Effect of Occlusal Contact of the Loading Rod Tip on the Fracture Strength of Ceramic Crowns

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Abstract

Aim: The aim of this study was to verify the effect of the occlusal contact of the rod tip on the fracture strength of crowns made with different ceramic systems. Materials and Methods: Conical preparation was performed on bovine teeth with diamond burs in mechanical lathe, and crowns were made for all-ceramic, metal-ceramic, In Ceram, and IPS Empress 2 ceramic systems according to manufacturers’ instructions in prosthetic laboratory. The crowns were fixed with resin-modified glass ionomer cement or dual-curing composite resin under a static load of 4 kg for 1 min. To simulate the clinical contact between loading and ceramic crowns, the rod tip was made in accordance with the occlusal form of the ceramic crown. After storage in distilled water at 37°C for 24 h, the samples were submitted to 60,000 mechanical cycles at a load of 35 N/2 Hz immersed in distilled water. The fracture strength test was performed in an Instron with a cross-speed of 0.5 mm/min. Results: Data submitted to one-way ANOVA for randomized experiments followed by Tukey’s test (α = 0.05) showed greater value for IPS Empress 2 (208.12 kgf) with significant difference in relation to all-ceramic (149.32 kgf) and In Ceram (142.25 kgf), whereas metal-ceramic showed intermediary value (182.83 kgf). Conclusion: The loading of the rod tip in occlusal contact with the crown did not promote premature failures during the mechanical fatigue test, and two-ceramic systems showed different values of fracture strength after mechanical fatigue test, with better performance for crowns manufactured with IPS Empress 2.

Keywords: Ceramic system, fracture strength, luting agent, mechanical fatigue

INTRODUCTION

Although researchers have studied important parameters, such as tooth preparation, and fatigue behavior of dental ceramics exposed to an aqueous environment, few explanations have been given for the structural stress before the ceramic failure and the conditions responsible for fractures that occur in the laboratory tests using rod with different configuration tips. A characteristic of the traditional laboratory tests is the high loading used to obtain the maximum ceramic strength, commonly in a range of 963–2800 N when compared to 5–364 N required for chewing food. The failures that occur in laboratory tests have shown greater number of fragments when compared to the typical fragment promoted in clinical function.

A previous study had shown that there was no significant difference in the fracture strength of teeth restored with all-ceramic crowns with 0.4- and 0.6-mm aluminum oxide copings, 0.6-mm zirconia ceramic copings, and metal-ceramic crowns. The characteristics of the crystalline phase were correlated to strengthening and toughening mechanisms of glass ceramics. No crown fracture was observed during 2-year follow-up; however, ten (50%) catastrophic failures of fixed partial dentures occurred. Five (25%) failures occurred within the 1-year clinical period and others within the 2nd year (25%). However, neither conventional adhesive cement nor self-etching adhesive cement affected the fracture strength of IPS e.max® crowns, whereas thermocycling decreased the fracture strength of the crowns in both cement systems.

Ceramic restorations support higher load when conditioned with hydrofluoric acid, silanized, and luted with adhesive resin.
when compared to nonadhesive systems.\cite{10} The load required to fracture ceramic crowns luted with adhesive systems was similar to those of porcelain-fused-to-metal crowns fixed with zinc phosphate cement.\cite{11} Fractured specimens showed remarkably similar failure modes, with nearly all specimens failing through a shear fracture of porcelain from load point to facial margin of the crown.\cite{12}

Comparative works are constant to assess the fracture strength of all-ceramic, IPS Empress 2, In Ceram, and porcelain-fused-to-metal crowns.\cite{13-15} Fracture strength of restorations with metal or zirconia framework was independent of the veneering techniques.\cite{16} In the current study, to simulate the masticatory effort that occurs among posterior antagonist teeth, the tip of the rod used for mechanical fatigue and fracture strength was made in accordance to occlusal form of the ceramic crown.

The aim of this study was to verify the effect of occlusal contact of the rod tip on the fracture strength of crowns of different ceramic systems. The hypothesis was that the fracture strength of crowns after submitted to mechanical fatigue would be influenced by different ceramic systems.

