Original Article

Effect of Cavity Design on the Fracture Resistance of Zirconia Onlay Ceramics

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Abstract

Objective: The purpose of this study was to evaluate the fracture resistance and failure modes of onlay restorations prepared with different preparation designs. **Materials and Methods:** A total of 42 extracted, mandibular first molars (36, 46) were used and divided into six groups according to preparation design, as follows 1A: Anatomic preparation of cusps/rounded shoulder margin/occlusal groove; 1B: Flat preparation of cusps/rounded shoulder margin/occlusal groove; 2A: Anatomical preparation of cusps/occlusal groove; 2B: Flat preparation of cusps/occlusal groove; 3A: Complete anatomical reduction of cusps/rounded shoulder margin; 3B: Complete flat reduction of cusps/rounded shoulder margin groups; intact tooth: No preparation. Onlays were constructed with 0.5-mm copings of Zirconia ceramic. The copings were veneered with porcelain (IPS e. max Ceram). All samples were subjected to fracture resistance testing. Data were analyzed with Kruskal–Wallis and Bonferroni-Dunn tests. **Results:** Fracture resistance varied significantly according to preparation design. Among the anatomic occlusal preparation designs, fracture resistance was significantly lower in Group 3 when compared to Groups 1 and 2 ($P < 0.05$). Among the flat occlusal preparation designs, fracture resistance was significantly higher in Group 1 when compared to Groups 2 and 3 ($P < 0.05$). **Conclusion:** Preparation design affected the fracture resistance of onlay restorations. Cavities with flat occlusal preparation designs, a groove and shoulder margins (1B) resulted in the highest fracture resistance, whereas teeth prepared with a complete reduction of cusps and shoulder margins (3A) had the lowest fracture resistance.

Keywords: *Fracture resistance, onlay restoration, preparation design, zirconia*

Introduction

Maximum preservation of sound tooth structure and maintenance of the vitality of restored teeth is critical for the longevity of teeth as well as restorations,[1,2] especially in cases, where a large amount of tooth tissue has been lost due to wear and/or trauma.[3] As the demand for conservative tooth treatment increases, so does the need for partial ceramic crowns. In addition to traditional cusp capping, simplified designs have been recommended in certain cases, such as fractured teeth and teeth with large caries.[4] According to the cusp coverage, the types of restorations can be classified as inlays, which is not covered cusps, onlays, which is covered at least one cusp, or overlays, and which is covered all cusps.[5]

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Onlay restorations not only provide superior esthetics but also minimize tooth-tissue loss, making them a good treatment choice for posterior teeth with extensive cavities formed due to caries.[6] Moreover, by covering more than one tooth cusp, onlays provide a favorable distribution of stress, reducing the risk of tooth and restoration fracture.[7]

A variety of materials may be used for posterior teeth onlay restorations. Typically, onlays may be fabricated

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from gold, composite resin, or dental ceramics,[6] including zirconia, whose superior mechanical properties[8,9] have made it the material of choice for indirect restorations of posterior teeth.

Zirconia dental restorations can be produced using computer-aided design/computer-aided manufacturing (CAD/CAM) and copy milling techniques and are stronger and more fracture resistant than other ceramic materials.[10,11]

In addition to the mechanical properties of the material used, preparation design may also play a role in tooth/restoration fracture. Some authors have shown that occlusal reduction reduces the chance of restoration failure.[12,13] Others have shown that large preparation designs results in a reduced chance of possible fracture occurred in tooth tissue.[14,15]

While different preparation designs have been described in the literature,[6-10,16,17] the most appropriate design will vary according to the restorative material to be used. Despite the fact that partial ceramic crowns are increasingly advocated as alternative restorations for extensively damaged teeth, the literature includes limited studies examining the use of different preparation designs with this type of restoration. To date, confusing and contradictory results have been obtained regarding the effects of preparation design on the fracture resistance and stress distribution of tooth structure restored with partial ceramic crowns.[3,18] Therefore, this study investigated the effects of six different preparation designs on the fracture resistance of Zirconia ceramic onlays. The hypothesis was that different designs would affect the fracture resistance of onlay restorations.

