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Flexural Strength of Glass-Infiltrated Zirconia/Alumina-Based Ceramics and Feldspathic Veneering Porcelains

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Abstract

Purpose: To compare the flexural strength of two glass-infiltrated high-strength ceramics and two veneering glass-ceramics.
Materials and Methods: Four ceramic materials were tested: two glass-infiltrated high-strength ceramics used as framework in metal-free restorations [In-Ceram Zirconia IZ (Gr1) and In-Ceram Alumina IA (Gr2)], and two glass-ceramics used as veneering material in metal-free restorations [Vita VM7 (Gr3) and Vitadur-α (Gr4)]. Bar specimens ($25 \times 5 \times 2$ mm^3) made from core ceramics, alumina, and zirconia/alumina composites were prepared and applied to a silicone mold, which rested on a base from a gypsum die material. The IZ and IA specimens were partially sintered in an In-Ceram furnace according to the firing cycle of each material, and then were infiltrated with a low-viscosity glass to yield bar specimens of high density and strength. The Vita VM7 and Vitadur-α specimens were made from veneering materials, by vibration of slurry porcelain powder and condensation into a two-part brass Teflon matrix ($25 \times 5 \times 2$ mm^3). Excess water was removed with absorbent paper. The veneering ceramic specimens were then removed from the matrix and were fired as recommended by the manufacturer. Another ceramic application and sintering were performed to compensate the contraction of the feldspar ceramic. The bar specimens were then tested in a three-point bending test.
Results: The core materials (Gr1: 436.1 $\pm$ 54.8; Gr2: 419.4 $\pm$ 83.8) presented significantly higher flexural strength (MPa) than the veneer ceramics (Gr3: 63.5 $\pm$ 9.9; Gr4: 57.8 $\pm$ 12.7).
Conclusion: In-Ceram Alumina and Zirconia were similar statistically and more resistant than VM7 and Vitadur-α.

Due to the relatively low strength of feldspathic porcelains, McLean[1] developed an alumina-reinforced porcelain core material, used for the fabrication of porcelain jacket crowns. This new restoration alternative provided esthetics for anterior teeth, but exhibited a lower flexural strength, which limited its use for posterior teeth.

Recently, new dental materials and techniques have been introduced to fabricate esthetic ceramic restorations with improved strength.[2] This becomes more important for posterior areas in the mouth, where the forces are much higher than for the anterior region, reaching 522 N in the average individual.[3,4] Several improved types of core materials have been developed. The benefits of these materials include substantial improvement in strength and longevity.[5]

High-strength all-ceramic biomaterials currently used in dentistry include alumina, zirconia, and pressed, castable, or machinable glass-ceramics.[6] Zirconia-based ceramic is a new ceramic material that can withstand high levels of stress without failure. The remarkable mechanical properties of zirconia, already exploited in several medical and engineering applications, are mainly due to the tetragonal to monoclinic phase transformation, which can be induced by external stresses, such as grinding, cooling, and impact, resulting in a 4% increase of volume that causes compressive stresses. These stresses may develop on a ground surface or in the vicinity of a crack tip. It is this clamping constraint about the crack tip that must be overcome by the crack in order to propagate, explaining the increased fracture toughness of zirconia compared to other ceramics.[7] Also, new ceramic systems without a metal substructure allow for greater light transmission to the enamel and dentin, with satisfactory mechanical properties compared to metal substructure.[8]

One of the most representative zirconia-based ceramics is In-Ceram Zirconia (Vita Zahnfabrik, Bad Säckingen, Germany). This ceramic was developed by adding 33% 12 mol% CeO_2 partially stabilized zirconia to In-Ceram Alumina to combine the toughening mechanism due to the phase transformation of zirconia with the versatility and ease of use of the partially sintered glass-infiltrated alumina.[9]

The new Vita VM7 is a two-phase glassy feldspathic ceramic that has properties comparable to other veneers. Scanning electron microscopy, back scattering image, and energy dispersive scanning analysis revealed a two-phase glassy feldspathic ceramic with the following average composition: Si 19.6%; Al 4.9%; K 4.0%; Na 2.4%; Ca 0.7%; C 25.7%; and O 42.2%.[10]

The purpose of this study was to compare the flexural strength of two core alumina and alumina/zirconia ceramic materials and two feldspathic veneering ceramics.

