Fracture Resistance of Three Ceramic Inlay-Retained Fixed Partial Denture Designs. An In Vitro Comparative Study

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Keywords
Inlay-retained fixed partial denture; ceramic; fracture resistance.

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Accepted August 25, 2009

doi: 10.1111/j.1532-849X.2010.00621.x

Abstract

Purpose: The fracture resistance of ceramic inlay-retained fixed partial dentures (CIRFPDs) was studied.
Materials and Methods: Thirty CIRFPDs were constructed using ice zircon milled ceramic material. Specimens were divided into three groups, 10 specimens each, according to the abutment preparation: inlay-shaped (occluso-proximal inlay + proximal box), tub-shaped (occluso-proximal inlay), and proximal box-shaped preparations. Each group was then subdivided into two subgroups of five specimens each, according to the span of the edentulous area representing a missing premolar or molar. All specimens were subjected to a fracture resistance test.
Results: CIRFPDs with inlay-shaped retainers showed the highest fracture resistance values for missing premolars and molars. CIRFPDs with box-shaped retainers showed lower fracture resistance values. Statistical analysis revealed a significant difference between the three tested CIRFPD designs. There was a statistically significant difference between CIRFPDs constructed for the replacement of molars and those constructed for the replacement of premolars. The CIRFPD constructed for the replacement of molars gave lower fracture resistance values with the three tested designs. All the fracture resistance values obtained in this study were superior to the assumed maximum mastication forces. Failure mode was delamination and chipping of the veneering material.
Conclusions: There was a statistically significant difference between the three designs of CIRPFDs tested. There was a statistically significant difference between CIRFPDs constructed for the replacement of molars than those constructed for the replacement of premolars. The CIRFPDs constructed for the replacement of molars gave lower fracture resistance values with the three tested designs. All fracture resistance values obtained in this study were superior to the assumed maximum mastication forces.

A significant disadvantage of porcelain-fused-to-metal and all-ceramic fixed partial dentures (FPDs) is the removal of a large amount of sound tooth structure of the abutment teeth. Although implant-supported FPDs are highly qualified alternatives to tooth-supported FPDs, patients often refuse this option due to their high cost and/or their surgical intervention.[1,2] An inlay-retained FPD (IRFPD) is, however, a less-invasive treatment modality and a more conservative option for restoration of damaged teeth, because it requires minimal tooth reduction, preserves healthy tooth structure, and maintains the periodontal tissue's integrity.[3–6] IRFPDs are, therefore, alternatives to both anterior and posterior complete coverage conventional restorations.[7–11]

IRFPDs can be constructed by using dental alloys, ceramic materials, and fiber-reinforced composite. Clinical results for metal IRFPDs are considered favorable; however, visibility of the metal retainer and the change in natural tooth translucency are considered esthetically unfavorable. Failures of inlay-retained, all-ceramic FPDs are delamination, chipping of the veneer, and debonding of at least one inlay retainer.

Although the use of all-ceramic materials in dentistry has become increasingly important, early generations of all-ceramic IRFPDs often fail to withstand posterior mastication forces, and their use is limited by the special mechanical properties of the material. Yet with the introduction of densely sintered yttria-tetragonal zirconia polycrystal (Y-TZP) and the ability of Y-TZP to prevent crack propagation, the production of strong inlay-anchored FPDs has become possible.[12–15]

The fracture strength of materials depends on several factors, including the elastic modulus of the supporting substructure, the properties of the luting agent, the thickness of restoration, and the preparation design.[16–17] Song et al[18] studied the effects of two preparation designs and pontic distance on bending and fracture strength of fiber-reinforced composite inlay FPDs. They concluded that the box-shaped tooth preparation may be considered for restoration of a missing single posterior tooth with fiber-reinforced inlay adhesive FPDs.

Kiliçarslan et al[3] studied the in vitro fracture resistance of posterior metal-ceramic and all-ceramic inlay-retained resin-bonded FPDs. They reported that zirconia-based, inlay-retained, resin-bonded FPDs showed surprising resistance to fracture, in comparison to metal-ceramic full-coverage FPDs.