Materials and Methods

A total of 42 extracted (due to periodontal and orthodontic treatment reasons-in accordance with the ethics committee of Afyon Kocatepe University (protocol No: 2017/11-260), sound, caries-free human mandibular first molars (36, 46) of similar size and shape were used and randomly divided into six groups (n = 7) according to preparation design as follows 1A: Anatomic preparation of buccal cusps/rounded shoulder margin/occlusal groove; 1B: Flat preparation of buccal cusps/rounded shoulder margin/occlusal groove; 2A: Anatomical preparation of buccal cusps/occlusal groove; 2B: Flat preparation of buccal cusps/occlusal groove; 3A: Complete anatomical reduction of buccal cusps/rounded shoulder margin; and 3B: Complete flat reduction of buccal cusps/rounded shoulder margin groups; intact tooth: no preparation. All samples were prepared,[19] according to the protocol shown in Figure 1. To ensure standardized preparations, one operator prepared the cavities using a parallelometer (Paraskop, Bego, Bremen, Germany) was used. Intact teeth (control group) were not prepared. To simulate the periodontal ligament and alveolar bone, roots of teeth were covered with a 0.3-mm layer of a polyether impression material (Impregum; 3M ESPE, St Paul, Minn, and embedded in a polystyrene (Meliodent, Heraeus Kulzer, Hanau, up to 2 mm below the cementoenamel junction.[20,21]

All onlays were constructed with 0.5-mm copings and without porcelain veneers. In total, 42 copings (n = 7 for each models) were fabricated from zirconia blocks (Katana 95H10, Zirkonzahn) with CAD/CAM system (CAD/CAM, M5, Zirkonzahn) and then placed on a firing tray and sintered in a furnace (Zirkonofen 600/V2, Zirkonzahn) for 12 h at 1500°C. The inner surfaces of the copings were sandblasted with 50 μm aluminum oxide at three bar pressure, rinsed, and dried. The sintered copings were veneered with porcelain (IPS e.max Ceram), and then, the specimens were fired in a vacuum furnace (Programat P300; Ivoclar Vivadent AG, Schaan, Liechtenstein) for 30 min at 720°C. Specimens were cemented with dual-cured resin cement (Multilink, Ivoclar Vivadent, Liechtenstein) under 50N according to the manufacturer's instructions. Each onlay restoration was treated with a primer (Monobond S, Ivoclar Vivadent) for 60 s. Each prepared surface was then treated with 37% phosphoric acid for 30 s on the enamel, and for 15 s on the dentine, followed by application of a bonding agent (Excite, Ivoclar Vivadent) onto the cavity for 15 s. Finally, dual-cured resin cement (Multilink, Ivoclar Vivadent) was mixed and applied on the surface of each onlay restoration; then, the onlay restorations were placed in the cavities. Excess cement was removed and was cured for 60 s. Following cementation, all restorations were stored in distilled water at 37°C for 24 h before fracture testing.

Fracture resistance was tested by placing each onlay restoration on a universal testing machine (Instron 5583, Instron, Norwood) at a 15° angle relative to the long axis of the tooth and using a 3.5-mm diameter stainless-steel ball to apply a load to the buccolingual cusp midway between the buccal and lingual aspects at a crosshead speed of 1.0 mm/min until fracture. The force at fracture was measured and recorded in Newton (N). Statistical analysis was performed using Kruskal–Wallis and Bonferroni-Dunn tests. A difference of $P < 0.05$ was considered statistically significant.

Results

Mean fracture resistance and standard deviations of the groups are shown in Figure 2. Fracture resistance

