation of their results to those of our study may not be appropriate. The literature documented that coronal coverage significantly reduced the risk of tooth fracture in teeth subjected to root canal treatment, so cuspal coverage have to be considered [10–12, 47, 48].

The findings of our study suggest that restoration of anterior teeth may be possible without the use of a post. This is an advantage because more tooth substance is preserved, and the clinical procedure may be easier to achieve. Ferrule lowers the impact of the post and core system, luting agents, and the final restoration on the performance of ETT [48].

The third null hypothesis that there is no difference in the fracture patterns of teeth restored with an endocrown, short post, and long post has to be rejected. Our results showed that groups restored with a long post presented fractures located in areas where intraoral repair is impossible, which means that, in clinical reality, the tooth must be extracted. This was not the case when short posts or endocrowns were used, as shown in Fig. 3.

From a clinical point of view, since endocrown restorations are fabricated from a single block, they have the advantage of reducing the interface of the restorative system. The clinical implication of this finding is important, as restorable root fracture prolongs the clinical longevity of endodontically treated teeth. Results obtained by the present study reinforce the advantages that have been presented in the clinical experiences of various authors on posterior teeth. Endocrowns and crowns with a short post are mechanically superior to conventional crowns with a long post [50]. Endocrowns are easy to make, cost less, and demand less clinical time when compared with conventional crowns with short and long posts. Through elimination of the post and filling core, the number of bond interfaces is also reduced. However, in vitro tests are known to have limitations in producing the mechanisms responsible for the occurrence of clinical failure. Nonetheless, the use of endocrowns has other technical limitations: the remaining pulp chamber should be of sufficient width and depth to provide adequate bulk and retention of the restoration, and an adequate dentin thickness around the pulp chamber is required for the tooth restoration continuum rigidity and strength [15, 51].

The most important task of conservative therapy is to restore a non-vital tooth which can resist fatigue forces without failures such as root fracture, structural failure of the post itself, or loss of retention. Preservation of coronal dental tissue, the use of dowels with elastic properties similar to dentine, and effective post adhesion are the principal factors for successful restorations of endodontically treated teeth.

We have demonstrated that anterior teeth can be restored with an endocrown or by using a short post. Nevertheless, in vivo validation of this finding is necessary before this technique can be safely recommended for clinical use.

Conclusions

The use of endocrowns or a short glass fiber post with an adhesive crown is sufficient for the restoration of largely destroyed anterior teeth provided with a ferrule effect of at least 2 mm. Coronal restorations with endocrowns and short posts were associated with repairable fractures, whereas long posts induced catastrophic failures under load. As no significant differences were observed between restorative materials, crowns fabricated from machinable composite resin blocks are a viable alternative to all-ceramic crowns for the restoration of anterior endodontically treated teeth.

Acknowledgments The authors thank the help with illustrations provided by Edgar Ramírez. We also appreciate the help of manufacturers for graciously providing us the materials for the present study—Kuraray (Osaka, Japan), Ivoclar Vivadent (Schaan, Liechtenstein), and 3M ESPE (Germany).

Conflict of interest The authors declare that they have no conflict of interest.

References

1. Goodacre CJ, Spolnik KJ (1995) The prosthodontic management of endodontically treated teeth: a literature review. Part III. Tooth preparation considerations. J Prosthodont 4:122–128
2. Abramovitz L, Lev R, Fuss Z, Metzger Z (2001) The unpredictability of seal after post space preparation: a fluid transport study. J Endod 27:292–295
3. Akkayan B, Gulmez T (2002) Resistance to fracture of endodontically treated teeth restored with different post systems. J Prosthet Dent 87:431–437
4. Goldberg AJ, Burstone CJ (1992) The use of continuous fiber reinforcement in dentistry. Dent Mater 8:197–202
5. Mannocci F, Ferrari M, Watson TF (1999) Intermittent loading of teeth restored using quartz fiber, carbon-quartz fiber, and zirconium dioxide ceramic root canal posts. J Adhes Dent 1:153–158
6. Krejci I, Duc O, Dietschi D, de Campos E (2003) Marginal adaptation, retention and fracture resistance of adhesive composite restorations on devital teeth with and without posts. Oper Dent 28:127–135
7. Dietschi D, Duc O, Krejci I, Sadan A (2007) Biomechanical considerations for the restoration of endodontically treated teeth: a systematic review of the literature—Part 1. Composition and micro- and macrostructure alterations. Quintessence Int 38:733–743
8. Garbin CA, Spazzin AO, Meira-Junior AD, Loretto SC, Lyra AM, Braz R (2010) Biomechanical behaviour of a fractured maxillary incisor restored with direct composite resin only or with different post systems. Int Endod J 43:1098–1107
9. Isidor F, Brondum K, Ravnholt G (1999) The influence of post length and crown ferrule length on the resistance to cyclic loading of bovine teeth with prefabricated titanium posts. Int J Prosthodont 12:78–82
10. Nissan J, Dmitry Y, Assif D (2001) The use of reinforced composite resin cement as compensation for reduced post length. J Prosthet Dent 86:304–308
11. Nissan J, Barnea E, Bar Hen D, Assif D (2008) Effect of remaining coronal structure on the resistance to fracture of crowned endodontically treated maxillary first premolars. Quintessence Int 39:183–187
12. Nergiz I, Schmage P, Platzer U, Ozcan M (2002) Bond strengths of five tapered root posts regarding the post surface. J Oral Rehabil 29:330–335
13. Scotti N, Scansetti M, Rota R, Pera F, Pasqualini D, Berutti E (2011) The effect of the post length and cusp coverage on the cycling and static load of endodontically treated maxillary premolars. Clin Oral Investig 15:923–929
14. Hikita K, Van Meerbeek B, De Munck J, Ikeda T, Van Landuyt K, Maida T, Lambrechts P, Peumans M (2007) Bonding effectiveness of adhesive luting agents to enamel and dentin. Dent Mater 23:71–80
15. Lander E, Dietschi D (2008) Endocrowns: a clinical report. Quintessence Int 39:99–106
16. Zarone F, Sorrentino R, Apicella D, Valentino B, Ferrari M, Aversa R, Apicella A (2006) Evaluation of the biomechanical behavior of maxillary central incisors restored by means of endocrowns compared to a natural tooth: a 3D static linear finite elements analysis. Dent Mater 22:1035–1044
17. Reiss B, Walther W (2000) Clinical long-term results and 10-year Kaplan-Meier analysis of Cerec restorations. Int J Comput Dent 3:9–23
18. Rusin RP (2001) Properties and applications of a new composite block for CAD/CAM. Compend Contin Educ Dent 22:35–41
19. Wittneben JG, Wright RF, Weber HP, Gallucci GO (2009) A systematic review of the clinical performance of CAD/CAM single-tooth restorations. Int J Prosthodont 22:466–471
20. Krejci I, Lutz F, Reimer M, Heinzmann JL (1993) Wear of ceramic inlays, their enamel antagonists, and luting cements. J Prosthet Dent 69:425–430
21. Krejci I, Lutz F (1991) Marginal adaptation of Class V restorations using different restorative techniques. J Dent 19:24–32
22. Lutz F, Krejci I, Imfeld T, Elzer A (1991) The hydrodynamic behavior of dentinal tubule fluid under occlusal loading. Schweiz Monatsschr Zahnmed 101:24–30
23. Murphy TR (1965) The timing and mechanism of the human masticatory stroke. Arch Oral Biol 10:981–994
24. Bates JF, Stafford GD, Harrison A (1976) Masticatory function—a review of the literature III. Masticatory performance and efficiency. J Oral Rehabil 3:57–67
25. Neill DJ, Kydd WL, Nairn RI, Wilson J (1989) Functional loading of the dentition during mastication. J Prosthet Dent 62:218–228
26. Heintze SD, Cavalleri A, Zellweger G, Buchler A, Zappini G (2008) Fracture frequency of all-ceramic crowns during dynamic loading in a chewing simulator using different loading and luting protocols. Dent Mater 24:1352–1361
27. Loney RW, Moulding MB, Ritsco RG (1995) The effect of load angulation on fracture resistance of teeth restored with cast post and cores and crowns. Int J Prosthodont 8:247–251
28. Volwiler RA, Nicholls JI, Harrington GW (1989) Comparison of three core buildup materials used in conjunction with two post systems in endodontically treated anterior teeth. J Endod 15:355–361
29. Pene JR, Nicholls JI, Harrington GW (2001) Evaluation of fiber-composite laminate in the restoration of immature, nonvital maxillary central incisors. J Endod 27:18–22
30. Zhi-Yue L, Yu-Xing Z (2003) Effects of post-core design and ferrule on fracture resistance of endodontically treated maxillary central incisors. J Prosthet Dent 89:368–373
31. Hu YH, Pang LC, Hsu CC, Lau YH (2003) Fracture resistance of endodontically treated anterior teeth restored with four post-and-core systems. Quintessence Int 34:349–353
32. Schmitter M, Huy C, Ohlmann B, Gabbert O, Gilde H, Rammelsberg P (2006) Fracture resistance of upper and lower

incisors restored with glass fiber reinforced posts. J Endod 32:328–330
33. Hayashi M, Takahashi Y, Imazato S, Ebisu S (2006) Fracture resistance of pulpless teeth restored with post-cores and crowns. Dent Mater 22:477–485
34. Salameh Z, Sorrentino R, Ounsi HF, Goracci C, Tashkandi E, Tay FR, Ferrari M (2007) Effect of different all-ceramic crown system on fracture resistance and failure pattern of endodontically treated maxillary premolars restored with and without glass fiber posts. J Endod 33:848–851
35. Tan PL, Aquilino SA, Gratton DG, Stanford CM, Tan SC, Johnson WT, Dawson D (2005) In vitro fracture resistance of endodontically treated central incisors with varying ferrule heights and configurations. J Prosthet Dent 93:331–336
36. Plotino G, Grande NM, Bedini R, Pameijer CH, Somma F (2007) Flexural properties of endodontic posts and human root dentin. Dent Mater 23:1129–1135
37. Stewardson DA, Shortall AC, Marquis PM, Lumley PJ (2010) The flexural properties of endodontic post materials. Dent Mater 26:730–736
38. Chuang SF, Yaman P, Herrero A, Dennison JB, Chang CH (2010) Influence of post material and length on endodontically treated incisors: an in vitro and finite element study. J Prosthet Dent 104:379–388
39. Asmussen E, Peutzfeldt A, Sahafi A (2005) Finite element analysis of stresses in endodontically treated, dowel-restored teeth. J Prosthet Dent 94:321–329
40. Seow LL, Toh CG, Fok AS, Wilson NH (2008) A finite element analysis of ceramic restorations in endodontically treated premolars. Am J Dent 21:331–336
41. Vivadent I (issued October 2011) Retrieved online January 2013 from: http://wwwivoclarvivadentus/en-us/download-center/scientific-documentation/
42. ESPE M (Issued 2000) Retrived online January 2013 from: http://multimedia3mcom/mws/mediawebserver?6666660Zjcf6lVs6EVs666zQcCOrrrQ-
43. Ferrari M, Cagidiaco MC, Grandini S, De Sanctis M, Goracci C (2007) Post placement affects survival of endodontically treated premolars. J Dent Res 86:729–734
44. Fragou T, Tortopidis D, Kontonasaki E, Evangelinaki E, Ioannidis K, Petridis H, Koidis P (2012) The effect of ferrule on the fracture mode of endodontically treated canines restored with fibre posts and metal-ceramic or all-ceramic crowns. J Dent 40:276–285
45. Dietschi D, Duc O, Krejci I, Sadan A (2008) Biomechanical considerations for the restoration of endodontically treated teeth: a systematic review of the literature, Part II (Evaluation of fatigue behavior, interfaces, and in vivo studies). Quintessence Int 39:117–129
46. Fokkinga WA, Kreulen CM, Vallittu PK, Creugers NH (2004) A structured analysis of in vitro failure loads and failure modes of fiber, metal, and ceramic post-and-core systems. Int J Prosthodont 17:476–482
47. Heydecke G, Butz F, Strub JR (2001) Fracture strength and survival rate of endodontically treated maxillary incisors with approximal cavities after restoration with different post and core systems: an in-vitro study. J Dent 29:427–433
48. Juloski J, Radovic I, Goracci C, Vulicevic ZR, Ferrari M (2012) Ferrule effect: a literature review. J Endod 38:11–19
49. Giovani AR, Vansan LP, de Sousa Neto MD, Paulino SM (2009) In vitro fracture resistance of glass-fiber and cast metal posts with different lengths. J Prosthet Dent 101:183–188
50. Biacchi GR, Basting RT (2012) Comparison of fracture strength of endocrowns and glass fiber post-retained conventional crowns. Oper Dent 37:130–136
51. Nayyar A, Walton RE, Leonard LA (1980) An amalgam coronal-radicular dowel and core technique for endodontically treated posterior teeth. J Prosthet Dent 43:511–515

PUBLISHED PAPER 2

Marginal adaptation of endodontically treated teeth restored with composite and ceramic CAD-CAM crowned: an in-vitro study

Anaïs Ramírez[1,2], Tissiana Bortolotto[2], Miguel Roig[1], Ivo Krejci[2]

[1]Department of Endodontic and Restorative Dentistry,
Universitat Internacional de Catalunya, Spain.
[2]Division of Cariology and Endodontology, School of Dentistry,
University of Geneva. Switzerland.

Operative Dentistry 2013, April 9.
Impact Factor: 1.238 (2011 JCR Science Edition) (2nd Quartil)

composite core, and ceramic full-coverage computer-aided design/computer-assisted manufacturing (CAD-CAM) crown. Group 2 was restored with a short fiberglass post, composite core, and ceramic full-coverage CAD-CAM crown. Group 3 was restored with a large fiberglass post, composite core, and composite full-coverage CAD-CAM crown (LPCpr). Group 4 was restored with a short fiberglass post, composite core, and composite full-coverage CAD-CAM crown (SPCpr). Groups 5 and 6 were restored with ceramic and composite CEREC machined endocrowns, respectively (EndoCer and EndoCpr). The restored teeth were loaded thermomechanically in a computer-controlled chewing machine. Impressions of each restoration were made in a polyvinylsiloxane material before and after loading. Gold-coated epoxy replicas were prepared for scanning electron microscopy examination at 200× magnification.

Results: Loading had a statistically significant effect ($p<0.05$) on the percentage of "continuous margin" in all groups. The LPCpr, SPCpr, and EndoCpr groups showed the highest percentage of continuous margin initially and after loading. The effect of the different post lengths on marginal adaptation was not significant ($p>0.05$).

Conclusion: CAD-CAM crowns fabricated from millable composite resin blocks (Paradigm MZ100) offer a superior option to all-ceramic crowns (IPS Empress CAD).

