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Fracture Resistance of Zirconia Restorations with Four Different Framework Designs

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ABSTRACT

Objectives: This study assessed the fracture resistance of zirconia crowns with four framework designs, fabricated by computer-aided design/computer-aided manufacturing (CAD/CAM) technology.

Materials and Methods: In this experimental study, a maxillary central incisor was prepared and scanned with a CAD/CAM scanner, and 40 frameworks with 4 designs (N=10) were fabricated as follows: simple core, dentine core with a design similar to dentine, 3mm trestle design collar in the lingual aspect with proximal buttresses, and monolithic or full-contour. After porcelain applying and 20h immersion in distilled water (37°C), crowns were cemented on metal dies using zinc phosphate cement. Fracture resistance was measured by a universal testing machine. Data were analyzed with one-way ANOVA (alpha=0.05).

Results: Fracture resistance was maximum in the monolithic group, followed by the dentine core, trestle design, and simple core groups, respectively. The mean fracture resistance of the monolithic group was significantly higher than that of the simple core group ($P<0.005$).

Conclusion: Zirconia restorations with frameworks that provided higher and more support for porcelain, showed increased fracture resistance.

Keywords: Flexural Strength; In-Ceram Zirconia; Crowns; Dental Prosthesis Design

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INTRODUCTION

All-ceramic fixed prostheses are commonly being used as a substitute for metal-ceramic restorations as a result of their optimal esthetics and excellent biocompatibility [1]. Three main criteria that are conventionally considered in selection of full-coverage restorations include strength, esthetics, and adaptation, which determine the clinical longevity of a restoration [2]. All-ceramic restorations have optimal properties such as favorable esthetics, great appearance, high wear and fracture resistance, ideal biocompatibility, and optimal color stability [3]. Their disadvantages include substandard marginal adaptation, unnecessary wear of the opposing teeth, invasive tooth preparation design, high technical sensitivity, and predisposition to fracture [3,4]. However, the newer ceramic systems have attempted to minimize these shortcomings. Porcelain has low tensile strength and high compressive strength; nevertheless, by designing the framework to support a uniform thickness of veneering porcelain, the shear and tensile fractures of porcelain could be minimized [3]. The clinical failure of layered-core all-ceramic systems is usually the result of formation of extensive cracks between the core and the veneering ceramic [1]. These cracks could initiate from the occlusal surface, the cervical margin, or the cement-core interface. Moreover, under excessive load application and repetitive superficial tensions, radial cracks may develop in the core (cement-core interface), resulting in catastrophic failure of the entire system [5]. Therefore, high-strength core materials like zirconia and alumina are suggested to preserve the porcelain veneering by minimizing tension at the cement-core interface [5,6]. However, chipping of the veneering ceramic is still among the most important clinical complications of layered zirconia restorations [1]. Although the differences in coefficient of thermal expansion between the core and veneering ceramic, and inadequate chemical bond play major roles in these fractures [7], framework design could also be a significant factor [4,8]. In another words, like metal-ceramic restorations, non-uniform thickness of veneering ceramic due to inappropriate framework design could be a possible cause for chipping in all-ceramic restorations [9]. Modifications in the framework design have been suggested to increase the fracture resistance of ceramic restorations. It is often recommended to connect a lingual collar to proximal struts for better support of the veneering ceramic in these critical regions [10-12]. The effect of design modification on fracture resistance of all-ceramic single crowns has not been adequately studied [5]. Although non-layered monolithic zirconia crowns have been proposed as a substitute for layered zirconia crowns, they might not be suitable for all situations [7,13].

Considering all the possible effects of framework design on the fracture strength of veneering ceramic in zirconia restorations, this study sought to assess the fracture resistance of zirconia crowns with four different framework designs, fabricated by CAD/CAM technology. The null hypothesis was that there is no difference between three-layered zirconia crowns with monolithic zirconia crowns in terms of fracture strength.

