FRACTURE RESISTANCE OF METAL CERAMIC RESTORATIONS WITH TWO DIFFERENT MARGIN DESIGNS AFTER EXPOSURE TO Masticatory Simulation

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Statement of problem. Although the esthetic outcome of a collarless metal ceramic restoration is superior to that of a restoration with a metal margin, its mechanical strength has not been evaluated.

Purpose. The purpose of this study was to evaluate and compare the fracture resistance of metal ceramic restorations with metal margins to that of metal ceramic restorations with circumferential porcelain margins, after exposure to masticatory simulation.

Material and methods. Twenty-four metal ceramic restorations were fabricated and paired with 24 cobalt-chrome tooth analogs. Twelve of the specimens had metal margins, while the remainder had circumferential porcelain margins. The restorations were cemented on the metal tooth analogs with a resin-modified glass ionomer luting agent (Fujifilm). All specimens were subjected to cyclic loading by a texture analyzer. A total of 600,000 loading cycles in an aqueous environment was performed, with a minimum load of 0 N and a maximum load of 200 N. Controlled loads were then applied to the teeth until fracture, using a stainless steel rod with a 2-mm-wide, rounded end, mounted in a universal testing machine. The specimens were examined under a stereomicroscope to determine failure mode. Descriptive statistics and the independent t test (α=.05) were used to determine the effect of failure loads among the tested groups.

Results. The independent t test revealed statistically significant differences among the 2 tested groups (P<.001). The 2 groups presented different failure modes. Metal ceramic restorations with metal margins presented cohesive failures starting from the point of load application. Metal ceramic restorations with circumferential porcelain margins demonstrated a combination of adhesive and cohesive failures, starting from the point of load application and extending to the highest point of the proximal margins.

Conclusions. Metal ceramic restorations with metal margins required significantly greater loads (P<.001) to fracture than metal ceramic restorations with circumferential porcelain margins. (J Prosthet Dent 2009;102:172-178)

Clinical Implications
Metal ceramic restorations with metal margins are preferred over metal ceramic crowns with circumferential porcelain margins when heavy occlusal loads or parafunctional activity are anticipated.
All-ceramic restorations are widely used for the maxillary anterior region because of their excellent esthetic results. They exhibit light transmission characteristics comparable to those of natural teeth. However, metal ceramics are still used extensively, primarily due to their superior physical properties and acceptable esthetics. Metal ceramic restorations combine the strength of the metal and the esthetic quality of the ceramic material. A disadvantage of this type of restoration comes from the increased light reflectivity from the opaque porcelain used to mask the metal substructure. The area where this problem of reflectivity is more severe is the cervical third of the restoration, because the porcelain is thinner in this section. Another problem is the light gray discoloration that often occurs at the adjacent gingival tissues due to the increased reflectivity exhibited by metal ceramic restorations.

The use of the porcelain labial margin was introduced in the 1970s. Several methods of porcelain margin fabrication have been reported, including the platinum foil and the direct-lift techniques, with marginal accuracy comparable to that of metal margins. Bacterial plaque accumulation has also been reported to be less on porcelain margins as compared to metal margins. The porcelain labial margin has significantly improved the esthetics of metal ceramic restorations. However, light transmission properties in the cervical area of the restoration were not greatly improved, as incidental light failed to be transmitted through the entire body of the tooth due to the presence of the lingual metal margin. The quest for improved esthetics led to the circumferential collarless metal ceramic restoration. Treatment involving this type of restoration is time consuming, as the achievement of a clinically acceptable marginal fit often requires multiple firings. Nevertheless, with this technique, both diffuse transmission of the light from the crown to the root, as well as a reduction of the unesthetic grayish shadow in the cervical area, can be achieved.

Although the esthetic outcome of the collarless metal ceramic restoration is better than the outcome with the metal margin, its mechanical strength has not been evaluated. Gardner et al, in an in vitro study, tested the fracture load of metal ceramic restorations with metal collar margins in comparison to those with porcelain facial margins. The authors concluded that the load required for fracturing porcelain from crowns with facial porcelain margins was significantly greater than that for crowns with metal margins. These findings were in contrast with those of Goodacre et al, who reported that crowns with porcelain margins were less rigid than those with a metal margin.

The purpose of this study was to evaluate the fracture resistance of metal ceramic restorations with metal margins, as well as that of metal ceramic crowns with circumferential porcelain margins, after exposure to masticatory simulation. The null hypothesis was that the fracture resistance of metal ceramic restorations with metal margins would not be different from that of metal ceramic restorations with porcelain margins.