INTRODUCTION

Advances in adhesive dentistry and technologic developments with computer-aided design/computer-assisted manufacturing (CAD-CAM) technologies have resulted in new systems for dental restoration. Various machinable materials are used currently with CAD/CAM systems to fabricate restorations at the chairside. The CEREC 3 CAD/CAM system was introduced more than 15 years ago and it is the only system that can be used in both clinical practice and the laboratory.[1]

The successful restoration of endodontically treated teeth (ETT) does not depend exclusively on the endodontic treatment; the method of restoration is also important.[2,3] Coronal leakage at the margin of the restoration might result in recurrent caries and failure of both the restoration and the root canal treatment.[4]

For decades, metal-ceramic crowns have been the major type of restoration system used in fixed prosthodontics. Nowadays, all-ceramic anterior crown restorations may be used as an alternative to metal-ceramic crowns.[5,6] In spite of the advantages of all-ceramic restorations, including the esthetic appearance, biocompatibility, and durability they afford, such materials present some disadvantages.[7-9] However, considerable progress has been made in the manufacture of composite resins. Recently, a new resin composite block (Paradigm MZ100, 3M ESPE Dental Products, Seefeld Germany) has been introduced for the CEREC system, which, according to the manufacturer, combines some of the best attributes of ceramics and polymers.[10] Few studies have been performed to evaluate the survival and success rates of single-tooth all-composite resin and all-ceramic complete restorations manufactured with a CAD/CAM system. Rammelsberg and others[11] found that composite resin crowns showed an acceptable survival rate of 96% after three years. However, an excellent marginal adaptation is one of the most important factors for the longevity of esthetic crowns, and further research and evaluation of CEREC 3 composite resin crowns are necessary to improve the probability of clinical success.[12,13]

The quality of the marginal adaptation has been criticized by many researchers, but improvements in the CEREC machine and software have made the fit more acceptable. Numerous studies have evaluated the marginal accuracy of crown restorations and have described promising results. To date, ceramic-based materials have been used with all CAD/CAM systems for anterior teeth. However, there are no reported investigations that have examined the marginal adaptation of CEREC 3 anterior crowns in ETT fabricated from Paradigm Z100 (3M ESPE Dental Products).

The aim of the present study was to evaluate the quality of the marginal adaptation of crowns made out of composite and ceramics on devitalized anterior teeth before and after a thermomechanical fatigue test that simulated a clinical service of 2.5 years. Three types of restorative procedures for the root canal were tested: a 10-mm post, a 5-mm post, and an endocrown. The specimens were loaded at an inclination of 45° with respect to the longitudinal tooth axis. The null hypotheses tested were that 1) There is no effect of fatigue conditions on marginal adaptation; 2) There is no influence of the restorative crown material (ceramic or composite) on the marginal adaptation at either interface, tooth–luting cement or luting cement–crown; and 3) There is no influence of post length on marginal adaptation.

MATERIALS AND METHODS

Forty-eight sound upper central human incisors that had been stored in 0.1% thymol solution were divided randomly into six equal groups. The bucco-palatal and mesio-distal dimensions and root lengths of all the teeth selected were measured using digital calipers. The inclusion criteria were that the teeth had to be free of carious lesions with complete apexification and straight roots, had to have a crown up to 2 mm above the cemento-enamel junction (CEJ), and had to have an absence of visible fracture lines in the root.

Endodontic Treatment

Before endodontic treatment of each specimen, the root surface was sealed using a filled light-curing adhesive (Lot No. 2957717, Optibond FL, KerrHawe Neos, Orange, CA, USA). The pulp chamber of each tooth was opened following a standardized procedure and the working length was determined visually by placing a size No. 10 K-file (Dentsply-Maillefer, Ballaigues, Switzerland) at the apical foramen. The root canals were instrumented using stainless-steel K-files 10, 15, and 20 (Dentsply-Maillefer) followed by rotary nickel-titanium instruments (ProTaper U®, Dentsply-Maillefer), in accordance with the manufacturer's instructions. All of the canals were prepared up to an F5 size instrument, and instruments were discarded after use in four root canals or if instrument deformation was visible. The root canals were irrigated between instruments with 1 mL of 4.2% sodium hypochlorite. All of the teeth were obturated using the warm vertical condensation technique (System B and Gutapercha Extruder, Elements Obturation Unit™, Analytic Endodontics, Sybron Endo, Orange, CA, USA) using calibrated gutta-percha (Autofit®, Analytic Endodontics) and an endodontic sealer (AH Plus, Dentsply-Maillefer). Following this step, the access cavity was sealed with a light-cured, resin-reinforced glass ionomer restorative (Fuji II® LC, GC America Inc, Alsip, IL, USA). After a setting period of 48 hours, each tooth was fixed on a custom-made metallic holder (Provac FL, Balzers, Liechtenstein), and the root bases were stabilized with a self-curing acrylic resin (Technovit 4071, Heraeus Kulzer GmbH, Wehrheim, Germany).

Root Preparation, Post Selection, and Luting Procedure

The crown of each tooth was sectioned 2 mm above the CEJ. The prepared teeth were divided randomly into six groups of eight teeth each, as follows: 1) long post, composite core, and ceramic crown (LPCer); 2) short post, composite core, and ceramic crown (SPCer); 3) long post, composite core, and composite crown (LPCpr); 4) short post, composite core, and composite crown (SPCpr); 5) ceramic endocrown (EndoCer); and 6) composite endocrown (EndoCpr) (Table 1).

Translucent glass-fiber posts of a standard size (Lot No. 35052, FRC Postec Plus, Size 3, Ivoclar Vivadent, Schaan, Liechtenstein) were selected for placement in each root canal. Gutta-percha was removed with a size 3 reamer (Ivoclar Vivadent) using a handpiece at 800-1220 rpm. The composition of the adhesive system and restorative materials are detailed in Table 2a and b.

Each post was inserted into the root canal and cut to an adequate length with a diamond rotary cutting instrument, and its incisal end was covered with at least 1 mm of resin composite. The surface of the glass-fiber post was pretreated with etching gel (K-Etchant Gel, Kuraray Europe GmbH) for 15 seconds, sandblasted with 27-μm silicatized Al_2O_3 powder (CoeJet, 3MEspe, Seefeld, Germany), and silanized (Lot No. 2550, Clearfil Ceramic Primer, Kuraray Europe GmbH) for 60 seconds. The bonding system (Lot No. 41119, Clearfil DC Bond, Kuraray Europe GmbH) was applied to the post and dried with air, which was applied for five seconds using a dental syringe.

All materials used in the root canals were applied using microbrushes. The following bonding protocol was adopted, strictly following the manufacturer's instructions: 37% phosphoric acid (K-Etchant Gel, Kuraray Europe GmbH) was applied to the surfaces of the canal walls for 15 seconds, and the conditioned areas were rinsed thoroughly with water for at least 15 seconds. Water was removed from the rinsed canals with a soft blow of air and paper points. A moist surface was left, to avoid desiccating the dentin. The adhesive (Clearfil DC Bond, Kuraray Europe GmbH) was dispensed onto a disposable microbrush and rubbed immediately onto all root canal surfaces for at least 20 seconds. The solvent was removed by gentle blowing with air from a dental syringe for at least five seconds. The posts were then luted with a dual-cured resin cement (Clearfil Esthetic Cement, Kuraray Europe GmbH), in accordance with the manufacturer's instructions.

Table 1: *Scheme of the Study Design*

maxillary upper incisors (n=8)	maxillary upper incisors (n=8)	maxillary upper incisors (n=8)	maxillary upper incisors (n=8)	maxillary upper incisors (n=8)	maxillary upper incisors (n=8)
Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
Long post + composite core + **ceramic CAD/CAM crown** (10mm glass fiber post)	Short post + composite core + **ceramic CAD/CAM crown** (5mm glass fiber post)	Long post + composite core + **composite CAD/CAM crown** (10mm glass fiber post)	Short post + composite core + **composite CAD/CAM crown** (5mm glass fiber post)	**Ceramic CAD/CAM** endocrown	**Composite CAD/CAM** endocrown
LPCer	**SPCer**	**LPCpr**	**SPCpr**	**EndoCer**	**EndoCpr**

The luting cement was applied to the post and to the post space with a microbrush. The posts were seated into the root canals and stabilized, and the excess cement was cleaned up with paper points. The resin cement and the adhesive material were light-cured simultaneously for 60 seconds using a Demi LED Light Curing Unit (Kerr Corp, Middleton, WI, USA) applied in direct contact with the post. To ensure appropriate light intensity, the emitted light was measured before each exposure with the digital radiometer (Bluephase meter, Ivoclar Vivadent) Prior to our study the light intensity measured 1340 mW/cm^2.

Core Preparation

After the posts had been luted, the core was prepared using the same adhesive system (Clearfil DC Bond, Kuraray) and following the same application technique described above. The core was built up using a dual-cured core material (Clearfil Photo Core, Kuraray), which was light-cured for 40 seconds. Transparent matrices (Hawe Striproll, KerrHawe) were used to confine the restorative material. Preparation of the core was finished with diamond burs (Advanced Preparation Set for CEREC Anterior Restorations, Intensiv, Lugano, Switzerland). All crown margins were located in dentin with a ferrule effect of 2 mm. The anatomical shape was reduced with the following minimum requirement: The incisal width of the preparation measured at least 1 mm (based on milling tool geometry) in order to achieve optimal milling of the incisal edge during CAD/CAM processing.

Crown Design and Milling

In group 5 (EndoCer) and group 6 (EndoCpr), ceramic and composite endocrowns, respectively, were prepared with a CAD/CAM system (CEREC 3D, software V2.40 R1800, Sirona, Bensheim, Germany). After crown preparation, the surface was covered uniformly with an antireflecting powder (VITA CEREC Powder, Vita Zahnfabrik, Bad Säckingen, Germany), and a digital impression was obtained with the three-dimensional camera. The digital design and milling of the crowns was performed with the CEREC software. Composite and ceramic crowns were milled from prefabricated blocks (Paradigm MZ100, 3M ESPE, and IPS Empress CAD, Ivoclar Vivadent, respectively) with a cylindrical pointed bur and a step bur size 10. All restorations were milled in "Endo" mode, and a new set of milling burs was used for each group, even though this was not requested by the software manufacturer.

Tooth/Core Preparation for the Luting Procedure

The bonding agent (Clearfil DC Bond, Kuraray) was applied in accordance with the manufacturer's

Table 2: *Mode of Application, Composition, and Manufacturer of the Tested Materials*

Material	Product Name (manufacturer)	Composition (Main Constituents)	Application Mode	Batch Numbers
a				
Fiber post	FRC Postec Plus (Ivoclar Vivadent, Schaan, Liechtenstein)	Glass fibers (70 vol%), dimethacrylate resin matrix (21 vol%), ytterbium fluoride (9 vol%)		35052
Ceramic blocks	IPS Empress CAD [14]	Components: SiO_2 Additional contents: Al_2O_3, K_2O, Na_2O, CaO, and other oxides, pigments		57343
Composite blocks	MZ100 (3M Espe, Germany)	Conventional hybrid composite resin, Bis-GMA, TEGDMA, and ultrafine zirconia silica ceramic particles as filler Particles have a spherical shape and average size of 0.6 mm		20071221
B				
Dual-cure, resin-based cement system	Clearfil Esthetic Cement (Kuraray)	Clearfil Ceramic Primer: 3-MPS; 10-MDP; ethanol	Apply primer to ceramic and air-dry. Mix equal quantities of pastes A and B. Apply and light-cure for 40 s	13ABA
		Paste A: Bisphenol A diglycidylmethacrylate; TEGDMA; methacrylate monomers; silanated glass filler; colloidal silica		
		Paste B: Bisphenol A diglycidylmethacrylate; TEGDMA; methacrylate monomers; silanated glass filler; silanated silica; colloidal silica; benzoyl peroxide; CQ: pigments		
Adhesive system	Clearfil DC Bond (Kuraray)	K-Etchant gel	Etch for 15 s; rinse with water spray and gently dry with air and paper points; mix liquids A and B (1:1); apply with a brush; gently air-dry for 2-3 s.	41119
		Liquid A: HEMA; MDP; Bis-GMA; DL-camphorquinone; benzoyl peroxide; colloidal silica		
		Liquid B: water; ethanol		
Build-up	Clearfil Photo Core (Kuraray)	Silanated silica, silanated barium, glass, CQ, bisphenol A diglycidylmethacrylate	Apply to the tooth; light-cure for 40 s	2295BA

Abbreviations: Bis-GMA, bisphenol-A-diglycidylether dimethacrylate; CQ, camphorquinone; HEMA, 2-hydroxyethyl methacrylate; TEGDMA, triethyleneglycol-dimethacrylate; 10-MDP, 10-methacryloxydecyl dihydrogen phosphate; 3-MPS, 3-methacryloxypropyltrimethoxysilane.

instructions: the dentin was etched for 15 seconds with 37.5% phosphoric acid, rinsed abundantly, and air-dried for five seconds, and then the adhesive agent was applied with a light brushing motion for 20 seconds. The composite core was treated by airborne-particle abrasion with 27-µm silicatized Al_2O_3 powder (CoeJet, 3M ESPE). Subsequently, the surface was rinsed with water for 20 seconds and air-dried. Silane (Clearfil Ceramic Primer) was applied to the surface and air-dried after an

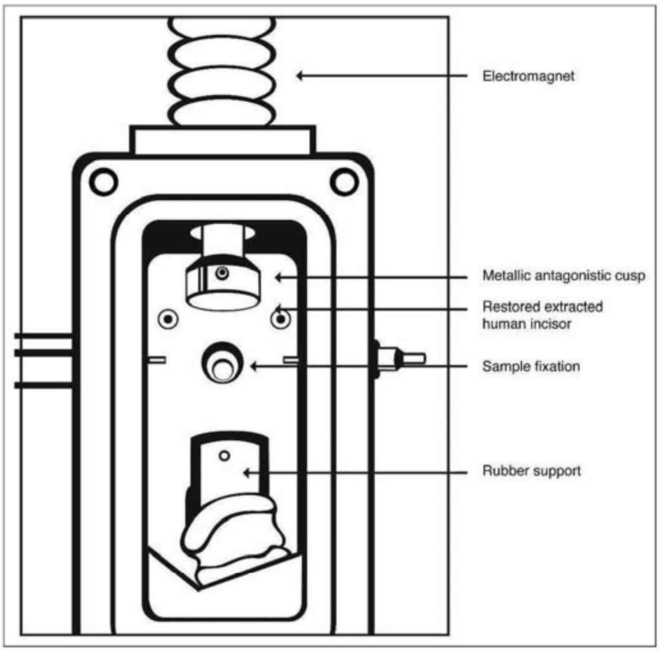

Figure 1. *Custom made device used for occlusal loading of the samples.*

exposure time of 60 seconds. One coat of adhesive resin (Clearfil DC Bond) was then applied to the surface and left unpolymerized until the application of the luting material.

Crown Preparation for the Luting Procedure

In the leucite-reinforced glass-ceramic groups (groups 1, 2, and 6), the internal surface of the crowns was etched with hydrofluoric acid (Vita Ceramic Etch, Vita Zahnfabrik) for 60 seconds. Following this step, silane (Clearfil Ceramic Primer, Kuraray) was applied and blown dry after an exposure time of 60 seconds. Finally, the bonding agent (Clearfil DC Bond) was applied and the excess was blown out. In the microhybrid composite groups (groups 3, 4, and 5), the internal surface of the crowns was treated with 27-µm silicatized Al_2O_3 powder (CoeJet, 3M ESPE). Subsequently, the surface was rinsed with water for 20 seconds and air-dried. A silane (Clearfil Ceramic Primer) was applied and blown dry after an exposure time of 60 seconds. Finally, the bonding agent (Clearfil DC Bond) was applied and the excess was blown out. The crowns from all groups were luted adhesively with a dual-cured luting cement (Clearfil Esthetic Cement, Kuraray) and cured with the same light-curing device mentioned above. Finally, all of the margins were finished and polished under 10× magnification using abrasive discs (Soft-Lex XT, 3M ESPE) and intermittent water spray.

Mechanical Loading, Marginal Adaptation, and Scanning Electron Microscopy (SEM) Evaluation of Samples

The restored teeth were loaded on the palatal surface at an angle of 45° with respect to the longitudinal axis of the root in a computer-controlled chewing machine and were subjected to 600,000 mechanical cycles at 49 N and 1500 thermal cycles in which the temperature varied between 5°C and 55°C (Figure 1). The position of the artificial cusps in the test chambers of the mechanical fatigue device (Department of Restorative Dentistry & Endodontics and Laboratory of Electronics of the Medical Faculty, University of Geneva) was adjusted to maintain a distance of 1 mm from the top of the core, allowing free initial movement. The artificial cusps that contacted the samples were made of stainless steel, the hardness of which is similar to that of natural enamel (Vickers hardness: enamel=320-325; Actinit stainless steel=315).