MATERIALS AND METHODS

A sound extracted human maxillary central incisor was selected and a cone-beam computed tomography scan (CBCT) was obtained to evaluate the enamel thickness. The tooth was mounted in resin (Acropars, Marlic Medical Industries Co., Iran) so that the acrylic level was 3mm apical to the cemento-enamel junction (CEJ) of the tooth. Next, a silicon index was obtained from the tooth using condensational impression material (Speedex, COLTENE/Whaledent, Switzerland) and the unprepared tooth was scanned for later use in the monolithic group using an intra-oral scanner (LMTmag, Optical 3D Scanner, Open Technologies SRL, Italy). Afterwards, the tooth received an anatomical full-ceramic crown preparation 1mm coronal to the CEJ by a diamond bur and high-speed headpiece under air and water spray as follows: 1.5mm reduction of the incisal edge, 1mm axial reduction, and 6° taper with a heavy chamfer finish line [14]. All the sharp edges and angles were rounded, and the reductions were checked using the primary silicon index of the sound tooth. Next, the prepared tooth was scanned (LMTmag, Optical 3D Scanner, Open Technologies SRL, Italy) (Figure 1), and the four frameworks were designed by EXOCAD software (EXOCAD Dental CAD, Darmstadt, Germany) as follows:

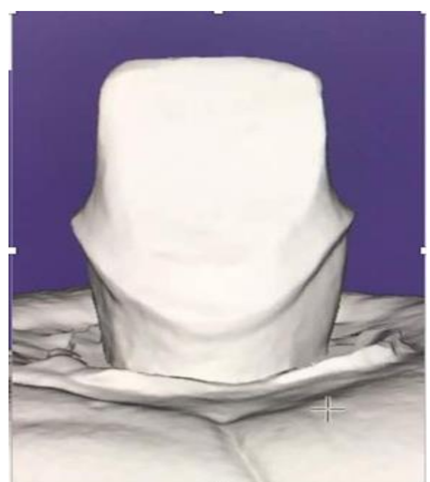

Fig. 1. Representative scan of a prepared maxillary central incisor

- Simple zirconia core with no anatomical contour and with an equal thickness of 0.5mm (Figure 2A)
- Zirconia core with trestle design contour, similar to a metal-ceramic restoration (MCR) crown with a 3-mm collar in the lingual surface and proximal buttresses extending to half of the proximal height (Figure 2B)