**MATERIAL AND METHODS**

An epoxy resin maxillary central incisor analog (Viade Products, Inc, Camarillo, Calif) was prepared for a metal ceramic restoration. A 2-mm incisal reduction along with a 1.5-mm uniform axial wall reduction was accomplished. The facial surface was reduced in 2 planes. The anatomy of the lingual surface was preserved. The axial walls had an approximate taper of 6 degrees. Neither a milling machine nor a surveyor was used for the preparation procedure, so that clinical conditions would be simulated. The finish line was a 1.5-mm shoulder that extended 360 degrees around the tooth with a rounded internal angle, following the outlined cemento-enamel junction. All dimensions were verified by means of an initial silicone (Lab-Putty; Coltène/Whaledent, Inc, Cuyahoga Falls, Ohio) index.

Impressions of the prepared tooth analog were made with polyether material (Impregum Penta; 3M ESPE, St. Paul, Minn). Autopolymerizing acrylic resin (Pattern Resin LS; GC America, Alsip, III) was measured and mixed according to the manufacturer’s instructions and then poured under vibration (Vibrator No. 200; Buffalo Dental Mfg Co, Syosset, NY) into the impressions. Afterwards, the impressions were placed in a compression chamber (Wiropress SL; BEGO, Bremen, Germany) using 3 bars of pressure for 20 minutes. Twenty-four acrylic resin (Pattern Resin LS; GC America) patterns were fabricated, invested with phosphate-bonded investment (Fujivest II; GC America), and then cast with cobalt-chrome ceramic alloy (Wirobond C; BEGO). The tooth analogs (Fig. 1) were diced, placed in an ultrasonic cleaner, and inspected under x10 magnification (Olympus BH2; Olympus Corp, Tokyo, Japan) for surface irregularities on the prepared crown parts. Positive irregularities were removed with a round bur (H 1/2 round bur; Brasseler USA, Savannah, Ga).

Two coats of die spacer (Belle de St Claire; KerrHawe SA, Bioggio, Switzerland) were directly applied on the prepared cast tooth analogs. A circumferential zone of 1 mm close to the finish line was left unpainted. Die lubricant (Slick Lube; KerrHawe SA) was applied, and wax (ABF Wax; Metalor Dental AG, Oensingen, Switzerland) was used for direct wax patterns. A full-contour wax pattern for all specimens was obtained. The wax patterns were then cut back, leaving a 0.5-mm wax thickness. This was verified by means of a silicone (Lab-Putty; Coltène/Whaledent, Inc) index. Every wax pattern was paired to a tooth analog. The wax patterns were then invested with phosphate-bonded investment (Fujivest II; GC America) and cast with a gold-palladium...
(54.2% Au-31% Pd) metal ceramic alloy (V-Deltaloy, Metalor Dental AG). The castings were divested, placed in an ultrasonic cleaner, and inspected under x10 magnification (Olympus BH2; Olympus Corp) for surface irregularities. Positive internal irregularities were removed with a round bur (H1 1/2 round bur; Brasseler USA). The die spacer was removed from the metal tooth analogs by use of acetone and steam cleaning.

For 12 of the specimens, the metal was circumferentially reduced 2 mm short of the shoulder preparation. No modification was performed for the other 12 specimens. The veneering surface was prepared for all castings, first with a carbide bur (H139EUF; Brasseler USA), and then with ceramic-bound stone (Cerasiv Blue 1; Metalor Dental AG). A 0.4-mm casting thickness was finally obtained and verified with a dial caliper (Dial Caliper D; Aura-Dental, Aura an der Saale, Germany). All castings were airborne-particle abraded (externally and internally) with 50-μm aluminum oxide particles under 2.8 kg/cm² pressure and steam cleaned.

Standard porcelain application procedures followed. Two coats of opaque porcelain (EX-3; Noritake Dental, Aichi, Japan) were applied and fired at 650°C to 960°C with a heat rate of 55°C/min under a vacuum of 72 cm Hg, and a holding time of 1 minute at the end of the firing cycle. Shoulder porcelain was applied to 12 castings by use of the direct lift technique and fired at 650°C to 945°C with a heat rate of 55°C/min/under a vacuum of 72 cm Hg. Two firings were required for a satisfactory marginal adaptation to be obtained. Dentin porcelain was applied and fired at 600°C to 930°C with a heat rate of 45°C/min/under a vacuum of 72 cm Hg. A cut-back followed and enamel and incisal porcelains were then applied. Porcelain was fired at 600°C to 930°C with a heat rate of 45°C/min under a vacuum of 72 cm Hg and was then contoured with abrasive wheels. After verification of the desired dimensions and shape, a glazing cycle was performed at 650°C to 930°C with a heat rate of 50°C/min with no vacuum. Porcelain application for all specimens was accomplished by the same operator (Figs. 2 and 3).

