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Influence of Veneering Materials on the Marginal Fit and Fracture Resistance of an Alumina Core System

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All-ceramic; alumina core; veneering material; marginal gap; fracture resistance; core/veneer interface.

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Abstract

Purpose: This study was undertaken to assess the influence of three-veneering materials on the marginal fit, fracture resistance, and failure pattern of In-Ceram alumina crowns.
Materials and Methods: Forty In-Ceram cores were constructed and divided into four groups of ten each. Ten alumina cores were left unveneered, forming the first group for core testing, while the other 30 copings were divided into three groups depending on the veneering material used. The vertical marginal gaps of the alumina copings were measured before and after veneer placement at 16 sites using an optical microscope. The specimens were then loaded to fracture at a crosshead speed of 1 mm/min. Fractured specimens were examined, and the fracture patterns of the crowns were recorded. Selected specimens were examined using scanning electron microscope. Data were presented as means and standard deviation values. One-way ANOVA was used to compare between mean gap areas and fracture resistance of the three materials. Duncan's post hoc test was used for pairwise comparison between the means when ANOVA test was significant.
Results: Vitadur-N-veneered crowns showed statistically the highest mean vertical gaps, while no significant difference was evident between the marginal fits of Vitadur-α- and VM7-veneered crowns. Regarding the strength, a statistically significant decrease in fracture resistance of the cores was evident after veneering with Vitadur-N; however, no significant change in mean fracture resistance value of Vitadur-α- and VM7-veneered crowns was evident compared to the alumina cores. VM7-veneered crowns showed the highest fracture resistance values.
Conclusions: Vitadur-N-veneered crowns showed the highest mean vertical gaps and the lowest mean fracture resistance values of the tested groups, while VM7-veneered crowns combined the highest fracture resistance values and clinically acceptable margins. The best interface quality and finest ceramic texture were evident in case of VM7 material.

An ideal all-ceramic restoration, which combines excellent physical properties, marginal fit, and esthetics, is the goal of the dental profession. Reinforced all-ceramic restorations are mostly composed of layered structures with a high-strength core material, laminated with esthetic but weak veneer porcelains.[1] Glass-infiltrated sintered alumina (In-Ceram, Vita Zahnfabrik, Bad Sackingen, Germany), one of these many systems, is based on the slip casting of an alumina core with its subsequent glass infusion. This core material is veneered with esthetic feldspathic porcelain. The partially sintered porous core is composed of 85% Al_2O_3, which is subsequently infiltrated with molten lanthanum glass infiltration in a second-firing process. It reaches a flexural strength of approximately 400 MPa.[2-4]

Two important factors affect the performance of all-ceramic restorations: marginal adaptation and strength. For all-ceramic restorations to be successful, they must satisfy both tenets. Furthermore, the strength of these all-ceramic systems is greatly affected by the quality of the core/veneer interface.

Restoration longevity is related to marginal fit, as defective margins have been reported as the cause of approximately 10% of restoration failures.[5] Conflict exists regarding optimum margin design for In-Ceram restorations. Authors recommend a deep chamfer or shoulder finish line.[6-9] Comparison of marginal accuracy between all-ceramic restorations and metal-ceramic restorations has demonstrated a significantly higher accuracy of metal-ceramic over all-ceramic restorations;[10,11] however, others reported no difference.[12–14]

Variation exists regarding what constitutes a clinically acceptable margin.[14] McLean and von Fraunhofer[15] proposed that the current clinically acceptable marginal opening should be between 40 and 120 μm. Authors reported values of mean marginal discrepancy for In-Ceram crowns ranging between 12 and 161 μm.[7,8,10,16–25]

The fit and strength of dental ceramics are considered by many to be inferior to metal-ceramic restorations.[26] Castellani et al[10] evaluated the response of In-Ceram crowns to repeated firing cycles and reported an increase in vertical gap, which appeared to stabilize in subsequent firings, after the initial firing. On the other hand, Pera et al[19] reported that dimensional stability of In-Ceram substructure was maintained during firing of the Vitadur-N veneer and successive glazing. Balkaya et al[20] reported an acceptable marginal fit, even though veneer-firing cycle affected the fit of In-Ceram. Yeo et al[22] concluded that In-Ceram gaps were clinically acceptable, even though they presented the largest and most variable-gap dimensions compared to metal-ceramic restorations.

The survival of multimaterial structures is influenced by material thickness ratios, geometric design factors, processing variables, and thermal properties, in addition to mechanical and elastic properties of component materials. The opinion that veneering porcelain influences the strength of two-layer specimens is shared by many.[26–30] Successful performance and reliability of veneered ceramic restorations may be limited by adhesion of the veneering porcelain to the substrate.

The effect of veneer porcelain on the fit,[19,20,22,24,26] strength,[27,28,30] and failure pattern[28,29] of all-ceramic restorations has been well documented. This study was undertaken to assess some clinically relevant properties of three veneering materials developed for In-Ceram alumina core material as they relate to the clinical performance of the system. A hypothesis was proposed that the type of veneering materials affects the fit, strength, and failure pattern of In-Ceram alumina crowns.