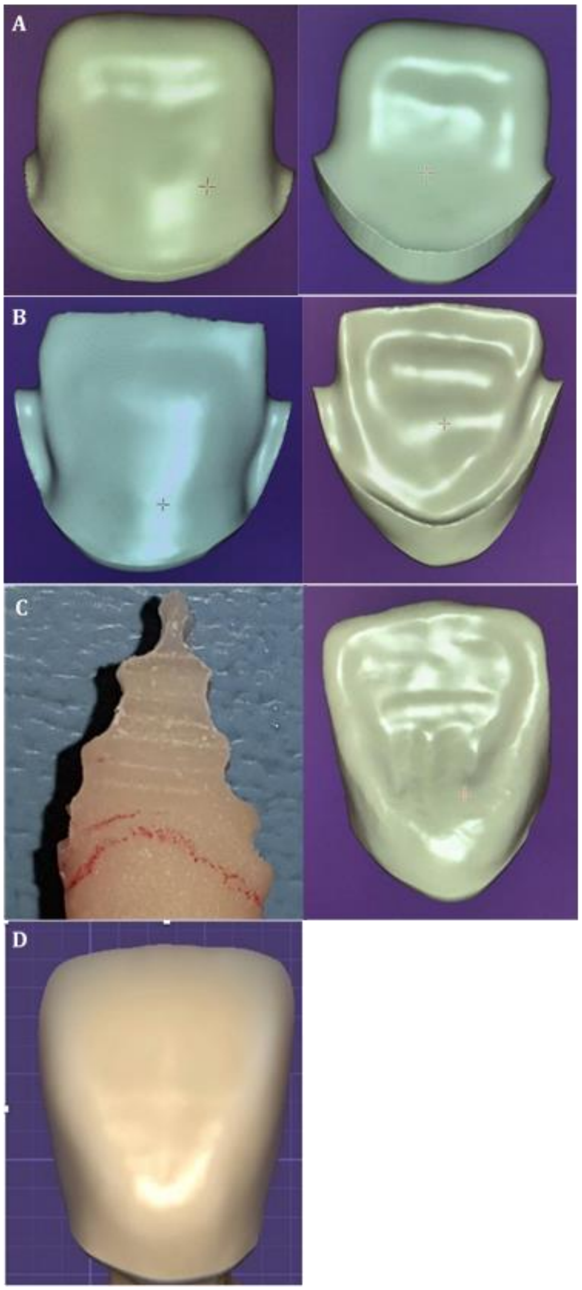

Fig. 2: Framework designs using EXOCAD software. (A) simple core design, buccal and lingual views; (B) trestle design, buccal and lingual views; (C) dentine core design, buccal and lingual views; (D) monolithic or full-contour design, buccal view.

- Zirconia core with a dentine-like contour (dentine core)14. Considering the different thicknesses of dentin and enamel in different parts of the tooth and consequently different thicknesses of the core and veneering in different parts of the crown, dentine core could not be designed by the device. Thus, an acrylic sample (temporary crown resin, Tempron, GC, Tokyo, Japan) of the tooth was fabricated using the putty index of the sound tooth. Before tooth preparation the enamel thickness was evaluated by a CBCT ; however, since the mean values were required, the mean enamel thickness was calculated in 5 points of the incisal, mesial, distal, buccal and lingual aspects according to the method proposed by Harris et al. [15]. The acrylic sample was divided into five horizontal and three vertical segments. Grooves with a depth corresponding to enamel thickness were created by a diamond bur (Teeskavan Co., Iran, Tehran) and connected. Eventually, the sample was prepared and scanned as the model for dentine core design (Figure 2C).

- Monolithic zirconia crown, which was based on the scan of the primary contour of the sound tooth, prior to preparation (Figure 2D).

Zirconia blanks (Katana, Kuraray Noritake Dental Inc., Japan) were milled using Arum bur (Doowon ID, Korea), and 40 zirconia crowns with four different framework designs (N=10 in each group) were fabricated. An expert technician applied porcelain on all specimens (except for the monolithic group) according to the primary putty index using Zr-FS (GC initial Zr-FS, GC company, Germany) porcelain. For porcelain baking, first the framework modifier was preheated at 450° and fired at 831°C followed by preheating the first dentine layer at 450° and firing at 830°C, preheating the second dentine and enamel layer at 600°C and a temperature of 810°C, and final glazing by preheating at 480°C and firing at 832°C. All procedures were based on the manufacturers' instructions.

In the pilot study, resin dies were used before conducting the loading test. Based on the results, since the strength of resin was less than zirconia, dies fractured before the restorations. Therefore, metal dies were fabricated from premium chromium-cobalt (ARUM, Korea) using the scanned file of the prepared tooth (Figure 3) and CAD/CAM (Rainbow ™ Mill-Metal, Dentium, Korea) [4,16]. Each sample was placed on a die and the seating of all crowns was evaluated by a fit-checker (GC Fit Checker, GC Corp, Tokyo, Japan) and adjusted when needed. Crowns were cemented with zinc phosphate cement (Master Dent, Dentonics Inc, USA) to the metal dies [12,17]. Load was applied on all crowns for 15min by finger pressure of the same operator until the cement was set [4]. Next, the crowns were immersed in distilled water at 37°C for 24h [3].

Fig. 3: Metal dies fabricated from premium chromium-cobalt. Left: Polymethyl methacrylate die; Right: chromium-cobalt die.

Prior to the loading test, the die-crown assembly was mounted in resin (Acropars, Marlic Medical Industries Co., Iran) and was placed in the holder at a 135°C angle. A universal testing machine (SANTAM, Iran, Tehran) was used to measure the fracture resistance. Compressive load was applied at a crosshead speed of 0.5mm/min by a stainless-steel blade at a 135° angle relative to the longitudinal axis of the tooth, on a stop on the lingual side of the crowns (Figure 3) [2]. Load application continued until the crowns fractured. The maximum load (N) leading to fractures was recorded. Data were analyzed using one-way ANOVA and post hoc Tukey pair comparison test at a significance level of 0.05.

