Assessment of an Indirect Metal Ceramic Repair System

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Abstract

Purpose: This study was designed to compare an alternative indirect treatment to repair fractured or chipped veneering metal ceramic using recently developed ultra-low-fusing ceramics.
Materials and Methods: One conventional feldspathic ceramic, Vita Omega, and three ultra-low-fusing ceramics (ULFC), Finesse, Duceram LFC, and Vision-low, were used. Forty ceramic specimens were prepared and divided into two groups. Group I (n = 20) was designed for bond strength testing. It comprised four subgroups (A, B, C, D): one Ceramic-resin (A) and three Ceramic-ULFC disc specimens of different diameters (B, C, D). Group II was composed of repaired ceramic discs using direct and indirect repair methods for biaxial testing. It was comprised of five subgroups: the fractured discs from subgroup A; Omega discs (n = 20) formed the repaired specimens of the four remaining subgroups: B, C, D, E. Data were presented as means and standard deviation (SD) values. One-way analysis of variance (ANOVA) was used for comparison between means. Tukey's post hoc test was used for pairwise comparison between the means when ANOVA test was significant. The significance level was set at $p \leq 0.05$.
Results: Within group I, Omega-Ducera LFC showed the statistically highest mean bond strength (25.8 MPa) values, followed by Omega-Finesse (15.8 MPa). No statistically significant difference was apparent between Omega-Vision (9.3 MPa) and the control Omega-Composite group (7.5 MPa). Regarding group II, the Control Omega subgroup showed statistically the highest mean biaxial strength values (168.8 MPa). No statistically significant difference was evident between the values of Omega-Finesse (78.7 MPa), Omega-Vision (78.4 MPa), and Omega-Composite (82.5 MPa). Omega-Ducera LFC subgroup, showed statistically the lowest mean values (53 MPa).
Conclusions: Omega-Ducera LFC yielded the statistically highest mean bond strength values, and the lowest biaxial strength values. All values were within the reported bond strength values for resin repair. All the tested groups showed significantly lower values compared to the initial biaxial strength mean values of the Omega ceramic; however, two of the tested ULFC (Vision, Finesse), recorded means that were statistically equal to the resin-ceramic direct subgroup. Duceram LFC showed the lowest values, probably due to its totally glass composition, which showed low strength values of the repaired specimens. The recorded bond and biaxial values suggest that indirect repair of fractured LFC using some ULFC ceramics may offer an alternative solution to the traditional direct resin repair method; however, the choice of the used ceramic should be one containing some leucite crystals. Further studies are needed to investigate the long-term performance of the proposed repair treatment.

Metal ceramic restorations continue to be widely used in dental practices, as they combine esthetics with superior mechanical properties. Although these ceramic materials provide an excellent, durable, and compatible restorative service, failures still occur due to their brittle nature. These have been reported as the second greatest cause for replacement of restorations after dental caries.[1] According to some clinical reports, ceramic fractures represent 2.3% to 8% of all failures.[1-4] Other studies indicate an even higher prevalence of ceramic failures, ranging between 5% and 10% over 10 years of service.[5] Furthermore, failures occur most frequently in visible areas, compromising esthetics.[6] Causes of failure cover a wide spectrum, ranging from iatrogenic factors to laboratory mistakes. Other factors are related to the inherent structure of the ceramic or, simply, trauma.[7] When a fractured restoration continues to fulfill the requirements of preserving dento-periodontal health, and replacement is not feasible, repair may be the solution to reestablish function and esthetics.[8,9]

Repair methods may be classified as direct or indirect. Direct repairs include techniques that use composites applied directly to the fractured restoration,[10–15] while indirect repairs include those that use porcelain prepared in the laboratory and bonded to the fractured restoration.[16–19] Intraoral repair of failed porcelain restorations typically involves adhesion of a composite resin to fractured porcelain. A combination of surface alterations of porcelain using acid etching or airborne-particle abrasion (50 μm Al_2O_3), in conjunction with chemical agents such as silane coupling agents, are used to promote adhesion to fractured porcelain;[15,20,21] however, intraoral use of hydrofluoric acid is hazardous due to its caustic effect, and while airborne abrasion alone provides insufficient bond strength, excessive particle abrasion has been found to induce chipping and a high loss of ceramic material.[22] Many reports are skeptical about the long-term durability of silane bond due to its hydrolysis, making long-term efficiency doubtful.[23]