**Materials and Methods**

**Experimental design**

This study was designed to consider one variation factor: the fracture of the ceramic crown after mechanical fatigue. During the mechanical test, the loading rod tip simulated the occlusal contact between teeth that occurs in clinical conditions during the masticatory function. Four ceramic systems were used to verify the strength of the crowns after submitted to mechanical fatigue [Table 1].

**Tooth preparation**

Recently extracted bovine teeth were cleaned and stored in 0.9% sodium chloride at 5°C until 3 months before crown preparation. The tooth was individually fixed in polyvinyl chloride cylinders by the root using self-cured acrylic resin. Conical preparation was performed on each tooth with diamond burs using mechanical lathe, in the following dimensions: larger base with 8.0 mm in diameter, smaller base with 4.2 mm in diameter, height of 7.0 mm, occlusal convergence of 8°, and beveled shoulder with 0.8 mm in width. A reference notch was made at the margin of the preparation to standardize the adjustment of the crowns always in the same position. The specimens were stored in distilled water at 37°C during the intervals of laboratory procedures and in the same water storage conditions until the procedure of the fracture resistance test (24 h after the luting).

Impressions were carried out by double-molding technique with polyvinyl siloxane-based material (President Jet Plus; Coltene Whaledent, NY, USA) manipulated according to manufacturer’s instructions. An impression was made for each preparation totalizing 60-silicone molds, which were poured with high resistance gypsum (GC Fujirock EP; GC Europe, Leuven, Belgium) proportioned according to manufacturer’s recommendations (20 mL water/100 g powder) and manipulated under vacuum (Vac-U-Mixer; Whip Mix, Louisville, KY, USA) for 35 s.

**Coping preparation**

**In Ceram**

Fifteen stone dies with two spacer layers (interface varnish; Vita Zahnfabrik, Bad Säckingen, Germany) were used to make In Ceram copings. Stone die impressions were carried out using the double-molding technique (President Jet Plus; Coltene), and the molds were poured with refractory investment (Vita In-Ceram Alumina; Vita) vacuum manipulated for 30 s (Multivac 4; Degussa, Guarulhos, SP, Brazil).

The ceramic system was prepared in Vitasonic II ultrasonic mixer (Vitasonic II; Vita North America, Yorba Linda, CA, USA) according to manufacturer’s instructions. The mixture was applied with brush in successive layers until reaching the thickness desired for the ceramic coping. The ceramic coping was submitted to firing cycles in oven (In Ceramat; Vita) according to manufacturer’s recommendations and after adapted to the stone die. The glass powder (Voldera Mill; Vita) and distilled water moisture were infiltrated using conventional firing cycles in oven (Vita In Ceramat; Vita) at 200°C for 30 min followed by 1120°C for 120 min. After laboratory finishing procedures, the crowns were submitted to firing at 960°C without vacuum for 10 min and sandblasting with aluminum oxide (Trijet; Dental Larcon, Maringa, PR, Brazil).

**IPS Empress 2**

Fifteen stone dies with two spacer layers (Cement Spacer Blue; Kerr, Orange, CA, USA) were used to make IPS Empress 2 copings. Melted wax (Picodip; Renfert GMbH, Hilzingen, Germany) was used to obtain a layer with a thickness of 0.8 mm. The wax pattern was embedded in phosphate-based investment (IPS PressVEST; Ivoclar-Vivadent, Barueri, SP, Brazil) prepared according to manufacturer’s instructions and chemically mixed at vacuum (Multivac Compact; Degussa, Guarulhos, SP, Brazil). The wax pattern was removed by the lost wax technique. Two IPS Empress 2 ceramic tablets were used for casting crowns according to manufacturer’s recommendations and later cooled at room temperature. The coping was withdrawn from the investment, sandblasted with glass particles, and immersed in 0.01% hydrofluoric acid (Invex; Ivoclar Vivadent) for 25 min to remove possible investment residues.

| Ceramic system   | Fracture strength |
|------------------|-------------------|
| IPS Empress 2     | 208.12±46.74 (a)  |
| Metal-ceramic    | 182.83±53.63 (a, b) |
| All-ceramic      | 149.32±40.37 (b)  |
| In Ceram         | 142.25±55.36 (b)  |