Before and after the stress was applied, gold-sputtered epoxy resin replicas of all the samples were fabricated using polyvinylsiloxane impressions (President light body, Coltène-Whaledent, Altstätten, Switzerland). The replicas were used for a semiquantitative analysis of the external adhesive interfaces by SEM (Philips XL 20, Eindhoven, The Netherlands), which was performed at a standard 200× magnification using a custom-made module programmed within the image processing software. Two evaluation parameters were considered, "continuity" (C) and "marginal opening" (MO), in order to enable the quantitative evaluation of marginal adaptation to characterize each portion of the interface.

Statistical Analysis

Data analysis was performed using specific software (Statgraphics 5.0 Plus). The values for marginal adaptation (%) at the interface between the tooth and the luting cement (TC-interface) and between the luting cement and the crown (CC-interface) were introduced as the first dependent variables. The following parameters were introduced as independent variables: testing interval (before loading and after loading), type of material (ceramic or composite), type of restoration (long post, short post, or endocrown), and type of interface (tooth–luting cement or luting cement–crown) (Figure 2).

Multifactorial analysis of variance (ANOVA) and *post hoc* Tukey tests were performed to assess the effect of four independent variables on marginal adaptation for each tested interface after confirming normal distribution with the Leven test ($p<0.05$) and the homogeneity of variance with the Shapiro-Wilks test ($p>0.05$). The level of confidence was set to 95%.

RESULTS

All of the teeth and restorations survived thermo-mechanical loading in the computer-controlled chewing machine without loss of retention or fracture and could be used for the quantitative analysis of marginal adaptation.

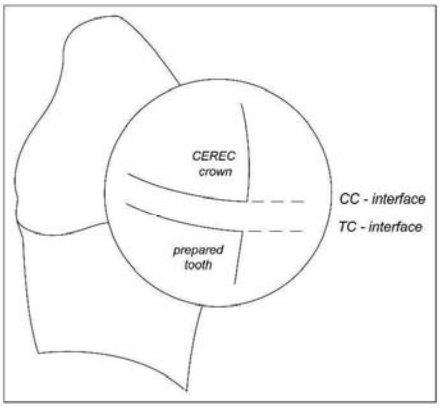

Figure 2. *Tooth–luting cement interface (TC) and luting cement–crown interface (CC).*

The results for marginal adaptation at the tooth–luting cement interface are shown in Table 3. Multifactorial ANOVA revealed a significant effect of testing interval ($p<0.05$) and of the type of material ($p<0.05$) on marginal adaptation.

Before loading, the percentages of continuous margin at the tooth–luting cement interface were greater than 90%, and no significant differences were observed among the different groups ($p=0.062$). However, a trend was observed for better behavior of the composite in comparison with the ceramic material.

After loading, statistically significant differences were detected between the composite (LPCpr, SPCpr, and EndoCpr) and ceramic (LPCer, SpCer, and EndoCer) crowns ($p=0.0001$). The highest scores for marginal adaptation were observed in the LPCpr, SPCpr, and EndoCpr groups, namely, composite crowns restored with long posts, short posts, or endocrowns. The performance of the ceramic crowns at the marginal level was significantly lower, independent of the type of root retention that was used.

The results for marginal adaptation at the luting cement–crown interface are also shown in Table 3. No significant differences among groups were detected either before or after loading ($p=0.9834$). However, the groups LPCpr, SPCpr, and EndoCpr (with composite restorations) showed the highest percentages of continuous margin after loading.

Table 3: *Percentages of Continuous Margins (%CM) at Both Interfaces Before and After Loading for the Different Groups. Small Capital Letters Indicate Statistically Significant Differences Between Materials ($p \leq 0.05$)*

Groups	Tooth–Luting Cement Interface %CM, Mean (SD)		Luting Cement–Crown Interface %CM, Mean (SD)	
	Before Loading	After Loading	Before Loading	After Loading
LPCpr	99.3 (0.85) A	91.3 (6.75) A	98.7 (2.4) A	97.8 (2.63) A
SPCpr	99.2 (0.97) A	85.5 (6.47) A	99.5 (0.62) A	97.7 (1.24) A
EndoCpr	94.4 (6.13) A	80.9 (8.14) A	100 (0.07) A	99.9 (0.00) A
LPCer	94.3 (6.52) A	65.9 (14.18) B	92.9 (7.1) A	95.2 (3.54) A
SPCer	90.2 (12.2) A	57. 7 (18.2) B	89.1 (5.17) A	84.6 (10.18) A
EndoCer	93.9 (5.00) A	68.4 (23.6) B	94.8 (6.47) A	90.1 (4.57) A

Abbreviations: EndoCer, ceramic endocrown; EndoCpr, composite endocrown; LPCer, long post, composite core, and ceramic crown; LPCpr, long post, composite core, and composite crown; SD, standard deviation; SPCer, short post, composite core, and ceramic crown; SPCpr, short post, composite core, and composite crown.

The effect of the different post lengths on marginal adaptation was not significant ($p=0.549$). Thus, the percentages of marginal adaptation were similar in groups restored with long posts, short posts, and endocrowns.

SEM micrographs that are representative of the different groups are shown in Figure 3. The main difference between the ceramic and composite crowns was observed at the tooth–luting cement interface. Dentin cracks could be observed on loaded specimens that had been restored with ceramic crowns, whereas no cracks were evident in the dentin when composite crowns were used as the restorative material (Figure 3).

DISCUSSION

In the *in vitro* study described herein, we compared the marginal adaptation of natural anterior teeth that had been restored by endocrowns, short-post, and long-post retained CAD/CAM composite and ceramic crowns when they were loaded in a computer-controlled chewing machine and evaluated by SEM. Excellent marginal adaptation extends the longevity of restorations.[15,16] Lack of adequate fit is potentially detrimental to both the tooth and the supporting periodontal tissues, as a result of cement solubility or plaque retention.[17] The present study focused exclusively on the quality of marginal adaptation *in vitro* as an indispensable prerequisite for clinical success.[18] Within the limitations of laboratory studies, quantitative analysis of marginal

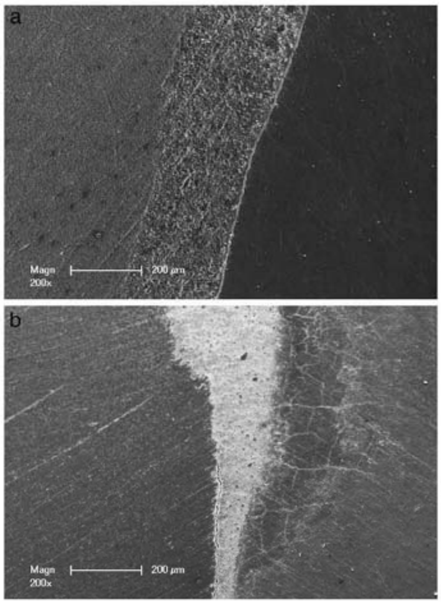

Figure 3. *SEM photographs (200×) of marginal interfaces of a CEREC anterior crown. Left: dentin; right: restoration. (a) Composite anterior endocrown (EndoCpr) after thermomechanical loading. (b) Ceramic anterior endocrown (EndoCer) after thermomechanical loading, with small cracks in the dentin.*

adaptation by SEM has proven to be an exact and reliable method of assessment for the evaluation of the marginal adaptation of adhesive restorations.[19,20] Materials and interfaces normally fail because of stresses and repeated loading. The quality of the SEM analysis is expressed as the percentage of "continuous margin" and "marginal opening" along the total marginal length at both the tooth–luting cement[15] and the luting cement–crown (CC) interfaces. To evaluate marginal adaptation, a replica-based, computer-assisted quantitative SEM analysis of the margin was performed before and after loading. The replica-based approach has several advantages: it is quantitative, nondestructive, and highly discriminatory.[21,22] Although there have been numerous investigations using light microscopy, most authors[23,24] have concluded that SEM imaging provides more appropriate and realistic observations than do light microscopy-based systems of analysis.

Thermomechanical loading was used in an attempt to simulate the oral environment. Stressing the restorations for 600,000 cycles *in vitro* simulates 2.5 years of clinical use. It can be assumed that the results of the present study have a degree of clinical relevance.[16,25,26]

The materials that were chosen for performance assessment, composite blocks and ceramic blocks, are both widely used restorative materials in modern conservative dentistry. In the present study, no artificial periodontium was placed around the abutment roots; the silicone cannot be standardized and varies between 300 and 700 μm, which leads to uncontrolled, and unstandardized, mobility of the abutment teeth. In the clinical situation, increased mobility only occurs in teeth that have severely compromised periodontium, with a loss of attachment of 6 mm or more.[27]

As shown by the SEM analysis of the margin, dentinal adhesion was very successful before loading: the percentages of continuous margins before loading were high for most groups. One explanation could be that all systems that involve etch-and-rinse adhesives combined with conventional luting resin composites result in a very good bond.[28] However, the degree of adhesion changed considerably after loading as a result of marginal degradation at the tooth–luting cement interface. Given that significant differences in marginal adaptation were identified among the groups, the first null hypothesis tested in the study was rejected; marginal adaptation was affected by fatigue conditions. This confirms the results of previous studies[28,29] in which thermomechanical loading resulted in a deterioration of marginal quality.

In the present study there was also a significant influence of the material of the restorative crown (ceramic or composite) on the marginal adaptation of both interfaces, tooth–luting cement[15] and luting cement–crown (LC). Groups LPCpr, SPCpr, and EndoCpr showed the highest percentage of continuous margin after loading. The rigidity of dental restorative materials is considered to be a very important issue when evaluating the adhesive tooth-restoration interface. Composite materials are more resilient than ceramics, and this could have an effect on the stress that is transferred to the margin walls. On the basis of these observations, we also had to reject the second null hypothesis. Even if there is a lack of scientific evidence that correlates dentin cracks with the long-term clinical behavior of ceramic restorations, cracks may be interpreted as a sign of early failure. According to the manufacturer, the IPS Empress CAD block is a conventional feldspathic ceramic, whereas the MZ100 block is a millable composite resin formed of 85% (by weight) ultrafine zirconium-silica ceramic particles that reinforce a highly cross-linked polymeric matrix. The polymeric matrix consists of bisphenol-A- diglycidylether dimethacrylate and triethylene glycol dimethacrylate. Different inherent mechanical properties of the two esthetic materials (ceramic and composite) used for crown fabrication, such as stiffness and flexural strength, might also have influenced the marginal adaptation after thermomechanical loading. The manufacturers report that the modulus of elasticity is approximately 65.4 GPa for the IPS Empress CAD and 30 GPa for MZ100 blocks, whereas the flexural strength is purported to range from 120 to 140 N/mm^2 for the IPS Empress CAD and is reported to be 150 MPa for MZ100 blocks.

Paradigm MZ100 could represent a departure from the more popular ceramic materials. Composites can be more easily adjusted and polished intraorally than can ceramic materials. The repair of ceramic restorations intraorally has not proven to be more than a moderately effective temporary technique. With Paradigm MZ100, the restoration surface can be air-abraded and a hybrid composite can be bonded to the abraded surface. Although it has not been tested for clinical longevity, this affords an easy and efficient intraoral repair procedure for Paradigm MZ100 restorations.

The definition of marginal fit varies considerably among investigators, and often the same term is used to refer to different measurements. In a recent study, Tsitrou and others[30] showed that the marginal gap of resin composite crowns manufactured with the CEREC 3 system is within the range of clinical acceptance. In a study of posterior teeth, Krejci and others[31] showed an excellent marginal adaptation for adhesive composite restorations. The composite resin crowns might demonstrate higher resiliency with more absorption of load than ceramic crowns; these results are in agreement with the findings of other investigators.[9,32-35] Our results are supported by similar *in vitro* findings. In a recent article,[29] ceramic overlays showed approximately 10% lower marginal adaptation than did composite overlays. Resin composite had a greater stress-dissipating effect than did ceramic.

Given that there is still no consensus on the optimal way to restore ETT, and given that the retention of adhesive restorations is based mainly on adhesion and does not require macroretentive elements,[35] the third null hypothesis, that there is no difference in the marginal adaptation of teeth restored with endocrowns or short or long posts, has to be accepted. Independent of post length, no relationship related to the percentage of continuous margin on both interfaces was found. It can be assumed that the three types of root retention could withstand intraoral masticatory forces to a similar degree.

CONCLUSIONS

In conclusion, thermomechanical loading had a significant effect on the marginal adaptation of both ceramic and composite restorations. CAD-CAM crowns fabricated from millable composite resin blocks (Paradigm MZ100) offer a superior option to all-ceramic crowns (IPS Empress CAD). However, the conclusions drawn from this *in vitro* study must be confirmed by controlled clinical trials before they can be applied as recommendations for routine clinical work.

Conflict of Interest

The authors have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

(Accepted 30 November 2012)

REFERENCES

1. Mormann WH, Brandestini M, Lutz F, & Barbakow F (1989) Chairside computer-aided direct ceramic inlays *Quintessence International* **20(5)** 329-339.
2. Robbins JW (2002) Restoration of the endodontically treated tooth *Dental Clinics of North America* **46(2)** 367-384.
3. Schwartz RS, & Robbins JW (2004) Post placement and restoration of endodontically treated teeth: A literature review *Journal of Endodontics* **30(5)** 289-301.
4. Saunders WP, & Saunders EM (1994) Coronal leakage as a cause of failure in root-canal therapy: A review *Endodontic and Dental Traumatology* **10(3)** 105-108.
5. Coornaert J, Adriaens P, & De Boever J (1984) Long-term clinical study of porcelain-fused-to-gold restorations *Journal of Prosthetic Dentistry* **51(3)** 338-342.
6. Leempoel PJ, Eschen S, De Haan AF, & Van't Hof MA (1985) An evaluation of crowns and bridges in a general dental practice *Journal of Oral Rehabilitation* **12(6)** 515-528.
7. Attia A, & Kern M (2004) Fracture strength of all-ceramic crowns luted using two bonding methods *Journal of Prosthetic Dentistry* **91(3)** 247-252.
8. Magne P, Oh WS, Pintado MR, & DeLong R (1999) Wear of enamel and veneering ceramics after laboratory and chairside finishing procedures *Journal of Prosthetic Dentistry* **82(6)** 669-679.
9. Dalpino PH, Francischone CE, Ishikiriama A, & Franco EB (2002) Fracture resistance of teeth directly and indirectly restored with composite resin and indirectly restored with ceramic materials *American Journal of Dentistry* **15(6)** 389-394.
10. Rusin RP (2001) Properties and applications of a new composite block for CAD/CAM *Compendium of Continuing Education in Dentistry* **22(Supplement 6)** 35-41.
11. Rammelsberg P, Spiegl K, Eickemeyer G, & Schmitter M (2005) Clinical performance of metal-free polymer crowns after 3 years in service *Journal of Dentistry* **33(6)** 517-523.
12. Manhart J, Chen HY, Neuerer P, Scheibenbogen-Fuchsbrunner A, & Hickel R (2001) Three-year clinical evaluation of composite and ceramic inlays *American Journal of Dentistry* **14(2)** 95-99.
13. Behr M, Rosentritt M, & Handel G (2003) Fiber-reinforced composite crowns and FPDs: A clinical report *International Journal of Prosthodontics* **16(3)** 239-243.
14. Ivoclar Vivadent (issued October 2011) Retrived online January 2013 from: http://www.ivoclarvivadent.us/en-us/download-center/scientific-documentation/#I.
15. McDonald AV, King PA, & Setchell DJ (1990) In vitro study to compare impact fracture resistance of intact root-treated teeth *International Endodontic Journal* **23(6)** 304-312.
16. Lutz F, Krejci I, & Barbakow F (1991) Quality and durability of marginal adaptation in bonded composite restorations *Dental Materials* **7(2)** 107-113.
17. Holmes DC, Diaz-Arnold AM, & Leary JM (1996) Influence of post dimension on stress distribution in dentin *Journal of Prosthetic Dentistry* **75(2)** 140-147.
18. Kramer N, Lohbauer U, & Frankenberger R (2000) Adhesive luting of indirect restorations *American Journal of Dentistry* **13(Spec No)** 60D-76D.
19. Bortolotto T, Onisor I, & Krejci I (2007) Proximal direct composite restorations and chairside CAD/CAM inlays:

Marginal adaptation of a two-step self-etch adhesive with and without selective enamel conditioning *Clinical Oral Investigations* **11(1)** 35-43.

