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# Resistance to Fracture of Two All-Ceramic Crown Materials Following Endodontic Access

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## Contents

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## Statement of problem

There is currently no protocol for managing endodontic access openings for all-ceramic crowns. A direct restorative material is generally used to repair the access opening, rendering a repaired crown as the definitive restoration. This endodontic procedure, however, may weaken the restoration or initiate microcracks that may propagate, resulting in premature failure of the restoration.

## Purpose

The purpose of this in vitro study was to evaluate how an endodontic access opening prepared through an all-ceramic crown altered the structural integrity of the ceramic, and the effect of a repair of this access on the load to failure of an all-ceramic crown.

## Material and methods

Twenty-four alumina (Procera) and 24 zirconia (Procera) crowns were fabricated and cemented (Rely X Luting Plus Cement) onto duplicate epoxy resin dies. Twelve crowns of each were accessed to simulate root canal treatment therapy. Surface defects of all accessed specimens were evaluated with an environmental scanning electron microscope. The specimens were repaired with a porcelain repair system (standard adhesive resin/composite resin protocol) and were loaded to failure in a universal testing machine. Observations made visually and microscopically noted veneer delamination from the core, core fracture, shear within the veneer porcelain, or a combination thereof. A Kruskal-Wallis test was used to determine if a significant difference ($\alpha$=.05) in load to failure existed between the 4 groups, and a Mann-Whitney test with a Bonferroni correction ($P$<.0125) was used for multiple comparisons. A Weibull analysis was also used to estimate the Weibull modulus and characteristic failure for each group.

## Results

All specimens exhibited edge chipping around the access openings. Some displayed larger chips within the veneering porcelain, and 4 zirconia crowns showed radial crack formation. There was a significant difference in load to failure among all groups with the exception of the alumina intact and repaired specimens ($P$=.695). The alumina crowns generally showed fracture of the coping with the veneering porcelain still bonded to the core, whereas the zirconia copings tended not to fracture but experienced veneering porcelain delamination.

## Conclusion

Endodontic access through all-ceramic crowns resulted in a significant loss of strength in the zirconia specimens but not in the alumina specimens.

### Clinical implications

*Repair of an endodontically accessed all-ceramic crown may provide an adequate interim restoration, provided radial cracks or other visible fracture formations are not apparent. Remake of the restoration should be discussed with the patient prior to preparation of the crown and prior to endodontic therapy, if needed.*

A common, yet frustrating occurrence in dentistry is the need to treat a diseased pulp through an indirect restoration. It is estimated that 20% to 50% of root canal treatments are performed through complete-coverage crowns.[1, 2] Any tooth receiving an indirect restoration should be tested for vitality before definitive treatment is rendered. Ideally, if root canal treatment is indicated, it should be completed prior to placement of the restoration. Nonetheless, Bergenholtz and Nyman[3] have reported that approximately 15% of vital teeth need endodontic treatment on completion of prosthetic therapy.

Root canal treatment through an existing crown presents 2 challenges. First, access orientation is difficult because the crown masks the coronal tooth structure, so clinicians must use their best judgment to determine pulp chamber location. Second, the restorative dentist must determine how to manage the access opening, either by placing a direct restorative material or remaking the entire restoration. For the tooth with minimal or no dental caries, application of a restorative material to prevent marginal and intermaterial leakage should be considered. With this approach, the long-term success of the root canal treatment through an existing artificial crown is highly dependent on the seal of the restored access opening. Unfortunately, there is no evidence-based research suggesting the best material for these access repairs. Trautmann et al[1] presented the results of a survey given to endodontists, prosthodontists, and general practitioners as to material of choice for a direct repair. The preferred and most frequently used material to restore a metal crown was a bonded silver amalgam restoration, whereas composite resin was the material of choice for metal-ceramic crowns.

All-ceramic crowns are a routine treatment option and pose additional challenges to those previously mentioned when root canal therapy is indicated. Ceramics are poor conductors of heat, making it difficult to control heat formation during access opening preparation. In addition, preparation of endodontic access openings through all-ceramic restorations may initiate microcracks, which have the potential to propagate with time and result in fracture. Considering these challenges, the use of a diamond rotary cutting instrument in a high-speed handpiece with light brush strokes and heavy water spray has been suggested.[4, 5] Furthermore, the decision to place a direct restorative material in the access opening or replace the existing crown will depend on the extent of visible microcracks introduced during access preparation. The long-term prognosis for this repaired restoration, however, is unknown.

A few studies have evaluated the effect of endodontic access on the structure of all-ceramic crowns. Teplitsky and Sutherland[4] evaluated the effect of endodontic access opening on 56 extracted teeth restored with crowns consisting of an aluminous ceramic core and compatible porcelain veneer (Cerestore; Ceramco Inc, East Windsor, NJ). Scanning electron microscope (SEM) evaluation showed that none of the crowns fractured. However, chips and roughness were present around all of the access openings. Two studies evaluated castable glass ceramic (Dicor; Dentsply Intl, York, Pa) crowns. Cohen and Wallace[6] examined 6 Dicor crowns on extracted teeth before and after endodontic access. With the exception of 1 crown cracking at the gingival collar during removal from the tooth, chipping was noted around the access openings of all of the crowns. Sutherland et al[7] compared the access openings made with diamond rotary cutting instruments and tapered fissure carbide burs on 42 Dicor crowns. The authors concluded carbide burs produced more fractures and craze lines than diamond rotary cutting instruments. In another study, Haselton et al[8] quantitatively characterized damage to crowns following endodontic access. Using SEM analysis on 28 Lucite-reinforced pressed glass-ceramic crowns (IPS Empress; Ivoclar Vivadent, Amherst, NY), the authors classified the damage into 3 categories: (1) edge chipping–a disruption of the outline form; (2) visual microcrack–a crack with no separation of porcelain, and (3) fracture–a crack resulting in 2 or more parts. The authors reported edge chipping in all specimens, microcracks in 4 specimens (14%), and fractures in 3 specimens (11%), 2 using a diamond rotary cutting instrument and 1 using a carbide bur.[8]

