Marginal Adaptation of 1 Fiber-Reinforced Composite and 2 All-Ceramic Inlay Fixed Partial Denture Systems

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Purpose: The aim of this in vitro study was to evaluate the marginal adaptation and retention of inlay fixed partial dentures (IFPDs) made with 1 fiber-reinforced composite and 2 different ceramic materials using quantitative scanning electron microscope analysis after thermal cycling and mechanical loading, which simulated approximately 5 years of oral service. ***Materials and Methods:*** Eighteen IFPDs made with fiber-reinforced composite (SR Adoro/Vectris), zirconium oxide-TZP (Cercon), and magnesia partially stabilized zirconia (DC-Leolux) covered with silica-based ceramics were tested in this study. The specimens were mechanically loaded in the vestibular cusp of the pontic element in a computer-controlled masticator with 1,200,000 half-sinusoid mechanical cycles of maximum 49 N each at a frequency of 1.7 Hz. A total of 3,000 thermocycles at 5°C and 55°C, 2 minutes each, were performed simultaneously. The marginal adaptation was analyzed at the interface of the luting composite and the abutment inlay/onlay (CI) and at the interface of the tooth and the luting composite (TC). ***Results:*** The percentages of continuous margin at the CI interface were 94.6 ± 3.1 and 88 ± 6.7 for Adoro/Vectris, 92.9 ± 5 and 85.7 ± 6.1 for Cercon, and 96.2 ± 2.1 and 82.2 ± 9.8 for DC-Leolux, respectively, before and after loading. The percentages of continuous margin at the TC interface were 86.7 ± 6.7 and 62.5 ± 16.4 for Adoro/Vectris, 93.3 ± 3.4 and 83.2 ± 5.9 for Cercon, and 96.1 ± 2.4 and 75.3 ± 7 for DC-Leolux. Statistically significant differences were found after loading between the fiber-reinforced composite and the 2 ceramic systems at the TC interface. ***Conclusion:*** Within the limitations of this experimental study with regard to the sample size and contacting vectors, the results showed that flexibility of the framework may play an important role in the marginal adaptation of the IFPDs. More rigid materials may transfer less stress to the margins, thus promoting a more stable adhesion to the dental tissues. *Int J Prosthodont 2006;19:373–382.*

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Missing single-tooth situations present several reconstructive treatments modalities. The traditional method is reconstruction with a conventional metal-ceramic fixed partial denture (FPD).[1] This technique requires a full-coverage preparation of the abutment teeth. Consequently, a large quantity of sound tooth structure is destroyed during the preparation.[2] This is particularly problematic in healthy and young teeth with large pulpal chambers. In order to limit this destruction and thanks to the evolution of adhesive dentistry[3] and implantology, adhesive FPDs[4] and dental implants[5] represent the current alternatives. These treatments have several advantages to conventional FPDs, especially regarding conservation of tooth structure and reversibility.[6] Nevertheless, when an implant is contraindicated or refused by the patient, metal-free restorative options may be attractive. The use of composite or ceramic compared to metal alloys offers better bonding properties to composite cements, more appropriate biomechanical behavior, and enhanced esthetics. Inlay, onlay, and partial crown-anchored FPDs can be bonded to adjacent teeth and show acceptable short-term results.[7,8] Fiber-reinforced composites (FRC),[9] high-strength reinforced ceramics,[10] and a combination of these 2 materials[11] have been proposed for the fabrication of metal-free inlay FPDs (IFPDs).

FRC is a new material group with a significantly shorter history of use than more traditional materials. Glass fibers have been reported to considerably improve the strength of dental polymers when the fibers were silanated and preimpregnated with the polymer.[12] The combination of resin composite and fiber seems to better comply with stress and provides a straightforward procedure in the laboratory because casting is unnecessary.[13] After simulation of oral stresses, the fracture resistance and marginal adaptation of IFPDs made with FRC were better than those of all-ceramic restorations.[14]

Clinicians' interest in all-ceramic systems is rapidly increasing as stronger and tougher materials are developed and commercialized along with novel processing technologies. Recently, this development has led to the application of zirconia-based ceramics in dentistry. Moreover, computer-aided design/computer-assisted manufacture (CAD/CAM) is among the most recent advances in dental technology for direct fabrication of all-ceramic restorations.[15] The framework must then be veneered with conventional feldspathic porcelain in order to simulate the appearance of the natural dentition. Adjustments via grinding may be required to improve the fit of the restoration, and sandblasting of the inner surface of the restoration is often used to enhance the adhesion of the luting agent to the framework.[16] Yttrium oxide, a stabilizing oxide, is added to pure zirconia (Y-TZP) to stabilize it at room temperature and to generate a multiphase material known as partially stabilized zirconia. The high initial strength and fracture toughness of Y-TZP results from the physical properties of partially stabilized zirconia. The so-called transformation toughening ability of Y-TZP—to transform from a tetragonal crystalline structure to a more voluminous monoclinic structure that helps to prevent crack propagation—contributes to the strength and toughness of the ceramic.[17,18] In vitro studies of Y-TZP specimens have demonstrated a flexural strength of 900 to 1,200 MPa. Y-TZP-based materials have demonstrated a fracture toughness of 9 to 10 $MPam^{1/2}$, which is almost twice the value demonstrated by alumina-based materials, and almost 3 times the value demonstrated by lithium disilicate–based materials.[19] An in vitro study evaluating Y-TZP FPDs under static load demonstrated a fracture resistance of more than 2,000 N.[20]

Issues still in question are the loading forces that can be withstood and the quality of marginal adaptation that might be reached with FRC and high-strength ceramic systems when used for IFPD restorations. The most relevant mechanical properties for reduction of clinical failures during loading are flexural strength and fracture toughness, but little information is available on IFPDs. Since mechanical failure is mainly caused by excessive stresses or deformation, which can have a destructive effect on the tooth-restoration interface, a full understanding of the stress fields that develop in FPDs becomes particularly important. On one hand, some studies with finite element analysis[21,22] suggest that IFPDs made with FRC may be a viable alternative to traditional, more invasive FPDs. Resiliency of the composite may prevent the development of harmful stresses at the adhesive interface, and reinforcement of the fibers may protect the pontic from excessive strains, thus allowing the restoration to withstand high functional loads. On the other hand, zirconia-ceramic IFPDs exhibited the highest fracture resistance compared to metal-ceramic and glass-ceramic FPDs, and the failures of all-ceramic FPDs were always cohesive (located at the connector area that represent the weakest parts of the FPD).[23]