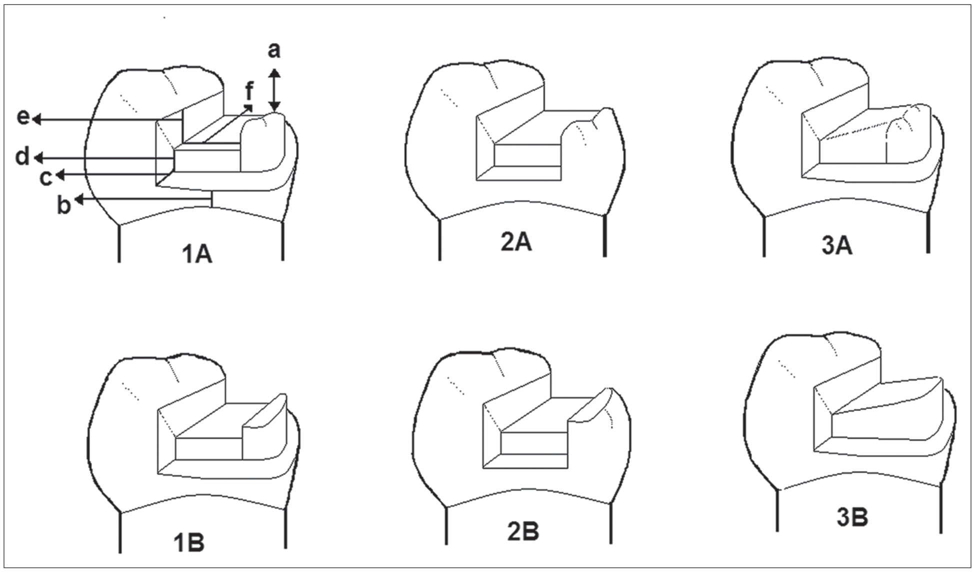

Figure 1: 1A: Anatomic preparation of buccal cusps/rounded shoulder margin/occlusal groove; 1B: Flat preparation of buccal cusps/rounded shoulder margin/occlusal groove (a: 2 mm for anatomical preparation/2.5 mm for flat preparation, b: 1 mm, c: 1.5 mm, d: 1.5 mm, e: 2.5 mm, and f: 3 mm); 2A: Anatomical preparation of buccal cusps/occlusal groove; 2B: Flat preparation of buccal cusps/occlusal groove; 3A: Complete anatomical reduction of buccal cusps/rounded shoulder margin; 3B: Complete flat reduction of buccal cusps/rounded shoulder margin groups

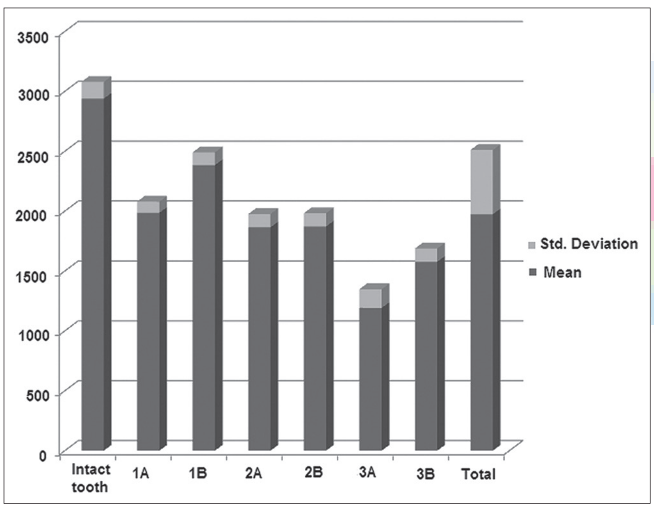

Figure 2: Mean fracture resistance and standard deviations of the groups (Intact tooth[a]; 1A[b]; 1B[ab]; 2A[bc]; 2B[bc]; 3A[d]; 3B[cd], differences in subscript uppercase letters indicate statistical differences between groups, $P < 0.05$)

varied significantly according to preparation design. The highest fracture resistance was found in Group 1B, which had a flat occlusal preparation design with a groove and shoulder margin. Fracture resistance values varied significantly between Group 3A and Groups 1, 2 and tooth ($P < 0.05$).

Among the anatomic occlusal preparation designs, fracture resistance was significantly lower in Group 3 when compared to Groups 1 and 2 ($P < 0.05$).

Among the flat occlusal preparation designs, fracture resistance was significantly higher in Group 1 when compared to Groups 2 and 3 ($P < 0.05$).

There were no significant differences in fracture strength values between flat and anatomic occlusal preparation designs.

Discussion

The study hypothesis that different preparation designs would affect the fracture resistance of onlay restorations was accepted since specimens with grooves designs had statistically significant differences in fracture resistance values.

Preparation is governed by three principal criteria: the preservation of dental structure, the physical properties of the restorative material used,[22] and the retention form.[23] However, extensive carious lesions and loss of tooth structure in endodontically treated posterior teeth may make it impossible to create an "ideal" onlay preparation design. In situations where the clinician encounters a tooth without a cusp or with a partial cuspal fracture, a different approach to preparation design may be required. When an indirect restoration is determined to be the best treatment option, the clinician must keep in mind the mechanical properties of the restorative materials in designing the geometric configuration of the cavity.[4,24]

Some researchers have suggested that the best restorations in teeth with large cavity preparations are onlays.[17] Some studies have shown that fracture resistance of onlay restorations was similar to that of intact teeth.[25,26]

