Strength, Reliability, and Mode of Fracture of Bilayered Porcelain/Core Ceramics

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Purpose: The aim of this investigation was to compare the biaxial flexural strength, its reliability, and the mode of fracture of bilayered disks made of two core materials (In-Ceram Alumina and In-Ceram Zirconia), both veneered with conventional feldspathic porcelain (Vita Alpha). **Materials and Methods:** One hundred forty specimens (monolithic and bilayered) of In-Ceram Alumina, In-Ceram Zirconia, and Vita Alpha were made and tested with the biaxial flexural test. Finite element analysis was used to estimate the maximum tensile stress at fracture. Data were analyzed with one-way ANOVA, Tukey HSD, and Weibull distribution. SEM was used to identify the initial crack and characterize the fracture mode. **Results:** All specimens with the core material on the bottom surface were statistically significantly stronger and more reliable than those with the porcelain on the bottom surface. Among them, In-Ceram Zirconia was stronger than In-Ceram Alumina. There was no statistically significant difference among groups when the porcelain underwent tension. Two different modes of fracture were observed in the bilayered samples according to which material was on the bottom surface. **Conclusion:** The material that underwent tensile stress dictated the strength, reliability, and fracture mode of the specimens. The design of the restorations and the actual distribution of the tensile stresses must be taken into account; otherwise, the significant contribution of stronger and tougher core materials to the performance of all-ceramic restorations may be offset by the weaker veneering porcelain. *Int J Prosthodont 2004;17:142–149.*

Novel alumina- or zirconia-based ceramics, such as In-Ceram Zirconia (IZ; Vita), have been introduced to allow the fabrication of more reliable all-ceramic restorations. IZ was developed by adding 33 wt% partially stabilized zirconium oxide to In-Ceram Alumina (IA; Vita). The addition of zirconia to IA has resulted in a moderately stronger and tougher material.[1–4] Although the use of a stronger and tougher core material has been advocated to improve the clinical performance of all-ceramic restorations,[5] little is known about the mode of fracture and its influence on the ultimate strength when the stronger core is veneered with conventional porcelain.

Clinically and in vitro–failed all-ceramic fixed partial dentures (FPD) made with IA and porcelain veneer fractured at the connector area.[6] Seventy-eight percent of fractures originated at the interface between the core ceramic and the porcelain. Finite element analysis (FEA) and fractography analyses confirmed this finding, showing that the peak tensile stress and fracture origin were located at the connector.[6,7] These authors[6] also claimed that the properties of the veneering porcelain control the failure of the restoration. An in vitro exemplification of the clinical condition of failure from the connector area of an FPD may be obtained by loading bilayered core/porcelain bar- or disk-shaped specimens with the core material on top (facing the loading plunger) and the porcelain at the bottom

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Table 1 Composition of Each Group

Group	Material	Type
A/IA	Vita Alpha (top) In-Ceram Alumina (bottom)	Bilayered
IA/A	In-Ceram Alumina (top) Vita Alpha (bottom)	Bilayered
A/IZ	Vita Alpha (top) In-Ceram Zirconia (bottom)	Bilayered
IZ/A	In-Ceram Zirconia (top) Vita Alpha (bottom)	Bilayered
IZ	In-Ceram Zirconia	Monolayer
IA	In-Ceram Alumina	Monolayer
A	Vita Alpha	Monolayer

top = top surface facing loading piston; bottom = bottom surface facing jig.