Direct intraoral repair techniques offer many advantages due to their simplicity, yet they have their shortcomings. They are dependent on resin composite bonding, which may fracture or discolor. In addition, their esthetic success may be limited by the operator's artistic skill in reproducing the original contour and the monochromatic appearance of composites. Wear and surface deterioration are also problems associated with direct repair.[24] Furthermore, once a composite surface has been altered by contamination, polishing, or aging, the bond strength of a new composite is compromised.[25–27]

A more long-term solution to the problem of a fractured or chipped veneer of an otherwise functional restoration would be its retrieval, and indirect repair in the laboratory using feldspathic porcelain. Numerous clinical techniques have been suggested for removal of definitively cemented crowns or retainers of fixed partial dentures (FPDs). Retrieval of intact crowns was possible 86% of the time and 68% to 72% of the time in FPD cases.[28,29] Suggested devices and techniques include the use of a matrix band,[30] a hemostat,[31] a Richwil crown remover (Richwil Laboratories, Orange, CA),[29] an acrylic resin mold compressed with a curved hemostat,[29] ultrasonics,[32] and a pneumatic crown remover.[33,34]

Ultra-low-fusing porcelains (ULFCs) with firing temperatures less than 850°C have been recently developed.[35–37] Duceram LFC (660°C) is a leucite-free hydrothermal ceramic with claims of low wear of opposing teeth and excellent surface properties. Unlike most ceramics, its flexural strength and resistance to disintegration seem to increase significantly after hydrolytic testing. Finesse is another ULFC (760°C) strengthened by fine-grained leucite. It causes minimal wear to opposing dentition, as it contains a small amount of crystals with finer grain size than conventional porcelains.[37] Vision-low is also a ULFC (660°C) which claims that its vital shade reproduction and natural fluorescence correspond to natural teeth. The three ULFCs combine low hardness values close to that of enamel.

Problems encountered with conventional low-fusing veneering porcelains over the years have included poor color stability, abrasiveness, and devitrification with multiple firings.[38,39] Consequently, the idea of attempting to repair fractured ceramic veneers with ULFCs with lower fusion ranges, would minimize the risk of cloudiness, which could occur with repair attempts using conventional ceramics.

Workers have tested the success of intraoral repair by shear testing, but shear alone cannot predict the performance of the repaired restoration. Long-term success, especially in load-bearing surfaces, is contradictory. This study was designed to propose an alternative treatment modality to repair fractured or chipped veneering metal ceramics using recently developed ULFCs. Bond and biaxial strength were considered, as both seem relative to the long-term performance of the repaired restorations during clinical service.

Materials and methods

Four types of ceramics were used in this study: one conventional feldspathic ceramic, Vita Omega (Vita Zahnfabrik Bad Sackingen, Germany), and three ULFCs [Finesse (Dentsply, York, PA), Duceram LFC (Ducera LFC, Rosbach, Germany), Vision-low (Furstentum, Liechtenstein)]. Two Teflon rings of different diameters were used to prepare the specimens for testing. Forty Omega ceramic disc samples (12 mm diameter × 2 mm thick) were constructed using the larger split Teflon ring. The slurry was packed and vibrated into the ring, and excess water was blotted out. The discs were fired in a programmable and calibrated vacuum furnace according to their recommended firing cycle (920°C). Corrective firing was done after caliper control, and defective specimens were adjusted by porcelain addition. A final glaze firing was done. The forty discs were divided into two groups: group I (n = 20, 4 subgroups A, B, C, D) were prepared for bond strength testing by adding a smaller disc of resin or ceramic to the previously fired ceramic disc, and group II (n = 20) for biaxial strength testing of the repaired ceramic discs.