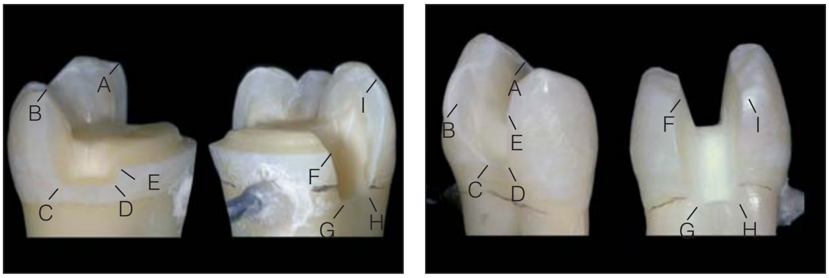
These studies provide insight into a number of biomechanical issues, but they do not reveal the marginal adaptation at the tooth-restoration interface during occlusion and clenching. Although these new materials showed positive mechanical behavior, further investigations should be performed on their marginal quality.

The aim of this in vitro study was to evaluate the marginal adaptation of IFPDs made with 1 FRC and 2 different all-ceramic high-strength materials using quantitative scanning electron microscope (SEM) analysis after simultaneous thermal cycling and mechanical loading with dentinal fluid that simulated approximately 5 years of oral service. The null hypothesis was that there is no difference between the marginal adaptation of the IFPDs before and after fatigue using materials with varying flexural strengths and Young's moduli.

Materials and Methods

Thirty-six human caries-free molars and premolars of nearly identical size with completed root growth that were stored in a 0.1% thymol solution were selected for this study. The teeth were randomly and equally divided into 3 groups. The apex of each root was sealed with an adhesive bonding system and resin composite (Optibond FL, Kerr) without removal of pulpal tissue and fixed with the composite onto aluminum bases.

Fig 1 The holding device. Teeth were blocked together at a distance of 10 mm to prevent any movement.



Figs 2a and 2b The onlay preparation in the molar (**a**) and inlay cavity in the premolar (**b**) had mesial margin in the enamel (*left*) and distal margin in the dentin (*right*). The margins were divided into different portions to analyze the marginal adaptation in a selective way. A–B: occlusal enamel; B–C, D–E: approximal enamel; C–D: cervical enamel; F–G, H–I: approximal dentin; G–H: cervical dentin.

Afterwards, the teeth and aluminum bases were immersed in an autopolymerizing resin (Technovit 4071, Heraeus-Kulzer) to an apical depth of two thirds of the root length to create a strong load-resistant support. Each pair of teeth (1 molar and 1 premolar) was blocked together with the same autopolymerizing resin, with a distance of 10 mm between each tooth to prevent movement during the preparation, impression, and luting procedures. In this way, the device simulated an edentulous space resulting from the loss of 1 molar. A plastic holding device with 2 holes was used as a support for the IFPDs. Two rubber dampers slightly taller than the holes were placed in the holding device to simulate the resilience of the human periodontium.[24] Eccentric holes were drilled into the rubber dampers to create a larger distance between the abutments and to increase the tilting of the abutments toward the gap when placed under load. The diameter of the rubber dumpers was the same as the aluminum bases. In this way, the load was distributed equally to the underlying structure, thus avoiding interference with the marginal adaptation.[25,26] One holding device with the same distance between the rubber dumpers was created (Fig 1). To simulate the intrapulpal pressure during cavity preparations and luting procedures, a cylindrical cavity was prepared in each pulpal chamber 1.5 mm below the amelocementum junction. A metal tube with a diameter of 1.4 mm was luted into the cavity with the same adhesive and composite used to fix the roots onto the bases. The pulpar chamber was evacuated with a vacuum pump (Vacubrand) through a connecting silicone tube, filled with a bubble-free mixture of horse serum (PAA Laboratories) and phosphate-buffered saline solution (PBS, Oxoid) with the aid of a 3-way valve, and then connected to a serum-infusion bottle. This bottle was placed vertically 34 cm above the specimen to simulate the normal hydrostatic pressure of 25 mm Hg within the tooth until the test was terminated.

Tooth Preparation

Different cavity preparations were made on the teeth to simulate this frequent clinical situation and to create the space accommodation for the different structure frameworks. The cavities were prepared with a rotating diamond bur (25 to 80 µm grain size, FG 8113NR, 3113NR; Intensiv; Sirius 180 XL red contra-angle handpiece, Micro-Mega) with water cooling.

The inlay preparation in the premolar was a mesial-occlusal-distal cavity with the mesial margin in dentin 1 mm below the cementoenamel junction (CEJ), and the distal margin in enamel 1 mm above the CEJ. The vestibular-palatal width was 3 mm at the cervical margin and increased to 4 mm at the upper part of the cavity; the cervical preparation width was 2 mm, similar to the occlusal depth. The onlay preparation in the molar was a 2-cusp partial covering with the mesial margin in dentin 1 mm below the CEJ and the distal margin in enamel 1 mm above the CEJ. The vestibular-palatal width was equal to that of the premolar preparation and the reduction of the cusps was 2.5 mm, with 2 mm of occlusal depth in the central fossa (Figs 2a and 2b).