Table 2 Firing Conditions for Porcelain and Glazing Condition Used for All Specimens

Firing	Predrying temperature (°C)	Predrying time (min)	Rising time (min)	Rising temperature (°C/min)	Holding temperature (°C)	Holding time (min)	Vacuum time (min)
First	600	6	6	60	960	1	6
Second	600	6	6	58	950	1	6
Glaze	600	–	4	85	940	1	–

(facing the jig). Several investigators[2,8–10] have used this model to study the influence of the veneering porcelain, failure mode, and failure origins, with contradictory results. Some showed that the test methodology and core thickness/veneer thickness (ct/vt) ratio influence the mode of fracture of bilayered samples.[10,11] Despite the differences brought about by the test methodology, most investigators agree that the veneering porcelain dictates the ultimate strength of the restoration.[2,6,8–10,12] Some authors conclude that all areas of the restoration that are subjected to tensile stress should not be veneered with porcelain.[8,9]

The mode of fracture of all-ceramic crowns is different from that of an FPD because the stress distribution is different. The crack origin of clinically failed Dicor porcelain crowns (Dentsply) was on the internal surface.[13] In vitro studies on planar samples have demonstrated that fracture initiates from the bottom core surface, corresponding to the inner surface of a crown.[8,9,11] These findings are consistent with FEAs of all-ceramic crowns that suggest that the inner surface of the crown, directly below the occlusal loading, is subjected to the greatest tensile stress.[14,15] One study reviewed the damage mode for bilayered samples and described the development of radial cracking at the inner surface of a planar simulation of a crown.[5] The extension of the radial cracking is thought to be responsible for the premature clinical failure of crowns. From the standpoint of material selection, the replacement of the glass-infiltrated alumina with greater-strength ceramic should improve the crown performance.[5]

The purpose of the present study was to compare the biaxial flexural strength, its reliability, and the mode of fracture of layered disks of two core materials (IA and IZ), both veneered with a conventional feldspathic porcelain (Vita Alpha, Vita). Two hypotheses were tested: *(1)* the strength and reliability of bilayered ceramic disks made from IZ veneered with Vita Alpha will be greater than those of bilayered disks made from IA and Vita Alpha; and *(2)* the fracture mode will be different in the two combinations as a result of the different properties of the core material.

Materials and Methods

One hundred forty disk specimens were prepared and divided into seven groups of 20 specimens each (Table 1). Twenty monolithic specimens of Vita Alpha (A; Dentine A3.5, lot No. 6411) were made in a silicone mold. The mixing liquid and ceramic powders were combined in proportions recommended by the manufacturer. The slurry of porcelain powder was vibrated and packed into the mold. The disks were then fired (Table 2). After the first firing, more porcelain was added and fired to compensate for the shrinkage resulting from the first sintering. All specimen surfaces were then polished with diamond disks (nominal grit size 120, 70, 30, 15, 9, 3, and 1 μm) up to a thickness of approximately 2 mm. A special stainless steel holder was used to ensure accuracy of thickness and parallelism of the surfaces during grinding and polishing.

Monolithic and bilayered specimens with core material were prepared from slips of IA (lot No. 6153; IA,

Table 3 Mean Flexural Strength (Standard Deviation), Weibull Modulus, Elastic Moduli, and Fracture Toughness of Each Group of Specimens

Group	Flexural strength (MPa)*	Weibull modulus (m)	Young's modulus (GPa)	Poisson's ratio	Fracture toughness (MPa·m$^{1/2}$)
A/IZ	590 (70)^1	8.5	–	–	–
IZ	580 (60)^1	10.5	242†	0.265†	4.0†
IA	520 (55)^2	9.5	257†	0.255†	3.2†
A/IA	490 (55)^2	8.0	–	–	–
A	95 (15)^3	5.0	60	0.220	0.9‡
IZ/A	80 (11)^3	7.0	–	–	–
IA/A	70 (15)^3	5.0	–	–	–

*Supercripted numbers denote Tukey grouping.
†Guazzato et al.[4]
‡Indicative value for fracture toughness of a dental porcelain.[2]