20. Onisor I, Bouillaguet S, & Krejci I (2007) Influence of different surface treatments on marginal adaptation in enamel and dentin *Journal of Adhesive Dentistry* **9(3)** 297-303.

21. Roulet JF (1994) Marginal integrity: Clinical significance *Journal of Dentistry* **22(Supplement 1)** S9-S12.

22. Gladys S, Van Meerbeek B, Inokoshi S, Willems G, Braem M, Lambrechts P, & Vanherle G (1995) Clinical and semiquantitative marginal analysis of four tooth-coloured inlay systems at 3 years *Journal of Dentistry* **23(6)** 329-338.

23. Groten M, Girthofer S, & Probster L (1997) Marginal fit consistency of copy-milled all-ceramic crowns during fabrication by light and scanning electron microscopic analysis in vitro *Journal of Oral Rehabilitation* **24(12)** 871-881.

24. Schmalz G, Federlin M, & Reich E (1995) Effect of dimension of luting space and luting composite on marginal adaptation of a class II ceramic inlay *Journal of Prosthetic Dentistry* **73(4)** 392-399.

25. Lutz F, Krejci I, Imfeld T, & Elzer A (1991) The hydrodynamic behavior of dentinal tubule fluid under occlusal loading *Schweiz Monatsschr Zahnmed* **101(1)** 24-30.

26. Krejci I, Kuster M, & Lutz F (1993) Influence of dentinal fluid and stress on marginal adaptation of resin composites *Journal of Dental Research* **72(2)** 490-494.

27. Heintze SD, Cavalleri A, Zellweger G, Buchler A, & Zappini G (2008) Fracture frequency of all-ceramic crowns during dynamic loading in a chewing simulator using different loading and luting protocols *Dental Materials* **24(10)** 1352-1361.

28. Frankenberger R, Lohbauer U, Schaible RB, Nikolaenko SA, & Naumann M (2008) Luting of ceramic inlays in vitro: Marginal quality of self-etch and etch-and-rinse adhesives versus self-etch cements *Dental Materials* **24(2)** 185-191.

29. Dere M, Ozcan M, & Gohring TN (2010) Marginal quality and fracture strength of root-canal treated mandibular molars with overlay restorations after thermocycling and mechanical loading *Journal of Adhesive Dentistry* **12(4)** 287-294.

30. Tsitrou EA, Northeast SE, & van Noort R (2007) Evaluation of the marginal fit of three margin designs of resin composite crowns using CAD/CAM *Journal of Dentistry* **35(1)** 68-73.

31. Krejci I, Duc O, Dietschi D, & de Campos E (2003) Marginal adaptation, retention and fracture resistance of adhesive composite restorations on devital teeth with and without posts *Operative Dentistry* **28(2)** 127-135.

32. Brunton PA, Cattell P, Burke FJ, & Wilson NH (1999) Fracture resistance of teeth restored with onlays of three contemporary tooth-colored resin-bonded restorative materials *Journal of Prosthetic Dentistry* **82(2)** 167-171.

33. Bremer BD, & Geurtsen W (2001) Molar fracture resistance after adhesive restoration with ceramic inlays or resin-based composites *American Journal of Dentistry* **14(4)** 216-220.

34. Shor A, Nicholls JI, Phillips KM, & Libman WJ (2003) Fatigue load of teeth restored with bonded direct composite and indirect ceramic inlays in MOD class II cavity preparations *International Journal of Prosthodontics* **16(1)** 64-69.

35. Hikita K, Van Meerbeek B, De Munck J, Ikeda T, Van Landuyt K, Maida T, Lambrechts P, & Peumans M (2007) Bonding effectiveness of adhesive luting agents to enamel and dentin *Dental Materials* **23(1)** 71-80.

PUBLISHED PAPER 3

Reconstrucción del diente endodonciado en sector anterior con técnicas adhesivas - revisión de la literatura

Anaïs Ramírez-Sebastià, Miguel Roig Cayón

Revista Nacional de Endodoncia
Enviado a fecha de Abril del 2013 – Pendiente de aceptación
Editor: Josep Pumarola Suñé

Reconstrucción del diente endodonciado en sector anterior con técnicas adhesivas - revisión de la literatura

Reconstruction of endodontically treated anterior teeth with modern restorative adhesive procedures - a literature review

Anaïs Ramírez-Sebastià, Miguel Roig Cayón

Universitat Internacional de Catalunya, Sant Cugat del Vallès, Barcelona.
Josep Trueta s/n, 08195 Sant Cugat del Vallès.

RESUMEN

Objetivo: Las opciones de tratamiento del diente endodonciado y sus cambios biomecánicos son motivo de controversia. El objetivo de esta revisión es mostrar las alteraciones de composición y estructura de la pérdida de vitalidad pulpar y proporcionar diferentes enfoques restaurativos adhesivos en dientes posteriores para restaurar el diente endodonciado.

Método de la revisión: El proceso de búsqueda incluyó una revisión en la base de datos de Pub/Med entre el 2000 y el 2012 usando una serie de palabras clave solas y combinadas.

Información relevante y conclusiones: El impacto de la pérdida de vitalidad parece moderado o insignificante en términos de humedad o propiedades físicas. Por el contrario, los cambios más importantes en la biomecánica y la resistencia a la fractura se asocian con un defecto estructural generado por caries, traumatismos o preparación del diente. Por lo tanto, el método más utilizado en la actualidad para la restauración de los dientes no vitales se basa en los preparativos de invasión mínima con la conservación máxima de los tejidos. Técnicas adhesivas y materiales con propiedades físicas próximas a la dentina parecen ser la opción más adecuada. Sin embargo, estudios más clínicos son necesarios para predecir el éxito a largo plazo.

Palabras clave: adhesive anterior restoration, ceramic restoration, composite restoration, endodontictally treated teeth, ferrule effect, fiber posts, indirect restorations, non vital tooth, post and core.

ABSTRACT

Objective: Biomechanical alterations and treatment options related to endodontically treated teeth are a matter of controversy. The aim of this review is to present the composition and structural alterations resulting from loss of pulp vitality and to provide different approaches to restorative adhesive procedures for anterior endodontically treated teeth.

Review method: The basic search process included a review of the PubMed/Medline database between 2000 and 2012 using single or combined key words and a perusal of the references completed the review.

Relevant information and conclusions: The impact of vitality loss appears moderate to negligible in terms of moisture or physical properties. Conversely, the most important changes in biomechanics and fracture resistance are associated with structural defect generated by caries, trauma or tooth preparation. Therefore, the most widely used approach at present for restoring nonvital teeth is based on minimally invasive preparations with maximal tissue conservation. Adhesive techniques and materials with physical properties close to natural dentin seem to be the most suitable option. However, more clinical studies are needed to predict a long-term success.

Key words: adhesive anterior restoration, ceramic restoration, composite restoration, endodontictally treated teeth, ferrule effect, fiber posts, indirect restorations, non vital tooth, post and core.

INTRODUCCIÓN

La restauración del diente endodonciado representa un reto para el clínico (1) y es un tema que ha sido muy polémico y discutido en la literatura dental (2-7). Los autores concluyen que la salud apical depende mucho más de la restauración coronal que de la calidad técnica del tratamiento de endodoncia (4). La elección del enfoque clínico es difícil debido a la falta de normas clínicas aceptadas y consenso sobre el método óptimo de restauración de los dientes no vitales y la amplia gama de materiales de restauración y técnicas disponibles (8, 9).

El tratamiento de conductos no debe considerarse completo hasta que la restauración coronal se ha logrado (10, 11). El pronóstico del tratamiento endodóntico depende no sólo del tratamiento en sí, sino también en el sellado de los conductos y minimizar la fuga de los fluidos orales y bacterias en zonas perirradiculares con la colocación de una restauración coronal (4, 5). El 60% de dientes endodonciados que son extraídos fracasan debido a una restauración inadecuada (12). La tasa de éxito de un tratamiento endodóntico aumenta significativamente con una restauración coronal de calidad. Por lo tanto, las decisiones sobre el tratamiento y las estrategias deben basarse en la evidencia disponible, antes de tomar una decisión sobre el tratamiento, el médico debe evaluar la calidad del tratamiento endodóntico, el estado periodontal y el estado de la estructura dentaria remanente.

Se acepta que los dientes tratados endodónticamente son más propensos a la fractura, lo que no puede explicarse por diferencias en las propiedades biomecánicas o el contenido de humedad de los tejidos duros, pero si por el defecto estructural generado durante la preparación del diente (8). De hecho, la conservación de los tejidos es el tema más crítico cuando se trata de un diente no vital. Preservar estructuras intactas y sobre todo preservar y mantener el tejido cervical para crear un efecto ferrule son cruciales para la optimización de las propiedades biomecánicas del diente restaurado (1, 2, 7).

Teniendo en cuenta los principios tradicionales de la prótesis fija, se recomendaba para fortalecer la estructura dental remanente, la colocación de una corona (13). En la actualidad, el protocolo ha cambiado debido a las mejoras en el material adhesivo y las técnicas, allanando así el camino para la era post-amalgama (14). Macro elementos de retención ya no son obligatorios, siempre y cuando se disponga de suficiente superficie. Preparaciones mínimamente invasivas con la conservación máxima de los tejidos ahora se consideran el estándar para la restauración de los dientes tratados endodónticamente (9).

REVISIÓN

El método de análisis se realizó utilizando la base de datos PubMed / Medline para revistas dentales basadas en las palabras clave siguientes: diente tratado endodónticamente, diente no vital, biomecánica dental, restauraciones indirectas adhesivas posteriores, restauración posteriores, postes de fibra, endocoronas, efecto ferrule. La revisión sistemática de la literatura se cubrió desde el 2005 al 2012.

Consideraciones biomecánicas del diente endodonciado

Varios estudios han propuesto que la dentina en los dientes tratados endodónticamente es sustancialmente diferente de la dentina en dientes vitales (15, 16). Se pensó que la dentina en los dientes tratados endodónticamente era más frágil debido a la pérdida de agua (15) y la pérdida de colágeno (16).

Sedgley y Messer estudiaron las propiedades biomecánicas de la dentina de los dientes tratados endodónticamente y de dientes vitales del lado contralateral, y llegaron a la conclusión que los dientes tratados endodónticamente no son más frágiles (17). Los cambios más importantes en la biomecánica del diente se atribuyen a la pérdida de tejido (18). Caries, preparación de la cavidad, el acceso a la pulpa coronal, la ampliación del conducto y la preparación quimio-mecánica pueden alterar la integridad del diente (9). El hipoclorito de sodio, agentes quelantes y el hidróxido de calcio de uso común para la desinfección interactúan con la dentina radicular, ya sea con contenido de minerales (agentes quelantes) o sustrato orgánico (hipoclorito de sodio), pero ninguna o sólo pequeñas diferencias en los valores de microdureza se encontraron entre vital y no vital de la dentina de los dientes contralaterales después de 0,2 a 10 años; grandes diferencias pueden existir, pero son atribuidas a la raíz, ubicación y la microestructura dentina (peritubular o intertubular) (8, 9).

Así que después de un tratamiento de conductos, el diente no es más frágil o débil con respecto a la resistencia a la compresión o tracción. No hay diferencia entre dientes vitales y no vitales y no hay otra evidencia de alteración química debida a la eliminación de tejido de la pulpa (8).

La cantidad restante de tejido es el principal factor que influye en la biomecánica (5, 8). La pérdida de la estructura dental durante la preparación de la cavidad de acceso afecta a la rigidez del diente en sólo un 5% y los resultados son mayores con la pérdida de las crestas marginales; parte la literatura informa de una pérdida del 14% a 44% y 20% a 63% de reducción en la rigidez del diente después de preparaciones ocluso-mesial (OM) oclusal mesio distal (MOD) respectivamente. Los resultados de máxima fragilidad se combina con una preparación del acceso endodóntico con una preparación MOD (8).

Resistencia a la fractura del diente endodonciado

La pérdida de tejido por caries, trauma o ambos, hace que los dientes tratados endodónticamente sean más susceptibles a la fractura (3, 6). La resistencia a la fractura de un diente restaurado tratado endodónticamente disminuye a medida que aumenta la cantidad tejido perdido (19).

La pérdida de estructura del diente reduce la capacidad del diente para resistir las fuerzas intraorales. El espesor de la pared de dentina en la circunferencia de la raíz es crítica y existe una correlación directa entre el diámetro de la raíz y la capacidad de los dientes para resistir las fuerzas laterales y evitar la fractura (19, 20).

La profundidad de la cavidad, istmo y la configuración, son factores muy importantes que determinan la reducción de la rigidez del diente y el riesgo de fractura. Por otro lado, el efecto ferrule aumenta la resistencia a la fractura, se considera necesario un mínimo de 1 mm para estabilizar el diente restaurado (21-23).

La conservación de la estructura dental es crucial para ofrecer resistencia a la fractura (8, 9).

Uso de postes

La creencia convencional y extendida entre los clínicos es que todos los dientes tratados endodónticamente son más débiles o más frágiles que los dientes vitales y por lo tanto requieren un refuerzo agresivo. Este tratamiento agresivo ha consistido tradicionalmente en la inserción de un poste metálico o espiga para reforzar el diente seguido de la colocación de una corona para protegerlo. Aunque algunos estudios de análisis de elementos finitos (FEM) indican que un poste rígido puede fortalecer el diente en su parte cervical por medio de interfaces totalmente cohesivos (24), la mayoría de los estudios sugieren que los postes no tienen ningún efecto de refuerzo (9, 25). Muchos autores incluso desalientan el uso de postes, la preparación de un espacio para el poste y su colocación puede debilitar la raíz y puede conducir a la fractura de la raíz de forma catastrófica. En realidad, un poste se considera sólo como una función de retención en casos muy específicos (1, 26).

La necesidad de la colocación de un poste depende del tipo de diente. Para molares tratados endodónticamente, el clínico puede tomar ventaja de la anatomía, la cámara pulpar y los conductos para proporcionar un núcleo de acumulación. Gracias a las características anatómicas, los molares no requieren postes (6, 9). Sin embargo, en un caso de una pérdida excesiva de la estructura del diente natural, los postes puede ser necesarios y deben ser colocados en el conducto más grande y recto para evitar el debilitamiento y la posible perforación de la raíz durante su colocación. El conducto distal de molares mandibulares y el conducto palatino de molares superiores por lo general son los mejores conductos para la colocación de un poste. Los premolares tienen menos tejido dental y pequeñas cámaras pulpares de retención y los postes se requieren con más frecuencia (6). Además de conicidad y curvatura radicular, muchas raíces de premolares son delgadas en sentido mesiodistal y algunos tienen invaginaciones proximales profundas. Además, la corona del primer premolar inferior a menudo se inclina a lingual en relación con su raíz. Estas características anatómicas deben ser consideradas durante la preparación del espacio para el poste para evitar la perforación de la raíz.