All dentin surfaces were sealed immediately after the tooth preparation with a 3-step adhesive system (Optibond FL, Kerr; batch no. 25881). Phosphoric acid (Ultraetch, Ultradent) was applied to the dentin for 15 seconds and then rinsed for 30 seconds. The primer was spread on the dentin for 30 seconds with a microbrush without scrubbing and then the adhesive was applied to the dentin. After a minimum penetration time of 20 seconds, the resin was air thinned and polymerized (Optilux 500, Demetron) for 60 seconds. Butt joint cavity finishing lines were finished under a stereomicroscope (Leica MZ6) with a diamond bur (25 µm grain size, no. 3113 NR) with water cooling. The polymerized adhesive was removed with the same diamond bur only from the cavity enamel finish lines, without touching the sealed dentin. Impressions were made with Imprint II polyvinyl siloxane (3M ESPE) with a simultaneous mixing technique according the manufacturer's instructions. Provisional restorations were made with Fermit N (Ivoclar Vivadent) and inserted without interim cement to simulate the clinical procedure.

Laboratory Manufacturing Process

Eighteen IFPDs were made using 3 different materials with different flexural strengths and Young's moduli. FRC (SR Adoro/Vectris, Ivoclar Vivadent) (Figs 3a and 3b), zirconium oxide-TZP (Cercon, DeguDent) and magnesia partially stabilized zirconia (DC-Leolux, DCS Dental) covered with silica-based ceramics were tested in this study (Figs 3a and 3b).

The FRC system (group 1) consisted of 2 materials: glass fibers with different orientations (Vectris) and a microfilled composite (Adoro) for the veneering of the fiber framework. The design of the fiberglass framework was premodeled with a photo-curing resin (Spectra Tray, Ivoclar) to obtain the oval shape, and its thickness checked against the molding model. The model was embedded in a transparent silicone impression paste (Transil) to form a mold. Next, this resin was removed and the fibers were applied into the silicone mold. The pre-impregnated pontic fibers were condensed in a deep-drawing polymerization process. After a cycle of vacuum-forming processes and then light curing in a VS1 unit (Ivoclar Vivadent) for 10 minutes according to the manufacturer's recommendations, the FRC was sandblasted using the Rocatec system (3M ESPE) with a small grain size of 80 μm at 2.5 bar of pressure for 10 seconds, and then treated with silane (Wetting agent, Ivoclar Vivadent). A sheet of wave fibers framework was placed on the pontic structure and VS1 cycle was repeated. The Adoro material was built incrementally using the quick pre-curing light unit. The final polymerization/tempering was performed in the Lumamat 100 unit by means of light and heat curing. An additional tempering step at 104°C was performed to maximize the strength and surface quality of the restorations.

Cercon (group 2) is a CAM system that can produce a framework of zirconium oxide-TZP. The Cercon brain machine automatically mills the framework from an unsintered zirconium oxide blank (Cercon base). Next, the chalky-soft state is sintered in the Cercon heat furnace at 1,350°C. Finally, the framework is veneered with low-fusing dental ceramic (Cercon ceram S) specially tailored to the coefficient of the thermal expansion of zirconium oxide.

The principle of the Precident system (DCS Dental) (group 3) is based on touchless, contact-free measurement and milling in a CAD/CAM process. These 2 operations are separated for organizational reasons. The data of the abutments are taken with the help of a noncontact laser (Preciscan), which at maximum resolution can take 300,000 points/minute. The acquired data are transferred by modem to the milling machine (Precimill), which prepares the substructure from a sintered magnesia partially stabilized zirconia (DC-Leolux). Finally, the framework is covered with low-fusing ceramic (Cercon ceram S). The framework of the ceramic IFPDs (groups 2 and 3) was extended up to 1 mm of the margins of the cavity preparation in order to have etchable silica-based ceramic on the closing margins and to optimize the adhesion with tooth tissue. All connections of the inlay/onlay with the pontic elements were 3.5 × 3.5 mm.

Adhesive Procedure

Provisional restorations were removed and the inner surfaces of the teeth previously sealed with bonding were sandblasted with CoJet system (3M ESPE) using a small grain size of 30 μm at 2 bar of pressure for 2 seconds. The inner surfaces of the FRC and the zirconium area of the ceramic IFPDs were treated with CoJet system (30 μm at 2 bar for 10 seconds). The closing ceramic margins were etched with 10% hydrofluoric acid for 60 seconds and 2 layers of silane-coupling agent (Monobond S, Ivoclar Vivadent) were applied and heated for 1 minute (ID 500, Colténe) on all inner surfaces. All enamel and dentin surfaces were luted with Optibond FL and Tetric Transparent (Ivoclar Vivadent) using the ultrasonic technique according to the manufacturer's instructions. The luting cement was light activated for 60 seconds each for the cervical, buccal, lingual, and occlusal surfaces. The margins of the restorations were then finished with 15 μm diamond burs (Composhape, Intensiv) and polished with a composite finishing and polishing kit (Hawe Neos Dental) using a slow-speed handpiece (Fig 4).

Evaluation

The samples were cleaned with rotating nylon brushes (Hawe Neos) and dentifrice (Signal Anti Caries) before making the impressions for the replicas. Seven partial impressions for each FPD before and after the thermal and mechanical tests were taken to compare the quality of the marginal adaptation. Six different regions—approximal enamel, approximal dentin, cervical enamel, cervical dentin, and occlusal and buccal enamel—were recorded to identify the areas with greater stress (Fig 5). Gold-sputtered (SCD 030, Provac) epoxy resin replicas (Epofix, Struers) of all samples were fabricated using polyvinylsiloxane impressions (President Plus Light-body, Colténe) and subjected to a quantitative evaluation of marginal adaptation at a standard 200×

Figs 3a and 3b Lateral view of the IFPD made with (**a**) FRC (Adoro/Vectris) and (**b**) zirconium oxide-TZP tetragonal zirconia (Cercon).

Fig 4 Adhesive IFPD made with FRC after the luting procedures.