The strength of dental ceramics is largely flaw dependent.[9] Flaws, which may be inherent or incurred during handling, are thought to exist in all ceramics and have the potential to worsen in aqueous environments with applied stresses.[10] Water allows the slow growth of cracks because it acts chemically on crack tips, allowing them to propagate.[10] All surfaces of the ceramic are vulnerable to water. Internally, water from dentinal tubules can moisten the dental cement and assist in propagating inner surface flaws of the ceramic, and externally, the ceramic is exposed to saliva. In these conditions, the additional damage and stress arising from an endodontic access procedure would seem to put the ceramic at increased risk of further complications.

Few studies have compared the strength of restorations before and after endodontic therapy. Stokes et al11 evaluated the fracture strength of all-ceramic crowns (Vita Dur N; VITA Zahnfabrik, Bad Sackingen, Germany) repaired with and without a silane primer and, subsequently, composite resin. Thirty identical maxillary central incisor crowns were divided into 3 groups: 10 crowns left intact to act as the control group, 10 standardized endodontic accesses with adhesive composite resin repair, and 10 standardized endodontic accesses with a silanating agent prior to an adhesive composite resin repair. The intact control crowns were stronger than both of the repaired groups, whereas there was no significant increase in fracture strength with the use of the silane agent. In a second study, Hachmeister et al12 studied endodontic access through complex amalgam restorations, which were then repaired with amalgam. The authors found the repaired restorations to be significantly weaker than the unrestored original complex amalgam restorations. Although not evaluating endodontic access openings, an analogous study was done by Torrado et al[13] comparing the porcelain fracture resistance of screw-retained and cement-retained implant-supported metal-ceramic crowns. The authors found that a significantly lower force was needed to fracture screw-retained crowns with an access opening of 2.5 mm in the center of a 5-mm-diameter crown than for the cemented intact crowns.

This in vitro study evaluated the load to failure of a simulated mandibular molar with an all-ceramic crown before and after an endodontic access was made and repaired. A mandibular molar was chosen because this tooth was determined to be treated most often with endodontic therapy.[14] Two types of all-ceramic crowns were included, 1 with an alumina core and 1 with a zirconia core, each with their respective veneering porcelain. The former has shown clinical success in posterior applications,[15, 16, 17] whereas the latter is representative of the trend of using core materials with greater flexural strength and fracture toughness.[10, 18] Endodontic access through these higher strength core ceramics has not been studied. The aim of this in vitro study was to examine how the endodontic access altered the veneering porcelain, the core material, and the interface between the 2, and secondly, to evaluate the effect of a repaired endodontic access on the load to failure of all-ceramic crowns. The null hypothesis was that there was no difference in the load to failure between the intact and accessed (with repair) crowns within each respective coping material.

## Material and methods

Twenty-four alumina (Procera; Nobel Biocare, Goteborg, Sweden) and 24 zirconia (Procera; Nobel Biocare) crowns were fabricated and cemented onto epoxy resin dies. Twelve crowns of each were accessed with a diamond rotary cutting instrument to simulate root canal treatment therapy. An environmental SEM (ESEM) was used to evaluate surface defects in the accessed specimens and representative intact specimens. After the accessed crowns were repaired with a porcelain repair system, all specimens were loaded to failure. Following loading, failure observations were made.

## Master die

A stainless steel master die was fabricated to simulate a mandibular molar all-ceramic crown preparation with the following dimensions: 6-mm occlusal flat surface diameter, 5-mm vertical height, and 1-mm rounded chamfer finish line with a total convergence taper of 16 degrees (Custom Machining, Welding and Prototyping, Milwaukee, Wis). A high-strength silicone rubber (Silastic E Base and Silastic E Curing Agent; Dow Corning, Midland, Mich) was used to make an impression of the master die. A high-heat epoxy resin (Viade Products Inc, Camarillo, Calif) reported to have an elastic modulus similar to dentin[19, 20, 21] was poured into this impression for a duplication of the master die. Using the duplicated master die, 24 molds were similarly created, and the same high-heat epoxy resin material was poured into each. Each mold was used 2 times to produce 48 duplicated dies.

## Crown fabrication

All duplicate dies were numbered and divided into 2 groups of 24. A scanner (Procera Scanner Model 50; Jemtab Systems, Akers, Sweden) was used to scan 24 of the dies for processing alumina copings with a thickness of 0.6 mm, and 24 for zirconia copings with a thickness of 0.6 mm. The coping thicknesses were based on computer software program processing dimensions for these materials. All copings were visually evaluated to ensure complete seating and marginal adaptation to their respective die, with no external or internal adjustments. External surfaces of the copings were airborne-particle abraded with 100-µm aluminum oxide at 60 psi and sonicated in distilled water. Prior to pressing the veneering porcelain, the copings were placed into a porcelain oven (PRO 100 Porcelain Oven; Whip Mix Corp, Louisville, Ky) at 538°C, with a temperature rise of 32°C/min to 1000°C, and then held under vacuum at 1000°C for 1 minute.