El alcance de la destrucción del tejido dentario no se puede evaluar métricamente, por lo que el tejido que permanece se basa en el número restante de paredes (5). El espesor mínimo de pared de la cavidad capaz de soportar las cargas funcionales se considera 1 mm y una altura mínima capaz de proporcionar un efecto suficiente de 1,5 mm (23).

El número de paredes de la cavidad restantes deben ser consideradas críticamente al colocar un poste (27). Basado en varios estudios in-vitro, si todas las paredes axiales permanecen y tienen un espesor mayor de 1 mm, no es necesario colocar un poste. En los casos que implican la pérdida de 1 o 2 paredes, no se requiere un poste, el tejido restante proporciona superficies suficientes para el uso de otros métodos, en particular, usando sistemas adhesivos (9). En los casos con un alto grado de destrucción en la que no queda paredes en la cavidad, la inserción de un poste es necesario para proporcionar la retención de material de núcleo. El efecto ferrule supone una gran influencia en la resistencia a la fractura en los dientes decoronados. El efecto ferrule se define como un collar de tejido de 360 º de la corona que rodea las paredes paralelas de la dentina coronal y se extiende hasta el hombro de la preparación. El resultado es una elevación en forma de resistencia de la corona (9, 28).

El ferrule presente es un problema más importante que la elección entre un poste y el núcleo, o de una reconstrucción de núcleo con rellenos adhesivos. El uso del efecto ferrule se ha demostrado en una mejor distribución de las fuerzas entre el poste y el núcleo y la raíz, a diferencia de lo que se observa cuando las fuerzas se aplican directamente al poste y el núcleo (29).

Al evaluar si un diente debe ser restaurado, el clínico debe considerar la cantidad de tejido que ha quedado supragingival. Libman y Nicholls, (1995) demostraron in-vitro que el ferrule eficaz mínimo debería ser de 1,5 mm (30). Sin embargo, McLean (1998) ha recomendado un mínimo de ferrule de 2 mm para compensar las dificultades de la preparación (31). En situaciones clínicas en las que la longitud sea insuficiente, el clínico puede considerar un alargamiento quirúrgico (5) o extrusión de ortodoncia (28).

Después de muchos años de trabajos científicos relacionados con la colocación de un poste, la indicación para la colocación es un tema de discusión y se ha producido un cambio apareciendo enormes ventajas de las restauraciones adhesivas (5).

En realidad, el uso de postes no parece ser obligatorio para la restauración de un diente no vital, a menos de una retención insuficiente del muñón. Cuando un poste es necesario, los postes de fibra con propiedades físicas próximas a la dentina y cementadas adhesivamente, parecen ser la opción más adecuada (2, 7, 32). Los postes metálicos generan grandes tensiones y a menudo conducen a fracturas radiculares no restaurables (26, 33).

Varios criterios se deben tener en cuenta con respeto a la indicación de la inserción de un poste: cantidad restante del tejido dental, efecto ferrule, la longitud del pose, el diámetro del poste, la cementación, el diseño del poste y el material del muñón. La combinación de postes prefabricados con los muñones de resina compuesta se ha asociado con una disminución en las fracturas catastróficas en comparación con el uso de pernos colados (32, 34).

Desde la década de 1980, cementos de resina se han preferido a los convencionales de fosfato de zinc-cementos para la cementación de un poste, ya que se ha demostrado que aumentan la retención del poste y la resistencia global contra la fractura. Debido al bajo módulo de elasticidad del cemento adhesivo, este puede actuar como un amortiguador, disminuyendo así el riesgo de fracturas de la raíz. Además, el módulo elástico de cementos compuestos es en la misma gama de la del poste de fibra y de la dentina. La unidad resultante es homogénea y permite una tensión más uniforme, preserva la estructura dental debilitada y reduce la microfiltración en la interfase dentina-cemento, caries secundaria y la reinfección del área periapical (34, 35).

En cuanto a longitud del poste, diversas recomendaciones se han propuesto en el pasado. Se creía que era necesario al menos de 4 a 5 mm de sellado apical, y su colocación en la parte más apical del conducto. Hoy en día, gracias a los actuales cementos adhesivos, las directrices relativas a la longitud del poste han cambiado y su longitud quizás podría acortarse dando valores iguales de resistencia a la fractura tanto en anteriores como en posteriores (36-38). En un estudio *in-vitro*, Zicari y cols. concluyeron que los postes cortos pueden producir incluso una mayor resistencia a la fractura que los postes largos. Por otra parte, los patrones de fractura asociadas con los postes cortos parecen ser más favorables porque permite la re-intervención y preservación del diente (34, 38, 39).

Recubrimiento cuspideo en los dientes endodonciados

La calidad de la restauración tienen una influencia directa sobre el pronóstico en relación con el éxito a largo plazo del diente (7, 12).

Aquilino y cols. compararon la relación entre la supervivencia de dientes endodonciados en sector posterior con o sin colocación de la corona. Llegaron a la conclusión de que la corona completa reduce el riesgo de fractura del diente, los dientes tratados endodónticamente con coronas tenían una tasa de supervivencia seis veces mayor que la de los dientes sin coronas (40).

Por el contrario, Mannocci y cols. evaluaron premolares tratados endodónticamente que habían sido restaurados (con y sin corona) con un poste o restauraciones directas de resina compuesta y las tasas de éxito fueron similares para ambos (41).

La pérdida de la estructura del diente aumenta el riesgo de fractura y en tales casos la protección cúspide con restauraciones indirectas está indicada, ya que protege las cúspides de la deflexión hacia el exterior (6, 31).

Las restauraciones directas de resina aumentan la resistencia a la fractura de los premolares con cavidades MOD cuando el espesor de pared restante es de 3 mm (42, 43). Contrariamente a esto, cuando el espesor de pared es de 2,25 mm o menos no existe la misma resistencia a la fractura (44).

En un estudio *in-vitro*, ElAyouti A y cols. mostraron que cuando el espesor de pared restante es 3 mm, una restauración de composite con recubrimiento cuspídeo aumenta significativamente la resistencia a la fractura en premolares cuando se compara con los restaurados sin recubrimiento cuspídeo. Incluso cuando el espesor de pared es de 1,5 mm y 2 mm, se observan resultados similares (20). El procedimiento adhesivo no es el único responsable de este efecto de refuerzo, la reducción de la pared débil puede provocar una disminución de las tensiones en la base, haciendo así que el diente sea más resistente a la fractura (45). Sorensen y cols. concluyen la evaluación retrospectiva de 1273 dientes tratados endodónticamente: la presencia de recubrimiento cuspideo fue la única variable significativa para predecir el éxito a largo plazo de un diente endodonciado (46).

Opciones terapéuticas actuales

Las restauraciones adhesivas con recubrimiento cuspideo total tipo overlays se han propuesto como alternativa a los métodos más tradicionales (coronas metal cerámicas) (47).

En comparación con las restauraciones adheridas, las coronas completas requieren un sacrificios superior de los tejidos duros, márgenes subgingivales y se asocian con una mayor inflamación gingival y caries secundaria.

El uso de restauraciones adhesivas de recubrimiento cuspideo (overlays en vez de coronas), se recomienda para reducir el riesgo de fractura y aumentar la resistencia mecánica coronal en los dientes tratados endodónticamente.

Experimentos *in-vitro* han demostrado que no hay diferencia de retención, adaptación marginal y resistencia a la fractura entre un diente vital y no vital con una restauración tipo overlay, favoreciendo de forma conservadora los dientes tratados endodónticamente (9).

Con la odontología adhesiva es factible restaurar los dientes posteriores mediante un overlay u onlay y, más recientemente, con endocoronas, sin el uso de postes radiculares y con el uso de toda la extensión de la cámara pulpar como superficie adhesiva y retentiva (9).

Un material de restauración ideal debería exhibir un módulo de Young idéntico a la estructura del diente. La resina compuesta parece ser el material ideal para la sustitución de la dentina. En general, el uso de la resina compuesta, en relación con los postes de fibra parece ser la técnica más eficaz para la restauración de dientes no vitales severamente deteriorados (9).

Las restauraciones adhesivas son más capaces de transmitir y distribuir las fuerzas funcionales a través del material restaurador y el diente, con la posibilidad de reforzar la estructura dental debilitada. Estos materiales tienen el potencial de disminuir la deflexión y la fractura de las cúspides bajo carga oclusal (19).

Endocoronas

La endocorona es una opción para restaurar dientes posteriores tratados endodónticamente con gran pérdida de estructura coronal y representa una alternativa interesante y conservador a las coronas de cobertura total (48). Este enfoque proporciona una adecuada función reparadora y estética, así como la integridad biomecánica de dientes posteriores no vitales comprometidas estructuralmente. La endocorona tiene ventajas sobre la corona convencional porque su comportamiento mecánico es mejor, cuesta menos, y se necesita menos tiempo para completar clínicamente. Por otra parte, el margen de la restauración se coloca supragingivalmente y evita las interferencias con los tejidos periodontales (48).

La endocorona fue descrita por primera vez por Blindl y Mörmann en 1999 y se caracterizaron como coronas de porcelana total fijas para dientes posteriores no vitales (49). Estas coronas se puede anclar a la parte interna de la cámara de la pulpa y en los márgenes de la cavidad, obteniendo una retención macroscópica proporcionada por la entrada de los conductos radiculares y una microretención que se alcanza con el uso de la cementación adhesiva. Se trata de un método especialmente indicado en casos en los que hay una pérdida excesiva de los tejidos (48-50).

En un estudio clínico, Bindl y Mörmann evaluaron el desempeño de 208 endocoronas cementadas a premolares y molares, y en los premolares observaron más fracasos que los molares. Esto ocurre porque los premolares tienen una superficie de adherencia más pequeña en comparación con los molares. Adicionalmente, los premolares tienen una mayor altura de la corona, que en consecuencia, compromete las propiedades mecánicas de los endocoronas (49).

Los estudios clínicos de endocoronas muestran una alta tasa de éxito (2, 51). Estudios in-vitro muestran también resultados similares (9, 49, 52). Los endocoronas exhibieron una resistencia significativamente mayor a la fractura. Otto reportó una tasa de supervivencia del 100% después de un período de 12 a 16 meses después de su colocación (53).

Cuando se utiliza el método de los elementos finitos (FEM), se observa también una favorable evolución de las restauraciones tipo endocoronas (24), incluso en los premolares (54). Muchos resultados obtenidos refuerzan las ventajas que se han presentado en las experiencias clínicas de varios autores. Teniendo en cuenta los dos parámetros evaluados, la fuerza y el modo de fallo, hubo una superioridad mecánica de las endocoronas.

Material de restauración: Composite vs Cerámica

Un área que merece una investigación adicional es ver si la cerámica o el composite son mejores como material de restauración para nuestras restauraciones adhesivas (47, 55, 56). A pesar de las ventajas de las restauraciones de cerámica, incluyendo la apariencia estética, biocompatibilidad y durabilidad, tales materiales presentan algunas desventajas como el potencial de rotura catastrófico y desgaste por abrasión de los dientes antagonistas naturales (56). La cerámica es un material frágil que no puede absorber gran cantidad de energía de deformación y muestra sólo una moderada resistencia al cizallamiento (47).

Manhart y cols. demostraron mejor forma anatómica y mayor integridad de las restauraciones cerámicas en comparación con las resinas compuestas. Sin embargo, la sensibilidad y la técnica de mayor costo, explica por qué se limita su uso a situaciones clínicas específicas (57). En la actualidad la resina compuesta también puede ser fabricada usando tecnología CAD / CAM y ofrece una ventaja considerable de tiempo de sillón (47).

Los avances en la odontología adhesiva y desarrollos tecnológicos con diseño y fabricación asistida por ordenador (CAD-CAM) son tecnologías que han dado lugar a nuevos sistemas para realizar restauraciones dentales. Diversos materiales mecanizados se utilizan en la actualidad con sistemas CAD / CAM para la fabricación de restauraciones en el sillón dental. El CEREC 3 CAD / CAM se introdujo hace más de 15 años y es el único sistema que puede ser utilizado en la práctica clínica y el laboratorio al mismo tiempo (58) .

En un estudio in-vitro, Magne y cols. evaluaron y compararon la resistencia a la fatiga de resina compuesta (Paradigm MZ100, 3M ESPE) y carillas de cerámica posteriores oclusales (IPS Empress CAD, Ivoclar Vivadent e IPS e.max CAD, Ivoclar Vivadent). Los autores concluyeron que las resinas compuestas CAD / CAM tienen una resistencia significativamente mayor en comparación con la cerámica, y a pesar de que nos encontramos una magnitud mayor de cargas en situaciones clínicas, no hubo fallos catastróficos, pero sólo grietas en el material de restauración (59). Esto constituye una demostración del enfoque "biomimético" de la restauración y del tejido subyacente.

La influencia de la selección de materiales (cerámica contra resina compuesta) y su efecto sobre la resistencia a la fatiga y el modo de fallo para las restauraciones de molares tratados endodónticamente se evalúan constantemente. Se demuestra una mayor fuerza de compresión de onlays de resina compuesta en comparación con las de cerámica. Se recomienda recubrimientos de resina compuesta en pacientes con grandes fuerzas de mordida y sospecha de hábitos parafuncionales como el bruxismo (59).

Magne y cols. demostraron que las restauraciones de resina compuesta (Paradigm MZ100) tuvieron una mayor resistencia y fallos más propensos a ser reparados (sólo 25% de las fracturas por debajo de la CEJ) en comparación con MKII (40% de las fracturas por debajo de la CEJ). Sus resultados están en concordancia con otros estudios que revelan altas tasas de fracasos sin posibilidad de restauración debido al tipo de material, fuerte y rígido. Otro parámetro que puede influir en el modo de fallo es la calidad de la adhesión. La alta resistencia a la dentina proporcionará una alta resistencia global (47).

CONLUSIONES

Como resultado de esta revisión se puede concluir que, a pesar de la falta de normas clínicas aceptadas y el consenso, la restauración de dientes no vitales ha evolucionado a partir de una aproximación empírica. La importancia de la conservación máxima del tejido y la presencia de un efecto ferrule se han demostrado ser básicos para optimizar el comportamiento biomecánico del diente no vital.

En cuanto a la restauración final, hay pruebas convincentes de que el recubrimiento cuspideo deberá indicarse en dientes posteriores tratados endodónticamente y la presencia de este recubrimiento cuspídeo es la única variable significativa para predecir éxito a largo plazo.

Con las mejoras en técnicas de adhesión y sobre la base de los principios de una preparación mínimamente invasiva, los conceptos relativos a la colocación de la colocación de un poste han cambiado y la indicación real está relacionada con la integridad de la estructura residual. Aunque, cuando un poste se necesita para aumentar la estabilidad del muñón, postes de resina de fibra con propiedades físicas próximas a la dentina es la opción más adecuada. La misma filosofía ("enfoque biomimético") se debe seguir cuando se elige el material para las restauraciones indirectas. A pesar de las controversias relativas a la interpretación de las resinas compuestas y cerámicas frente a la dificultad de encontrar estudios clínicos que comparen inlays / onlays y resinas compuestas, algunos estudios in-vitro han mostrado resultados prometedores para los composites.

En realidad, la invasión mínima con la conservación máxima de los tejidos sí es considerada el estándar para la restauración de dientes tratados endodónticamente. En esta perspectiva, las endocoronas son una alternativa interesante a las coronas completas, sobretodo cuando hay una gran pérdida de estructura coronal.