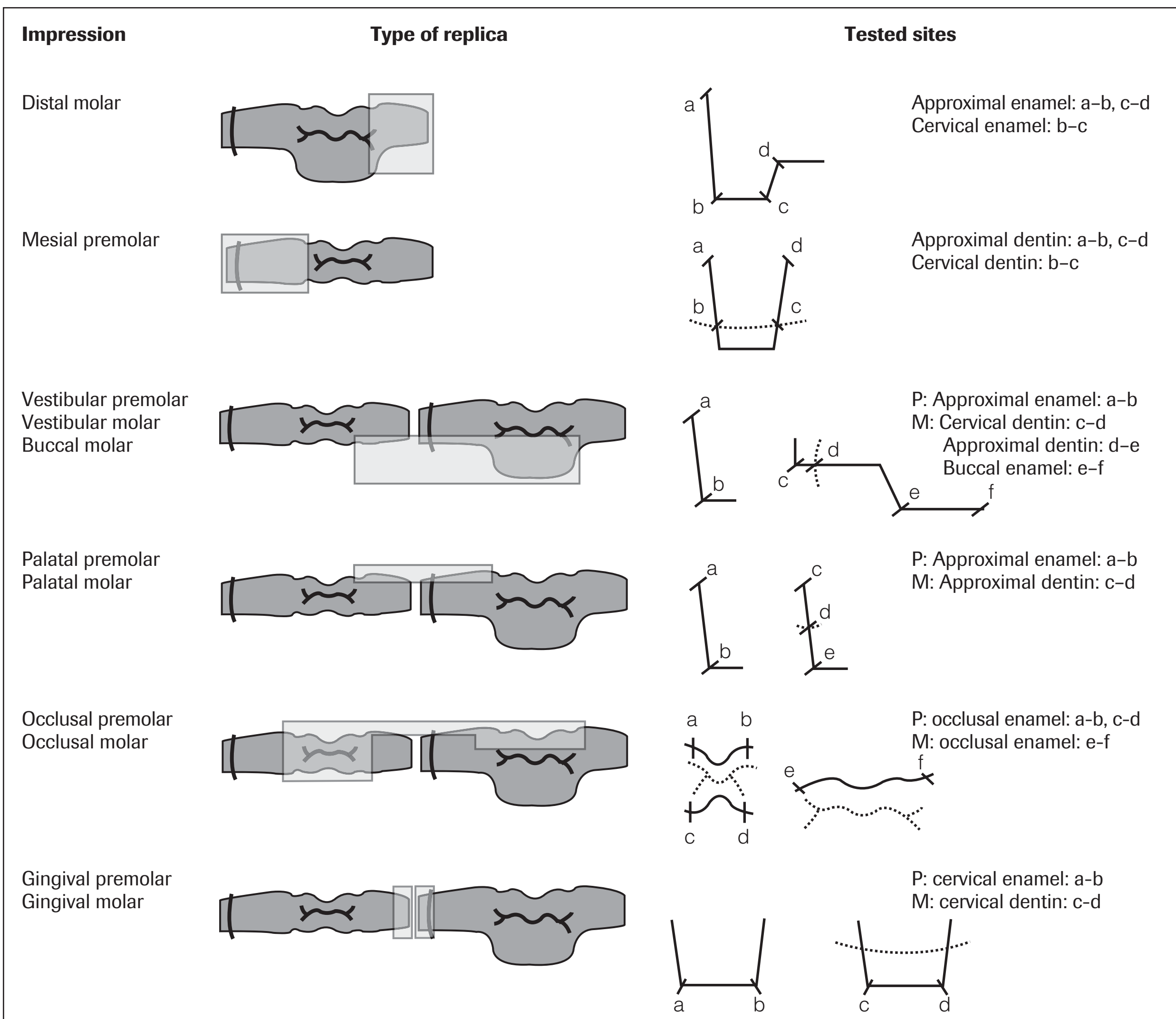


Fig 5 Outline of the nondestructive replica technique. P = premolar; M = molar.

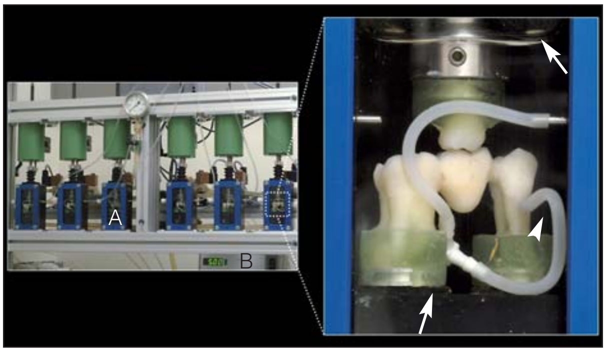


Fig 6 Loading machine with 6 watertight cells (A) and the thermocycle device (B). (*right*) The *black arrow* indicates the rubber dampers that increased the tilting of the abutments when placed under load. The *arrowhead* points to the silicone tube filled with a mixture of horse serum and phosphate-buffered saline solution used to simulate the intrapulpal pressure during all stress cycles. The *white arrow* shows the level of the water during the thermocycles.

Table 1 Percentage of Continuous Margin for the Total Marginal Length Before and After Loading (Means ± SD) at the CI and TC Interfaces

	Adoro/Vectris	Cercon	DC-Leolux
CI interface			
Before loading	94.6 ± 3.1	92.9 ± 5	96.2 ± 2.1
After loading	88.0 ± 6.7	85.7 ± 6.1	82.2 ± 9.8
TC interface			
Before loading	86.7 ± 6.7	93.3 ± 3.4	96.1 ± 2.4
After loading	62.5 ± 16.4	83.2 ± 5.9	75.3 ± 7.0