A waxing was made over 1 coping specimen with a uniform thickness of 1.5 mm (Fig. 1). A condensation silicone (Sil-Tech; Ivoclar Vivadent, Amherst, NY) matrix was made to preserve these contours for uniform thickness. The matrix was used as a guide for the subsequent standardized waxing of each crown (Fig. 1). Each coping with the waxing was invested (Noritake Press Investment; Noritake Dental Supply Co, Ltd, Nagoya, Japan), allowed a 30-minute bench polymerization, and placed into a preheated oven at 871°C for a 1-hour wax elimination. Ceramic ingots (Microstar Press-to-Alumina Ingots; Microstar Corp, Lawrenceville, Ga and Noritake CZR Ceramic Press Ingots; Darby Dental Lab Supply, Inc, Jericho, NY) were pressed over the alumina and zirconia copings, respectively, in a pressing oven (Shenpaz Gemini Pressing Oven; Shenpaz Industries Ltd, Tel Aviv, Israel). The veneering porcelain was pressed over the alumina copings to remain consistent with the zirconia processing, as well as to avoid inconsistencies with the hand-layering technique. All crowns were devested, the sprues were removed, and the crowns were fit to their respective dies.

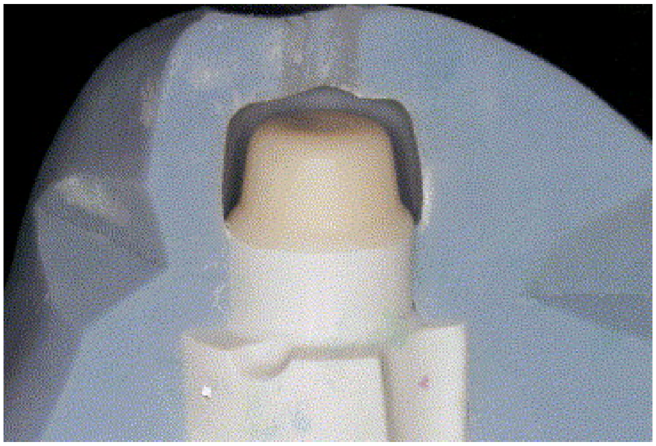

Fig 1. Silicone matrix made from original waxing used to guide and preserve uniform thickness of wax over all copings.

The crowns were ultrasonically cleaned in distilled water for 10 minutes and cemented, individually, with a resin-modified glass-ionomer luting agent (Rely X Luting Plus Cement; 3M ESPE, St. Paul, Minn). The crowns were then seated on the dies initially with finger pressure, followed by a constant 5-kg load for 10 minutes[19] applied by an apparatus capable of maintaining a static deadweight load. Excess cement was removed, and all specimens were stored in a humid saline environment for 24 hours at 21°C ± 1°C.

## Endodontic access

The 2 groups of 24 crowns were further divided into the following 4 groups for a total of 12 specimens in each group: intact alumina crowns (AI), alumina crowns with a standard endodontic access and repair (AR), intact zirconia crowns (ZI), and zirconia crowns with a standard endodontic access and repair (ZR). For Groups AR and ZR, a standardized, conservative endodontic round access opening with a diameter of 3.5 mm was marked with the use of a plastic template. The template was positioned at the center of the occlusal surface for each crown, and a marker was used to transfer the outline to the crown. One operator made the access openings with heavy water spray and light brush strokes using a new ultra-coarse-grit gold-shank diamond rotary cutting instrument (#2801.31.023; Brasseler USA, Savannah, Ga) for each crown in a high-speed handpiece.

## Defect characterization

All crown margins were painted with varnish (Copalite Varnish; Cooley & Cooley, Ltd, Houston, Tex) to prevent cement desiccation during subsequent microscopic analysis. All specimens in Groups AR and ZR, as well as representative specimens from Groups AI and ZI, were examined visually and under magnification with an ESEM (Leo 1450VP with Leo 32 software; Carl Zeiss SMT Inc, Thornwood, NY) for crack and defect characterization. An ESEM was selected over a traditional SEM to preclude the need for sputter coating the ceramic, as this coating would have interfered with the ceramic bond repair protocol. Each specimen was viewed in both backscattered electron and variable pressure secondary electron mode.

Digital ESEM micrographs of accessed crowns were obtained and analyzed. Defects associated with the access openings were categorized according to those established by Haselton et al,8 namely, edge chipping, microcracking, and fracture. For edge chipping, chips >0.7 mm in radial length were differentiated from edge chips of typical dimension (<0.4 mm). Additionally, voids at the core/cement interface were noted, as well as the length and origin of any microcracks.

## Access repair

The access openings in Groups AR and ZR were repaired with a porcelain repair system (All-Bond 2 Porcelain Repair Kit; Bisco, Inc, Schaumburg, Ill) and a direct restoration.[22, 23, 24] Each crown was individually repaired using the following protocol: porcelain etchant 4% hydrofluoric acid gel, 4 minutes, rinse; porcelain silane primer, 2 minutes, air dry; All-Bond 2 primer A & B, 5 coats, air dry; and dentin/enamel resin, air thin, light polymerize (Elipar Highlight; 3M ESPE, Seefeld, Germany), 40 seconds.[25] Two increments of composite resin (XRV Herculite Unidose Hybrid Composite Resin, shade enamel A3; Kerr Corp, Orange, Calif), each with a 40-second light polymerization, completed the repair. The occlusal aspect of the repair was made level with adjacent porcelain, and the external repair flash was removed with a carver (Hollenback 3S; Henry Schein Inc, Melville, NY). The composite resin repair and porcelain occlusal surface interface was smoothed with 1200-grit silicon carbide paper (Buehler Ltd, Lake Bluff, Ill). A repaired crown with a master die, duplicate die, intact crown, and accessed crown are shown in Figure 2.