Group I, subgroup A (control, direct resin-ceramic)

The Omega ceramic specimens were sandblasted using 50 μm Al_2O_3 at 3 bar pressure and etched using 9% buffered hydrofluoric (HF) acid, (Ultradent, South Jordan, UT) for 2 minutes, then rinsed and dried. The discs were coated twice with ceramic primer (Monobond-S, Ivoclar Vivadent, Schaan, Liechtenstein) and dried. Two coats of Adper adhesive were applied (Single Bond 2, 3M ESPE, Minneapolis, MN), dried gently for 5 seconds, and cured for 10 seconds using an LED (Trax Lighting, Chatsworth, CA). A smaller Teflon ring (6 mm diameter × 2 mm thick) was seated on the ceramic disc, and a thin film of Filtek Flow Z350 (3M ESPE) was applied before composite packing using Filtek Z250 (3M ESPE). Excess composite was removed, and the assembly was covered with a celluloid strip and a glass slab for even pressure. Curing for 20 seconds was done, followed by removal of the strip and slab; a further cure for 20 more seconds was done to ensure polymerization. The specimens were then finished and polished.

Group I, subgroup B, C, D specimen preparation

A slurry of each ULFC in turn was packed inside the smaller Teflon ring seated on the larger Omega ceramic disc. After vibration and excess moisture removal, the assembly was fired according to its recommended firing cycle.

Group II discs

Subgroup A (Control Omega group) and the repaired disc specimens (B, C, D, E) were used for biaxial strength testing. The ceramic fragments from the biaxial testing of the control subgroup A (two main large fragments) were carefully assembled inside the Teflon ring and repaired using either a direct repair (Omega-composite, Subgroup B) or indirect technique using one of the three ULFCs (B, C, D, E).

Resin repair specimen preparation (subgroup B)

The fractured ceramic specimens were beveled using a diamond stone and sandblasted using 50 μm Al_2O at 3-bar pressure to create a larger surface for bonding. Porcelain edges were etched using 9% buffered HF acid (Ultradent) for 2 minutes, then rinsed and dried. The fragments were then placed inside the Teflon ring and coated twice using ceramic primer (Monobond-S) and dried. Two coats of Adper adhesive were applied. The specimens were dried gently for 5 seconds and cured for 10 seconds using LED (Trax Lighting). A thin film of Filtek Flow Z350 was applied before composite addition (Filtek Z250) to repair and build the broken parts. Excess composite was removed, and the assembly was covered with a celluloid strip and a glass slab for even pressure. Curing for 20 seconds was done, followed by a further cure for 20 more seconds after strip removal to ensure polymerization. The specimens were then finished and polished using diamond points and a diamond polishing paste (Optrafine HP Polishing Paste, Vivadent).

The indirect repaired specimens (subgroups C, D, E) were reassembled inside the larger Teflon ring, and a slurry of each ULFC (Ducera LFC, Finesse, Vision) was mixed and added in turn to repair the broken ceramic fragments (two parts). Three firings were done to repair each fractured disc. The discs were fired according to their assigned firing cycles.

Shear bond strength test procedure

Each completed ceramic specimen was embedded in an autopolymerizing acrylic resin cylinder made using a Teflon tube (2 cm height, 1.5 cm diameter) in such a way that the flat surface of the ceramic disc was left flush with acrylic resin, leaving the disc at a higher level to facilitate shear bond testing (Fig 1). The specimens were horizontally mounted on a computer-controlled materials testing machine (Model LRX-plus, Lloyd Instruments Ltd., Fareham, UK) with a loadcell of 5 kN, and data were recorded using computer software (Nexygen-4.1, Lloyd Instruments). The specimens were secured to the lower fixed compartment of the testing machine by tightening the screws. Shearing test was done by compressive mode of load applied at the interface of both discs using a mono-beveled chisel-shaped metallic rod attached to the upper movable compartment of the testing machine traveling at a crosshead speed of 0.5 mm/min (Fig 1). The load required to debond the specimens was recorded in Newtons. The shear bond strength was calculated by dividing the load at failure by the bonding area:

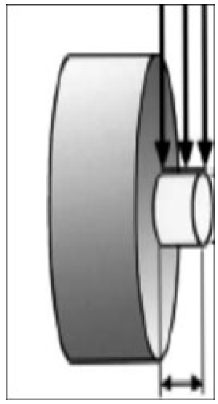

Figure 1 Smaller ULFC fired on larger ceramic disc.

$$\delta = P/\pi r^2$$

where:

δ = shear bond strength (MPa)
P = load at failure (N)
$\pi = 3.14$
r = radius of smaller ceramic disc (3 mm)

Specimen testing for biaxial strength

The biaxial strength test is widely used and is considered the most reliable method of assessing the strength of brittle dental ceramic materials.[36,40] Each disc (12 mm diameter) was centered and supported on three steel spheres positioned 120° apart on a concentric ring (8 mm diameter). The specimens were loaded centrally with a piston (3.8 mm diameter) at a crosshead speed of 0.5 mm/min to failure using a computer-controlled universal testing machine (Model LRX-plus) with a loadcell of 5 kN. The data were recorded using computer software (Nexygen-4.1).

A thin latex sheet 0.05 mm thick was placed between the loading piston and disc to achieve even stress distribution and minimize the transmission of local force peaks. The load to failure (N) of each specimen was recorded, and the biaxial flexural strength (MPa) was calculated according to the following equation suggested by the test standard (ASTM):[40]

$$\sigma = [3P(1+\nu)/4\pi h^2] \times [1 + 2\,\mathrm{In}(a/c) + (1-\nu/1+\nu)(1-(c^2/2a^2)(a^2/R^2)]$$

The load, P, is generally assumed to be distributed uniformly on the contact area between the piston and the loading surface in analytical modeling. The failure stress was calculated where P is

Table 1 ANOVA and Tukey's tests for the shear bond testing between the four subgroups

Direct repair		Indirect repair						
Subgroup A (Control) Omega + Composite		Subgroup B Omega + Duceram LFC		Subgroup C Omega + Finesse		Subgroup D Omega + Vision		
Mean	SD	Mean	SD	Mean	SD	Mean	SD	*p*-value
7.5[c]	1.5	25.8[a]	8	15.8[b]	2.8	9.3[c]	1.1	<0.001*

*Significant at $p \leq 0.05$. Means with different letters are statistically significantly different according to Tukey's test.

the maximum load, v is the Poisson's ratio (0.25 for ceramics), and a, c, and R are the radii of the supporting ring, the piston, and the disc, respectively.

Statistical analysis

Data were presented as mean and standard deviation (SD) values. One-way analysis of variance (ANOVA) was used for comparison between means. Tukey's post hoc test was used for pairwise comparison between the means when ANOVA test was significant. The significance level was set at $p \leq 0.05$. Statistical analysis was performed with SPSS 15.0® (Statistical Package for Scientific Studies for Windows, SPSS, Inc., Chicago, IL).

Results

Bond strength

Omega-Ducera LFC showed the highest statistically significant mean bond strength values, followed by Omega-Finesse. No statistically significant difference was observed between Omega-Vision and the control subgroup, Omega-Composite, which showed the lowest bond strength values (Table 1).

Surface examination of the failed specimens

All the failed specimens were cohesive within the Omega ceramic disc. The ULFC and the resin composite button always remained adhering to a fragment of the Omega disc ceramic.

Biaxial flexural strength

Control Omega subgroup A showed the statistically highest mean biaxial flexural strength (Table 2). No statistically significant difference was evident between Omega-Finesse, Omega-Vision, and Omega-Composite, which showed lower means. Omega-Ducera LFC showed the lowest statistically significant mean values.

Discussion

Silica-based ceramics, such as feldspathic porcelains and glass ceramics, are frequently used to veneer metal ceramic restorations.[41,42] They are mostly composed of two phases, a glassy (vitreous) phase surrounding a crystalline phase (10% to 20%). At a microstructural level, previous generation veneering materials had crystalline phases with leucite crystals that possessed an average size greater than 30 μm. Leucite was added as a crystalline phase to strengthen the base glass and enhance esthetics, in addition to increasing their coefficient of thermal expansion.[38,39] Although high-fusing ceramics exhibit good strength compared with low-fusing products, they have been reported to wear antagonists.[37] Another problem is that the leucite phase is not stable over multiple firings, as it can precipitate or dissolve within the glassy phase, causing thermal mismatches and opacity due to crystal growth.[36,38,39,41] Low-fusing temperatures have demonstrated less wear than conventional feldspathic porcelains.[43] They are more glassy in composition, with finer grains and, therefore were used for ceramic repair in this study.