A/IA, and IA/A) and IZ (lot No. 6214P; IZ, A/IZ, and IZ/A) (Table 1). After mixing, the slips were poured into a silicone mold resting on a cylinder of special plaster. Specimens were allowed to dry onto the special plaster material for at least 1 hour; they were then sintered in a high-temperature furnace (In-Ceramat II, Vita) as recommended by the manufacturer. After sintering, the specimens were gently manually ground with 1,200-grit SiC paper to almost the final thicknesses. For each material, 20 specimens were ground to approximately 2 mm thickness (monolithic), and 40 specimens, which would have been veneered with porcelain, were ground to approximately 1 mm. Next, all specimens were glass infiltrated with the corresponding glass. Excess infiltration glass was removed by sandblasting with 50-μm Al_2O_3 at the maximum pressure of 0.25 MPa. Each specimen was then fired and sandblasted a second time to ensure that all excess glass had been removed. Bilayered specimens were prepared by veneering the 1-mm-thick core material disks with Vita Alpha. The disks were put in a silicone mold, and the porcelain was vibrated and packed with the same manufacturing procedure as for the monolithic porcelain disks. After the second firing, the porcelain surface was ground as detailed above to a final thickness of approximately 2 mm. Finally, all specimens were cleaned with distilled water in an ultrasonic bath for 15 minutes and glazed (Table 2). After glazing, the final thickness (2.00 ± 0.03 mm) and diameter (14.00 ± 0.20 mm) were further measured with a digital caliper. The mean thickness of the specimens was calculated from three measurements taken in the middle of the sample.

The maximum load at failure was measured with the piston-on-three-ball method by using a universal testing machine (Shimadzu Autograph AG-G series). The disk specimens rested on three symmetrically spaced balls. The balls, of 1.5 mm diameter, were equidistant around a circle of radius 6 mm. The load was applied at the center of the top surface through the flat tip of a piston (diameter 1.5 mm) at a cross-head speed of 0.5 mm/min. The test was conducted at room conditions (22 ± 1°C, and 60% ± 5% relative humidity). In A/IA and A/IZ, the core material rested on the three ball (bottom surface) and the porcelain faced the loading piston (top surface). The position of the porcelain and core material was reversed in IA/A and IZ/A.

The Young's moduli and Poisson's ratios of IA and IZ (Table 3) were reported in a previous study.[3] The Young's modulus and Poisson's ratio of Vita Alpha were determined by testing three bars (2 mm × 5 mm × 30 mm) with a nondestructive dynamic method by impulse excitation of vibration according to ASTM D4065-82.[16]

Finite element (FE) models of all disk specimens were made and analyzed to examine the stresses that resulted from biaxial loading. FEA was conducted using Strand7 (G+D Computing).[17] Four axisymmetric bilayered disk models and three axisymmetric monolayer disk models were constructed, reproducing the same combinations and dimensions of the mechanically tested samples. For each model, the same FE size (0.05 mm × 0.05 mm) was used. Thus, 5,600 elements were used to construct every model. At the bottom of the disk, a ring support was placed at a radius of 6 mm from the axis of symmetry (Figs 1 and 2). Although not exactly replicating the three-ball support that exists in reality, the support structure was adequate to investigate the critical stresses existing along the axis of symmetry. A normal stress magnitude of 656.9 MPa was applied uniformly on top of the disk slice, radiating out from the axis of symmetry for a distance of 0.75 mm. This was the equivalent of applying a vertical uniform load of 1,000 N over an area of radius 0.75 mm. In effect, a piston loading of diameter 1.5 mm was simulated. Mention must be made of the fact that the resulting stresses described in the present study were proportional to the magnitude of the applied load. It can be surmised that if the load were to be doubled, the resulting stresses distributed in the disk would also double. This is the case for all stress types (ie, maximum

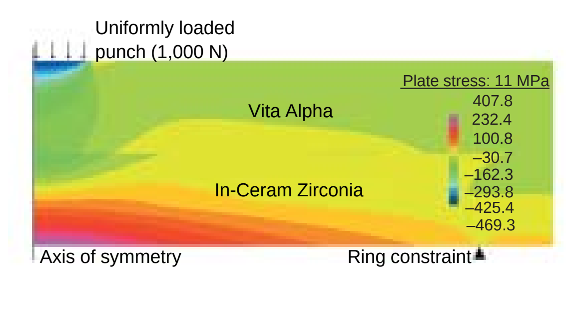

Fig 1 Maximum principal stress distribution of bilayered disk model 3, displayed in Vita Alpha *(top)* and In-Ceram Zirconia *(bottom).* The model with Vita Alpha and In-Ceram Alumina gave almost identical stress distribution.