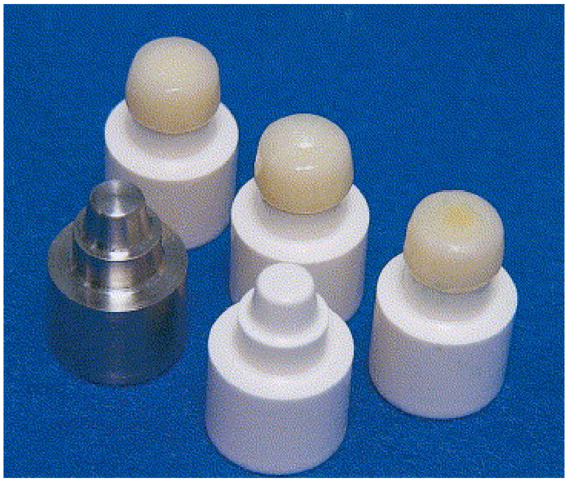

Fig. 2. Stainless steel master die and duplicated high-heat epoxy die (left to right, front diagonal row). Intact alumina crown, accessed alumina crown, and repaired alumina crown (left to right, back diagonal row).

## Mechanical testing

Specimens were positioned in a custom-made mechanical fixture positioned on a load cell. Each specimen was loaded to failure along its long axis at a rate of 0.2 mm/min in a universal testing machine (Model 55R1114; Instron Corp, Canton, Mass). The loading piston was 6.35 mm in diameter along its long axis, with its end machined to a curvature equivalent to a 50-mm diameter. A loading piston of this dimension avoids high-contact stresses on loading.[26, 27] The end of the loading piston contacted the center of the occlusal surface of each crown (Fig. 3). This loading position has been used in other studies[19, 20, 28] and, to maintain consistency, was used in loading both the intact and repaired specimens. After initial contact on the repaired specimens, the piston surface contacted both the composite resin repair as well as the surrounding porcelain. Failure load was recorded in kilogram force (kgf) and designated as the maximum compressive load prior to a greater than 5% drop in load and/or visualization of significant crack formation. Force data for all specimens were converted to newtons (N) and tested for normality with a Shapiro Wilk's test. The data were subsequently tested with a Kruskal-Wallis test to determine whether a significant difference ($\alpha$=.05) in load to failure existed between the 4 groups, and a Mann-Whitney test with a Bonferroni correction ($P$<.0125) was used for multiple comparisons. All statistical analysis was performed using a statistical analysis program (SPSS 13.0; SPSS Inc, Chicago, Ill). Additionally, a Weibull analysis was performed to estimate the Weibull modulus and characteristic failure load for each group. Following load-to-failure testing, all fractured specimens were visually and microscopically (American Optical Co, Buffalo, NY) observed, noting core fracture, veneer delamination from the core, shear within the veneer porcelain, or a combination thereof.

Fig. 3. Loading piston was 6.35 mm in diameter along its long axis, with its end machined to curvature equivalent to 50 mm in diameter, which contacted center and approximate same area of each crown.

# Results

## Endodontic access characterization by ESEM analysis

All alumina specimens exhibited circumferential irregularities or edge chipping of the veneering porcelain extending radially up to 0.4 mm from the access opening (Fig. 4). Six of the 12 alumina specimens had larger chips that extended radially greater than 0.7 mm (Fig. 4). One of these chips extended from the access to the proximal wall of the crown. The other 5 larger chips ranged from approximately 0.7 × 0.5 to 1.75 × 0.75 mm (radial length × circumferential width). Defects at the core/cement interface were also noted in some specimens. Figure 5 shows a void in the cement layer that appears to extend into the core, indicating that a section of core chipped away during the endodontic access procedure. No microcracks or fractures were observed within the alumina group.

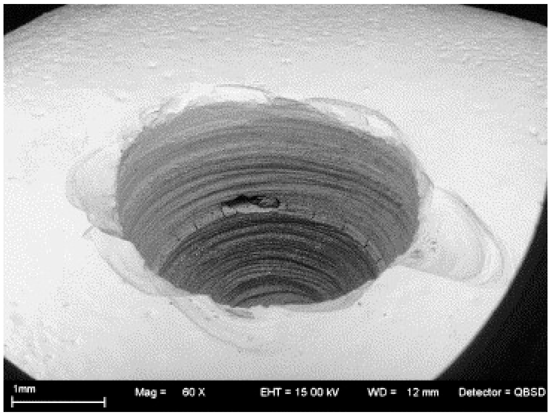


Fig. 4. ESEM of alumina crown showing significant chip as well as edge chipping within veneering porcelain. Backscattered electron (QBSD, bottom right) detector was used in obtaining this image. Original magnification ×60.

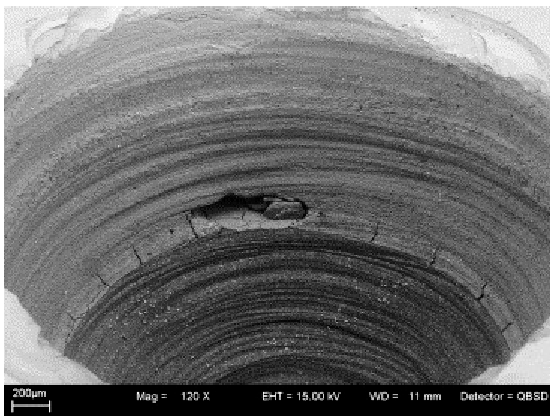


Fig. 5. ESEM of alumina crown showing void in cement layer that appears to extend into core, indicating that section of core chipped away during endodontic access procedure. Original magnification ×120.