RESULTS

Table 1 shows the mean fracture resistance of the specimens in all four groups. The fracture resistance was maximum in the monolithic group, followed by the dentine core, trestle design, and simple core design, in that order. The mean fracture resistance in the monolithic group was significantly higher than that of the simple core group (P=0.001); however, no other significant differences were found (P>0.05).

Table 1. Mean fracture resistance of the specimens in the four groups (N=10)

Group	Mean (N)	SD	SE
Dentine Core	1206.9	275.3	87
Monolithic	1570.5	298.5	94.4
Trestle Design	1193.9	323.5	102.3
Simple Core	968	352.4	111.4

SD: standard deviation; SE: standard error; N: Newton

DISCUSSION

This study assessed the effect of framework design on fracture resistance of layered zirconia crowns compared to monolithic zirconia crowns, fabricated by CAD/CAM technology. Based on our findings, the null hypothesis was rejected and fracture resistance in the monolithic group was maximum, followed by dentine core, trestle design, and simple core groups. The mean fracture resistance in the monolithic group was significantly higher than that of the simple core group.

Ferrari et al. [8] evaluated the effect of framework design on fracture resistance and compared three zirconia crowns including flat-, MCR-, and anatomically-guided -designs. The MCR design consisted of a 1.5mm collar at the palatal regions and an interproximal collar extending to 50% of the wall height. In the anatomically-guided design was similar to the MCR in collar design with the addition of a 0.5mm height to the axial wall for every 1.5mm increase in crown height. This was to ensure porcelain support during loading. They fabricated these crowns for a premolar tooth with a chamfer finish line and found no significant difference between the groups. The anatomical group in their investigation showed maximum fracture resistance, while the MCR design yielded a fracture resistance value almost similar to the trestle design in the present study. Bonfante et al. [5] also evaluated the effect of framework design on fracture resistance of glass-infiltrated alumina and MCR crowns with standard (simple core with 0.5mm thickness) and modified framework designs (2mm collar in the lingual and a 3.5mm strut in the proximal surfaces). In contrast to our study, they found a significant difference in fracture resistance of the groups, and reported that the MCR design showed maximum fracture resistance. The difference in findings may be because of the different materials used in the two investigations; however, in both studies, the fracture resistance of the trestle design was higher than that of the simple core design. The reduced chipping observed in both studies may be due to the fact that the veneer ceramic is being adequately supported by the framework.

There are no previous studies on the fracture resistance of all-ceramic crowns with core designs similar to that of dentine contour. For this design, we used cone-beam computed tomography scans of a natural central incisor to determine the dentin and enamel thicknesses at different parts. Therefore, the core thickness was designed according to dentine thickness, and the porcelain thickness was designed according to the enamel thickness to create an anatomical form resembling the natural tooth. Subsequently, due to the greater support of the veneering ceramic by the core in this group, the resultant crowns had higher fracture resistance than the trestle design group.

In the current study, the load was applied from the lingual aspect and at a 135° angle. This means that in the trestle design group, load was applied to an area where a lingual collar was present, which increased the fracture resistance due to greater support by the lingual collar and proximal struts. It appears that load application to the incisal or buccal surface would alter the difference between the fracture resistances of these two groups. Therefore, the dentin core design might be more effective than the trestle design in incisal and buccal areas. Further investigations are suggested to help confirm this hypothesis.

In this study, the monolithic group showed maximum fracture resistance; however, it was only significantly higher than that of the simple core group. Considering similar preparation conditions of all four groups, this result may be because the load was only applied from one direction, which is different from the oral environment where multi-directional loads are applied to the restorations. Similar future studies are required to simulate the clinical setting by thermocycling and cyclic loading. Also, the effect of dentine core design on fracture resistance of posterior crowns with occlusal loading should be evaluated.

CONCLUSION

Within the limitations of this study, the results showed significantly higher fracture resistance for the monolithic zirconia crown as compared to the crowns with simple zirconia core designs. Also, there was no statistically significant difference in fracture resistance of layered zirconia crowns between the three designs of zirconia cores.

CONFLICT OF INTEREST STATEMENT

None declared.

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