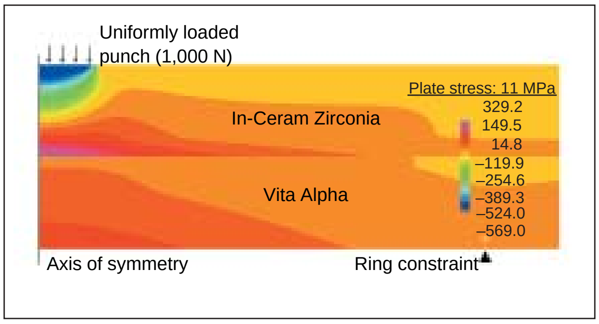

Fig 2 Maximum principal stress distribution of bilayered disk model 4, displayed in In-Ceram Zirconia *(top)* and Vita Alpha *(bottom).* The model with Vita Alpha and In-Ceram Alumina gave comparable stress distribution. Maximum tensile stress is located at the interface; a second peak with lower magnitude is located at the bottom of the porcelain surface.

principal, radial, hoop, etc). In all instances, the maximum tensile or principal tensile stress at fracture was used to quantify the biaxial strength. In the case of the biaxial stress, this occurred on the axis of symmetry, where the radial and circumferential stresses are equal and identical to the principal tensile stress.

All strength data were compared with one-way analysis of variance (ANOVA) and a series of Tukey honestly significant difference (HSD) post hoc tests. The alpha value *(P)* was set at .05. The variability of the strength, and consequently the homogeneity, of the materials was appraised through calculation of the Weibull modulus *(m).*[18] The Weibull modulus was obtained from the slope of the line generated by plotting the probability of the survival of each specimen $P_s(V_o)$ versus the normalized fracture stress (σ/σ_o):

$$\ln\left[\ln\left(1/P_s(V_o)\right)\right] \text{vs} \ln\left(\sigma/\sigma_o\right)$$

The Weibull modulus is related to the flaw size distribution, so a higher *m* value corresponds to a narrower flaw size distribution, higher homogeneity, and, consequently, greater reliability of the strength.

Scanning electron microscopy (SEM; XL 30, Philips) was used to identify the initial crack and characterize the fracture mode. Principles of fractography[6,19] were used to localize the fracture origin.

Results

ANOVA and the Tukey HSD test showed that all groups with the core material on the bottom surface (IA, IZ, A/IA, and A/IZ) were statistically significantly stronger than those with the porcelain on the bottom surface (A, IA/A, and IZ/A) ($P < .001$; Table 3). IZ and A/IZ were statistically significantly stronger than IA ($P = .048$ and .042, respectively) and A/IA ($P = .041$ and .040, respectively).

The Weibull modulus was consistent with data generated by the biaxial flexural test, and hence consistently influenced by the properties of the material on the bottom surface, whereas the material on top was less relevant. The presence of IZ always resulted in greater Weibull modulus when a group of specimens containing zirconia was compared to a group with similar configuration but without zirconia (eg, A/IZ vs A/IA or IZ vs IA). The influence of the veneering porcelain on the variability of the strength (which is indicated by the Weibull modulus) of the bilayered specimens was consistent in all combinations; namely, when the porcelain was at the bottom, the Weibull modulus was equivalent to or slightly greater than that of Vita Alpha alone, whereas when the porcelain was on top, the Weibull modulus was consistently decreased from that of IA or IZ by itself.

