Correlation of flexural strength of coupons versus strength of crowns fabricated with different zirconia materials with and without aging

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ABSTRACT

Background. The purpose of this study was to determine the presence of a correlation between flexural strength and simulated crown strength; a correlation between crown strength and mode of fracture; an effect of aging on the flexural strength; and an effect of aging on the crown strength.

Methods. Two hundred forty zirconia specimens were fabricated with 2 different designs, fully contoured crown shape specimens (n = 120) and rectangular coupons (n = 120), to provide 10 specimens each of 6 brands of zirconia (Lava Plus High Translucency [3M ESPE], Argen HT [Argen Corp], Zirlux [Ardent], BruxZir [Glidewell Laboratories], ZenoStar [Wieland Dental], and DDBioZX^2 [Dental Direkt]). One-half of each sample type was given a severe, simulated low-temperature aging treatment. The coupons were tested by 3-point flexural strength, and crowns were tested after luting to metallic abutments using resin cement. Statistical significance was evaluated by 2-factor analysis of variance ($P = .05$).

Results. Aging increased the mean (standard deviation [SD]) flexural strength for the following groups: Argen HT (995 [140] megapascals versus 677 [121] MPa before aging), Zirlux (939 [101] MPa versus 826 [169] MPa before aging), and ZenoStar (954 [81] MPa versus 764 [77] MPa before aging). There were statistical differences for the mean (SD) crown strengths for the following aged crowns: DDBioZX^2 had higher magnitudes (9,755 [1,095] MPa) than ZenoStar (8,864 [976] MPa), whereas Lava Plus High Translucency crowns had higher magnitudes (9,871 [942] MPa) than ZenoStar (8,864 [976] MPa). There was no effect of aging on the crown strength. There were statistical differences in the mode of fracture for the zirconia crowns between the following groups: nonaged and aged BruxZir ($P = .014$), nonaged and aged ZenoStar ($P = .0226$), and nonaged and aged Lava Plus High Translucency ($P < .0001$). There was no correlation between flexural strength and crown strength.

Conclusions. There was no direct correlation between ranking of flexural strength and crown strength in the range of properties exhibited by these dental zirconias.

Practical Implications. Flexural strength does not predict simulated clinical strengths for crowns.

Key Words. Coupons; crowns; flexural strength; low-temperature degradation; scanning electron microscopy; zirconia.

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Zirconia is an attractive dental material because of its high mechanical properties (average flexural strength = 1,200 megapascals) and color approaching that of a natural tooth. Veneering porcelain is often applied to zirconia for esthetic reasons, but chipping is a major problem without an apparent solution.[1] Machined monolithic zirconia restorations avoid the chipping problem, eliminate the veneering porcelain application, and substitute for full-gold restorations in cases of limited interocclusal clearance. These attributes lead to high anticipated future demand for monolithic zirconia restorations.

Supplemental material is available online.

Fracture strength (crown strength) is a mechanical property proposed to simulate clinical conditions of masticatory forces, especially in patients with abnormal conditions such as clenching and bruxism. Related to the crown strength of clinical restorations, variations in strength has been shown to be dependent on restoration design,[2] number of firings,[3] elastic modulus of the supporting structures,[4,5] preparation design,[6] size and shape of the natural teeth,[7] effect of various surface treatments,[8] and thickness of crown framework.[9]

Commercial zirconias have a range in flexural strengths because of variations in grain size, stabilizing agents, and processing. Small grain size,[10] yttria versus magnesia stabilization,[11] and minimal porosity[12] all favor high flexural strength. Flexural strengths of zirconia reported by manufacturers are typically measured without surface treatments and with a specific geometry.[13] The flexural strength of zirconia also can be affected by surface treatments.[14] Monolithic zirconia restorations have a complex geometry and are exposed to multiple processing steps including milling using a computer-aided design and computer-aided manufacturing system, sintering, sandblasting, grinding, and polishing. These treatments, which influence surface properties, may induce cracks in the restoration that reduce its strength.

