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Relationship of Margin Design for Fiber-Reinforced Composite Crowns to Compressive Fracture Resistance

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Abstract

Purpose: Fiber-reinforced composite restorations provide excellent esthetics; however, little is known regarding the influence of margin design on marginal fit and fracture resistance for this type of crown. This study evaluated the effect of variations in tooth-preparation design on the marginal fit and compressive fracture resistance of fiber-reinforced composite crowns.
Materials and Methods: Three metal dies with a total convergence of 5° and different margin designs (0.5-mm light chamfer, 1.0-mm deep chamfer, and 1.0-mm shoulder) were prepared. Sixty standardized crowns (FibreKor) were made on duplicated base metal alloy dies ($n = 20$ for each margin design). Marginal fit was stereoscopically evaluated by measuring the distances between each of the four pairs of indentations on the crowns and on the dies. The specimens were then subjected to a compressive fracture-loading test using a universal testing machine. The data were analyzed with one-way analysis of variance (ANOVA) followed by Ryan-Einot-Gabriel-Welsch multiple-range test ($\alpha = 0.05$).
Results: Analysis of marginal fit and fracture resistance disclosed a statistically significant difference for tooth-preparation design ($p < 0.001$). The marginal adaptation of preparations with the 0.5-mm light chamfer (66.2 μm) and 1.0-mm deep chamfer (69.7 μm) was significantly better than preparations with a shoulder finish line (92.8 μm) ($p < 0.001$). The fracture strength of the preparations with the 0.5-mm light chamfer (15.8 MPa) and 1.0-mm deep chamfer (15.1 MPa) was significantly greater than those of the preparations with the 1.0-mm shoulder (13.7 MPa) ($p < 0.001$).
Conclusions: Marginal fit of fiber-reinforced crowns was adversely affected by tooth-preparation design. The marginal gaps were greater for the shoulder margin specimens than in the light or deep chamfer margin specimens; however, the fracture strength of the chamfer margin specimens was greater than that of the shoulder margin specimens.

Metal ceramic restorations continue to be a popular option for fixed prosthodontics, based on their clinical longevity and acceptable esthetics.[1] Recently, concern has been expressed regarding corrosion of metal alloys and unwanted allergic or toxic side effects affecting some patients and laboratory personnel.[2,3] Moreover, the artifacts on magnetic resonance tomography (MRT) and computer tomography (CT) caused by metal and alloy may result in attenuation of signal intensity, image distortion, and signal loss, which severely influence image quality.[4]

All-ceramic crowns have proved popular due to their outstanding esthetics, biocompatibility, and durability. In addition, the discoloration of the gingiva caused by metallic systems can be avoided.[5,6] However, improved esthetics have been associated with increased failure rates due to brittle catastrophic fracture and abrasive wear of the opposing natural teeth except with the use of current low-fusing ceramic. Moreover, increased costs have restricted extensive use of all-ceramic crown systems.[7,8] The potential of brittle catastrophic fracture and abrasive wear of the opposing natural teeth except with the use of current low-fusing ceramics are considered among these disadvantages.[9–12]

Demand continues within the dental profession for restorations exhibiting high strength, natural color, good wear resistance, marginal integrity, and ease of fabrication. With the introduction of new composite resins, including fiber-reinforced systems, the restoration or replacement of a single tooth or multiple teeth with a fiber-reinforced crown or metal-free partial dental prosthesis is now an option.[13-15] Fiber-reinforced composite restorations have the potential to address some of the problems associated with conventional restorative materials. The systems have impressive mechanical properties, leading to extensive engineering applications. Their strength-to-weight ratios are superior to those of most alloys. Compared to metals, they offer many other advantages, including the lack of corrosion, good translucency, good bonding properties, and ease of repair.[16,17] They also offer the potential for chairside and laboratory fabrication.[18-20] Moreover, these materials have advantages over ceramic materials, including higher flexural strength and lower opposing tooth wear; also, intraoral repair is less complicated.[21,22]

Marginal fit and fracture resistance are considered crucial factors in the success and longevity of an indirect restoration.[23] Marginal fit has never been strictly defined, and reference points for measurements vary considerably among clinicians; however, there are a large number of approaches to the measurement and assessment of marginal fit,[24-26] and although the results showed a high variation, most were within a clinically acceptable level, 100 μm.[27] Lin et al[28] reported that the finish line influenced the marginal adaptation of all-ceramic Procera crowns, while Pera et al[29] demonstrated that improved marginal fit was obtained with In-Ceram ceramic crowns fabricated on chamfer and 50° shoulder tooth preparations compared with 90° shoulder margins. Gavelis et al[30] suggested that the specific type of finish line helps the cement to escape, improving marginal adaptation in cast metal crowns; however, Syu et al[31] reported that cast crown fit was not influenced by the design of the finish line. A similar result was reported in another study.[32] Shearer et al[33] showed no significant difference between chamfer and shoulder margins in the fit of In-Ceram crowns; however, Sulaiman et al[34] and Grey et al[35] reported 160 μm and 123 μm marginal gap, respectively. Testing Celay In-Ceram, Beschnidt and Strub[36] reported mean marginal gaps of 78 μm in maxillary incisor crowns; however, Groten et al[23] reported a lower value of 18.3 μm. Moreover, Beschnidt and Strub[36] tested the marginal fit of IPS Empress 2 (Ivoclar Vivadent, Schaan, Liechtenstein) and found the marginal opening to be 62 μm, which was similar to the results of this study.