Means followed by different letters show statistically significant differences by Tukey’s test (5%)
Metal-ceramic
Fifteen wax patterns embedded in phosphate-based investment (Microfine; Talladium/Talmax, Curitiba, PR, Brazil) proportioned according to manufacturer’s recommendations and mechanically mixed at vacuum (Multivac Compact; Degussa, Guarulhos, SP, Brazil) were used to make metal copings by the lost wax technique. Ni-Cr alloy without beryllium (Wiron 99; Wilcos, RJ, Brazil) was melted in ceramic crucible with gas-oxygen torch and processed in centrifuge (J. Safrany, SP, Brazil). After investment removal, the metal coping was sandblasted with 50 μm-aluminum oxide (Trijato; Dental Larcon, Maringa, PR, Brazil) and cleaned with isopropyl alcohol for 5 min.

All-ceramic
Silicone molds obtained from impressions of crown preparations were used to made 15 refractory dies with phosphate-based investment (Begoform; Bego-Wilcos, Petropolis, RJ, Brazil), which were prepared and manipulated according to manufacturer’s instructions.

Application of ceramic material
The crowns manufactured with In Ceram (glass-infiltrated alumina core ceramic + layering feldspathic Vitadur Alpha ceramic-Vita), IPS Empress 2 (lithium disilicate hot-pressed ceramic + layering Eris E2 ceramic—Ivoclar/Vivadent), metal-ceramic (metal cast coping + layering leucite-reinforced VMK 95 ceramic-Vita), and all-ceramic (leucite-reinforced core ceramic + layering Omega 900 ceramic-Vita) were made in a laboratory accredited by the respective systems (n = 15).

Crown treatment and luting agent
Different ceramic treatments and luting materials for each experimental group were accomplished according to manufacturers’ recommendations which are described as follows: Group 1 – In Ceram: 50 μm-AI₂O₃ sandblasting of inner surface for 5 s + Rely X luting (resin-modified glass ionomer cement; 3M™/ESPE™), Group 2 – IPS Empress 2:50 μm-AI₂O₃ sandblasting of inner surface for 5 s + internal surface etching with 10% hydrofluoric acid for 20 s and monobond silane application + Variolink II Luting (dual-curing composite system; Ivoclar Vivadent), Group 3 – metal-ceramic: 50 μm-AI₂O₃ sandblasting of inner surface for 5 s + Rely X Luting 2 (3M/ESPE), and Group 4 – all-ceramic: 50 μm-AI₂O₃ sandblasting of inner surface for 5 s + internal surface etching with 10% hydrofluoric acid for 2 s + Variolink II Luting (Ivoclar Vivadent).

Mechanical fatigue test
After water storage in an incubator at 37°C for 24 h, the specimens were submitted to mechanical fatigue in an MCM apparatus (MCM tester; Sao Carlos, SP, Brazil) calibrated to operate at 60,000 cycles/2 Hz and load of 30 N exerted on the occlusal surface of the crowns immersed in distilled water at 37°C. In each cycle, five individual samples were submitted simultaneously to the mechanical fatigue. The tip of the steel rod used in the mechanical fatigue was made according to the occlusal morphology of the ceramic crown in order to establish a similar relationship that occurs in intraoral occlusion [Figure 1].

Fracture strength test
The fracture strength test by compression was accomplished in an Instron machine (4511/H4188; Instron, Sao Jose Dos Pinhais, PR, Brazil) with a cross-speed of 0.5 mm/min until crown fracture (catastrophic or not), and the ultimate strength was registered in kgf. The same steel rod for mechanical fatigue was used in the fracture strength test.

Statistical analysis
Data of the fracture strength were submitted to one-way ANOVA for randomized experiments, considering the fracture factor after the mechanical fatigue as variable. Multiple comparisons were performed using the Tukey’s post hoc test (α = 0.05).

Scanning electron microscope image
Scanning electron microscope(SEM) images of the ceramic crown occlusal surface after mechanical fatigue were obtained from epoxy resin replicas (Coating resin; Alec Tiranti; London, UK) gold coated under high vacuum (Balzers, SCD 050, Germany) and analyzed in MEV (LEO 435 VP; London, UK). The images were captured in all groups after mechanical fatigue. This procedure aimed to verify if the mechanical fatigue promoted damages to surface ceramic crown (abrasion and microcracks) that could previously compromise the strength of the crowns.

Since this situation was not observed in any experimental group, only one representative image was considered in the manuscript [Figure 2].