The FEA of the bilayered specimens showed that the stress distribution was different according to which material was on the bottom. Regardless of which core material was on the bottom surface, when the porcelain was on top there was a relatively uniform distribution of the stresses, with a peak of compressive stress on the surface of the porcelain immediately underneath the loading piston (Fig 1). This stress gradually decreased with increasing distance from the surface to become tensile within the core material and reached its peak at the bottom surface on the loading axis. Conversely, when the core material was on top and the porcelain was on the bottom surface, the peak of tensile stress was located at the core-porcelain interface (Fig 2). A second tensile peak with lower magnitude

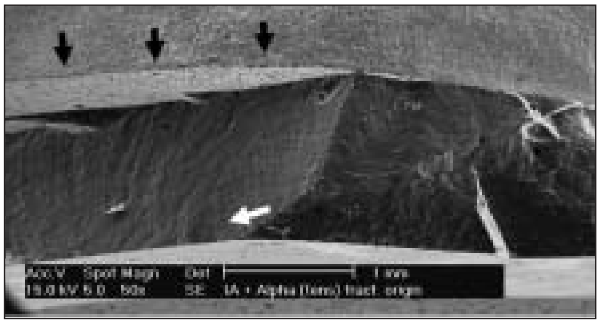

Fig 3a Core material *(top)* and Vita Alpha *(bottom):* fracture origin at bottom surface of porcelain layer *(white arrow); black arrows* = delamination at interface.

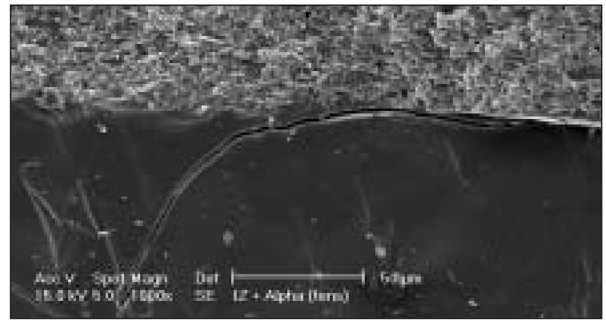

Fig 3b Core material *(top)* and Vita Alpha *(bottom):* crack originated at bottom surface of porcelain is deviated by stresses from loading piston, residual stresses, and material defects; it is then hindered by the core material and propagates in the vicinity of interface.

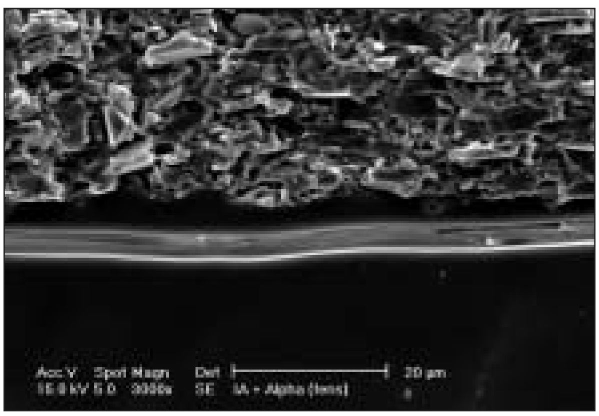

Fig 3c Core material *(top)* and Vita Alpha *(bottom):* typical delamination in vicinity of interface observed in the majority of specimens where delamination occurred. Crack propagates in lowest-toughness phase; however, thin layer of porcelain is bound to core material, indicating that toughness of interface is greater than that of porcelain.

Table 4 Location of Fracture Origin and Occurrence of Delamination in Bilayered Specimens

Group	Fracture origin	Delamination
A/IA	20 surface–0 interface	0/20
A/IZ	20 surface–0 interface	4/20
IA/A	16 surface–4 interface	12/20
IZ/A	17 surface–3 interface	11/20

was localized at the bottom surface of the porcelain. There was no difference in the above-mentioned models whether the core material was IA or IZ.