One reason for using onlays is to preserve residual tooth structure.[24] According to Edelhoff and Sorensen,[27] onlay preparation removes 39% of the total tooth structure, whereas preparation for a complete crown requires removal of between 72.3% and 75.6%. Many authors have noted that 1.5–2.0 mm of occlusal tooth reduction leaves adequate bulk for maintaining the strength of ceramic inlays and onlays.[28,29]

It was found that the fracture resistance of the posterior tooth and lithium-disilicate glass-ceramic restoration complex was decreased with cuspal coverage design. Teeth restored with zirconia ceramic inlays or onlays had similar fracture resistance when compared to intact teeth.[22]

Seo *et al*.[19] used three different preparation designs in onlay crowns, and buccal cusps were prepared flat reduction in their study. Based on the study of Seo *et al*.,[19] similar designs were shown in the present study. In the present study, it was used in anatomical occlusal preparation designs in addition to the flat reduction designs used in their study.

Soares *et al*.[20] found differences in preparation design did not affect the fracture resistance of teeth restored with a laboratory-processed composite resin, although intact teeth were found to be more fracture resistant than restored teeth, regardless of restoration type.

It was found that no statistical differences in fracture strength values between preparation designs in zirconia-based ceramic groups.[22] Similarly, Federlin *et al*.[18] found preparation design had no effect on the visible crack formation and van Dijken *et al*.[30] found no statistical differences in the fracture resistance of partial and complete posterior ceramic restorations bonded to both dentine and enamel over a 5-year follow-up period. However, some *in vitro* studies have demonstrated occlusal reduction of 1.5–2.0 mm to reduce the likelihood of failure of posterior ceramic restorations.[12,13] In a study by Soares *et al*.[16] that examined the fracture resistance of partial ceramic restorations placed on molars with different preparation designs, preparations involving greater loss of tooth structure were found to reduce the fracture resistance of the tooth-restoration complex. In the present study, it was found that specimens with flat preparation designs had higher mean fracture resistance values than those with anatomic preparation designs; however, it was showed that this result was not statistically significant.

In the current study, fracture resistance of samples ranged from 1011.73 to 2568.76N. This range is higher than the values reported by some previous studies and lower than others.[16,31-33] The differences in values may be due to differences in preparation design; veneer material; cement type; localization; direction; quantity; type of load applied; and test speed.

The fracture load and cracking path were found to be very sensitive to a loading position in the all-ceramic inlay and onlay crowns.[34,35] Teeth in the posterior region are subject to functional and para-functional forces of varying magnitudes and directions.[23] Maximum occlusal bite forces generated during mastication have been reported to vary between 216 and 847N,[36,37] with the highest bite force recorded in the first molar region.[36] Even the lowest fracture resistance values obtained in the present study (1011.73N-Group 3A) were much higher than normal masticatory forces and also higher than the forces generated by bruxism and chewing hard objects.

The rehabilitation of patients with high masticatory forces due to bruxism or other parafunctions represents a particular challenge in restorative dentistry.[38] Metal occlusal surfaces, the standard of care for these patients, have not met esthetic demands;[39] however, because of the increased risks of fracture, patients with parafunctions have generally been excluded from studies of all-ceramic restorations. Although some types of ceramic restorations have only limited use in the posterior region, where masticatory forces are severe,[4,40,41] Zirconia, the strongest and toughest of all dental ceramics, has a flexural strength of 800–1200 MPa that meets the mechanical requirements for high-stress-bearing posterior restorations.[9,41] Zirconia material was selected in the present study due to its strength and esthetic properties. As mentioned above, the fracture resistance values obtained in the present study (1011.73–2568.76 N) indicate that Zirconia onlay restorations are able to withstand the high masticatory forces associated with bruxism and other parafunctions.

This study has a number of limitations, namely, only one type of ceramic material and one type of cement were examined. Moreover, clinical conditions such as cycling fatigue and accumulated damage from stress and water were not accurately represented. Thus, further studies are required to address these issues.

Conclusions

Within the limitations of this study, differences in preparation designs were shown to result in significant differences in the fracture resistance of Zirconia ceramic onlays. A groove and shoulder margins design resulted in the highest fracture resistance, whereas cavities prepared with a complete reduction of cusps and shoulder margins (3A) had the lowest fracture resistance. A groove leads to high fracture resistance values under occlusal load. The flat and anatomic occlusal preparation designs affected the fracture resistance of restorations.

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Conflicts of interest

There are no conflicts of interest.

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