©Operative Dentistry, 2013, **38-6,** 663-673

Composite vs Ceramic Computer-aided Design/ Computer-assisted Manufacturing Crowns in Endodontically Treated Teeth: Analysis of Marginal Adaptation

A Ramírez-Sebastià • T Bortolotto • M Roig
I Krejci

Clinical Relevance

In adhesive dentistry, the computer-aided design/computer-assisted manufacturing composite crown offers a superior option to the ceramic crown in the restoration of endodontically treated anterior teeth.

SUMMARY

Objectives: To compare the marginal adaptation between ceramic and composite CEREC crowns in endodontically treated teeth restored with endocrowns or with a short or a long post.

Methodology: Forty-eight intact maxillary incisors were used. After endodontic treatment, the crowns were sectioned 2 mm coronally to the cemento-enamel junction, which provided a ferrule of 2 mm. The prepared teeth were divided randomly into six groups (n=8). Group 1 was restored with a large fiberglass post,

*Anaïs Ramírez-Sebastià, MD, DDS, Universitat Internacional de Catalunya, Department of Endodontic and Restorative Dentistry, C/Josep Trueta s/n, Sant Cugat del Valles, Barcelona 08195, Spain

Tissiana Bortolotto, Geneva School of Dentistry, Department of Cariology and Endodontology, Rue Barthélémy-Menn 19, Geneva, 1205, Switzerland

Miguel Roig, MD, PhD, Universitat Internacional de Catalunya, Restorative Dentistry, Josep Trueta s/n, Sant Cugat del Valles, Barcelona 08195, Spain

Ivo Krejci, Geneva School of Dentistry, Department of Cariology and Endodontology, Rue Barthélémy-Menn 19, Geneva, 1205, Switzerland

*Corresponding author: Universitat Internacional de Catalunya, Department of Endodontic and Restorative Dentistry, C/Josep Trueta s/n, Sant Cugat del Valles, Barcelona 08195 Spain; e-mail: annaisramses@uic.es

DOI: 10.2341/12-208-L

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, Kerr-Hawe 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, sand-blasted 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