Materials and methods

Specimen preparation

Beam specimens with dimensions of $25 \times 5 \times 2$ mm^3 (ISO 6872) were produced in four ceramic materials, according to the manufacturer's instructions (n = 10).

Two core glass-infiltrated ceramics

(1) Alumina-based ceramic (IA) (In-Ceram Alumina) and (2) zirconium/alumina-based ceramic (IZ) (In-Ceram Zirconia) were the two core glass-infiltrated ceramics. Bar specimens ($25 \times 5 \times 2$ mm^3), made from core ceramics, were prepared and applied into a silicone mold, which rested on a base from a gypsum die material. The IA and IZ specimens were obtained by mixing In-Ceram powder with the liquid, obtaining the slip, and drying for 24 hours. Then, the IA and IZ specimens were partially sintered in an In-Ceram furnace (Vita Zahnfabrik) according to the firing cycle of each core material. Finally, the specimens were infiltrated with a low-viscosity glass to yield a ceramic bar of high density and strength.

Two feldspar veneering ceramics

Bi-phase glass ceramic (Vita VM7, Vita Zanhfabrik) and alumina-reinforced feldspathic ceramic (Vitadur Alpha, Vita Zanhfabrik) were the two feldspar veneering ceramics. Bar specimens were made from veneering materials, by vibration of slurry porcelain powder and condensation into a two-part brass Teflon matrix ($25 \times 5 \times 2$ mm^3). Excess water was removed with absorbent paper. The veneering ceramic specimens were then removed from the matrix and were fired as recommended by the manufacturer. Another ceramic application and sintering were performed to compensate for the sintering contraction of the feldspar ceramic.

The beam specimens of the core and veneer ceramics were wet ground with 320-, 600-, 1200-, and 4000-grit siliceous carbide paper, successively. Sizes were controlled using a digital caliper with an accuracy of 0.05 mm. All specimens were stored in distilled water at 37°C for 24 hours.

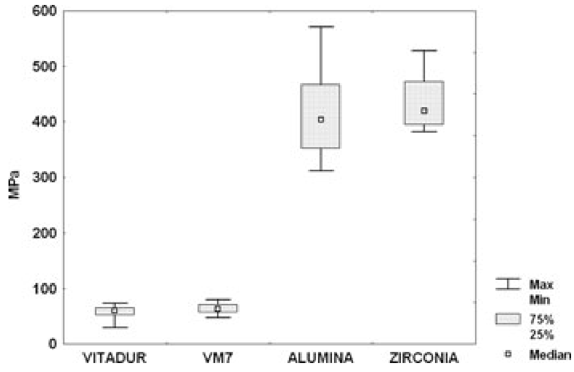

Figure 1 Flexural strength data.

Three-point bending test

For the three-point bending test, the bars were placed flat on a mountain jig with rounded supporting rods 20 mm apart. The specimens were loaded in the center with a rounded chisel (radius 2 to 5 mm) at a crosshead speed of 0.5 mm/min until fracture, with a universal testing machine (EMIC DL-1000, São José dos Pinhais, Brazil).

For flexural strength calculation (σ), the following equation was used: $\sigma = 3Wl/2bd^2$, where W is the fracture load (N); l is the distance between bearers (mm) and loading points (here a = L/2); b is the width of the specimen (mm); and d is the thickness of the specimen (mm).

The flexural strength values were statically analyzed by Kruskal-Wallis one-way analysis of variance (ANOVA) and post hoc test (Dunn's test at $\alpha = 0.05$).

Results

The flexural strength data are graphically represented in Figure 1.

ANOVA on rank data (Kruskal-Wallis test) shows that there is a significant difference for mean values (kw = 29.62; df = 3; $p = 0.001$). Dunn's test indicated that there was no significant difference between the flexural strengths (MPa) of the alumina-based ceramic (419.4 ± 83.8) and zirconium/alumina-based ceramic (436.1 ± 54.8). The flexural strengths of the high ceramics were significantly higher than those of feldspathic-based ceramic (Vitadur: 57.8 ± 12.7; VM7: 63.5 ± 9.9). There was no difference between the feldspathic ceramics.

Discussion

In this study the mean flexural strength (MPa) for alumina-based ceramic (419.4 ± 83.8) and zirconium/alumina-based ceramic (436.1 ± 54.8) were within the range reported by Hornberger et al[11] (400 to 650 MPa) and Rizkalla et al[6] (400 to 547.53 MPa).