Direct intraoral repair of fractured porcelain traditionally relies on mechanical roughening of the fracture surface, followed by application of a silane coupling agent to enhance the resin-to-porcelain bond. Indirect repair techniques include fabrication of a pin onlay with a porcelain veneer cemented to the labial surface,[44,45] fabrication of a pin-retained casting with a fused porcelain veneer,[16] and fabrication of a new ''overlay'' metal-ceramic crown.[46–48] These techniques require clinical and laboratory procedures, but are advantageous because of the esthetic

Table 2 Results of ANOVA and Tukey's tests for comparison of biaxial strengths of the five subgroups

Group II		Direct repair		Indirect repair with ULFC						
Subgroup A (Control) Vita Omega		Subgroup B Omega + Composite		Subgroup C Omega + Ducera LFC		Subgroup D Omega + Finesse		Subgroup E Omega + Vision		
Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	*p*-value
168.8[a]	5.8	82.5[b]	24	53[c]	1.3	78.7[b]	9.9	78.4[b]	12.8	<0.001*

*Significant at $p \leq 0.05$. Means with different letters are statistically significantly different according to Tukey's test.

ability of porcelain to match the remaining ceramic units.[49] Repair of fractured conventional ceramic was attempted using a direct composite resin technique as control and a suggested indirect technique using three ULFCs.

Material selection and clinical recommendations on resin bonding to ceramics are based on mechanical laboratory tests that show great variation in materials and methods.[13,48,50] Research on porcelain repair has included shear, tensile, and three-point bending.[51] Shear bond strength test is widely used in dentistry, as it is particularly important in the study of interfaces between two materials.[30] Several authors have used shear bond testing for evaluating the success of intraoral repaired ceramics. They reported bond strength values in the range of 6 to 29.9 MPa.[5,51-57] These values will be used as a baseline for comparisons to the suggested treatments in this study.

The shear strength recorded is the maximum stress that a material can withstand before failure in a shear mode of loading. All the values found in the current study were within the reported data in the literature (6 to 30 MPa); however, if we take the resin ceramic bond strength as a baseline of comparison, we find that Omega-Ducera LFC scored three times its value. Vita Omega is a conventional low-fusing porcelain (920°C) with large grain sizes compared to the finer grain sizes of the newly developed ULFC. It is primarily composed of SiO_2 (64%) and Al_2O_3 (18%) with various amounts of K_2O and Na_2O (85% to 10%) to control expansion. The low flexural strength of these feldspathic ceramics is the principle reason for using a metal substructure to reinforce them.[58] Ducera LFC is a hydrothermal low-fusing glass designed to be applied over conventional ceramic. The superiority of its bond to Omega is probably due to its single-phase homogenous glass composition, with no leucite crystals. This glassy composition probably caused the high bond values due to an ionic chemical bond with Omega ceramic. Its low fusion temperature (660 to 680°C) ensured that Omega ceramic remained unaffected by this firing temperature, thus protecting it from devitrification by further crystallization and cloudiness. The recorded bond strength value is three times the value of the control resin-repair group, and significantly higher than the two other ULFCs, making it an excellent alternative to the traditional repair materials regarding both bond and esthetics.

Omega-Finesse bond strength yielded lower values than that of the former ceramics (15.8 MPa), but still significantly higher than the recorded resin ceramic values. Finesse ceramic contains a low amount of crystals (6%), meaning that it possesses a high glass component available for ionic bonding with Omega ceramic along with its fine grain structure.[37,59] This glass component is less than that of Duceram LFC, which is totally glass, and therefore may explain the difference in bond values obtained. Derand and Vereby[37] demonstrated that Finesse possessed low hardness and roughness values and attributed this to its glassy structure. Its fine grain size reported by Wright et al[59] along with its low leucite content of 6%, probably promoted its bond to Omega conventional ceramic.

As for Omega-Vision ceramic, the values observed were close to those recorded for resin composite and still within the reported bond strength values for resin repair. Some chemical combinations of ceramics probably record different bond strength values due to their different compositions and the presence of certain elements, which could play a role in the bond.