All zirconia specimens exhibited similar edge chipping of the veneering porcelain around the access openings (Fig. 6), including 1 specimen with an additional significant veneer chip of approximately 1.25 × 1.25 mm. Radial crack formation during access preparation was unique to 4 zirconia specimens. ESEM analysis confirmed the number of cracks of these specimens to range from 2 to 5 (Fig. 7), with 1 specimen having 2 of the 5 cracks reach the proximal walls. A close-up view of a radial crack is shown in Figure 8. A chip, discontinuation, or void of the zirconia core and/or cement was noted in several specimens. One specimen had 3 core chips that were approximately 170 µm, 100 µm, and 300 µm in circumferential length (Fig. 9), whereas other specimens had single voids ranging from 100 µm to 500 µm in length. All of the accessed alumina and zirconia specimens viewed with the ESEM showed regularly spaced, vertical cracks within the cement layer. After additional investigative ESEM analysis, the cause of the cement cracking was believed to be due to the crown seating or access procedures rather than cement desiccation.

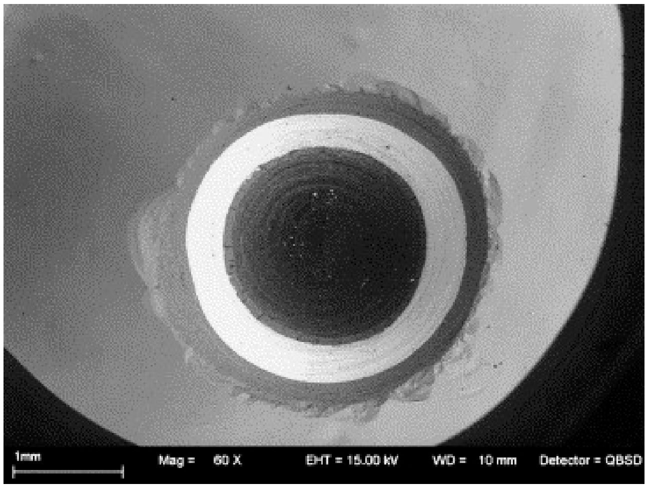


Fig. 6. ESEM of zirconia crown showing edge chipping. Zirconia core is area in *white*. Original magnification ×60.

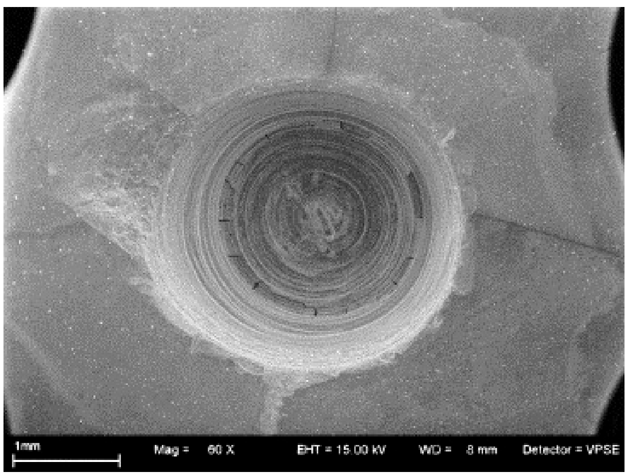


Fig. 7. ESEM of zirconia crown showing radial crack formation from access. Variable pressure secondary electron (VPSE, bottom right) detector was used in obtaining this image. Original magnification ×60.

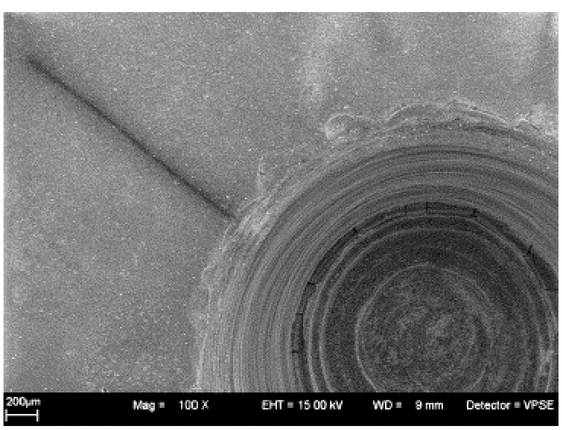


Fig. 8. ESEM of zirconia crown showing close-up view of radial crack formation from access. Original magnification ×100.

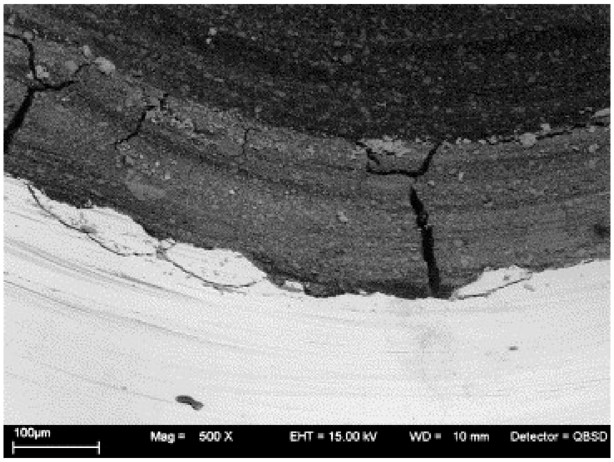


Fig. 9. ESEM of zirconia crown showing 3 core chips. In this view, die material is at *top*, cement in *middle*, and zirconia core at *bottom*. Original magnification ×500.