Compressive fracture resistance is affected by the modulus of elasticity of the supporting substructure, properties of the luting agent, tooth-preparation design, surface roughness, residual stress, and restoration thickness.[37-39] It was shown that tooth preparations with 1.2-mm shoulder margins produced the strongest Dicor crowns, while 0.8-mm deep chamfer margins produced the weakest restorations when cemented to metal dies.[40,41] However, other studies have reported that Dicor crowns luted with a resin luting agent were unaffected by the type of margin design prepared.[42]

Although several publications have characterized the materials science aspects of fiber-reinforced composites,[43-46] little mention has been made in the technical literature on the fracture resistance and marginal fit of fiber-reinforced composite crowns.[47] The purpose of this investigation was to evaluate the effect of variations in tooth-preparation design on the marginal fit and compressive fracture resistance of fiber-reinforced composite crowns. The null hypothesis was that margin-design modification of tooth preparations would have no influence on marginal fit and fracture resistance of fiber-reinforced composite crowns.

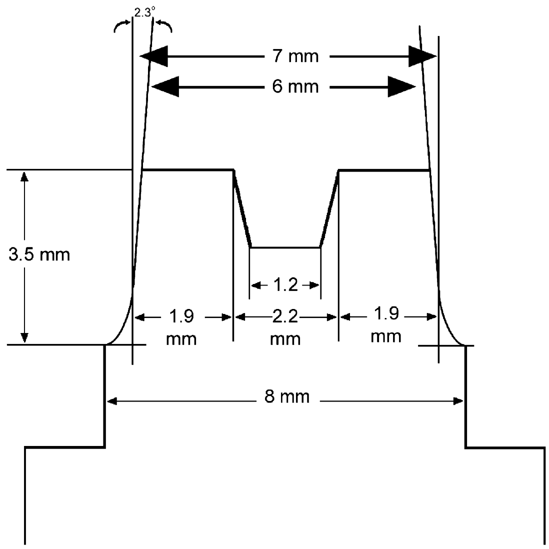

Figure 1 Longitudinal cross-section of master complete crown tooth preparation.

Materials and methods

Three metal master dies with one of three cervical margins were designed to simulate complete fiber-reinforced composite crown preparations (Fig 1). These comprised 0.5-mm light chamfer margin, 1.0-mm deep chamfer margin, and 1.0-mm shoulder margin with a sharp axiogingival line angle (Fig 2). Sixty impressions (20 impressions for each margin design) were made of the master metal dies with poly(vinyl siloxane) (Examix, GC America Inc., Chicago, IL) using a single-mix technique in individual polycarbonate trays (Ash Instruments, Potters Bar, UK). The impressions were poured with type IV

Figure 2 Metal master dies with different finish lines; Right, light chamfer (0.5 mm); Middle, deep chamfer (1.0 mm); Left, shoulder (1.0 mm).

die-stone (Jade stone, Whip Mix Corp., Louisville, KY). A custom cellulose acetate crown index of an intact ivorine molar tooth was used to standardize the fiber-reinforced composite crown dimensions.

Die hardener (Surface hardener, Renfert GmbH, Hil-Zingen, Germany) and die separator (Picosep, Renfert GmbH) were applied to the stone dies. Die spacer (Picosep) was applied to all dies. Copings (1-mm thick) made of Conquest/Sculpture (Jeneric/Pentron, Wallingford, CT) were photo-polymerized for 5 minutes on each die (Cure-light device). Then, one layer of the unidirectional-fiber preimpregnated FiberKor (shade clear, 6-mm width) was manually wrapped around the coping and photo-polymerized for a further 5 minutes. The crown was shaped using dentin and enamel facing material from Conquest/Sculpture. The fabrication procedure was completed with the cellulose acetate index. The completed restoration was post-polymerized in the Conquestomat device for 10 minutes at 107°C. After postpolymerization, final finishing was performed with stone points, rubber, and wheel instruments (Polierset, Ivoclar Vivadent, Schaan, Liechtenstein) following the manufacturer's recommendation. A total of 60 (20 for each margin design) FiberKor/Sculpture crowns were fabricated. One investigator prepared all specimens. Specimens were stored 24 hours in 100% humidity at 37°C.