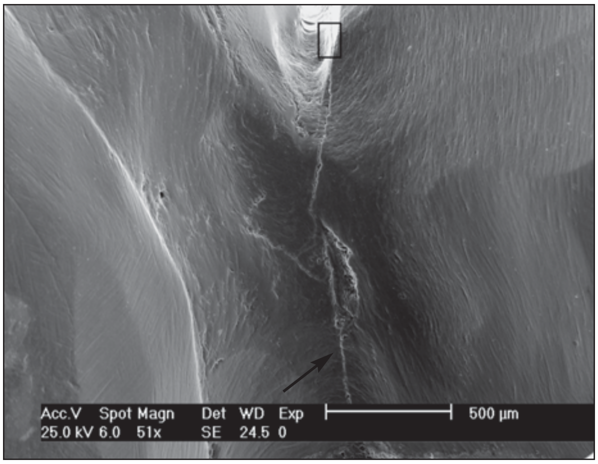
magnification using SEM (XL20, Philips) with a custom-made module programmed within image processing software (Scion Image, Scion). All specimens were subjected to quantitative evaluation and examined for continuous margins (no gap, no interruption of continuity), noncontinuous margins (gap due to adhesive or cohesive failure, fracture of restorative material, or fracture of enamel related to restoration margins), overhangs, and underfilled margins. The percentages of continuous/noncontinuous margin were evaluated separately for tooth-luting composite and luting composite-restoration interfaces. The specimens were mechanically loaded at the vestibular cusp of the pontic element in a computer-controlled masticator with 1,200,000 cycles of 49 N each at a frequency of 1.7 Hz. Flat palatal cusps of maxillary first molars were used as an antagonist to ensure that the vestibular cusps did not slide into the central fossa of the pontic element. In this way, the contacting vectors of all FPDs were similar in each sample because the main loading was parallel to the long axis of the abutments. A total of 3,000 thermocycles at 5°C to 55°C to 5°C were performed simultaneously (Fig 6). The chamber was automatically emptied after 2 minutes with 10 seconds of air pressure to avoid mixing the cold and warm water.[27,28] By having the specimen holders mounted on a rubber rest, a sliding movement of the FPDs was produced during loading. These conditions are believed to simulate approximately 5 years of clinical service.[29,30] Differences in means were compared with the use of matched paired *t* tests and 1-way analysis of variance (ANOVA). The level of significance was set at $P = .05$.

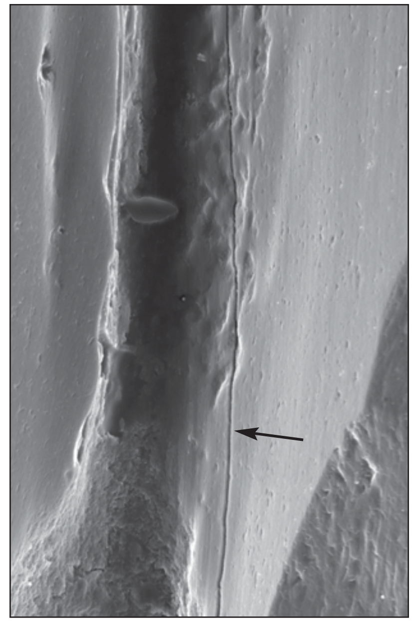
Results

All restorations were still in place after the stress test was complete, meaning that the retention amounted to 100% for all groups. No fractures of the restorations or abutments were found after fatigue loading. Only 2 hairline fractures of the veneering material, which spread into the buccal and vestibular areas, were found in the gingival part of the connection between the pontic and the abutment tooth in the FRC group (Figs 7a and 7b).

Marginal adaptation was analyzed at the interface of the luting composite and the abutment inlay/onlay (CI) and at the interface of the tooth and luting composite (TC) (Fig 8). The results of the marginal adaptation are shown in Table 1. Statistically significant differences ($P < .05$) were found for all groups before and after loading concerning the percentage of continuous margins as the total marginal length at the CI and TC interfaces. No differences were observed after the cycle test between the 3 groups at the CI interface (Fig 9). However, significant differences were found after loading between the FRC group and the 2 ceramic systems at the TC interface (Fig 10).

The prevailing marginal defect in all groups was pure marginal opening (Figs 11a and 11b). Some fractures found after the final observation were traced to enamel-dentinal fractures (EF) and filling fractures (FF). No significant difference was detected in the subfracture of the dental tissue (EF) near the margin between the 3 groups. However, significant differences ($P < .05$) were found in hairline cracks in the restoration (FF) along the margins between DC-Leolux (4.1%), FRC (0.4%), and Cercon (1.7%) after loading. In some cases,





Figs 7a and 7b Hairline fracture of the veneering material in the gingival part of the connection between the pontic and the abutment in the FRC group. The *arrow* indicates the microcrack that spread into the vestibular area. The *black frame* (*above*) indicates the fissure in the resin composite, which is also shown at 200× magnification (*right*).

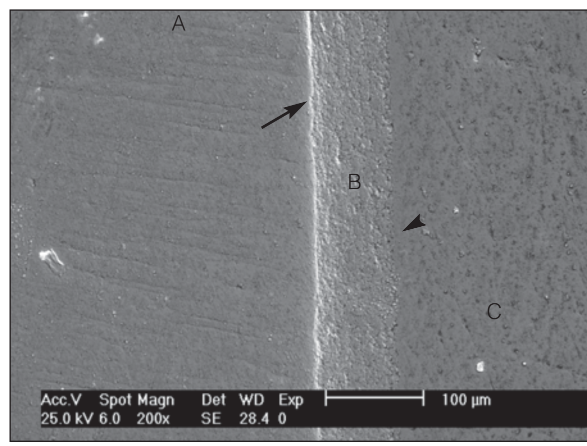


Fig 8 Continuous margin of the FRC restoration. A = the enamel; B = the luting cement; C = the restoration. The *arrow* indicates the TC interface; the *arrowhead* indicates the CI interface.

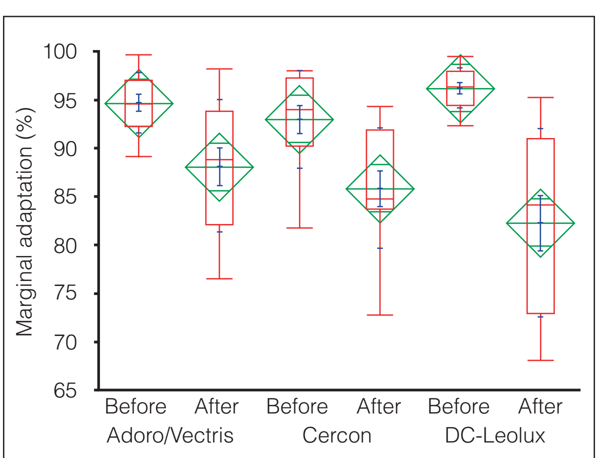


Fig 9 Continuous margin at the CI interface with quantities (*red lines*), means/ANOVA (*green lines*), and means and SDs (*blue lines*).