Results
Table 1 shows the mean values of the fracture strength of ceramic crowns submitted to mechanical fatigue. Greater value was shown for IPS Empress 2 with statistically significant difference in relation to all-ceramic and In Ceram systems, whereas metal-ceramic showed an intermediary value.
There is no difference in strength. Moreover, types of zirconia crowns veneered with computer-aided design/computer-aided manufacturing generated by sintering showed high fracture strength than those veneered with other ceramic systems. Although different aspects need to be focused in relation to ceramic fracture strength, such as marginal adaptation, abrasion strength, biocompatibility, long-term durability, and esthetics.

Ceramics containing lithium disilicate crystals show higher flexural and fracture strengths in relation to leucite-reinforced ceramic and feldspathic ceramic of low fusion. The improved mechanical properties of the lithium disilicate ceramic were attributed to the size and distribution of the crystals and not necessarily to composition changes. Moreover, types of substrate and chemical and/or mechanical retentions are factors that exist at the tooth/ceramic crown interface that may also change the resistance level.

Many factors may influence the fracture strength of ceramic crowns: heat-pressed disilicate crowns showed more fracture strength than zirconia/fluorapatite pressed-over crowns, zirconia coping presented increased fracture strength, and catastrophic fracture occurred for lithium disilicate crowns. Fracture strength values for three all-ceramic systems were significantly different (In Ceram > Top-Ceram = IPS Empress II), and coping fracture pattern was highest for Top-Ceram system. Zirconia crowns veneered with computer-aided design/computer-aided manufacturing generated by sintering showed high fracture strength than those veneered with feldspathic ceramic layering or glass-ceramic heat-pressing technique. There was no difference in fracture resistance between crowns made of high- or low-translucent zirconia, and fracture strength of crown with metal or zirconia copings was independent of the pressable or layering veneering techniques, but pressing technique on metal showed higher fracture load than zirconia coping.

In addition, different all-ceramic crown systems submitted to soft loading until fracture showed that zirconia crowns fractured at significantly higher loads than alumina and glass-ceramic crowns. There is no difference in strength between crowns made of high-translucent or low-translucent zirconia and, at equal thickness, the strength of zirconia crowns was significantly greater than that of lithium-disilicate glass-ceramic crowns. An interesting result showed that the elastic modulus of the supporting die structure is a significant factor in determining the fracture strength of all-ceramic crowns.

Another important factor in terms of fracture strength of ceramic crowns is the effect of the association between luting agent and ceramic material. Although the In-Ceram crowns cemented with either glass ionomer or resin cements exhibited a higher fracture strength than IPS Empress-2 crowns, the fracture strength of IPS Empress-2 and In-Ceram crowns was not affected by the type of cement used for luting. Although the thermocycling had decreased the fracture strength of the crowns in both luting procedures, neither conventional adhesive cement nor self-etching adhesive cement affected the fracture strength of IPS e.max crowns.

In the current study, IPS Empress 2 crowns fixed with dual-curing resin system showed higher fracture strength when compared to all-ceramic crowns fixed with the same luting system. The strength of In-Ceram crowns fixed with resin-modified glass ionomer cement was similar to all-ceramic crowns fixed with dual-curing resin system. Metal-ceramic crowns fixed with resin-modified glass ionomer cement were similar to other ceramic crowns fixed with dual-curing resin or resin-modified glass ionomer cement [Table 1]. Considering that the bonding agent has only minor effect on the bond strength of the different Co-Cr/ceramic systems, it is possible to infer that the same alleged effect occurred with the different ceramic systems analyzed in the present work. This hypothesis seems to be supported by the fact that ceramic crowns manufactured on metal copings or ceramic copings showed similar fracture strength values, whatever the luting agent used in the study.

Mechanical tests with traditional rods with different tip configurations (sphere, chisel, conical tip, and other) establish two or three compressive points on the occlusal surface due to occlusal morphology of the crown. This mechanical loading type may cause surface defects (microfractures and microcracks) compromising previously the strength of the ceramic crowns by the concentration of stresses in the surface.

**Figure 2:** Representative scanning electron microscope image (×25) of the ceramic crown occlusal surface after mechanical fatigue
defects. SEM images showed that such surface defect types were not observed on the occlusal surface of the crowns after the fatigue strength [Figure 2].