The high flexural strength of glass-infiltrated In-Ceram Alumina depends on the strength of the fired bond between the aluminum oxide particles and the complete wetting of the pore microstructure by lanthanum glass infiltration.[11-13] According to the literature, an addition of about 33wt% of zirconia (In-Ceram Zirconia) resulted in an increase in flexural strength values from 500 to 750 MPa.[6,9,14]

The In-Ceram Zirconia system has 35% zirconia crystals, which significantly enhances the mechanical properties of this ceramic.[15] Giordarno[16] reported In-Ceram Zirconia flexural strength of 700 MPa, higher than observed in this study.

Itinoche et al[17] verified the flexural strengths of zirconia- and alumina-reinforced ceramic framework materials after mechanical cycling; the results achieved from both ceramics tested in this study met the requirements of American Dental Association (ADA) specifications that recommend a minimum flexural strength value of 100 MPa for this type of ceramic restorative material. Also, the mean flexural strength values of zirconia from this work are in agreement with the results from other studies.[14,16,18]

Mean flexural strength (MPa) of the high-strength ceramics recorded in this study were significantly higher than the ones of feldspar-based ceramic (Vitadur: 57.8 ± 12.7; VM7: 63.5 ± 9.9). There was no statistically significant difference between the two, which was expected because they had basically the same structures and both were feldspathic porcelains.[19] These data were within the range reported by other investigators.[20,21]

Two of the dental ceramics evaluated in this study (In-Ceram Zirconia and In-Ceram Alumina), have different microstructures and performance than conventional feldspathic ceramics that are basically composed of glass. The failures most commonly found in the latter are related to the presence of the crystalline phase in the glassy matrix.[22]

Flexural strength is an important indicator of a material's mechanical properties, brittle materials are much weaker in tension then in compression. The four-point flexure test is one method of assessing this property. Previous studies employed this method,[21,23-26] but only the control of flaw distribution can validate this approach.

Donassollo et al[27] determined the flexural strength of a glass-infiltrated zirconia-reinforced dental ceramic (IZ, Vita In-Ceram Zirconia) using three- and four-point bending tests, testing the hypothesis that the strength values resulting from the three-point bending test are higher than the values generated by the four-point bending test. The authors verified that even though the equations consider the differences in load application and stress distribution between tests, the mean flexural strength value resulting from the three-point bending test was higher than the flexural strength values using the four-point bending test, which confirmed the testing hypothesis. This can be explained by the relation between stress and defect distribution in favor of small stressed areas, which is the case in the three-point bending test.

As explained by Zeng et al,[28] mean flexural strength values vary according to the test method and test environment. A change in test method alone can result in significantly different mean flexural strength values.[21,27-29] For example, mean biaxial flexural strengths of In-Ceram Zirconia were 620 MPa,[30] higher values than the ones obtained in this study.

A 2-year follow-up of feldspathic ceramic inlays showed that quantitative margin analysis should be included in clinical long-term trials on this type of restoration to recognize possible deficiencies in ceramic, composite resin luting material, and the luting interfaces.[31]

Based on a systematic literature review, an evidence-based selection and assessment of clinical studies of VITA In-Ceram Classic ceramics was carried out by Wassermann et al,[32] who reported that In-Ceram Classic Alumina can be recommended for anterior and posterior crowns as well as for anterior single-retainer resin-bonded fixed partial dentures (RBFPDs). In addition, further studies should be initiated to evaluate in detail the clinical performance of In-Ceram Classic Alumina FPDs. For In-Ceram Classic Zirconia crowns or FPDs no statement can be made presently because of insufficient data.

Long-term clinical studies of In-Ceram are still very scarce; however, as these materials have improved with respect to strength, restorations based on these materials may be expected to show a lower incidence of fracture.

Conclusions

Within the limitations of this study, the following conclusions can be drawn:

(1) In-Ceram Zirconia and In-Ceram Alumina were not significantly different. The phase transformation of zirconium oxide appears not to improve the flexural strength of IZ.
(2) Vitadur Alpha and VM7 veneering ceramics were not statistically different and were weaker than the core ceramics.
(3) Further studies are necessary to fully understand the influence of each toughening mechanism on the mechanical properties and to evaluate in detail the clinical performance of the studied dental ceramics.

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