Two modes of fracture were observed in the bilayered samples according to which material was on the bottom surface. When the core material was on top (facing the loading piston) and the porcelain on the bottom, fracture tended to initiate at the bottom surface (Fig 3a), accompanied by apparent delamination (Table 4) at the interface and followed by failure of the core material (Fig 3). In a few specimens, the fracture origin was localized at the porcelain–core material interface. Conversely, when the porcelain was on top and the core material on the bottom, fracture initiated at the bottom surface (Fig 4) where the maximum peak of tensile stress was located. Regardless of the fact that the fracture originated from the tensile surface of the core material, a Hertzian cone crack was consistently observed on the surface of the porcelain facing the piston. The cone crack was often much more pronounced in A/IZ than in A/IA. Furthermore, in four A/IZ specimens, the extension of the cone crack to the interface caused crushing of the porcelain and apparent partial delamination (Fig 4b).

Discussion

The present investigation, as well as previous studies conducted on clinically failed all-ceramic crowns and FPDs[6,20] and on in vitro–tested bilayered samples,[2,5,8,9] indicated that the strength, reliability, and mode of

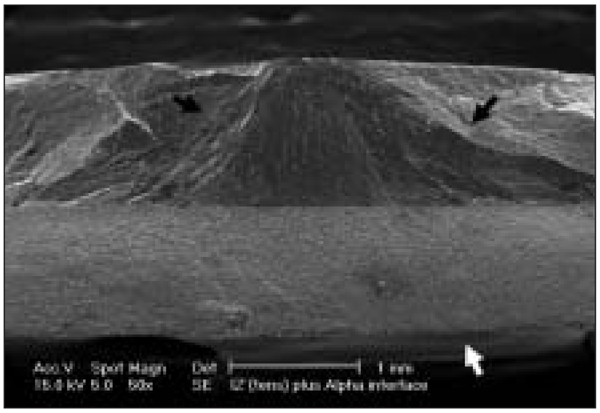

Fig 4a In-Ceram Zirconia *(bottom)* and Vita Alpha *(top):* fracture surface of typical failed disk. River markings on fracture surfaces point back to lower portion of core material, where fracture initiated *(white arrow).* Twist hackle markings *(black arrows)* are associated with compressive stress near Hertzian cone crack.

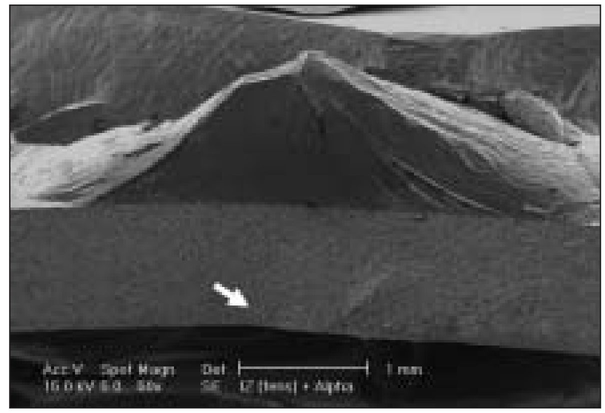

Fig 4b In-Ceram Zirconia *(bottom)* and Vita Alpha *(top):* loading of porcelain resulted in extension of Hertzian cone crack with crunching of porcelain and apparent delamination in four IZ/A specimens. Bulk fracture originates at bottom of core material *(white arrow).*

fracture of bilayered ceramic composite are mainly dictated by the material on the bottom surface undergoing biaxial tensile stress.