In a study of the fracture strength of all-ceramic posterior IRFPDs, Wolfart et al[19] reported that when considering the maximum chewing forces in the molar region it seems clinically possible to use yttria partially stabilized zirconia (YPSZ) as a core material for IRFPDs with a connector size between 9 and 16 mm.[2] Ohlmann et al[12] concluded from their clinical study that improved adhesion between resin cement and inlay retainer is desirable before general recommendation of all-ceramic IRFPDs.

The purpose of this study was to test the in vitro fracture resistance of three ceramic IRFPD (CIRFPD) designs fabricated with a newly introduced zirconia-based ceramic.

Materials and methods

Model construction

Twelve artificial teeth representative of four maxillary first and second premolars and first and second molars (three teeth each) received the different preparation designs for IRFPDs. Each artificial tooth received one preparation. The intracoronal preparation procedures were performed in accordance with general principles for ceramic intracoronal ceramic restorations.[5]

Intracoronal preparations of the abutments (inlay, tub-shaped, and proximal box-shaped) had the following dimensions: The inlay preparation consisted of an occluso-proximal box and was designed with rounded internal edges, smooth rounded corners, and rectangular floor without bevels at the occlusal or gingival margins. The occlusal inlay had a preparation depth that allowed a thickness of 2.0 mm for the ceramic. The occlusal preparation was 4 mm wide and extended 4 or 6 mm mesiodistally for the premolar or molar models, respectively. The proximal box was 1 mm wide and had approximately 6° divergence, extending 2 mm apical to the isthmus floor.[18] The preparations corresponded to a proximal connector area of 4 mm × 4 mm for molars and premolars. The tub-shaped preparation consisted of an occluso-proximal inlay and was prepared with the same dimensions as the inlay-shaped preparation, except for the proximal box preparation. The proximal box featured the same dimensions as the proximal box of the inlay-shaped preparation. Dimensions were measured with a digital caliper ruler.

The prepared teeth were inserted and bonded using self-cure acrylic resin (Acrostone, WHW Plastics, East Yorkshire, UK) in six prefabricated acrylic casts (El-Banna, Alexandria, Egypt). The sockets of the missing teeth were filled with self-cure acrylic resin and shaped in the form of a ridge.

The distances between the abutments were set to 7 and 11 mm, to represent the loss of a premolar and molar, respectively.[20] The premolar was prepared with an occlusodistal and the molar with a occlusomesial intra-coronal preparation.

Impression of the prepared teeth and the edentulous area was performed using addition silicone elastomeric impression material (Virtual, Ivoclar Vivadent, Schaan, Liechtenstein) with putty-wash impression technique. Then the impression was poured using blue casting wax (Crown & Bridge, Bego, Bremen, Germany). The wax pattern was then sprued, invested, and cast in a cobalt–chromium alloy (Wironit, Bego). Therefore, standardized and nearly identical CIRFPDs were produced. To construct 30 CIRFPDs, six metallic partial models of the maxilla consisting of a missing posterior tooth (second premolar or first molar) with different type of preparation designs (inlay, tub, or proximal box) were constructed.

CIRFPD construction

Thirty bridges were constructed using ice zircon milled ceramic material (Zirkonzahn GmbH, Bruneck, Italy). Composite resin frames (Zirkonzahn GmbH) were constructed. Then using the concept of precision copy milling, ice zircon blocks were manually milled using "the zirkograph," a special milling device After milling, frameworks were colored with color liquid (Zirkonzahn GmbH), dried, and sintered in a special oven ("zirkonofen"). The frameworks were then checked for seat and margin fit, sandblasted, cleaned, and finally veneered using ice zircon ceramics. All steps were performed according to manufacturer instructions.

Grouping

Specimens were divided into three groups, ten specimens each, according to abutment preparation. These three groups were inlay-shaped, tub-shaped, and proximal box-shaped preparations. Each group was subdivided into two subgroups of five specimens each, according to the edentulous span representing a missing premolar or molar.