## Load to failure

The load-to-failure data and the Weibull parameters are shown in Table I. A Kruskal-Wallis test identified that a significant difference existed between the 4 groups ($P$<.001, chi-square=31.9, $df$=3). The Mann-Whitney test was used for multiple comparisons among the 4 groups, the results of which are shown in Table II. There was a significant difference between all pairings, with the exception of the alumina intact and repaired specimens. Most importantly, within the zirconia group, 3 of the 4 specimens with the observed crack formation exhibited the 3 lowest loads to failure.

Table I. Mean (± SD) and Weibull parameters of load-to-failure testing

| Group | Load to failure (N) | Weibull modulus | Weibull characteristic load to failure (N) |
|---|---|---|---|
| AI | 1410 ± 111 | 12.8 | 1459 |
| AR | 1436 ± 223 | 6.2 | 1531 |
| ZI | 2432 ± 181 | 13.4 | 2514 |
| ZR | 2075 ± 348 | 5.4 | 2246 |

Table II. Mann-Whitney multiple comparison significance values (significant if $P$<.0125) for load to failure between all relevant groupings

| Multiple comparisons | | Mann-Whitney 2-tailed exact significance level |
|---|---|---|
| AI | AR | 0.695 |
| ZI | ZR | 0.006 |
| AI | ZI | 0.000 |
| AR | ZR | 0.000 |

## Fracture observation

Table III presents the primary fracture observations for the 4 groups. In general, a majority of the alumina coping crowns showed fracture of the coping with the veneering porcelain still bonded to the core. The zirconia copings tended not to fracture, but the veneering porcelain delaminated from the core material in a majority of specimens. It should also be noted that the die material fractured before the core material fractured in 3 instances within the intact zirconia group. In addition, a few specimens remained unfractured after failure as previously defined, so a fracture mode was not noted.

Table III. Percentage (frequency) of specimens showing each mode of fracture

| **Group** | **Fractured core** | **Veneer delaminated from core** | **Veneer shear from veneer** | **Core fracture with veneer delamination** | **Core fracture with veneer shear** |
|---|---|---|---|---|---|
| AI | 55.6% (5) | 0 | 11.1% (1) | 0 | 33.3% (3) |
| AR | 33.3% (3) | 0 | 44.4% (4) | 0 | 22.2% (2) |
| ZI | 0 | 90.9% (10) | 0 | 9.1% (1) | 0 |
| ZR | 0 | 70.0% (7) | 0 | 30.0% (3) | 0 |

## Discussion

Endodontic therapy and subsequent repair of the access in all-ceramic crowns will be an inevitable event as these restorations become more widely used. To establish a protocol, it is necessary to understand the long-term prognosis of the restored crown when a purposeful, careful, and conservative access opening is made.

Endodontic access through all-ceramic crowns will create a variety of flaws, some of which may have the potential to cause failure of the restoration. Thus, before any treatment is performed and prior to preparation of the crown and any needed endodontic therapy, remake of the restoration should be discussed with the patient. Through ESEM evaluation in this study, edge chipping was noted in all of the access openings of both the alumina and zirconia specimens. These findings are consistent with those of Haselton et al[8] as well as Teplitsky and Sutherland.[4] Crack formation was found in 16.6% of the specimens in the present study, which is comparable to the 14% found by Haselton et al[8] but greater than the observations of Cohen and Wallace[6] (0 cracks in 6 specimens) and Teplitsky and Sutherland[4] (1 crack in 56 specimens). Additionally, a unique finding of the present study was that chipping of the core at the core/cement interface occurred in several specimens. Whether the repair material is able to adequately fill these voids was not determined but warrants further research, as voids have been shown to be stress concentrators or crack initiation sites.[9]

Creating an endodontic access and then repairing it significantly decreased the strength of the zirconia crowns but did not significantly alter the strength of the alumina crowns. Thus, the null hypothesis was rejected for the zirconia crowns but accepted for the alumina crowns. Reasoning for this observation may be related to the difference in strengths between the 2 materials. As shown in Table I, the zirconia specimens were stronger than the alumina specimens, which is not surprising given zirconia's greater flexural strength and fracture toughness.[18] Within the limitations of the study discussed later, the repair was not able to restore the stronger crown (zirconia) to its original strength, but appeared to do so satisfactorily for the alumina crowns. The decrease in strength found with the zirconia specimens was consistent with the findings of studies by Stokes et al[11] and Hachmeister et al.[12] However, caution is advised for a direct comparison, as different crown systems (metal substructure or all-ceramic), repair protocols, and loading conditions were used.

For both the alumina and zirconia groups, endodontic access did affect the reliability of the crowns, as shown by the greater Weibull modulus values for the intact versus the repaired specimens. The higher modulus of the intact groups signifies a closer grouping of results as compared to the moduli for the repaired groups. This would seem reasonable considering the variation that occurs within each access and the subsequent repair, in addition to the introduction of more flaws in this class of material known to have flaw-dependent strength.[9] This reduced reliability is also suggested by the approximate doubling of the standard deviations between the intact and repaired groups of both systems. Important to note from a clinical perspective is that 3 of the specimens with radial crack formation failed at lower loads than all other repaired zirconia specimens. The visualization of crack formation on access should assist the clinician in the decision to remake the crown.