The biaxial flexural strength of the groups with the core material at the bottom was much greater than that of the groups with the porcelain on the bottom. Furthermore, when porcelain was on the bottom surface, and therefore undergoing biaxial tension, the flexural strength of the bilayered samples was not statistically significantly different from that of the monolithic samples of porcelain. Surprisingly, IZ/A and IA/A were slightly weaker than Vita Alpha. A similar result was reported by White et al,[8] who related it to the development of residual stresses because of the mismatch of the coefficient of thermal expansion, fabrication procedures, or surface damage. It is normally anticipated that the coefficient of thermal expansion of the porcelain will be slightly lower than that of the core materials, so as to induce a slight residual compressive stress. This should have resulted in higher applied stresses to cause fracture than for the monolithic disks of porcelain.[8]

As seen for the strength values, the Weibull modulus was mainly related to the material on the bottom surface. However, the material on top seemed to have some influence as well. For example, when the porcelain was at the bottom, the Weibull modulus was 5 for Vita Alpha and IA/A, a typical value for a conventional feldspathic dental ceramic, and 7 for IZ/A. An explanation most likely lies in some difference in consistency in the relative proportions of the powder and liquid constituents used in the manufacture of the porcelain layer.[21] Our results are consistent with another study where the strength and Weibull modulus of bilayered beams, made from the same combination of materials, were greater for IZ.[2]

The fracture mode of bilayered samples was substantially different according to which material underwent biaxial tensile stresses on the bottom. When the core material was on top and the porcelain on the bottom, the fracture tended to originate from a major defect at the bottom surface of the porcelain and propagate toward the interface. The failure mode of the porcelain consisted of a star-like crack configuration radiating across the bottom tensile surface.[22] Invariable failure from two such cracks, opposite each other, extended through the entire specimen. Those cracks generally met the core normal to the interface and were not deflected at the interface. Some of the other star cracks initiated at the bottom surface did not approach the core normal to the interface and were further deflected to run along the porcelain-core interface. This behavior is expected because of the elastic modulus and fracture toughness mismatch between core and porcelain. The higher-modulus core creates a greater mode II, or shear crack, loading as the crack approaches the interface, resulting in a more inclined crack (Fig 3b).

Microscopy showed that when delamination occurred (50% of the specimens), the crack normally propagated through the lowest-toughness phase, the porcelain (Fig 3c). In only a small number of specimens did the fracture originate at the interface, where, according to FEA, there was (within the stronger core material) the greatest peak of tensile stress. Other investigators have shown that the fracture origin and fracture mode are greatly influenced by the test methodology and ct/vt ratio.[8–11] We chose the biaxial flexural test because it is unaffected by edge failure and better resembles clinical conditions compared to the uniaxial flexure test. In fact, the biaxial flexure test more realistically replicates the in vivo situation, as it generates the greatest number of interfacial failures. Furthermore, the disk-shaped specimens have an area similar to dental restorations.[10,23] The site of crack initiation shifts from the veneering porcelain to the inner core as the core/porcelain thickness ratio increases.[10,11] A ct/vt ratio of 1:1 was chosen in the present study as an acceptable tradeoff between the situation of a crown and an FPD.

When the core material was on the bottom and subjected to biaxial tension, a Hertzian cone crack was seen in the porcelain layer of all specimens. Despite the consistent presence of the Hertzian cone crack in the porcelain layer, the bulk fracture originated from radial cracks initiated at the bottom surface (core material), where the maximum peak of tensile stress was located. Cone cracking was significantly more extended in A/IZ, and partial delamination occurred in four specimens as a result of the extension of the cone crack up to and along the interface (Fig 4b). In contrast, none of the IA/A specimens was seen to delaminate. Although the elastic moduli of these two materials are slightly different, the more extended cone crack present in A/IZ compared to A/IA appeared to be related to the strengthening effect of IZ. This is consistent with the results of the mechanical strength tests whereby higher forces were applied in the case of A/IZ than A/IA. These higher loads applied to the upper surface by the piston resulted in deeper Hertzian cone cracks extending within the porcelain to the interface for the A/IZ prior to fracture. These were highly inclined cracks meeting the porcelain-core interface and resulting in the observed extension along the interface and delamination.