Fracture resistance test

Each metallic model was duplicated into five epoxy resin models (Kemapoxy 165, DMAG Co., Cairo, Egypt) to simulate the modulus of elasticity of normal teeth. The all-ceramic posterior IRFPDs were cemented on their corresponding epoxy resin models using adhesive cement (Multilink, Ivoclar Vivadent). The models were primed using the mixed Multilink primers. The cemented restorations were then stored in distilled water at 37 °C for 24 hours and then underwent thermocycling (6000 × 5–55 °C) with 30 seconds dwell time using a laboratory-made thermocycling apparatus. The testing assemblies "epoxy resin models + ceramic restorations" were then subjected to fracture resistance test. A universal testing machine (Lloyd Instruments, West Sussex, UK) was used. To prevent primary cracks at the point of loading, 0.5-mm thick tin foil was inserted between the steel ball and the pontic. Load was centrally applied from the occlusal direction on the pontic using a steel ball (Ø = 12 mm) with a crosshead speed of 1 mm/min until failure. Failure loads were determined, and their values (*N*) were recorded.

Table 1 Fracture resistance (SD) of the tested groups (*N*)

Design preparation	Inlay		Tub		Proximal box	
Edentulous area	Premolar	Molar	Premolar	Molar	Premolar	Molar
Means	1055[a] (43)	869[d] (36)	932[b] (43)	767[e] (49)	784[c] (65)	624[f] (41)

Different letters denote statistically significant difference.

Statistical tests

Data were collected, calculated, tabulated, and statistically analyzed using one-way ANOVA. A Tukey test was performed to determine significant differences between the tested groups using a confidence level of 0.05 ($\alpha < 0.05$).

Results

Means and standard deviations of the fracture resistance values for the tested groups are presented in Table 1. Results showed that the CIRFPDs with inlay-shaped retainers had the highest fracture resistance value. CIRFPDs with tub-shaped retainers recorded 932 N, 767 N for missing premolars, molars, respectively. CIRFPDs with box-shaped retainers design gave rise to the lowest fracture resistance values. Tukey's test revealed a statistically significant difference between the three CIRFPD designs. Results also showed that there was a statistically significant difference between CIRFPDs constructed for the replacement of molars and those constructed for the replacement of premolars. The CIRFPDs constructed for the replacement of molars gave lower fracture resistance values with the three tested designs. Fracture resistance values obtained in this study were superior to the assumed maximum mastication forces (500 N).[25] With regards to the fracture pattern, the observed mode of failure was delamination and chipping of the veneering material.

Discussion

Minimal or no tooth preparation of the abutment teeth is desirable for the replacement of missing teeth. IRFPDs require less tooth reduction and maintain the integrity of the periodontal tissues. Therefore they are a conservative option for the restoration of damaged teeth.[3] In this study, fracture resistance of zirconia-based CIRFPDs was evaluated using three types of preparations (inlay-shaped, tub-shaped, proximal box-shaped). Contrary to complete coverage retainers, inlay design used in IRFPDs is not standard.[4] Researchers have suggested various inlay designs, such as grooves, tub, box-shaped proximal preparations, and occluso-proximal preparations. They have also suggested the use of a rest seat on the occlusal surface, lingual tooth reduction, and retentive-slot preparations.[10,21-24] The size of these preparation features depends on the size of the tooth. The three tested designs are, in fact, the most used in CIRPFDs.[1,3,12,18,19,21]

A recently designed precision copy milling apparatus, "zirkograph," and zirconia-based ceramic material, "ice zircon," for the fabrication of all-ceramic restorations were used in this study. This ceramic has yttrium stabilized zirconium dioxide as at least 93.69% of its composition. A zirconia-based ceramic was selected for this study, due to the fact that zirconia-based CIRFPDs demonstrate higher fracture resistance than metal ceramic and glass ceramic.[3,19,25] Summitt et al[26] reported that for inlay restorations, ceramics are preferred due to their superior esthetic properties, their biocompatibility, and their reliable bonding procedures.