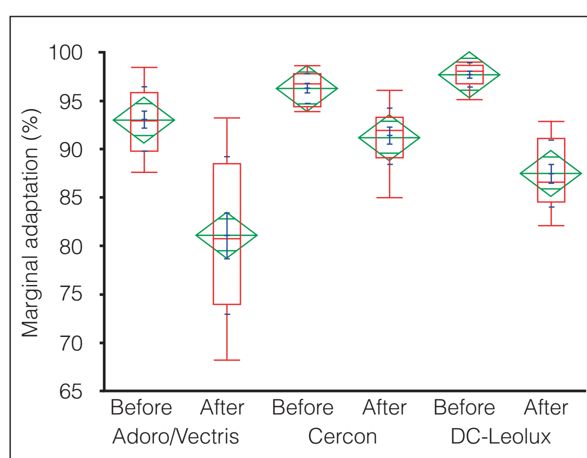
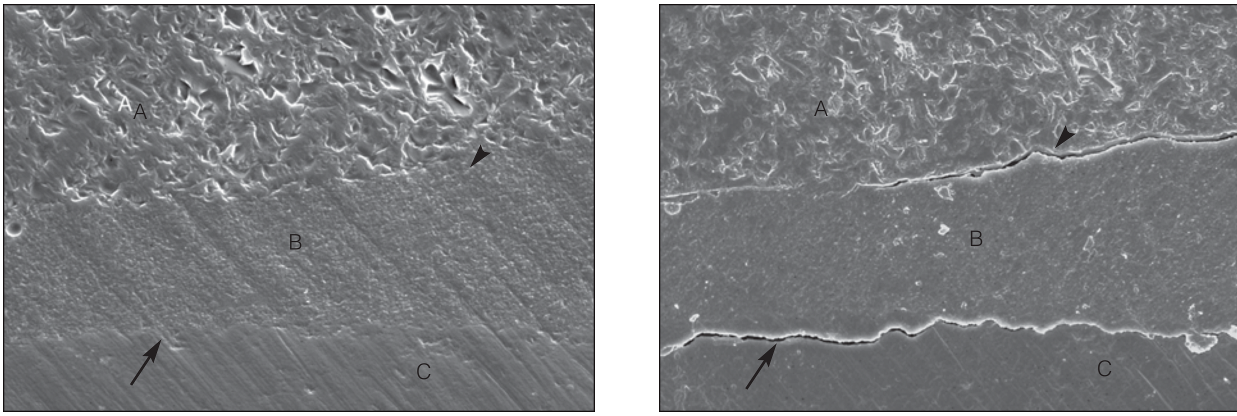


Fig 10 Continuous margin at the TC interface with quantities (*red lines*), means/ANOVA (*green lines*), and means and SDs (*blue lines*).



Figs 11a and 11b The same portion before (*left*) and after (*right*) the stress cycles. The inner area (A) shows the ceramic restoration (Cercon), the middle area (B) shows the luting cement, and the lower area (C) shows the dental tissue. The *arrowheads* and *arrows* indicate the continuous (*left*) and noncontinuous (*right*) margins as a result of the simulated 5-year period.

noncontinuous pure margin identified only as open margin changed in EF or FF. No more than 0.5% of overhangs and underfilled margins were found before and after loading, with no significant differences among the groups. No difference in continuous margin was detected between approximal enamel and approximal dentin. The within-group comparisons between the onlay preparation (molar) and the inlay cavity (premolar) did not show significant differences ($P > .05$). Severe changes in continuous margin were detected at the TC interface in the dentinal margin after the test. The values were 20.8% for group 1, 53.8% for group 2, and 32.2% for group 3. Significant differences were found between Cercon and the other 2 groups ($P < .05$).

Discussion

Although this study has some limitations in terms of its clinical relevance, especially regarding the restricted sample sizes, the absence of detachments or fractures of the IFPDs suggests that both ceramic and FRC systems could be used in clinical practice. Nevertheless, some remarks must be made regarding the quality of the margins and the hairline fractures found in the FRC group. The most critical area in FPDs and particularly in IFPDs is the connection at the gingival portion of the pontic between the abutments, because this surface constitutes the tensile side of the beam.[31] When occlusal forces are applied directly to the long axis of the FPD at the midspan (pontic), compressive stresses will develop at the occlusal aspect of the connector at the marginal ridge, and tensile stresses will develop at the gingival surface of the connector.[32] These tensile stresses could contribute to the propagation of microcracks at the gingival surface of the connector through the veneering material in an occlusal direction, and may eventually result in fracture of the composite. The presence of hairline fractures in the gingival area of the pontic in 2 IFPDs of the FRC group could be related to the greater flexibility of the fiber framework compared to the ceramic materials supported by zirconia. These microcracks can compensate for the reduced stiffness of the fiber, but could lead to delamination or fracture of the layering material.

The clinical fracture resistance of IFPDs is related to span of the pontic and the size, shape, and position of the connectors. The basis for the proper design of the connectors and the pontic is the law of beams: deflection of a beam increases as the cube of its length, is inversely proportional to its width, and is inversely proportional to the cube of its height.[33] Moreover, the flexibility of the beam is in direct relation to the amount and type of fibers that compose the framework. The position of the FRC layer had an effect on the flexural strength of the test specimen. The highest flexural strength was achieved when the FRC layer was located at the tension side of the test specimens. The particulate filler composite was the weakest part of the test specimen; when it is located on the tension side, fracture can easily result. The FRC structure benefits most when the tensile stresses can be transferred to the reinforcing fibers. The veneering particulate filler composite is strong in compression stress, and thus the FRC structure requires fewer reinforcement fibers on the compression side.[34]

Usually, it is better to place the FRC laminates symmetrically to the FRC framework to prevent polymerization shrinkage effects and deformations, as well as thermal stresses.[35] Nevertheless, it is often very difficult to design the FRC framework with an optimal design because of the abutment location and occlusal parameters.