For marginal fit measurements, the finished crowns were fit passively to their respective metal master dies. Four pairs of index indentations were placed with a 1/2 round bur at equal distances around the circumference of each specimen and the metal master dies; these represented mesial, lingual, buccal, and distal locations. These indentations served as specific points for determining marginal gap. A spring-loaded holding device with a force of 98 N, which permitted axial rotation of the specimen, was used to ensure the crowns fully seated on the master dies. The same examiner visually assessed the macroscopic fit of all copings on the respective dies prior to measurement. Copings with short margins or overhang on the finish line were rejected and replaced to ensure 20 copings per group. Using a 100× magnification light microscope (Nikon Measurement, MM-11, Nikon Inc., Garden City, NY), direct measurements in micrometers of the marginal gap were measured. The four measurements for each specimen were averaged. Gap distance was defined as the distance along a line perpendicular to the most cervical extent of the marginal level and the most cervical extension of the fiber-reinforced crown.

For fracture resistance, each crown was luted to its master metal die with dual-polymerizing resin luting agent (Nexus 2; Kerr Corp., Orange, CA) according to the manufacturer's instructions. Luted crowns were light polymerized for 3 minutes under 4.9 N of axial loading (LTC, Chatillon LTC, Greensboro, NC). Light intensity was 730 mW/cm^2, as measured by a radiometer (Optilux Model 100, SDS Kerr, Danbury, CT) at a 10-mm distance from the specimens. Excess cement was removed, and restoration margins were cleaned. The failure loads for luted crowns were determined with a 1/8-inch diameter cylindrical steel bar brought into contact with the center of the buccal and lingual triangular ridges in a universal testing machine (Model 4202, Instron Corp., Canton, MA) in compressive mode with a 0.05 mm/min crosshead speed. The maximum loads (N) were recorded and divided by the total surface area (mm^2) of the tooth preparation to obtain an estimate of the fracture resistance in megapascals (MPa). The surface area of the axial walls was calculated by the equation:

$$\text{Surface area} = \frac{\text{height of preparation}}{\cos(\text{taper}/2)} \times \frac{\text{circumference of (occlusal plane + finish line)}}{2}$$

The data were analyzed with one-way ANOVA followed by Ryan-Einot-Gabriel-Welsch multiple-range test ($\alpha = 0.05$).

Table 1 Margin gap and fracture resistance among different preparation designs

	Mean ± Standard deviation	
Margin design	Margin gap (μm)	Fracture strength (MPa)
Light chamfer	66.2 (10.9)^a	15.8 (1.7)^c
Deep chamfer	69.7 (7.4)^a	15.1 (1.7)^c
Shoulder	92.8 (15.8)^b	13.7 (2.1)^d

One-way ANOVA within column showed a significant difference in marginal gap and fracture strength of fiber-reinforced composite crowns ($p < 0.001$). Same letters (a, b, c and d) indicate values that were not significantly different ($p < 0.05$).

Results

One-way ANOVA revealed a statistically significant difference among marginal fits ($p < 0.001$) and between fracture resistance of each margin design ($p < 0.001$). The results of the marginal fit and the breaking strength are summarized in Table 1. The lowest mean marginal gap (SD) was obtained from preparations with the 0.5-mm light chamfer and 1.0-mm deep chamfer; however, the marginal gap (SD) for preparations with a 1.0-mm shoulder margin was significantly higher ($p < 0.001$). The highest mean fracture resistance (SD) was found for the preparations with the 0.5-mm light chamfer and 1.0-mm deep chamfer margins; however, fracture resistance (SD) for preparations with 1.0-mm shoulder margin was significantly lower ($p < 0.001$).

Discussion

The data support the null hypothesis of the study, that margin-design modification of tooth preparations appeared most conducive to the development of better margin fit and high fracture resistance of fiber-reinforced composite crowns. Clinical observations over a 4-year period have shown that fiber-reinforced composite restorations have similar longevity to ceramic restorations.[36] In addition to esthetics, marginal fit and fracture strength are important criteria to ensure clinical success.[14] The majority of researchers agree on the importance of marginal fit and fracture resistance for the long-term success of restorations.[8,21,22,29,37] In the current study, the marginal discrepancy of the fiber-reinforced composite crowns was similar to that of the all-ceramic crowns and was within a clinically acceptable level, 100 μm.[27]

Various aspects of tooth-preparation design have been cited in the literature; however, considerable focus has been

Table 2 Comparative hardness values as retrieved from dental literature,[39] and from data sheets of the manufacturers