Finalmente, la decisión debe tomarse en consideración con algunos elementos clínicos, que no pueden ser evaluados *in-vitro* (variables no controladas) tales como, el riesgo de caries, los factores determinantes de oclusión (canino o guía de grupo, tipo de oclusión, resalte y sobremordida) y la presencia de parafunciones, que puede influir en el potencial de la biomecánica de la restauración.

BIBLIOGRAFÍA

(1) Zarow M, Devoto W, Saracinelli M. Reconstruction of endodontically treated posterior teeth--with or without post? Guidelines for the dental practitioner. Eur J Esthet Dent 2009: 4: 312-327.

(2) Robbins JW. Restoration of the endodontically treated tooth. Dent Clin North Am 2002: 46: 367-384.

(3) Heydecke G, Butz F, Strub JR. Fracture strength and survival rate of endodontically treated maxillary incisors with approximal cavities after restoration with different post and core systems: an in-vitro study. J Dent 2001: 29: 427-433.

(4) Heling I, Gorfil C, Slutzky H, Kopolovic K, Zalkind M, Slutzky-Goldberg I. Endodontic failure caused by inadequate restorative procedures: review and treatment recommendations. J Prosthet Dent 2002: 87: 674-678.

(5) Peroz I, Blankenstein F, Lange KP, Naumann M. Restoring endodontically treated teeth with posts and cores--a review. Quintessence Int 2005: 36: 737-746.

(6) Cheung W. A review of the management of endodontically treated teeth. Post, core and the final restoration. J Am Dent Assoc 2005: 136: 611-619.

(7) Schwartz RS, Robbins JW. Post placement and restoration of endodontically treated teeth: a literature review. J Endod 2004: 30: 289-301.

(8) Dietschi D, Duc O, Krejci I, Sadan A. Biomechanical considerations for the restoration of endodontically treated teeth: a systematic review of the literature--Part

1. Composition and micro- and macrostructure alterations. Quintessence Int 2007: 38: 733-743.

(9) Dietschi D, Duc O, Krejci I, Sadan A. Biomechanical considerations for the restoration of endodontically treated teeth: a systematic review of the literature, Part II (Evaluation of fatigue behavior, interfaces, and in vivo studies). Quintessence Int 2008: 39: 117-129.

(10) Ray HA, Trope M. Periapical status of endodontically treated teeth in relation to the technical quality of the root filling and the coronal restoration. Int Endod J 1995: 28: 12-18.

(11) Torabinejad M, Ung B, Kettering JD. In vitro bacterial penetration of coronally unsealed endodontically treated teeth. J Endod 1990: 16: 566-569.

(12) Vire DE. Failure of endodontically treated teeth: classification and evaluation. J Endod 1991: 17: 338-342.

(13) Colman HL. Restoration of endodontically treated teeth. Dent Clin North Am 1979: 23: 647-662.

(14) Lutz F, Krejci I. Resin composites in the post-amalgam age. Compend Contin Educ Dent 1999: 20: 1138-1144, 1146, 1148.

(15) Helfer AR, Melnick S, Schilder H. Determination of the moisture content of vital and pulpless teeth. Oral Surg Oral Med Oral Pathol 1972: 34: 661-670.

(16) Rivera EM, Yamauchi M. Site comparisons of dentine collagen cross-links from extracted human teeth. Arch Oral Biol 1993: 38: 541-546.

(17) Sedgley CM, Messer HH. Are endodontically treated teeth more brittle? J Endod 1992: 18: 332-335.

(18) Reeh ES, Messer HH, Douglas WH. Reduction in tooth stiffness as a result of endodontic and restorative procedures. J Endod 1989: 15: 512-516.

(19) Soares CJ, Soares PV, de Freitas Santos-Filho PC, Castro CG, Magalhaes D, Versluis A. The influence of cavity design and glass fiber posts on biomechanical behavior of endodontically treated premolars. J Endod 2008: 34: 1015-1019.

(20) Elayouti A, Dima E, Judenhofer MS, Lost C, Pichler BJ. Increased apical enlargement contributes to excessive dentin removal in curved root canals: a stepwise microcomputed tomography study. J Endod 2011: 37: 1580-1584.

(21) Zhi-Yue L, Yu-Xing Z. Effects of post-core design and ferrule on fracture resistance of endodontically treated maxillary central incisors. J Prosthet Dent 2003: 89: 368-373.

(22) Fragou T, Tortopidis D, Kontonasaki E, et al. The effect of ferrule on the fracture mode of endodontically treated canines restored with fibre posts and metal-ceramic or all-ceramic crowns. J Dent 2012: 40: 276-285.

(23) Juloski J, Radovic I, Goracci C, Vulicevic ZR, Ferrari M. Ferrule effect: a literature review. J Endod 2012: 38: 11-19.

(24) Asmussen E, Peutzfeldt A, Sahafi A. Finite element analysis of stresses in endodontically treated, dowel-restored teeth. J Prosthet Dent 2005: 94: 321-329.

(25) Mohammadi N, Kahnamoii MA, Yeganeh PK, Navimipour EJ. Effect of fiber post and cusp coverage on fracture resistance of endodontically treated maxillary premolars directly restored with composite resin. J Endod 2009: 35: 1428-1432.

(26) Akkayan B, Gulmez T. Resistance to fracture of endodontically treated teeth restored with different post systems. J Prosthet Dent 2002: 87: 431-437.

(27) Naumann M, Koelpin M, Beuer F, Meyer-Lueckel H. 10-year survival evaluation for glass-fiber-supported postendodontic restoration: a prospective observational clinical study. J Endod 2012: 38: 432-435.

(28) Stankiewicz NR, Wilson PR. The ferrule effect: a literature review. Int Endod J 2002: 35: 575-581.

(29) Massa F, Dias C, Blos CE. Resistance to fracture of mandibular premolars restored using post-and-core systems. Quintessence Int 2010: 41: 49-57.

(30) Libman WJ, Nicholls JI. Load fatigue of teeth restored with cast posts and cores and complete crowns. Int J Prosthodont 1995: 8: 155-161.

(31) McLean A. Criteria for the predictably restorable endodontically treated tooth. J Can Dent Assoc 1998: 64: 652-656.

(32) Hayashi M, Sugeta A, Takahashi Y, Imazato S, Ebisu S. Static and fatigue fracture resistances of pulpless teeth restored with post-cores. Dent Mater 2008: 24: 1178-1186.

(33) Aggarwal V, Singla M, Miglani S, Kohli S. Comparative evaluation of fracture resistance of structurally compromised canals restored with different dowel methods. J Prosthodont 2012: 21: 312-316.

(34) Zicari F, Van Meerbeek B, Scotti R, Naert I. Effect of fibre post length and adhesive strategy on fracture resistance of endodontically treated teeth after fatigue loading. J Dent 2012: 40: 312-321.

(35) Chuang SF, Yaman P, Herrero A, Dennison JB, Chang CH. Influence of post material and length on endodontically treated incisors: an in vitro and finite element study. J Prosthet Dent 2010: 104: 379-388.

(36) Nissan J, Dmitry Y, Assif D. The use of reinforced composite resin cement as compensation for reduced post length. J Prosthet Dent 2001: 86: 304-308.

(37) Scotti N, Scansetti M, Rota R, Pera F, Pasqualini D, Berutti E. The effect of the post length and cusp coverage on the cycling and static load of endodontically treated maxillary premolars. Clin Oral Investig 2011: 15: 923-929.

(38) Nissan J, Barnea E, Carmon D, Gross M, Assif D. Effect of reduced post length on the resistance to fracture of crowned, endodontically treated teeth. Quintessence Int 2008: 39: 179-182.

(39) Giovani AR, Vansan LP, de Sousa Neto MD, Paulino SM. In vitro fracture resistance of glass-fiber and cast metal posts with different lengths. J Prosthet Dent 2009: 101: 183-188.

(40) Aquilino SA, Caplan DJ. Relationship between crown placement and the survival of endodontically treated teeth. J Prosthet Dent 2002: 87: 256-263.

(41) Mannocci F, Bertelli E, Sherriff M, Watson TF, Ford TR. Three-year clinical comparison of survival of endodontically treated teeth restored with either full cast coverage or with direct composite restoration. J Prosthet Dent 2002: 88: 297-301.

(42) Trope M, Langer I, Maltz D, Tronstad L. Resistance to fracture of restored endodontically treated premolars. Endod Dent Traumatol 1986: 2: 35-38.

(43) Hurmuzlu F, Kiremitci A, Serper A, Altundasar E, Siso SH. Fracture resistance of endodontically treated premolars restored with ormocer and packable composite. J Endod 2003: 29: 838-840.

(44) Macpherson LC, Smith BG. Reinforcement of weakened cusps by adhesive restorative materials: an in-vitro study. Br Dent J 1995: 178: 341-344.

(45) Mondelli RF, Barbosa WF, Mondelli J, Franco EB, Carvalho RM. Fracture strength of weakened human premolars restored with amalgam with and without cusp coverage. Am J Dent 1998: 11: 181-184.

(46) Sorensen JA, Martinoff JT. Intracoronal reinforcement and coronal coverage: a study of endodontically treated teeth. J Prosthet Dent 1984: 51: 780-784.

(47) Magne P, Knezevic A. Influence of overlay restorative materials and load cusps on the fatigue resistance of endodontically treated molars. Quintessence Int 2009: 40: 729-737.

(48) Lander E, Dietschi D. Endocrowns: a clinical report. Quintessence Int 2008: 39: 99-106.

(49) Bindl A, Mormann WH. Clinical evaluation of adhesively placed Cerec endo-crowns after 2 years--preliminary results. J Adhes Dent 1999: 1: 255-265.

(50) Rocca G, Rizcalla N, Krejci I. Fiber-Reinforced Resin Coating for Endocrown Preparations: A Technical Report. Oper Dent 2012.

(51) Bindl A, Richter B, Mormann WH. Survival of ceramic computer-aided design/manufacturing crowns bonded to preparations with reduced macroretention geometry. Int J Prosthodont 2005: 18: 219-224.

(52) Biacchi GR, Basting RT. Comparison of fracture strength of endocrowns and glass fiber post-retained conventional crowns. Oper Dent 2012: 37: 130-136.

(53) Otto T. Computer-aided direct all-ceramic crowns: preliminary 1-year results of a prospective clinical study. Int J Periodontics Restorative Dent 2004: 24: 446-455.

(54) Seow LL, Toh CG, Fok AS, Wilson NH. A finite element analysis of ceramic restorations in endodontically treated premolars. Am J Dent 2008: 21: 331-336.

(55) Dietschi D, Magne P, Holz J. Recent trends in esthetic restorations for posterior teeth. Quintessence Int 1994: 25: 659-677.

(56) Attia A, Abdelaziz KM, Freitag S, Kern M. Fracture load of composite resin and feldspathic all-ceramic CAD/CAM crowns. J Prosthet Dent 2006: 95: 117-123.

(57) Manhart J, Chen HY, Neuerer P, Scheibenbogen-Fuchsbrunner A, Hickel R. Three-year clinical evaluation of composite and ceramic inlays. Am J Dent 2001: 14: 95-99.

(58) Mormann WH, Brandestini M, Lutz F, Barbakow F. Chairside computer-aided direct ceramic inlays. Quintessence Int 1989: 20: 329-339.

(59) Magne P, Schlichting LH, Maia HP, Baratieri LN. In vitro fatigue resistance of CAD/CAM composite resin and ceramic posterior occlusal veneers. J Prosthet Dent 2010: 104: 149-157.

6. DISCUSSION

Clinicians often encounter clinical fracture of endodontically treated teeth (7, 9).

The objectives of the present thesis were to evaluate marginal adaptation, fracture strength and mode of failures of 48 anterior incisors divided into 6 experimental groups: 1) Large post + composite core + CAD/CAM ceramic crown, 2) Short post + composite core + CAD/CAM ceramic crown, 3) Large post + composite core + CAD/CAM composite crown, 4) Short post + composite core + CAD/CAM composite crown, 5) Ceramic endocrown and 6) Composite endocrown.

In order to limit variables, anterior maxillary incisors were used in this thesis. Inclusion and exclusion criteria were clearly classified before sampling: absence of caries or previous restorations, absence of fracture lines, similar crown and root sizes.

Evaluation of marginal adaptation

We decided to evaluate marginal adaptation in all samples before and after loading. It is important to know that excellent marginal adaptation extends the longevity of restorations (64, 65). Lack of adequate fit is potentially detrimental to both the tooth and the supporting periodontal tissues, as a result of cement solubility or plaque retention (66). Our first manuscript focused exclusively on the quality of marginal adaptation *in-vitro* as an indispensable prerequisite for clinical success. Within the limitations of laboratory studies, quantitative analysis of marginal adaptation by SEM has been confirmed as an exact and reliable method of assessment for the evaluation of marginal adaptation of adhesive restorations (67).

Although there have been numerous investigations using light microscopy, most authors (68, 69) have concluded that SEM imaging provides more appropriate and realistic observations than do light microscopy-based systems of analysis.

Mechanical tests

To have a degree of clinical relevance, all groups were thermomechanically loaded in attempt to simulate the oral environment (65, 70). Restorations were stressed for 600,000 cycles (simulating 2.5 years of clinical use) at 49N with 1500 thermal cycles between 5 and 55ºC (70). The chewing force was applied to the specimens at 45º to the tooth long axis, in accordance with publications about fatigue testing followed by fracture strength test (Instron, Model 1114, Instron Corp, High Wycombe, Great Britain) of anterior teeth (71). Most studies use non fatigue specimens, therefore the extrapolation of their results compared to those of ours studies may not be adequate (72, 73). Each specimen was placed in a fixing device and a controlled load was applied using a stainless steel rod at a 45º with respect to the longitudinal axis of the root.

Loss of the tooth structure from caries, trauma or both makes endodontically treated teeth more susceptible to fracture (17, 30). Fracture resistance of a restored endodontically treated tooth decreases as the amount of dentin removed increases (31). The cavity depth, isthmus and configuration are highly critical factors that determining the reduction of tooth stiffness and risk of fracture. On the other hand, the ferrule effect increased tooth resistance to fracture; each tooth was prepared with a severe loss of coronal tooth structure preserving 2mm of ferrule effect; a minimal of 1mm ferrule is considered necessary to stabilize the restored tooth (33-36).

Load application area

Area of load application has been widely described as one of the paramount factors to achieve reliable laboratory results (9, 14, 30, 72, 74-76).

In our thesis, anterior teeth were evaluated (14, 30), specifically maxillary incisors; the load was always applied on the palatal aspect in an area ranging from 2 to 3 mm from the incisal margin. This is due to the gnatologic role of incisors, designed to bear non axial loads rather than axial forces. The area of load application coincides with the area of incisor guidance during stomatognatic functions.

When the fracture resistance of endodontically treated posterior teeth is investigated (9, 72, 75, 76), mainly maxillary premolars, the load is applied in regions varying from the center of occlusal surface to the supporting cusps.

Fiber posts

Several studies evaluated the mechanical resistance of endodontically treated teeth, in particular of upper incisors (34, 77-81). Most of these studies included specimens with different types of posts.

All groups were restored with fiber posts. Most studies have tried to identify the best technique and combination of materials to be used to increase the strength of the tooth-restoration complex (76, 82, 83). It has been demonstrated that restoration of endodontically treated teeth with fiber posts and direct resin composites is a treatment option, which in the short term conserves remaining tooth structure. When the posts are submitted to loading, they can better absorb the forces concentrated along the root, thus reducing the probability of fracture (84, 85).