A resin-modified glass ionomer luting agent (FujiCEM; GC Corp) was used for the cementation of the metal ceramic restorations to the tooth analogs. Manufacturer’s instructions were followed, and the cement was applied with a brush (Bendable Brush; 3M ESPE) to the intaglio surface of the crowns. The hydraulic pressure was released, and firm hand pressure was applied for a period of 10 minutes. Excess cement was removed with a curette. All cementations were performed by the same operator.

The tooth analogs with the cemented metal ceramic crowns were then embedded in autopolymerizing acrylic resin (Temporary Bridge Resin; Dentsply Caulk, Milford, Del). The top surface of the resin block was 2 mm below the margin of the crown. This design also simulated the clinical condition found in a healthy periodontium.

All specimens were subjected to cyclic loading by a texture analyzer (TA.XT2; Stable Micro Systems, Ltd, Godalming, Surrey, UK), which was connected to a personal computer. Appropriate software (Exponent; Stable Micro Systems, Ltd) was used to measure the fracture cycle. The loading cycle frequency was 1 Hz, with a minimum load of 0 N and a maximum load of 200 N. The force followed a sinusoidal function. Its most basic form is $y(t) = Ax \sin(\omega t + \theta)$, which describes a wavelike function of periodic time (t), where A is the amplitude, ω is the angular frequency, and θ is the phase. A total of 600,000 loading cycles was performed, simulating 2.5 years of clinical service. The load was applied 3 mm below the incisal edges of the specimens, at an angle of 130 degrees to the long axis of the tooth, using a stainless steel rod, 2 mm in diameter. The tooth analog-crown-acrylic resin block assembly was placed in a plastic container filled with distilled water (Fig. 4).

No crown debonding or porcelain fracture was macroscopically observed by the end of the cycle loading procedure. The specimens were additionally examined under x10 magnification with a stereomicroscope (Olympus BH2; Olympus Corp), using incidental light. No cracks were
observed.
A stainless steel rod with a 2-mm-wide, rounded end, mounted on a universal testing machine (Instron Corp, Norwood, Mass), was used to apply controlled loads to the teeth, at a crosshead speed of 2.5 mm/min, until fracture. The compressive load was applied palatally, 3 mm lower than the incisal edges of the specimens. The load required to fracture each specimen was recorded. A custom-made device allowed the load to be exerted at an angle of 130 degrees to the long axis of the tooth. This angle of loading was chosen to simulate a contact angle between maxillary and mandibular anterior teeth found in Angle’s Class I occlusal relationship. After fracture, the specimens were examined under x10 magnification with a stereomicroscope (Olympus BH2; Olympus Corp) to assess whether the failure mode was of a cohesive or adhesive type. Descriptive statistics and the independent t test (α=.05) were used to determine the effect of failure loads among the tested groups.

RESULTS
The means, standard deviations, minimum, and maximum fracture loads for the 2 groups are listed in Table I. The mean failure loads were 867.4 N and 996.7 N for the porcelain and metal margins, respectively (Table I) (Fig. 5). The metal margin group presented higher failure loads when compared to the porcelain margin group. The independent t test revealed significant differences among the 2 tested groups (t (22) = 7.33, P< .001).

<table>
<thead>
<tr>
<th>Groups</th>
<th>Mean</th>
<th>SD</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Porcelain margins</td>
<td>867.4</td>
<td>39.3</td>
<td>785.6</td>
<td>913.6</td>
</tr>
<tr>
<td>Metal margins</td>
<td>996.7</td>
<td>46.8</td>
<td>913.8</td>
<td>1064.9</td>
</tr>
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</table>
The 2 groups presented different failure modes. All metal ceramic crowns with metal margins presented cohesive failures within the porcelain (Fig. 6). Conversely, all metal ceramic crowns with circumferential porcelain margins demonstrated a combination of adhesive and cohesive failures, starting from the point of load application and extending to the highest point of the proximal margin (Fig. 7). All failures, for both groups, were on the palatal surface of the crowns.

DISCUSSION

The present study demonstrated that metal ceramic crowns with metal margins present a higher failure load than those with circumferential porcelain margins. Therefore, the null hypothesis was rejected. The results were demonstrated for anterior teeth and for loads exerted at 130 degrees to the long axes of the teeth.