Kilicarslan et al[3] and Song et al[18] drew attention to one limitation in their studies—their specimens were not subjected to an artificial aging process, such as thermocycling and mechanical load. Artificial aging would have simulated negative effects on fracture strength, similar to what happens intraorally. To overcome this limitation in the present study, the tested specimens were subjected to a thermocycling process; however, loading under clinical conditions is likely to be different from in vitro loading, where masticatory forces may act in various directions and may cause torque.[3]

The results indicated that CIRPFDs with inlay-shaped retainers showed the highest fracture resistance values, followed by CIRPFDs with tub-shaped retainers and finally CIRPFDs with box-shaped retainers, which recorded the lowest fracture resistance values. Statistical analysis revealed that there was a significant difference between these three CIRPFD tested designs. This may be attributed to the fact that the inlay design may have provided greater surface area to resist the forces than the other two tested designs.[18] The inlay design had an additional 2 mm wall of its proximal box when compared to the tub-shaped design, which followed it in order of fracture resistance values recorded. Magne et al[25] demonstrated that connector preparation of CIRFPDs is important because it is a concentrated stress area. Wolfart et al[19] recommended the use of a connector size between 9 and 16 mm when of using YPSZ as a core material for IRFPDs. In this study, the maximum connector size recommended by Wolfart et al[19] was used to increase the fracture resistance of the specimens.

Results showed that the long-span CIRPFDs constructed for the replacement of a molar gave fracture resistance values lower than the short-span CIRPFDs constructed for the replacement of a premolar with all three tested designs. These results are in agreement with Nohrström et al[27] and Song et al.[18] This may be attributed to the fact that all FPDs flex slightly when subjected to a load. In other words, the longer the span is, the greater the flexing will be; however, the relationship between deflection and span length is not simply linear but varies with the cube of the span length. Excessive flexing under occlusal loads may cause failure of a long-span FPD. It can lead to fracture of a porcelain veneer, breakage of a connector, loosening of a retainer, or an unfavorable soft tissue response.[5]

Reviewing the literature, Korber and Ludwig[28] summarized that posterior FPDs must be strong enough to withstand a load of 500 N. They added that the highest bite force was found in the first molar region. At the same time, Hikada et al[29] assumed maximum mastication forces of about 500 N in the posterior chewing areas. The fracture resistance of zirconia-based CIRFPDs recorded by all the tested groups in this research exhibited mean values ranging between 624 and 1055 N. These results showed that the fracture resistance of zirconia-based CIRFPDs with different tested designs was greater than the maximum mastication forces. Therefore, these restorations may be strong enough for clinical applications.

By the evidence of fracture pattern, the failure mode observed in this research was delamination and chipping of the veneering material. These observations indicate that the weak points of zirconia-based CIRFPDs are the adhesion between the framework and the veneering materials and the strength of the veneering material itself. This may be due to the fact that the core is a YPSZ consisting of partially stabilized zirconia particles densely sintered, resulting in a final microstructure in which voids, flaws, and cracks are reduced to a minimum.[30] This result is in agreement with the clinical study published by Ohlmann et al[12] who used zirconia-based IRFPDs. Also, the transformation toughening mechanisms increase the fracture strength of the material;[31,32] however, this result may contradict Al-Dohan et al,[33] who reported that the adhesive failure between veneer and ceramic does not occur in the presence of a good bond between a compatible ceramic core and the veneering material.

The results recorded in this study showed a relatively high standard deviation (minimum 36 N, maximum 65 N). Similarly, Kiliçarslan et al[3] in an in vitro study of the fracture resistance of posterior metal-ceramic and all-ceramic IRFPDs, recorded higher standard deviations for inlay-retained zirconia-based ceramic FPDs. Laboratory construction defects were probably the reason for the variation noted, despite standardization of the specimens.

Conclusions

(1) There was a statistically significant difference between the three designs of CIRPFDs tested.
(2) There was a statistically significant difference between CIRFPDs constructed for the replacement of molars and those constructed for the replacement of premolars. The CIRFPDs constructed for the replacement of molars gave lower fracture resistance values with the three tested designs.
(3) All fracture resistance values obtained in this study were superior to the assumed maximum mastication forces.

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