The findings of our second study: ***Adhesive restoration of anterior endodontically treated teeth: influence of post length on fracture strength,*** indicate that restorations may be possible without the use of a post. This is an advantage because more tooth substance is preserved and the clinical procedure may be easier to achieve. No differences were detected in the fracture strength scores of specimens restored either with an endocrown, a short (5mm) or a long (10mm) post. Based on our findings, the increase in post length did not increase the fracture resistance. This would mean that shorter posts might be used in anterior teeth. Since fiber posts are bonded within the root canal, their length could perhaps be shortened (44, 46, 86). The length of the post influences stress distribution in the root, and thereby affects its resistance to fracture. Various recommendations have been proposed in the past. It was believed that given at least 4-5 mm of apical seal, and post placed to the more apical part into the canal, a higher retention of the restoration was obtained but some authors asserted that posts may interfere with the mechanical resistance of treated teeth, leading to an increased risk of damage to residual tooth structure (9, 87). Nowadays, thanks to the optimization of bonding mechanisms of current adhesive composite cements, guidelines regarding post length may be revised.

Contrary to our findings, significantly higher values of fracture resistance have been recently observed in groups restored with 10 mm long glass fiber posts with respect to shorter post lengths (47). However, their material and methods were different, metallic crowns were cemented with a phosphate based cement. Because non adhesive anterior restorations were used to restore these teeth, it is reasonable to have better results with a long post, as these restorations are macromechanical retained.

One more advantage represented in the literature when using fiber posts is that they are able to improve the bending resistance and failures, if they occur, are more easily restorable. Our results showed that groups restored with a long post presented fractures located in areas where intra oral repair is impossible, which means that in clinical reality the tooth must be extracted. This was not the case when short post or endocrowns were used. Our results are in concordance with others studies where fracture patterns associated with shorter posts appeared to be more favorable because they allow re-intervention and preservation of the tooth (42, 45, 47).

Coronal restorations and restorative materials

Advances in adhesive dentistry and technologic developments with computer-aided design/computer-assisted manufacturing (CAD-CAM) technologies have resulted in new systems for dental restoration. Various machinable materials are used currently with CAD/CAM systems to fabricate restorations at the chairside. The CEREC 3 CAD/CAM system was introduced more than 15 years ago and it is the only system that can be used in both clinical practice and the laboratory (57).

Coronal leakage may lead to bacterial contamination; on the contrary, the longevity of an endodontic treatment is significantly increased by a correct coronal restoration (1).

Materials that were chosen, composite blocks (Paradigm Z100) and ceramic blocks (IPS Empress CAD), are both widely used restorative materials in modern conservative dentistry.

Quantitative analysis of marginal adaptation by SEM has proven to be an exact and reliable method of assessment for the evaluation of the marginal adaptation of adhesive restorations (67). Materials and interfaces normally fail because of stresses and repeated loading. The quality of the SEM analysis was expressed as the percentage of “continuous margin” and “marginal opening” along the total marginal length at both the tooth–luting cement and the luting cement–crown (CC) interfaces. To evaluate marginal adaptation, a replica-based, computer-assisted quantitative SEM analysis of the margin was performed before and after loading. The replica-based approach has several advantages: it is quantitative, non destructive, and highly discriminatory (88).

In our first manuscript: ***Composite vs Ceramic Computer-aided Design/Computer-assisted Manufacturing Crowns in Endodontically Treated Teeth: Analysis of Marginal Adaptation,*** there was also a significant influence of the material of the restorative crown (ceramic or composite) on the marginal adaptation of both interfaces, tooth–luting cement and luting cement–crown (LC). Groups LPCpr, SPCpr, and EndoCpr showed the highest percentage of continuous margin after loading. The rigidity of dental restorative materials is considered to be an essencial issue when evaluating the adhesive tooth-restoration interface. Composite materials are more resilient than ceramics, and this could have an effect on the stress that is transferred to the margin walls. Even if there is a lack of scientific evidence that correlates dentin cracks with the long-term clinical behavior of ceramic restorations, cracks may be interpreted as a sign of early failure. According to the manufacturer, the IPS Empress CAD block is a conventional feldspathic ceramic, whereas the MZ100 block is a millable composite resin formed of 85% (by weight) ultrafine zirconium-silica ceramic particles that reinforce a highly cross-linked polymeric matrix.

In spite of the advantages of all-ceramic restorations, including aesthetic appearance, biocompatibility and durability, such materials have some drawbacks such us the potential of brittle catastrophic fracture and abrasive wear of the opposing natural teeth (60). Porcelain is a brittle material that cannot absorb a large amount of deformation energy and shows only moderate resistance to localized shear and tensile stresses (50). In another *in-vitro* study, Magne el al. assessed and compared the fatigue resistance of composite resin (Paradigm MZ100, 3M ESPE) and ceramic posterior occlusal veneers (IPS Empress CAD, Ivoclar Vivadent and IPS e.max CAD, Ivoclar Vivadent). The authors concluded that CAD/CAM composite resins had significantly higher fracture resistance when compared to ceramic and despite the simulation of loads of a higher magnitude than is usually encountered in clinical situations, there were no catastrophic failures, but only cracks limited to the restoration material (63). This constitutes a demonstration of the “biomimetic” approach of the restoration and underlying tissue, simulating to some degree the enamel cracks stopped at the Cement Enamel Junction (CEJ).

Our results demonstrated the greater compressive strength of composite compared to ceramic in a simple load-to-failure test. Although the composite resin restorations are expected to wear more than ceramic, they also tend to preserve more of the antagonist, but this differential wear requires additional investigation.

In our second manuscript: ***Adhesive restoration of anterior endodontically treated teeth: influence of post length on fracture strength***, no significant differences could be detected between composite and ceramic restorations either. The similar values of flexural strength between ceramic and composite and the ferrule effect provided by 2mm of dentin may account for the present findings. The importance of preserving a minimum amount

(2mm) of coronal dentin height after preparation on the fracture resistance and prevention of root fracture on ETT has been reported in various studies (35).

According to these studies when the ferrule effect is present, stresses are redistributed in the outer surface regions of the coronal third of the root, thus a possible fracture in this area can be repairable. When the ferrule is absent, occlusal forces must be supported by a post that may fracture, and a vertical root fracture may occur. Fatigue studies have clearly demonstrated the importance of tissue conservation and presence of a ferrule effect to optimize tooth biomechanical behavior (20, 89).

7. CONCLUSIONS

CONCLUSIONS:

1. We found differences on marginal adaptation between ceramic and composite crowns, before and after loading. The main difference between the ceramic and composite crowns was observed at the tooth–luting cement interface. Dentin cracks could be observed on loaded specimens that had been restored with ceramic crowns, whereas no cracks were evident in the dentin when composite crowns were used as the restorative material.

2. We found no influence of restorative material, i.e composite or ceramic, on the fracture strength. Composite resin blocks are a viable alternative to all-ceramic crowns for the restoration of anterior endodontically treated teeth.

3. We found no differences on the fracture strength of teeth restored with endocrowns, short and long post. The use of endocrowns or a short glass fiber post with and adhesive crown is sufficient for the restoration of largely destroyed anterior teeth.

4. We found differences on fracture patterns of teeth restored with endocrowns, short and long post. Coronal restorations with endocrowns and short posts were associated with repairable fractures, whereas long posts induced catastrophic failures under load.

CONCLUSIONES:

1. Sí encontramos diferencias en cuanto a la adaptación marginal entre las coronas de cerámica y las coronas de composite antes y después de la fatiga. La principal diferencia entre cerámica y composite se observó en la interfase diente-cemento. Los cracks en dentina se pudieron observar en los dientes restaurados con coronas cerámicas, mientras no se observaron cracks evidentes en la dentina cuando se usaron coronas de composite.

2. No encontramos influencia alguna en cuanto a la resistencia a la fractura entre composite y cerámica. Los bloques de composite son una alternativa viable a las coronas de cerámica para restaurar dientes anteriores endodonciados.

3. No encontramos diferencias en cuanto a la resistencia a la fractura entre los dientes restaurados con endocoronas, con poste corto y con poste largo. El uso de endocoronas o poste de fibra corto es suficiente para restaurar dientes anteriores muy comprometidos.

4. Sí encontramos diferencias en los modos de fracturas entre los dientes restaurados con endocoronas, con poste corto y con poste largo. Los dientes endodonciados restaurados con endocoronas y poste corto se asociaron a fracturas reparables, mientras que los dientes restaurados con poste largo condujeron a fracturas catastróficas o no reparables.

8. RESUMEN

RESUMEN

El tratamiento endodóntico no debe considerarse terminado hasta la restauración del diente. El concepto de adhesión ha comportado un cambio en la odontología conservadora actual; incluso, hay algún autor que apoya la posibilidad de no usar elementos macrorretentivos (90). La necesidad de postes en dientes posteriores parece haberse puesto en duda (8), pero es poca i pobre la información que se encuentra en la literatura actual sobre el uso de éstos para la restauración de dientes anteriores.

La restauración directa con composite de los dientes tratados endodónticamente y sin la colocación de poste se ha estudiado por muchos autores (5-7). Incluso un reciente estudio en premolares comprometidos demuestra que no existen diferencias significativas entre dientes restaurados con o sin poste (8).

La odontología restauradora actual también evoluciona y aparecen los bloques de composite para el uso del sistema CAD/CAM. Sus mejoras en las propiedades mecánicas demuestran en los estudios una mayor resistencia a la fractura que los bloques usados de porcelana. A día de hoy, no se sabe si la adaptación y resistencia a la fractura de los dientes restaurados con bloques de cerámica es mayor que con el uso de bloques de composite (50, 91).

El objetivo de esta tesis se centró en la restauración de dientes endodonciados en sector anterior. Se evaluó la adaptación marginal, la resistencia y el modo de fractura entre dientes anteriores restaurados con endocoronas de composite y cerámcia, y coronas de cerámica y composite con previa colocación de postes de fibra de 5mm o 10mm de longitud.

32 incisivos centrales anteriores fueron divididos en 6 grupos experimentales. 1) Poste largo + muñón de composite + corona CAD/CAM de cerámica, 2) Poste corto + muñón de composite + corona CAD/CAM de cerámica, 3) Poste largo + muñón de composite corona CAD/CAM de composite, 4) Poste corto + muñón de composite + corona CAD/CAM de composite, 5) Endocrown de cerámica, 6) Endocrown de composite.

Una vez restaurados los dientes, se cargaron sobre la superficie palatina con una angulación de 45 grados siguiendo el eje longitudinal de la raíz en la máquina de fatiga realizando 600.000 ciclos mecánicos a una fuerza de 49 N y 1500 ciclos termales entre 5 y 55ºC (70). Antes y después del test de fatiga se realizaron réplicas de cada muestra para analizar las dos interfaces adhesivas externas (Dentina-Cemento y Cemento-Corona) mediante Microsopio Electrónico de Barrido (SEM, Philips XL 20, Eindhoven, The Netherlands) a 200x de magnificación con la ayuda del programa informático evaluando así la “continuidad” (C) o “márgen abierto” (MO) de cada interfase.

Después del test de fatiga, en el que sobrevivieron todas las muestras, éstas se sometieron a un test de resistencia a la fractura (Instron, Model 1114, Instron Corp, High Wycombe, Great Britain). Cada diente se colocó en un soporte de 45º y se le aplicó una fuerza controlada con una bola de acero inoxidable. La presión se localizó 3mm por debajo del eje incisal en la superficie palatina de la corona a una velocidad de 1mm/min. Todas las muestras se cargaron hasta su fractura que fue anotada en Newtons (N). Los modos de fractura se determinaron y se clasificaron como fractura reparable / no reparable o catastrófica. Las fracturas en la parte incisal de la raíz, en el muñón y la descementación del poste se valoraron como reparables y las fracturas por debajo, no reparables.

No se detectaron diferencias, en cuanto a adaptación marginal, entre los grupos antes y después de la fatiga (p=0.9834). Aún así, los grupos LPCpr, SPCpr y EndoCpr (restaurados con los bloques de composite) mostraron los porcentajes más altos de margen continuo después de la fatiga.

La presencia de composite o cerámica en las restauraciones y el tipo de poste (corto o largo) en la resistencia a la fractura no fue significativa (p=0,778). Aún así, si consideramos los valores absolutos, los grupos restaurados con poste corto presentaron la puntuación más alta en cuanto a resistencia a la fractura (552.4±54.4).

De acuerdo con los resultados obtenidos en los dos estudios, la primera hipótesis nula en cuanto a que no habrá diferencias en la adaptación marginal entre las coronas de cerámica y las coronas de composite, debe ser rechazada. La segunda y la tercera hipótesis nula en cuanto a que no habrá influencia alguna en la resistencia a la fractura entre composite y cerámica, y que la longitud del poste no presenta efecto alguno en la resistencia a la fractura de los dientes anteriores desvitalizados, deben ser aceptadas. No existieron diferencias significativas de resistencia a la fractura entre los valores conseguidos por los grupos de poste corto y largo. Basándonos en nuestros resultados, incrementar la longitud del poste no incrementa la resistencia a la fractura.

La cuarta hipótesis nula en la que no existe diferencia en los modos de fractura de los dientes restaurados con poste corto y largo debe ser rehusada. Nuestros resultados mostraron que los grupos restaurados con un poste largo presentaron fracturas localizadas en áreas dónde la reparación no es posible, lo que lleva a la extracción del diente en una realidad clínica. A largo plazo, es importante conseguir restaurar un diente no vital que sea resistente a las fuerzas de masticación y tenga un modo de fractura reparable. Pese a las limitaciones de esta tesis, podemos demostrar que los dientes anteriores endodonciados pueden ser restaurados usando un poste corto. Aún así, estudios *in-vivo* son necesarios para validar tales resultados antes de que esta técnica sea recomendada para su uso clínico.

9. BIBLIOGRAPHY

(1) Tronstad L, Asbjornsen K, Doving L, Pedersen I, Eriksen HM. Influence of coronal restorations on the periapical health of endodontically treated teeth. Endod Dent Traumatol 2000: 16: 218-221.

(2) Goldstein GR, Hudis SI, Weintraub DE. Comparison of four techniques for the cementation of posts. J Prosthet Dent 1986: 55: 209-211.

(3) Torabinejad M, Ung B, Kettering JD. In vitro bacterial penetration of coronally unsealed endodontically treated teeth. J Endod 1990: 16: 566-569.

(4) Colman HL. Restoration of endodontically treated teeth. Dent Clin North Am 1979: 23: 647-662.

(5) Stockton L, Lavelle CL, Suzuki M. Are posts mandatory for the restoration of endodontically treated teeth? Endod Dent Traumatol 1998: 14: 59-63.

(6) Baratieri LN, De Andrada MA, Arcari GM, Ritter AV. Influence of post placement in the fracture resistance of endodontically treated incisors veneered with direct composite. J Prosthet Dent 2000: 84: 180-184.

(7) Assif D, Nissan J, Gafni Y, Gordon M. Assessment of the resistance to fracture of endodontically treated molars restored with amalgam. J Prosthet Dent 2003: 89: 462-465.

(8) Krejci I, Duc O, Dietschi D, de Campos E. Marginal adaptation, retention and fracture resistance of adhesive composite restorations on devital teeth with and without posts. Oper Dent 2003: 28: 127-135.

(9) Akkayan B, Gulmez T. Resistance to fracture of endodontically treated teeth restored with different post systems. J Prosthet Dent 2002: 87: 431-437.

(10) Akkayan B. An in vitro study evaluating the effect of ferrule length on fracture resistance of endodontically treated teeth restored with fiber-reinforced and zirconia dowel systems. J Prosthet Dent 2004: 92: 155-162.

(11) Strub JR, Pontius O, Koutayas S. Survival rate and fracture strength of incisors restored with different post and core systems after exposure in the artificial mouth. J Oral Rehabil 2001: 28: 120-124.

(12) Zarow M, Devoto W, Saracinelli M. Reconstruction of endodontically treated posterior teeth--with or without post? Guidelines for the dental practitioner. Eur J Esthet Dent 2009: 4: 312-327.