One theoretical assertion is that lower-elastic modulus frameworks would produce a better stress transfer to the tooth and reduce tensile stresses at the adhesive interface,[36] although no scientific evidence has shown this to be true. Vallittu[37] hypothesized that a lower modulus of elasticity might allow the FPD to deflect to some extent during function without the formation of stresses that may cause debonding. Brunton et al[38] preferred restorative materials such as FRCs to ceramic materials because of the their flexibility, repairable properties, and equivalent fracture resistance. They reported that FRC materials showed similar fracture resistance when compared to ceramic materials under compressive loads for posterior restorations.

Contrary to these results, in our study the direct comparison between FRC and ceramic-reinforced systems suggests that different materials could have an influence on the quality of the margin, primarily at the TC interface. In any case, the null hypothesis was rejected. The statistical difference between the FRC and the all-ceramic restorations may be related to their varying levels of flexibility. Our results may suggest that the reduced stiffness of FRC can negatively influence the marginal adaptation under load. The fiber framework may absorb the stress generated during loading, but the increased flexibility might have led to opening of the margins.

Any significant differences between approximal enamel and approximal dentin was found within each group for both interfaces after the fatigue test. All margins are in enamel but deferred from the base of the cavity box. The first margin continues in the cervical enamel and the second continues in the cervical dentin. The opening of the margin in the cervical dentin does not have an influence on the overhanging enamel. The bonding between the luting composite and the enamel is so strong that the gap created at the dentin interface stopped at the CEJ. Marginal adaptation at the dentinal margins decreased dramatically after mechanical loading. The percentage of continuous margin changed from 21% to 54% after the test. A significant difference was found between the stiffer system (Cercon) and the other 2 groups. Regardless, the disintegration of the margins in dentin was so high in all groups that the IFPDs could be contraindicated when 1 or both abutments have margins in dentin, until the adhesion between the luting composite and the dentin is improved.

The marginal adaptation at the CI interface decreased after mechanical and thermal loading, but no significant differences were found between all groups. The values ranged between 82.2% and 88%.

Successful ceramic-resin bonding is achieved by the formation of chemical bonds and micromechanical interlocking at the resin-ceramic interface. With conventional silica-based ceramics, acid etching and application of a silane-coupling agent create a rough surface of increased wettability for successful ceramic resin bonds. Zirconium-oxide ceramics are not silica based and the application of acidic agents, such as hydrofluoric acid, does not create a sufficiently roughened surface for enhanced micromechanical retention. Advances in adhesive dentistry have resulted in the recent introduction of modern surface conditioning methods such as silica coating that require airborne particle abrasion of the surface before bonding to achieve high bond strength. In this technique, the surfaces are air abraded with aluminum oxide particles modified with silica.[39,40] The blasting pressure results in the embedding of silica into the ceramic surface, rendering the silica-modified surface more chemically reactive for the resin with silane-coupling agents. The tribochemical silica coating followed by silanization, which increased the silica content on the ceramic surface, evidently enhanced the bond between the ceramic surfaces and the luting cement. Since the silica layer is well attached to the ceramic surface, this provides a basis for silanes to enhance the resin bond. Airborne particle abrasion with aluminium oxide abrasive particles has proven to be effective both for composite and aluminium- and zirconium-oxide ceramics.[41] In this study, the adhesion between dental tissue and all-ceramic IFPDs was increased, leaving 1 mm or more of silica-based ceramic along the margins without zirconia at the interface. This treatment may explain the good results of the marginal adaptation at both adhesive interfaces of the all-ceramic systems.

Conclusions

Within the limitations of this experimental study with regard to the samples size and contacting vectors, several conclusions can be drawn. The flexibility of the framework may play an important role in the marginal adaptation of adhesive inlay/onlay FPDs. More rigid materials may transfer the stress to the margin to a smaller degree than flexible materials, which may result in a more stable bond to the dental tissues under load. When FRCs are used for IFPDs, high-fiber volume fraction and a well-designed framework shape is necessary to increase the maximum stiffness of the IFPDs. All-ceramic systems reinforced with zirconia could be used for IFPDs in clinical practice, but a simplified CAD/CAM technique is required to allow faster construction of the zirconia framework. As the marginal adaptation in dentin after load was low in all groups, IFPDs may be contraindicated when abutment margins reach dentin, independent of the material used, until adhesion between the luting cement and the dentin is improved.