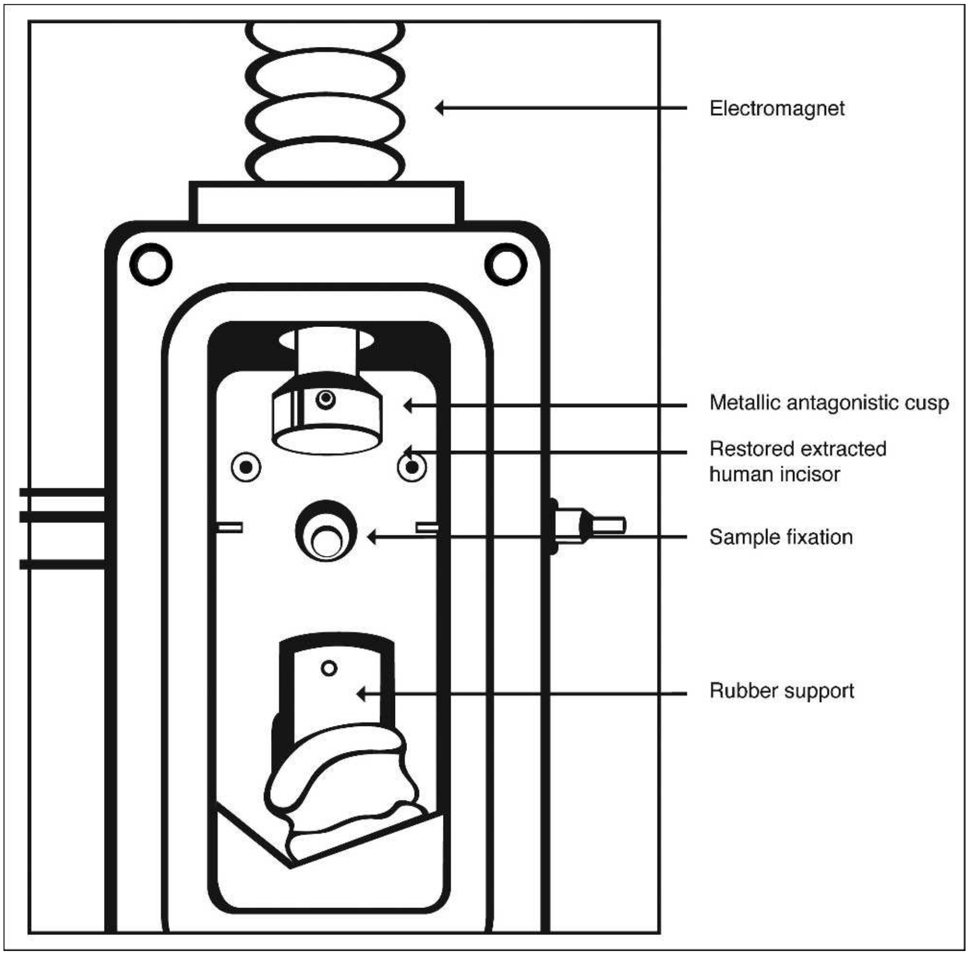

Figure 1. *Custom made device used for occlusal loading of the samples.*

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 thermomechanical loading in the computer-controlled chewing machine without loss of retention or fracture and could be used for the quantitative analysis of marginal adaptation.

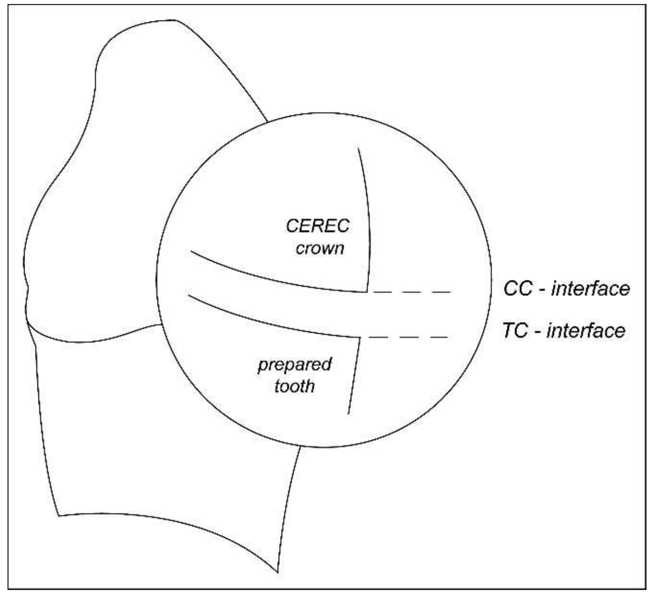

Figure 2. *Tooth–luting cement interface (TC) and luting cement–crown interface (CC).*

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

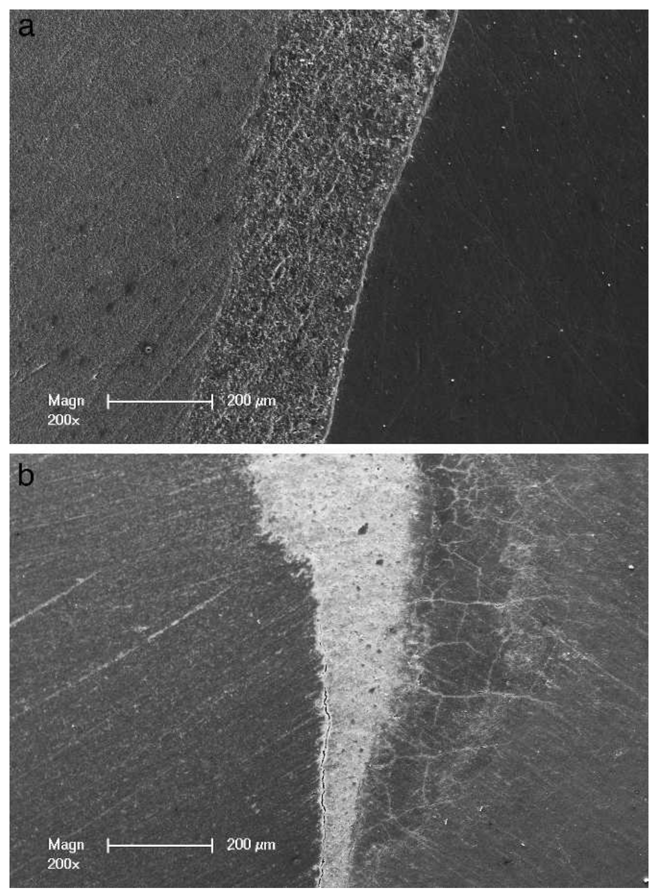

Figure 3. *SEM photographs (200×) of marginal interfaces of a CEREC anterior crown. Left: dentin; right: restoration. (a) Composite anterior endocrown (EndoCpr) after thermomechanical loading. (b) Ceramic anterior endocrown (EndoCer) after thermomechanical loading, with small cracks in the dentin.*

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.