Different modes of fracture were observed between the alumina and zirconia specimens. For the zirconia specimens, the core was intact after load-to-failure testing in all but 4 specimens, with the majority showing veneer porcelain delamination from the zirconia core. The opposite tended to occur in the alumina specimens, which showed no delamination but rather core fracture, veneer porcelain shear, or a combination of the above. It would be erroneous, however, to conclude from this study that the alumina core/veneer porcelain interface is stronger than the zirconia core/veneer porcelain interface, because the zirconia specimens failed at much greater loads. Furthermore, resolving which core/veneer porcelain interface is stronger is not possible, as the stress states at the interface were not determined. Although differences in testing methodology make direct comparison questionable, results from Al-Dohan et al[29] showed the mean shear strengths of alumina and zirconia copings to their respective porcelains to be statistically similar. In that study, delamination was not observed. However, Webber et al[28] evaluated the compressive load at fracture of alumina copings with varying thicknesses of veneering porcelain and found the majority of failure to be delamination of the veneer from the core. Unfortunately, there has been a limited amount of data presented on the behavior of zirconia core crowns, so no comparisons can be made. It should also be mentioned that these failure observations differ from the more rigorous determinations of failure origin that have been performed on in vitro[21] and clinically retrieved specimens.[9, 30]

Due to the fact that the integrity of the core material and overlying veneering porcelain has been disrupted, feasibility of a repair may be questionable. The results of this study, with its inherent limitations, suggest it is. As reported in previous literature, intraoral repair of porcelain is not without risk.[24] Repair of a layered all-ceramic crown has not been documented in the literature. It has been shown that hydrofluoric acid does not have an effect on higher strength ceramics, such as alumina and zirconia.[10] It does, however, etch the feldspathic veneering porcelain. The silane coupling promotes a chemical bond and increases the wettability of the adhesive resin.[22, 25] Whether the silane promotes micromechanical retention is unproven. The repair in the present study may have achieved a sandwich-like repair—bonding to both the inner layer (bondable die material[19] in this case, or dentin in clinical situations) and the outer layer (feldspathic veneering porcelain), with the unbonded core material in between. Of course, clinical studies are the definitive test as to the longevity of repaired all-ceramic crowns. Oden et al[17] followed 97 Procera AllCeram crowns in service for 5 years to find that 1 incisor and 1 molar crown required endodontic treatment through the crowns. The incisor was treated 14 days after cementation, whereas the molar was in the study for 4 years prior to treatment. Access openings were made with a diamond rotary cutting instrument, at which time no fractures were noted. The authors do not comment on how the access openings were repaired, but report that the crowns were still in service at the end of the 5-year study. Further research investigating the structure, seal integrity, and long-term prognosis of repaired endodontically treated all-ceramic crowns is warranted.

This study has several limitations. The specimens were symmetric, unlike the variation and curvatures found in natural teeth. This was purposely done to control geometric variables and allow consistent loading on a flat occlusal surface in the same location for each intact and repaired specimen. This loading was consistent with other studies.[19, 20, 28] Although rarely addressed in ceramic crown strength studies, it is conceivable that different loading locations may have a significant effect on the results. Furthermore, the specimens were loaded to failure in a single event along the long axis of each specimen. Dental ceramics typically fail as a result of many loading cycles or an accumulation of damage from stress and water.[31] In terms of in vivo loading, the masticatory cycle consists of a combination of vertical and lateral forces, putting the ceramic under a variety of off-axis loading forces. In this in vitro study, the crowns were stored in a humid environment, as compared to the dynamic intraoral environment, which may further accelerate ceramic fatigue. Nevertheless, in vitro parameters as recommended by Kelly[26] and Dong and Darvell[27] were considered in the design of this study. Testing parameters included use of a die material with a modulus of elasticity close to dentin, crown dimensions similar to what is prescribed intraorally, use of a commonly used dental luting cement, and the use of a large-radii indenting piston to prevent clinically unrealistic contact stresses that occur using loading devices with smaller radii.

## Conclusions

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

1. Endodontic access of all-ceramic crowns resulted in edge chipping around the access openings of all of the accessed specimens, in addition to crack formation and chipping of the core and/or cement on some specimens.

2. Endodontic access resulted in a significant strength ($P$=.006) decrease in zirconia specimens but not in alumina specimens. Specimens that had radial crack formation on access tended to fail at lower loads than other repaired specimens.

3. Both intact and repaired crowns with zirconia copings were stronger than those with alumina copings.

4. A porcelain repair protocol of an accessed Procera alumina or zirconia crown may provide an adequate interim restoration, provided radial cracks or other visible fracture formations are not apparent.

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## References


1 G. Trautmann, J.L. Gutmann, M.E. Nunn, D.E. Witherspoon, J.D. Shulman. **Restoring teeth that are endodontically treated through existing crowns. Part II: survey of restorative materials commonly used.** Quintessence Int, 31 (2000), pp. 719-728

2 M. Goldman, P. Laosonthorn, R.R. White. **Microleakage-full crowns and the dental pulp.** J Endod, 18 (1992), pp. 473-475

3 G. Bergenholtz, S. Nyman. **Endodontic complications following periodontal and prosthetic treatment of patients with advanced periodontal disease.** J Periodontol, 55 (1984), pp. 63-68

4 P.E. Teplitsky, J.K. Sutherland. **Endodontic access of Cerestore crowns.** J Endod, 11 (1985), pp. 555-558

5 M.W. Davis. **Providing endodontic care for teeth with ceramic crowns.** J Am Dent Assoc, 129 (1998), pp. 1746-1747

6 B.D. Cohen, J.A. Wallace. **Castable glass ceramic crowns and their reaction to endodontic therapy.** Oral Surg Oral Med Oral Pathol, 72 (1991), pp. 108-110