This is consistent with claims made in a review of the mode of fracture of flat bi- and trilayered specimens tested with the porcelain on top.[5] Formation of a cone crack developed as a result of the contact with a blunt indenter (corresponding to our loading piston), followed by radial cracks that initiated at the inner tensile surface and extended radially outward within this layer. Such cracks are believed to be responsible for bulk fracture. That study[5] also provided an analytic analysis that relates the radial cracks in bilayered specimens to the primary parameters and shows the linear dependence with strength and quadratic dependence with layer thickness. According to those authors, to improve the clinical performance of an all-ceramic crown, the strength of the core material should be improved and more attention should be paid to minimizing the formation of flaws.[5]

Conclusion

The first hypothesis was partially accepted, since the present study showed that the strength and reliability of bilayered specimens were greatly dictated by the material in tension. In bilayered groups with the core material in tension, the strength and reliability of the specimen were improved by the core material that possessed better mechanical properties. However, the contribution of a stronger and tougher core material, when the porcelain was in tension, merely resulted in a modest improvement of the reliability of strength. The second hypothesis was also partially accepted. No significant differences were noted in the fracture mode when the porcelain was in tension. In contrast, there was a significant increase of the extension of the Hertzian cone crack when the core material was in tension.

The present study suggests that the material that undergoes tensile stress dictates the ultimate strength of the all-ceramic restoration. The contribution of stronger and tougher core materials to the performance of all-ceramic restorations may be offset by the weaker veneering porcelain if the design of the restorations does not take into account the actual distribution of the tensile stresses. It may be advisable in the case of an FPD not to veneer the core material with conventional porcelain, at least in areas where esthetic considerations are not crucial. However, further studies are necessary to investigate the design and influence of the environment of restorations with the core material exposed. As far as crowns are concerned, the improvement of the mechanical properties of the core material should provide better clinical performance of the restoration, provided measures are taken to avoid the creation of spurious flaws during laboratory processing.

Acknowledgments

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Literature Abstract

The effect of silica coating on the resin bond to the intaglio surface of Procera AllCeram restorations.

The authors compared the effects of a silica-coating method on the shear bond strength of two resin composite cements to densely sintered, high-purity alumina specimens with and without long-term storage and thermocycling. One hundred square alumina samples (10 mm × 10 mm × 2 mm) were fabricated and divided into five groups (n = 20). Resin composite cylinders were bonded with Panavia 21 TC to *(1)* original alumina surfaces (PAN), *(2)* original alumina surfaces after silanization with Clearfil Porcelain Bond Activator (PAN-SIL), *(3)* alumina surfaces silicoated with the Rocatec System and silanized with ESPE-SIL (PAN-ROC); and bonded with RelyX ARC to *(4)* original ceramic surfaces after silanization with Ceramic Primer and Single Bond (REL-SIL), and *(5)* ceramic surfaces treated with Rocatec and silanization with ESPE-SIL (REL-ROC). Half of the samples in each group were tested after storage in distilled water for 3 days (short-term subgroup), and the other half were tested after storage in distilled water for 180 days and thermocycling (12,000 cycles between 5 and 60°C with a 15-second dwell time). After short-term storage, the REL-ROC subgroup showed the highest mean shear bond strength of 26.59 MPa (SD 3.91), significantly higher than other subgroups. Long-term storage and thermocycling decreased the bond strength of all subgroups significantly. PAN-SIL (12.07, SD 2.17) and PAN-ROC (11.69, SD 1.31) revealed the highest bond strengths among the subgroups after thermocycling. The use of a resin cement containing an adhesive phosphate monomer (Panavia 21 TC) with a silane coupling/bonding agent or after tribochemical silica/silane coating may achieve superior long-term shear bond strength to high-density alumina restorations.

Blatz MB, Sadan A, Blatz U. *Quintessence Int* 2003;34:542–547. **References:** 34. **Reprints:** Dr M. B. Blatz, Department of Prosthodontics, Louisiana State University Health Services Center School of Dentistry, 1100 Florida Avenue, Box 222, New Orleans, Louisiana 70119. e-mail: mblatz@isuhsc.edu—*Frederick C. S. Chu, Hong Kong*