Material	Hardness (K/mm^2)
Type III gold alloy	120
High Palladium alloy	350
Base metal alloy	391
Feldspathic porcelain	460
Zirconium	505-1300
Fiber-reinforced composite	471
Enamel	343
Dentin	68

directed toward the most appropriate margin design as innovative restorative systems are introduced. Manufacturers and authors offer different opinions as to the optimal form, but little scientific data are available. No definite criteria exist regarding what constitutes clinically acceptable marginal fit. McLean and von Fraunhofer[7] proposed that a restoration would be successful if marginal gaps and cement thickness of less than 120 μm could be achieved. An explanation of the lack of agreement may be variation in the methods used by various investigators studying marginal fit. Sulaiman et al[34] suggested the cause could be the use of different measuring instruments. Sample size and number of measurements per specimen may also have contributed to the variation. The current study demonstrated that clinically acceptable mean marginal discrepancies could be achieved for all groups tested.

The fracture strength of a clinical crown is influenced by several factors, such as material, cementation, loading condition, artificial aging, and the elastic modulus of the supporting die.[38] Shearer et al[33] concluded that as the elastic modulus of the supporting material increased, the fracture strength also increased. The elastic modulus of Conquest/Sculpture "Single" was approximately 21 GPa, superior to that of dentin (12 GPa), and 100 GPa for the supporting metal die.[16,17] If natural teeth were used as the supporting model, the fracture strength of the crown might be lower; however, natural teeth show large variations, thus causing difficulties in obtaining standardized abutments. Comparative hardness of the fiber-reinforced composite material used in this study was similar to others as retrieved from the literature[39] and from technical data sheets of manufacturers (Table 2).

Within the limitations of this in vitro study, the fiber-reinforced composite crowns could withstand loads more than 1000 N before fracture occurred, significantly higher than reported in the literature.[37] This fracture resistance is considered adequate for the occlusal force exerted on natural dentition. Moreover, it is higher than other researchers' conventional all-ceramic crown results.[9,11] The apparent fracture-strength increase of ceramic restorations bonded to dentin with a resin cement might be greater in fiber-reinforced composite crowns than in all-ceramic crowns because fiber-reinforced composite crowns have a similar resinous matrix as the resin cement.[12] Although it is not possible to achieve a parallel convergence angle clinically, none of the specimens showed marginal fracture of the fiber-reinforced composite crowns during load application in the present study. In addition, the overall surface area of the crowns was similar in the three tested groups. Therefore, it is suggested that crown coverage in the margin area rather than in the overall surface area would have a greater effect on the fracture strength of the restorations. For all-ceramic crowns, the use of a shoulder finish line was recommended in some reports, as this type of finish line does not invoke a wedging effect, as does a chamfer finish line, and may provide additional marginal bulk.[10,27] In contrast, the fracture strength of the fiber-reinforced composite crowns with a chamfer finish line was higher than that of the crowns with a shoulder finish line. Therefore, it seems that the marginal bulk of the Conquest/Sculpture did not contribute to the fracture strength as all-ceramic crowns. This result was consistent with the results obtained for the Artglass crown.[43] Therefore, as the fracture loads are higher in the experiment than the top of the range for clinically reported values, the material is acceptable for all margin designs.

One limitation of this study was that the crowns were not subjected to an artificial aging process, such as thermocycling and mechanical loading. Behr et al[13] reported that artificial aging has a significant negative effect on marginal integrity; however, Beschnidt and Strub[36] reported no significant influence of aging on the marginal fit in a chewing simulator. It might be concluded that the inclusion in future studies of clinically important aspects of failure, such as static chemical and cyclic mechanical fatigue phenomena, would be better. Another limitation of the current study was that metal dies were used in standardizing the preparation for all abutments. This is consistent with the method employed by Cho et al,[21] who showed that nonaxial loading produced fracture of the cervical portion in natural teeth and the epoxy resin dies; however, if natural teeth were used as the supporting models, the marginal discrepancies might have been reduced. Also, the exact point of fracture was not determined. In spite of the limitations of this study, the results suggest that tooth-preparation design has some effect on both the marginal integrity and the fracture strength of fiber-reinforced composite crowns. Further investigations to determine the most appropriate convergence angle for fiber-reinforced composite crowns and the effect of chemical and mechanical aging are required.

Conclusions

Within the limitations of this study, the following conclusions were drawn:

1. Marginal fit of fiber-reinforced composite crowns was adversely affected by the tooth-preparation design.
2. Mean marginal opening of each fiber-reinforced composite crown group was less than 100 μm, which was considered clinically acceptable. The lowest mean discrepancy was recorded for the two chamfer finish-line groups ($p <$ 0.001).
3. The fracture strength of the preparations with 1.0-mm shoulder margins produced the weakest restorations ($p <$ 0.001); however, the values were higher than those considered to be normal occlusal force.

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