Therefore, the design of the rod tip used for mechanical fatigue and fracture strength test was an important factor in the study. The occlusal relationship between crown and rod tip improves the stress distribution through the crown and consequent absence of premature surface defects. In addition, this relationship during the mechanical loading establishes a contact area as commonly occurs in intraoral function.

A previous study showed that the cracking may initiate in any area of the tooth–crown set submitted to stress, and it depends on the strength of each individual structure. Moreover, fatigued lithium disilicate-pressed zirconia and monolithic zirconia crowns showed better fracture strength than fluorapatite-pressed zirconia and monolithic lithium disilicate crowns. In the current study, the ceramic crowns showed different catastrophic failure types, whereas the metal-ceramic crowns exhibited fractures always exposing the metal coping. On the other hand, the majority of the bovine teeth resisted the compressive load, except one tooth for metal-ceramic crown and four for IPS Empress 2 system that showed tooth fracture associated with crown failure.

In this study, the bovine teeth were prepared with occlusal convergence of $8^\circ$ and beveled shoulder of 0.8 mm in width. According to previous studies, different designs and shoulderless preparation are responsible for higher fracture loads, whereas no difference was found between 0.4 mm and 0.8 mm-chamber preparations and different metal coping designs promoted significant influence on the fracture strength of zirconia crowns.

Another factor that may cause negative effect on the ceramic crown strength is the location of the stresses at the occlusal-axial line angle of the restoration. A possible cause for such failure is premature contact with the tooth structure or flexing of the axial walls under occlusal load; however, this situation was not observed in the present study. In this context, fractographic analysis shows that clinical crowns usually fail from cracks initiating in the cervical margins, whereas in vitro specimens fail from contact damage at the occlusal loading point, and zirconia crowns fractured at significantly higher loads than alumina and glass-ceramic crowns.

Therefore, it is evident that the configuration of the rod tip used in the compressive load played an important role when it does not promote premature failures, as those shown in previous studies. The complete contact between rod tip and occlusal morphology (groove, crest, and cusp) promoted better stress distribution through the ceramic crown. Considering this condition in both fatigue and compressive tests, it is possible that the ceramic resilience has been improved in the absence of premature defects. Moreover, the flexural strength and elastic modulus reflecting the rigidity of the material would be also improved. Thus, the occlusal contact type leads to the hypothesis that the load acted as if the crown occlusal surface was flat and regular, resulting in better stress distribution when compared to an irregular surface with greater possibility of stress concentration in the structural deformities.

This fact becomes more relevant in relation to premature failures and stress concentration in surface deformities as a previous study has shown that the grit size of the burs and the aging showed a significant effect on the fracture resistance of crowns. Thus, the fracture loads increased with decreasing grit size, and the use of fine and coarse burs for intraoral adjustments resulted in different fracture resistance of veneered zirconia crowns. In addition, the modulus of elasticity for the cement used to lute the ceramic crown plays a critical role in improving the fracture resistance of ceramic restorations and adhesive cementation of zirconia crowns improves fatigue resistance, whereas the predominant mode of failure was a fracture that initiated in the cement–ceramic layer. On the other hand, fracture loads for zirconia and alumina crowns were not influenced by the cement, whereas cementation with adhesive cement is essential for feldspar and polymer-infiltrated ceramics.

Although it is not the aim of this study, another significant aspect when the implant-supported ceramic crown resistance is considered is the mechanical instability occurred on the crown–adhesive–abutment interfaces and implant–abutment joints after fatigue. However, zirconium–lithium silicate glass-ceramic crowns cemented or screwed on implant revealed effective fatigue resistance on mean cyclic loading in an electrolyte solution.

It is also possible that microcracks occur under the action of higher number of mechanical fatigue cycles, and different crown margin curvatures may influence the strength levels and fracture patterns, factors that may be considered as limitations of the study.

**Conclusion**

Among the study conditions, it was possible to draw the following conclusions: (1) the loading of the rod tip in occlusal contact with the crown did not promote premature failures during the mechanical fatigue and (2) ceramic systems showed different values of fracture strength after the mechanical fatigue, with better performance for crowns manufactured with IPS Empress 2.

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**Conflicts of interest**

There are no conflicts of interest.

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