In the history of orthopedic applications of zirconia, femoral heads that articulated with polyethylene demonstrated limitations related to changes in the zirconia within the aqueous environment with time and function. This phenomenon was generally associated with low-temperature degradation (LTD) of the zirconia surface. The LTD "aging" in vivo can be simulated in vitro by a certain time and temperature of steam sterilization as recommended in International Organization for Standardization (ISO) 13356 standard[15] for aging of zirconia. For example, Chevalier and colleagues[16] demonstrated that the steam sterilization at 134°C for 5 hours is proposed to simulate 15 to 20 years at 37°C. The literature includes contradictory data regarding the effect of LTD on the flexural strength of dental-grade zirconia materials, with some authors documenting a decrease in the flexural strength[17] as affected by different theories[18-20] and others demonstrating the opposite.[21,22] Alghazzawi and colleagues[23] studied the effect of an LTD treatment on a variety of properties and monoclinic-to-tetragonal transformation of coupons fabricated from a single dental zirconia. Although the surface preparation of these coupons simulated restorations, the complex geometry of a crown was not studied.

This study sought to determine whether there is a correlation between the flexural strength (with and without a simulated LTD treatment) of coupons and crown strength using a standard restoration design in both aged and nonaged conditions for several commercially available dental zirconia dental materials. These results are significant to clinical applications in that it is important to establish if there is a relationship between material properties (flexural strength) and restoration performance (crown strength) and to determine if properties are altered by LTD.

The objectives of this study were to determine the existence of a correlation between flexural strength and simulated crown strength, a correlation between crown strength and mode of fracture, an effect of aging on the flexural strength, and an effect of aging on the crown strength.

The hypotheses were that higher flexural strength materials would exhibit higher crown strength, the magnitude of the crown strength after aging would exhibit differences in the mode of fracture, flexural strength would be decreased after aging, and crown strength would be affected by aging.

METHODS

In this experiment, we correlated the strength of zirconia material in the form of crowns to the flexural strength of the coupons with and without aging treatment.

One author (T.F.A) divided the specimens into groups for 2 designs: fully contoured monolithic crown-shaped specimens and rectangular-shaped zirconia coupons (Table 1). Six zirconia brands—Lava Plus High Translucency (Lav), Argen HT (Arg), Zirlux (Zir), BruxZir (Bru), ZenoStar (Zen), and DDBioZX^2 (DDB)—were used in the experiment for each specimen design, with 10 specimens used for each brand of zirconia. This resulted in a total of 240 specimens (120 specimens for each design). The author tested the rectangular-shaped coupons by a 3-point flexural strength, and fully contoured crown-shaped specimens were used to test the crown strength using simulated clinical conditions. One-half of each specimen type (crowns and rectangular coupons) fabricated from each zirconia brand underwent the aging treatment to correlate the effect. He designated nonaged and aged samples with an N and A, respectively. For example, aged Bru samples and associated data were labeled Bru-A. The commercial names of all materials and equipment used in this study with the corresponding manufacturers are listed in Table 2.

Fabrication of zirconia crowns. The author (T.F.A) prepared standardized zirconia monolithic crowns using a standardized metallic abutment analog in the shape of an anatomically prepared tooth. The metallic abutments were cast from chromium cobalt and scanned (3Shape Scanner, model D900L; 3Shape). He milled fully contoured zirconia crowns using a Roland DWX-50 in the white state and sintered according to the manufacturer's instructions (Table 3). He cleaned the crowns ultrasonically with isopropyl alcohol, followed by finishing and polishing to a high gloss. The crowns were mandibular first molars with buccolingual dimension of 10.6 millimeters and mesiodistal dimension of 10.9 mm. The molar crowns contained mesial, distal, and central fossas along with 5 cusps and mesial and distal marginal ridge forms. The crown thickness in the central fossa region was 0.8 mm.

Fabrication of zirconia coupons. The author (T.F.A) fabricated the rectangular-shaped zirconia specimens to mean (standard deviation [SD]) 2.96 (0.04) mm thick,

ABBREVIATION KEY. A: Aged samples. **Arg:** Argen HT. **Bru:** BruxZir. **CS:** Crown strength. **DDB:** DDBioZX^2. **EDS:** Energy-dispersive spectroscopy. **FS:** Flexural strength. **HF:** Hafnium. **ISO:** International Organization for Standardization. **Lav:** Lava Plus High Translucency. **LED:** Light-emitting diode. **LTD:** Low-temperature degradation. **N:** Nonaged samples. **O:** Oxygen. **Y:** Yttrium. **Zen:** ZenoStar. **Zir:** Zirlux. **ZR:** Zirconium.