References

1. Valderhaug J. A 15-year clinical evaluation of fixed prosthodontics. Acta Odontol Scand 1991;49:35–40.
2. Edelhoff D, Sorensen JA. Tooth structure removal associated with various preparation designs for posterior teeth. Int J Periodontics Restorative Dent 2002;22:241–249.
3. Perdigão J, Lopes M. Dentin bonding—State of the art 1999. Compend Contin Educ Dent 1999; 20:1151–1162.
4. Freilich MA, Duncan JP, Meiers JC. Preimpregnated, fiber-reinforced prostheses. Part I. Basic rationale and complete-coverage and intracoronal fixed partial denture designs. Quintessence Int 1998;29:689–696.
5. Leal FR, Cobb DS, Denehy GE, Margeas RC. A conservative aesthetic solution for a single anterior edentulous space: Case report and one-year follow-up. Pract Proced Aesthet Dent 2001;13:635–641.
6. Lutz F, Göhring TN. Fiber-reinforced inlay fixed partial dentures: maximum preservation of dental hard tissue. J Esthet Dent 2000;3:164–171.
7. Göhring TN, Schmidlin PR, Lutz F. Two-year clinical and SEM evaluation of glass-fiber-reinforced inlay fixed partial dentures. Am J Dent 2002;15:35–40.
8. Monaco C, Ferrari M, Miceli GP, Scotti R. Clinical evaluation of fiber-reinforced composite inlay FPDs. Int J Prosthodont 2003;16:319–325.
9. Krejci I, Boretti R, Giezendanner P, Lutz F. Adhesive crowns and fixed partial dentures fabricated of ceromer/FRC: Clinical and laboratory procedures. Pract Periodontics Aesthet Dent 1998;10:487–498.
10. Edelhoff D, Spiekermann H, Yildirim M. Metal-free inlay-retained fixed partial dentures. Quintessence Int 2001;32:269–281.
11. Rosentritt M, Behr M, Handel G. Fixed partial dentures: All-ceramics, fiber-reinforced composites and experimental systems. J Oral Rehabil 2003;30:873–877.
12. Karmaker AC, Di Benedetto AT, Goldberg AJ. Continuous fiber reinforced composite materials as alternatives for metal alloys used for dental applicances. J Biomater Appl 1997;11:318–328.
13. Vallittu PK. Prosthodontic treatment with a glass fiber-reinforced resin-bonded fixed partial denture: A clinical report. J Prosthet Dent 1999;82:132–135
14. Loose M, Rosentritt M, Leibrock A, Behr M, Handel G. In vitro study of fracture strength and marginal adaptation of fiber-reinforced-composite versus all ceramic fixed partial dentures. Eur J Prosthodont Restor Dent 1998;6:55–62.
15. Wiedhahn K. Cerec 3 as the first step in digitizing the dental office. Int J Comput Dent 2000;3:67–71.
16. Kern M, Wegner SM. Bonding to zirconia ceramic: Adhesion methods and their durability. Dent Mater 1998;14:64–71.
17. Ardlin BI. Transformation-toughned zirconia for dental inlays, crowns and bridges: Chemical stability and effect of low-temperature aging on flexural strength and surface structure. Dent Mater 2002;18:590–595.
18. Williams D. Ceramics transformed: Manipulating crystal structures to toughen bioceramics. Med Device Technol 1997;8:6–8.
19. Christel P, Meunier A, Heller M, Torre JP, Peille CN. Mechanical properties and short-term in-vivo evaluation of yttrium-oxide-partially-stabilized zirconia. J Biomed Mater Res 1989;23:45–61.
20. Tinschert J, Natt G, Mautsch W, Augthun M, Spiekermann H. Fracture resistance of lithium disilicate-, alumina-, and zirconia-based three-unit fixed partial dentures: A laboratory study. Int J Prosthodont 2001;14:231–238.
21. Magne P, Perakis N, Belser U, Krejci I. Stress distribution of inlay-anchored adhesive fixed partial dentures: A finite element analysis of the influence of restorative materials and abutment preparation design. J Prosthet Dent 2002;87:516–527.
22. Tanimoto Y, Nishiwaki T, Nemoto K. Numerical failure of glass-fiber-reinforced composites. J Biomed Mater Res. 2004;68A: 107–113.
23. Kılıçarslan MA, Kedici PS, Küçüke?men HC, Uludag BC. In vitro fracture resistance of posterior metal-ceramic and all-ceramic inlay-retained resin-bonded fixed partial dentures. J Prosthet Dent 2004;92:365–370.
24. Kolbeck C, Rosentritt M, Behr M, Lang R, Handel G. In vitro examination of the fracture strength of 3 different fiber-reinforced composites and 1 all-ceramic posterior inlay fixed partial denture systems. J Prosthodont 2002;11:248–253.
25. Göhring TN, Schmidlin PR, Lutz F. Marginal adaptation of inlay-retained adhesive fixed partial dentures after mechanical and thermal stress: An in vitro study. J Prosthet Dent 2001;86:81–92.
26. Krejci I, Lutz F, Gautschi L. Wear and marginal adaptation of composite resin inlays. J Prosthet Dent 1994;72:233–244.
27. Krejci I, Reich T, Lutz F, Albertoni M. An in vitro test procedure for evaluating dental restoration systems. 1. A computer-controlled mastication simulator [in German]. Schweiz Monatsschr Zahnmed 1990;100:953–960.
28. Krejci I, Kuster M, Lutz F. Influence of dentinal fluid and stress on marginal adaptation of resin composites. J Dent Res 1993;72:490–494.
29. 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.
30. Krejci I, Lutz F. In-vitro test results of the evaluation of dental restoration systems. Correlation with in-vivo results [in German]. Schweiz Monatsschr Zahnmed 1990;100:1445–1449.
31. Magne P, Versluis A, Douglas WH. Rationalization of incisor shape: Experimental-numerical analysis. J Prosthet Dent 1999;81:345–355.
32. Kelly JR, Tesk JA, Sorensen JA. Failure of all-ceramic fixed partial dentures in vitro and in vivo: Analysis and modeling. J Dent Res 1995;74:1253–1258.
33. Raigrodski A. Contemporary materials and technologies for all-ceramic fixed partial dentures: A review of the literature. J Prosthet Dent 2004;92:557–562.
34. Murphy J. Reinforced Plastics Handbook, ed 2. Oxford: Elsevier, 1998:237–267.
35. Lassila LVJ, Vallittu PK. The effect of fiber position and polymerization condition on the flexural properties of fiber-reinforced composite. J Contemp Dent Pract 2004;2:14–26.
36. Vallittu PK, Sevelius C. Resin-bonded, glass fiber-reinforced composite fixed partial dentures: A clinical study. J Prosthet Dent 2000;84:413–418.
37. Vallittu PK. Survival rates of resin-bonded, glass fiber–reinforced composite fixed partial dentures with a mean follow-up of 42 months: A pilot study. J Prosthet Dent 2004;91:241–246.
38. Brunton PA, Cattell P, Burke FJ, Wilson NH. Fracture resistance of teeth restored with onlays of three contemporary tooth-colored resin-bonded restorative materials. J Prosthet Dent 1999;82:167–171.
39. Kern M, Wegner SM. Bonding to zirconia ceramic: Adhesion methods and their durability. Dent Mater 1998;14:64–71
40. Özcan M. The use of chairside silica coating for different dental applications: A clinical report. J Prosthet Dent 2002;87:469–472.
41. Derand P, Derand T. Bond strength of luting cements to zirconium oxide ceramics. Int J Prosthodont 2000;13:131–135.