A strong resin-ceramic bond relies on micromechanical interlocking and chemical bonding to the ceramic surface, which requires roughening and cleaning for adequate surface activation.[60-67] Common treatment options are grinding,[61] abrasion with diamond rotary instruments,[61,62] airborne-particle abrasion with aluminum oxide, acid etching,[63] and combinations of any of these methods. Acid etching with solutions of HF acid at 2% to 10% for 2 to 3 minutes followed by silane application are the most common surface treatments.[63-70] The number, size, and distribution of leucite crystals influence the formation of microporosities created by acid etching.[71] Leucite crystals grow during the cooling phase of the ceramic-firing process. Some low-fusing ceramics and glass ceramics contain only minimal amounts of leucite crystals, which may inhibit the formation of highly retentive microporosities with HF acid etching.[72]

Many authors claim that the application of a silane coupling agent provides an adequate chemical bond between resin and silica ceramics.[15,21,23,49,57,59] Silanes are bifunctional molecules that bond SiO_2 with the OH group on the ceramic surface. They also have a degradable functional group that copolymerizes with the organic matrix of the resin. Silane coupling agents usually contain a silane coupler and a weak acid, which enhances the formation of siloxane bonds.[70] Studies on the efficacy of silanes after try-in procedures or resilanation of the ceramic restoration show conflicting results.[72,73] Silane coupling agents usually contain high amounts of solvents.[72] Single-bottle products have a limited shelf life and are susceptible to rapid solvent evaporation and hydrolization, making silane solutions useless. Furthermore, the ceramic/composite bond is susceptible to chemical,[72,73] thermal,[72] and mechanical[75] influences in intraoral conditions. Long-term water storage and thermocycling of bonded specimens reveal significant differences between early and late bond strength values.[76] Application of mechanical cyclic loading (fatigue load) causes significant reduction of bond strengths.[80,81]

Surface examination of the failed specimens using a magnifying glass revealed that all the failures were cohesive within the Omega ceramic disc. The ULFC and the resin composite button always remained adhering to a fragment of the Omega disc ceramic. This indicates that the bond strength between the repair material and the substrate was superior to the strength of the substrate itself, a behavior reported by many authors.[9,51,54,55,64,68,81] It is the ultimate quality of core–veneer interface.[82,83] The Cohesive Plateau theory states that the strength of a bonded interface should equal the cohesive strength of the substrate with which it is formed.[83]

Strength is an important mechanical property that can assist in predicting the performance of brittle materials.[84] Biaxial flexure testing is becoming widely recognized as a reliable technique for studying brittle materials, since the maximum tensile stress occurs within the central loading area, eliminating edge failure.[85] Specimen flaws, regardless of orientation, are taken into account,[86] and both tangential and radial stresses are simultaneously applied to the specimen in all directions. This allows more correct and reliable fracture strength evaluation regardless of crack orientation.[83,85]

All tested groups showed significantly lower values to the initial mean biaxial strength values of the Omega ceramic; however, two of the tested ULFCs (Vision, Finesse), recorded means that were statistically equal to the resin-ceramic group. Duceram LFC showed the lowest values, probably due to its totally glass composition, which promoted bond but showed low strength values of the repaired specimens. It would seem, depending on the outcome of the biaxial testing, that repair of LFC using some ULFC ceramics may offer a long-term solution to fractured ceramic restorations; however, the choice of the ceramic used should be one with some leucite in its composition to help in regaining strength values close to the initial values of the restored ceramic. Further studies are needed to investigate the long-term performance of the proposed repair treatment.

Conclusions

1. Omega-Ducera LFC indirect subgroup yielded the statistically highest mean shear bond and lowest biaxial strength values.
2. All values for the indirect method were within the reported bond strength values for resin repair.
3. Both direct and indirect repair subgroups showed significantly lower values compared to the initial biaxial strength mean values of the Omega ceramic.
4. Vision and Finesse subgroups (indirect repair), recorded means that were statistically equal to the direct repair resin-ceramic subgroup.

Clinical implication

The recorded bond and biaxial values in the current study suggest that indirect repair of fractured LFC using some ULFC ceramics may offer an alternative solution to the traditional direct resin repair of fractured ceramic restorations; however, the choice of the ceramic used should be one with some leucite crystals. Further studies are needed to investigate the long-term performance of the proposed repair treatment.

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