7 J.K. Sutherland, P.E. Teplitsky, M.B. Moulding. **Endodontic access of all-ceramic crowns.** J Prosthet Dent, 61 (1989), pp. 146-149

8 D.R. Haselton, P.M. Lloyd, W.T. Johnson. **A comparison of the effects of two burs on endodontic access in all-ceramic high lucite crowns.** Oral Surg Oral Med Oral Pathol Oral Radiol Endod, 89 (2000), pp. 486-492

9 J.Y. Thompson, K.J. Anusavice, A. Naman, H.F. Morris. **Fracture surface characterization of clinically failed all-ceramic crowns.** J Dent Res, 73 (1994), pp. 1824-1832

10 J.R. Kelly. **Dental ceramics: current thinking and trends.** Dent Clin N Am, 48 (2004), pp. 513-530

11 A.N. Stokes, J.A. Hood, P.B. Casley, R.M. Cawley, G.J. Cho. **Endodontic access cavities in porcelain jacket crowns—two methods of repair compared.** Restorative Dent, 4 (1988), pp. 56-58

12 K.A. Hachmeister, W.J. Dunn, D.F. Murchison, R.B. Larsen. **Fracture strength of amalgam crowns with repaired endodontic access.** Oper Dent, 27 (2002), pp. 254-258

13 E. Torrado, C. Ercoli, M.A. Mardini, G.N. Graser, R.H. Tallents, L. Cordaro. **A comparison of the porcelain fracture resistance of screw-retained and cement-retained implant-supported metal-ceramic crowns.** J Prosthet Dent, 91 (2004), pp. 532-537

14. B.E. Wayman, J.A. Patten, S.E. Dazey. **Relative frequency of teeth needing endodontic treatment in 3350 consecutive endodontic patients.** J Endod, 20 (1994), pp. 399-401

15 P. Odman, B. Andersson. **Procera AllCeram crowns followed for 5 to 10.5 years: a prospective clinical study.** Int J Prosthodont, 14 (2001), pp. 504-509

16 M. Andersson, M.E. Razzoog, A. Oden, E.A. Hegenbarth, B.R. Lang. **Procera: a new way to achieve an all-ceramic crown.** Quintessence Int, 29 (1998), pp. 285-296

17 A. Oden, M. Andersson, I. Krystek-Ondracek, D. Magnusson. **Five-year clinical evaluation of Procera AllCeram crowns.** J Prosthet Dent, 80 (1998), pp. 450-456

18 K.J. Anusavice, R.W. Phillips (Eds.), Phillips' science of dental materials (11th ed.), Elsevier, St. Louis(2003), pp. 655-715

19 G. Neiva, P. Yaman, J.B. Dennison, M.E. Razzoog, B.R. Lang. **Resistance to fracture of three all-ceramic systems.** J Esthet Dent, 10 (1998), pp. 60-66

20 Z. Harrington, A. McDonald, J. Knowles. **An in vitro study to investigate the load at fracture of Procera AllCeram crowns with various thickness of occlusal veneer porcelain.** Int J Prosthodont, 16 (2003), pp. 54-58

21 K. Pallis, J.A. Griggs, R.D. Woody, G.E. Guillen, A.W. Miller. **Fracture resistance of three all-ceramic restorative systems for posterior applications.** J Prosthet Dent, 91 (2004), pp. 561-569

22. K.A. Kupiec, K.M. Wuertz, W.W. Barkmeier, T.M. Wilwerding. **Evaluation of porcelain surface treatments and agents for composite-to-porcelain repair.** J Prosthet Dent, 76 (1996), pp. 119-124

23 M.A. Latta, W.W. Barkmeier. **Approaches for intraoral repair of ceramic restorations.** Compend Contin Educ Dent, 21 (2000), pp. 635-639, 642-4

24 A. Llobell, J.I. Nicholls, J.C. Kois, C.H. Daly. **Fatigue life of porcelain repair systems.** Int J Prosthodont, 5 (1992), pp. 205-213

25 J.H. Chen, H. Matsumura, M. Atsuta. **Effect of etchant, etching period, and silane priming on bond strength to porcelain of composite resin.** Oper Dent, 23 (1998), pp. 250-257

26 J.R. Kelly. **Clinically relevant approach to failure testing of all-ceramic restorations.** J Prosthet Dent, 81 (1999), pp. 652-661

27 X.D. Dong, B.W. Darvell. **Stress distribution and failure mode of dental ceramic structures under Hertzian indentation.** Dent Mater, 19 (2003), pp. 542-551

28 B. Webber, A. McDonald, J. Knowles. **An in vitro study of the compressive load at fracture of Procera AllCeram crowns with varying thickness of veneer porcelain.** J Prosthet Dent, 89 (2003), pp. 154-160

29 H.M. Al-Dohan, P. Yaman, J.B. Dennison, M.E. Razzoog, B.R. Lang. **Shear strength of core-veneer interface in bi-layered ceramics.** J Prosthet Dent, 91 (2004), pp. 349-355

30 J.R. Kelly, R. Giordano, R. Pober, M.J. Cima. **Fracture surface analysis of dental ceramics: clinically failed restorations.** Int J Prosthodont, 3 (1990), pp. 430-440

31 Y.G. Jung, I.M. Peterson, D.K. Kim, B.R. Lawn. **Lifetime-limiting strength degradation from contact fatigue in dental ceramics.** J Dent Res, 79 (2000), pp. 722-731