(13) Robbins JW. Restoration of the endodontically treated tooth. Dent Clin North Am 2002: 46: 367-384.

(14) Heydecke G, Peters MC. The restoration of endodontically treated, single-rooted teeth with cast or direct posts and cores: a systematic review. J Prosthet Dent 2002: 87: 380-386.

(15) Heling I, Gorfil C, Slutzky H, Kopolovic K, Zalkind M, Slutzky-Goldberg I. Endodontic failure caused by inadequate restorative procedures: review and treatment recommendations. J Prosthet Dent 2002: 87: 674-678.

(16) Peroz I, Blankenstein F, Lange KP, Naumann M. Restoring endodontically treated teeth with posts and cores--a review. Quintessence Int 2005: 36: 737-746.

(17) Cheung W. A review of the management of endodontically treated teeth. Post, core and the final restoration. J Am Dent Assoc 2005: 136: 611-619.

(18) Schwartz RS, Robbins JW. Post placement and restoration of endodontically treated teeth: a literature review. J Endod 2004: 30: 289-301.

(19) Dietschi D, Duc O, Krejci I, Sadan A. Biomechanical considerations for the restoration of endodontically treated teeth: a systematic review of the literature--Part 1. Composition and micro- and macrostructure alterations. Quintessence Int 2007: 38: 733-743.

(20) Dietschi D, Duc O, Krejci I, Sadan A. Biomechanical considerations for the restoration of endodontically treated teeth: a systematic review of the literature, Part II (Evaluation of fatigue behavior, interfaces, and in vivo studies). Quintessence Int 2008: 39: 117-129.

(21) Ray HA, Trope M. Periapical status of endodontically treated teeth in relation to the technical quality of the root filling and the coronal restoration. Int Endod J 1995: 28: 12-18.

(22) Vire DE. Failure of endodontically treated teeth: classification and evaluation. J Endod 1991: 17: 338-342.

(23) Smith CT, Schuman N. Restoration of endodontically treated teeth: a guide for the restorative dentist. Quintessence Int 1997: 28: 457-462.

(24) Lutz F, Krejci I. Resin composites in the post-amalgam age. Compend Contin Educ Dent 1999: 20: 1138-1144, 1146, 1148.

(25) Helfer AR, Melnick S, Schilder H. Determination of the moisture content of vital and pulpless teeth. Oral Surg Oral Med Oral Pathol 1972: 34: 661-670.

(26) Carter JM, Sorensen SE, Johnson RR, Teitelbaum RL, Levine MS. Punch shear testing of extracted vital and endodontically treated teeth. J Biomech 1983: 16: 841-848.

(27) Yang SF, Rivera EM, Walton RE. Vertical root fracture in nonendodontically treated teeth. J Endod 1995: 21: 337-339.

(28) Sedgley CM, Messer HH. Are endodontically treated teeth more brittle? J Endod 1992: 18: 332-335.

(29) Reeh ES, Messer HH, Douglas WH. Reduction in tooth stiffness as a result of endodontic and restorative procedures. J Endod 1989: 15: 512-516.

(30) Heydecke G, Butz F, Strub JR. Fracture strength and survival rate of endodontically treated maxillary incisors with approximal cavities after restoration with different post and core systems: an in-vitro study. J Dent 2001: 29: 427-433.

(31) Soares CJ, Soares PV, de Freitas Santos-Filho PC, Castro CG, Magalhaes D, Versluis A. The influence of cavity design and glass fiber posts on biomechanical behavior of endodontically treated premolars. J Endod 2008: 34: 1015-1019.

(32) Elayouti A, Dima E, Judenhofer MS, Lost C, Pichler BJ. Increased apical enlargement contributes to excessive dentin removal in curved root canals: a stepwise microcomputed tomography study. J Endod 2011: 37: 1580-1584.

(33) Stankiewicz NR, Wilson PR. The ferrule effect: a literature review. Int Endod J 2002: 35: 575-581.

(34) Zhi-Yue L, Yu-Xing Z. Effects of post-core design and ferrule on fracture resistance of endodontically treated maxillary central incisors. J Prosthet Dent 2003: 89: 368-373.

(35) Fragou T, Tortopidis D, Kontonasaki E, et al. The effect of ferrule on the fracture mode of endodontically treated canines restored with fibre posts and metal-ceramic or all-ceramic crowns. J Dent 2012: 40: 276-285.

(36) Juloski J, Radovic I, Goracci C, Vulicevic ZR, Ferrari M. Ferrule effect: a literature review. J Endod 2012: 38: 11-19.

(37) Asmussen E, Peutzfeldt A, Sahafi A. Finite element analysis of stresses in endodontically treated, dowel-restored teeth. J Prosthet Dent 2005: 94: 321-329.

(38) Mohammadi N, Kahnamoii MA, Yeganeh PK, Navimipour EJ. Effect of fiber post and cusp coverage on fracture resistance of endodontically treated maxillary premolars directly restored with composite resin. J Endod 2009: 35: 1428-1432.

(39) Naumann M, Koelpin M, Beuer F, Meyer-Lueckel H. 10-year survival evaluation for glass-fiber-supported postendodontic restoration: a prospective observational clinical study. J Endod 2012: 38: 432-435.

(40) Bolhuis HPB, De Gee AJ, Feilzer AJ, Davidson CL. Fracture strength of different core build-up designs. Am J Dent 2001: 14: 286-290.

(41) Hayashi M, Sugeta A, Takahashi Y, Imazato S, Ebisu S. Static and fatigue fracture resistances of pulpless teeth restored with post-cores. Dent Mater 2008: 24: 1178-1186.

(42) Zicari F, Van Meerbeek B, Scotti R, Naert I. Effect of fibre post length and adhesive strategy on fracture resistance of endodontically treated teeth after fatigue loading. J Dent 2012: 40: 312-321.

(43) Aggarwal V, Singla M, Miglani S, Kohli S. Comparative evaluation of fracture resistance of structurally compromised canals restored with different dowel methods. J Prosthodont 2012: 21: 312-316.

(44) Nissan J, Dmitry Y, Assif D. The use of reinforced composite resin cement as compensation for reduced post length. J Prosthet Dent 2001: 86: 304-308.

(45) Nissan J, Barnea E, Carmon D, Gross M, Assif D. Effect of reduced post length on the resistance to fracture of crowned, endodontically treated teeth. Quintessence Int 2008: 39: 179-182.

(46) Scotti N, Scansetti M, Rota R, Pera F, Pasqualini D, Berutti E. The effect of the post length and cusp coverage on the cycling and static load of endodontically treated maxillary premolars. Clin Oral Investig 2011: 15: 923-929.

(47) Giovani AR, Vansan LP, de Sousa Neto MD, Paulino SM. In vitro fracture resistance of glass-fiber and cast metal posts with different lengths. J Prosthet Dent 2009: 101: 183-188.

(48) Aquilino SA, Caplan DJ. Relationship between crown placement and the survival of endodontically treated teeth. J Prosthet Dent 2002: 87: 256-263.

(49) Mannocci F, Bertelli E, Sherriff M, Watson TF, Ford TR. Three-year clinical comparison of survival of endodontically treated teeth restored with either full cast coverage or with direct composite restoration. J Prosthet Dent 2002: 88: 297-301.

(50) Magne P, Knezevic A. Influence of overlay restorative materials and load cusps on the fatigue resistance of endodontically treated molars. Quintessence Int 2009: 40: 729-737.

(51) Biacchi GR, Basting RT. Comparison of fracture strength of endocrowns and glass fiber post-retained conventional crowns. Oper Dent 2012: 37: 130-136.

(52) Lander E, Dietschi D. Endocrowns: a clinical report. Quintessence Int 2008: 39: 99-106.

(53) Bernhart J, Brauning A, Altenburger MJ, Wrbas KT. Cerec3D endocrowns--two-year clinical examination of CAD/CAM crowns for restoring endodontically treated molars. Int J Comput Dent 2010: 13: 141-154.

(54) Bindl A, Windisch S, Mormann WH. Full-ceramic CAD/CIM anterior crowns and copings. Int J Comput Dent 1999: 2: 97-111.

(55) Rocca G, Rizcalla N, Krejci I. Fiber-Reinforced Resin Coating for Endocrown Preparations: A Technical Report. Oper Dent 2012.

(56) Bindl A, Richter B, Mormann WH. Survival of ceramic computer-aided design/manufacturing crowns bonded to preparations with reduced macroretention geometry. Int J Prosthodont 2005: 18: 219-224.

(57) Mormann WH, Brandestini M, Lutz F, Barbakow F. Chairside computer-aided direct ceramic inlays. Quintessence Int 1989: 20: 329-339.

(58) Otto T. Computer-aided direct all-ceramic crowns: preliminary 1-year results of a prospective clinical study. Int J Periodontics Restorative Dent 2004: 24: 446-455.

(59) Kunzelmann KH, Jelen B, Mehl A, Hickel R. Wear evaluation of MZ100 compared to ceramic CAD/CAM materials. Int J Comput Dent 2001: 4: 171-184.

(60) Attia A, Abdelaziz KM, Freitag S, Kern M. Fracture load of composite resin and feldspathic all-ceramic CAD/CAM crowns. J Prosthet Dent 2006: 95: 117-123.

(61) Dietschi D, Magne P, Holz J. Recent trends in esthetic restorations for posterior teeth. Quintessence Int 1994: 25: 659-677.

(62) Manhart J, Chen HY, Neuerer P, Scheibenbogen-Fuchsbrunner A, Hickel R. Three-year clinical evaluation of composite and ceramic inlays. Am J Dent 2001: 14: 95-99.

(63) Magne P, Schlichting LH, Maia HP, Baratieri LN. In vitro fatigue resistance of CAD/CAM composite resin and ceramic posterior occlusal veneers. J Prosthet Dent 2010: 104: 149-157.

(64) McDonald AV, King PA, Setchell DJ. In vitro study to compare impact fracture resistance of intact root-treated teeth. Int Endod J 1990: 23: 304-312.

(65) Lutz F, Krejci I, Imfeld T, Elzer A. [The hydrodynamic behavior of dentinal tubule fluid under occlusal loading]. Schweiz Monatsschr Zahnmed 1991: 101: 24-30.

(66) Holmes DC, Diaz-Arnold AM, Leary JM. Influence of post dimension on stress distribution in dentin. J Prosthet Dent 1996: 75: 140-147.

(67) Bortolotto T, Doudou W, Stavridakis M, Ferrari M, Krejci I. Marginal adaptation after aging of a self-etching adhesive containing an antibacterial monomer. J Adhes Dent 2007: 9: 311-317.

(68) Groten M, Girthofer S, Probster L. Marginal fit consistency of copy-milled all-ceramic crowns during fabrication by light and scanning electron microscopic analysis in vitro. J Oral Rehabil 1997: 24: 871-881.

(69) Schmalz G, Federlin M, Reich E. Effect of dimension of luting space and luting composite on marginal adaptation of a class II ceramic inlay. J Prosthet Dent 1995: 73: 392-399.

(70) Krejci I, Lutz F, Reimer M, Heinzmann JL. Wear of ceramic inlays, their enamel antagonists, and luting cements. J Prosthet Dent 1993: 69: 425-430.

(71) Mannocci F, Ferrari M, Watson TF. Intermittent loading of teeth restored using quartz fiber, carbon-quartz fiber, and zirconium dioxide ceramic root canal posts. J Adhes Dent 1999: 1: 153-158.

(72) Hayashi M, Takahashi Y, Imazato S, Ebisu S. Fracture resistance of pulpless teeth restored with post-cores and crowns. Dent Mater 2006: 22: 477-485.

(73) Sorrentino R, Salameh Z, Zarone F, Tay FR, Ferrari M. Effect of post-retained composite restoration of MOD preparations on the fracture resistance of endodontically treated teeth. J Adhes Dent 2007: 9: 49-56.

(74) Newman MP, Yaman P, Dennison J, Rafter M, Billy E. Fracture resistance of endodontically treated teeth restored with composite posts. J Prosthet Dent 2003: 89: 360-367.

(75) Fokkinga WA, Le Bell AM, Kreulen CM, Lassila LV, Vallittu PK, Creugers NH. Ex vivo fracture resistance of direct resin composite complete crowns with and without posts on maxillary premolars. Int Endod J 2005: 38: 230-237.

(76) Hannig C, Westphal C, Becker K, Attin T. Fracture resistance of endodontically treated maxillary premolars restored with CAD/CAM ceramic inlays. J Prosthet Dent 2005: 94: 342-349.

(77) Loney RW, Moulding MB, Ritsco RG. The effect of load angulation on fracture resistance of teeth restored with cast post and cores and crowns. Int J Prosthodont 1995: 8: 247-251.

(78) Volwiler RA, Nicholls JI, Harrington GW. Comparison of three core buildup materials used in conjunction with two post systems in endodontically treated anterior teeth. J Endod 1989: 15: 355-361.

(79) Pene JR, Nicholls JI, Harrington GW. Evaluation of fiber-composite laminate in the restoration of immature, nonvital maxillary central incisors. J Endod 2001: 27: 18-22.

(80) Hu YH, Pang LC, Hsu CC, Lau YH. Fracture resistance of endodontically treated anterior teeth restored with four post-and-core systems. Quintessence Int 2003: 34: 349-353.

(81) Schmitter M, Huy C, Ohlmann B, Gabbert O, Gilde H, Rammelsberg P. Fracture resistance of upper and lower incisors restored with glass fiber reinforced posts. J Endod 2006: 32: 328-330.

(82) Grandini S, Goracci C, Tay FR, Grandini R, Ferrari M. Clinical evaluation of the use of fiber posts and direct resin restorations for endodontically treated teeth. Int J Prosthodont 2005: 18: 399-404.

(83) Monticelli F, Goracci C, Ferrari M. Micromorphology of the fiber post-resin core unit: a scanning electron microscopy evaluation. Dent Mater 2004: 20: 176-183.

(84) Stewardson DA, Shortall AC, Marquis PM, Lumley PJ. The flexural properties of endodontic post materials. Dent Mater 2010: 26: 730-736.

(85) Chuang SF, Yaman P, Herrero A, Dennison JB, Chang CH. Influence of post material and length on endodontically treated incisors: an in vitro and finite element study. J Prosthet Dent 2010: 104: 379-388.

(86) Nissan J, Barnea E, Bar Hen D, Assif D. Effect of remaining coronal structure on the resistance to fracture of crowned endodontically treated maxillary first premolars. Quintessence Int 2008: 39: 183-187.

(87) Sornkul E, Stannard JG. Strength of roots before and after endodontic treatment and restoration. J Endod 1992: 18: 440-443.

(88) Gladys S, Van Meerbeek B, Lambrechts P, Vanherle G. Microleakage of adhesive restorative materials. Am J Dent 2001: 14: 170-176.

(89) Tan PL, Aquilino SA, Gratton DG, et al. In vitro fracture resistance of endodontically treated central incisors with varying ferrule heights and configurations. J Prosthet Dent 2005: 93: 331-336.

(90) Hikita K, Van Meerbeek B, De Munck J, et al. Bonding effectiveness of adhesive luting agents to enamel and dentin. Dent Mater 2007: 23: 71-80.

(91) Tsitrou EA, Northeast SE, van Noort R. Evaluation of the marginal fit of three margin designs of resin composite crowns using CAD/CAM. J Dent 2007: 35: 68-73.

10. APPENDIX

APROVACIÓN DEL PROYECTO DE TESIS

CARTA APROVACIÓN CER

CARTA DE APROVACIÓN CAD

CERTIFICADO ESTANCIA EN LA UNIVERSITÉ DE GENÈVE

INFORME DE LA UNIVERSITÉ DE GENÈVE

ARTÍCULOS ORIGINALES PUBLICADOS