An important result of the present study is that none of the specimens failed when subjected to a 600,000-cycle loading procedure in a wet environment. According to the literature, previous investigators have applied a load of 45-50 N.30,32 The 200-N load that was applied in the present study was selected because forces in the anterior dentition are usually in the range of 60-270 N, according to Kiliaridis et al.31 As previously mentioned, the loading force followed a sinusoidal function. Nevertheless, it should be recognized that mastication does not conform to such a function. It is a complex procedure influenced by age, gender, food texture, occlusal scheme, time, and presence of temporomandibular disorders. As a consequence, opening and closing velocities, directional changes, and width of lateral movements vary considerably among individuals. Additionally, in vivo temperature fluctuations and chemomechanic...
and microbiologic influences create a hostile environment for the longevity of the restorations. Therefore, cyclic loading can only provide a partial indication as to what may occur during mastication, by causing fatigue to restorative materials. Fatigue is described as the phenomenon in which the characteristics of the material change over time under constant conditions.

Although no fractures or cracks were observed when the specimens were evaluated under a stereomicroscope, the possibility of microcrack formation during cyclic loading cannot be excluded. It is known that small defects on the metal substructure or improper porcelain condensation may promote initial cracks. It has been demonstrated in the past that cyclic loading, especially under wet conditions, may cause crack propagation. The cracks eventually fuse to a growing fissure that weakens the crown. This can explain the lower failure loads observed in the present study. The mean catastrophic load applied by the universal testing machine was 867.4 N for crowns with porcelain margins and 996.7 N for crowns with metal margins. These values are about 3 to 15 times higher than the incising forces normally exerted in the anterior region. However, it should be mentioned that substantial horizontal or oblique forces may be produced during parafunctional activities. These forces can be 6 times higher than those recorded for non-parafunctional loads. Additionally, individuals with large occlusal forces in the range of 4340 N have also been reported in the literature.

As previously mentioned, the failure loads found in the present study were considerably lower than those reported by Gardner et al., which were 1350 N for crowns with metal collar margins and 1890 N for crowns with facial porcelain margins. Some differences in the methods and materials between the 2 studies may have contributed to the different results. In the study by Gardner et al, (1) the point of load application was at the lingual-incisal line angle; (2) the margin finish line for the crowns with the metal margin was at a 135-degree angle to the cavosurface; (3) the lingual surface metal ceramic junction was located 5 mm coronal to the midlingual margin; and (4) a cyclic loading procedure was not performed.

The results of the present study are in agreement with the findings of Goodacre et al. that crowns with porcelain margins are less rigid than those with metal margins. In the present study, a metal tooth analog was used to ensure dimensional uniformity among all specimens. Natural teeth were not used, because standardization would be difficult due to the large variation in age, size, shape, and quality that extracted human teeth present. Additional problems are the storage condition and time after extraction, since these 2 parameters can also affect both the load required for fracture and the fracture mode. Previous research has demonstrated that the fracture pattern of human teeth used in in vitro studies was different from that of teeth that fractured in vivo. An additional reason that human teeth were not used in the present study is that an investigation by Strub et al demonstrated that when metal ceramic crowns cemented on human teeth were statically loaded, the teeth fractured. However, the metal used for fabricating the teeth analogs presents a different modulus of elasticity (210 GPa) than human dentin (14.7 GPa). Other physical properties differ significantly, as well. As a result, the actual force distribution occurring on crowns cemented on natural teeth is different from the force distribution on those cemented on metal tooth analogs. In addition, bonding properties of cobalt-chrome alloys and dentin are different and may have affected the study outcome, since it has been demonstrated in the past that bonding of porcelain on dentin significantly increases the failure load. Although the use of finger pressure by the same operator during the cementation procedures simulates the clinical situation, it should be considered another study limitation, since it was not standardized. The design of the present in vitro investigation contains several limitations, making it difficult to obtain comparable results clinically. Long-term prospective clinical studies are required to confirm these findings.

CONCLUSIONS

Within the limitations of this in vitro study, the following conclusions were drawn:

1. Metal ceramic crowns with metal margins and metal ceramic crowns with circumferential porcelain margins did not fail after a 600,000-cycle loading procedure in a wet environment.

2. Metal ceramic crowns with metal margins required significantly greater loads (P < .001) to fracture than metal ceramic crowns with circumferential porcelain margins.

3. Metal ceramic crowns with metal margins demonstrated cohesive failures in the porcelain body, while metal ceramic crowns with circumferential porcelain margins presented a combination of adhesive and cohesive types of failure.

4. The failure loads for both metal ceramic crowns with metal margins and circumferential porcelain margins were considerably greater than the average occlusal forces in the anterior dentition (60-200 N).

REFERENCES


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