Materials and methods

A stainless steel die was machined to approximate dimensions for a prepared molar (6-mm high, 9-mm in diameter). The die had a standard recommended preparation for an all-ceramic crown including an 8º occlusal convergence, and a rounded 90º shoulder of 1-mm width to accommodate an In-Ceram crown. The die was coated with two layers of coat spacer (Vita Interspace Varnish, Vita Zahnfabrik) as recommended by the manufacturer. Forty In-Ceram cores were constructed and randomly divided into four groups of ten each. Ten cores were left unveneered, while 30 cores were veneered using three veneering materials: Vitadur-N, Vitadur-α, and the recently developed VM7 powder (Vita Zahnfabrik). The stainless steel die was duplicated 40 times in special plaster (Vita Zahnfabrik), using a special tray and rubber impression material.

A split counter die was designed to allow the production of a wax coping of 0.7 mm thickness for standardization of the core dimension. The wax coping was invested and cast to produce a metal coping of standardized dimension.

Eight polyvinylsiloxane impressions (Imprint II, 3M ESPE, Seefeld, Germany) were made with the metal coping seated on the stainless steel die to produce eight-enlarged rubber molds. A hole was made in the center of the mold to inject the slip.[31] Each rubber mold was in turn used five times to inject the slip material after seating the rubber mold on a plaster die, producing a total of 40 identical cores. The cores were subjected to their recommended firing cycle then glass infiltrated, fired, sandblasted, and re-fired. All firing cycles were set according to the manufacturer's recommended cycles.

Ten In-Ceram cores were left unveneered, forming the first group for core testing. This group did not undergo any further firing to be able to determine the effect of firing, the veneering material on the marginal accuracy, and the fracture resistance of the restoration. The other 30 copings were divided into three groups of ten each depending on the veneering material used. After the first firing, a second firing was required to compensate for porcelain shrinkage and voids, followed by a third firing to mimic the glazing firing.[20]

Vertical marginal gap measurement

The vertical marginal gaps of the alumina copings were measured before and after veneer placement. Each specimen was placed on the stainless steel die (after removing the spacer) and examined using a stereomicroscope (SZ 40, Olympus, Tokyo, Japan). A specially designed metal device was used to ensure correct seating of the crowns during microscopic measurements. Photos of the crowns were captured by a digital camera (P10, Olympus), which was linked to the microscope with original magnification 30×.

Image analysis software (Image J, 1.31, NIH, Bethesda, MD) was used to measure the gap between the crown margin and the finish line, by drawing a line from the cervical margin of the crown and the outer end of the finish line at four points on the same surface of the crown. Sixteen readings were taken for each core circumferentially, four readings at each quarter turn. The mean vertical marginal gap was calculated for each group of specimens and subjected to statistical analysis. The same procedure was repeated after veneer firing, and each crown was marked to compare its fit before and after veneering.

Fracture resistance test

The stainless steel die was duplicated in epoxy (Polypoxy 700 Polymer, C.I.C., Cairo, Egypt) for fracture testing, producing 40 epoxy dies. The specimens were cemented to the epoxy dies using glass ionomer cement (Fuji I, GC America, Chicago, IL). The crowns with their epoxy dies were vertically mounted on a computer-controlled testing machine (Model LRX-plus; Lloyd Instruments Ltd., Fareham, UK) with a load cell of 5 kN. Data were recorded using computer software (Nexygen-MT; Lloyd Instruments). The dies were secured to the lower fixed compartment of the machine by tightening screws so the long axis of each specimen was parallel to the force, and the "occlusal surface" of the specimen was aligned perpendicular to it. Load was applied with a custom-made load applicator (steel rod with half sphere tip with a diameter of 3.8 mm) placed at the center of the occlusal surface of crown specimens attached to the upper movable compartment of the machine. A

Table 1 Vertical marginal gap measurements of the three-veneering materials (μm)

Material veneer	Vitadur-N		Vitadur-α		VM7		p-value
	Mean	SD	Mean	SD	Mean	SD	
Before	129.8	13.7	132.7	13.7	131.5	7.9	0.864
After	157.8[a]	14.7	106.3[b]	7.5	111.4[b]	9.5	<0.001
p-value	<0.001		0.002		<0.001		

Means with different letters are statistically significantly different according to Duncan's test.

layer of rubber sheet was placed between the loading tip and the occlusal surface of crown specimens to achieve even stress distribution. Specimens were loaded to fracture at a crosshead speed of 1 mm/min, and the values were recorded in Newtons. Fractured specimens were examined using a magnifying lens, and the fracture pattern of each crown was recorded.

Scanning electron microscope (SEM)

Selected fractured specimens were prepared for electron scanning examination (JSMT 330 scanning microscope connected with EDAX, Energy Dispersive System link system, 860/500, JEOL, Tokyo, Japan). The specimens were mounted on copper stubs with double-sided adhesive tape and coated with Au using sputter coater (S150 A Edwards, Sussex, UK). The specimens were examined using JXA-840 A electron probe microanalyser (JEOL). Detections of crystal shape, size of various crystalline components, glassy phase, pore shape, size, and distribution were made. The microcrack pattern induced in the ceramic during loading was identified.

Statistical analysis

Data were presented as means and standard deviation values. One-way ANOVA was used to compare between mean gap areas of the three materials. Duncan's post hoc test was used for pairwise comparison between the means when ANOVA test was significant. The significance level was set at $p < 0.05$. Paired t-test was used to compare between measurements before and after veneering. Statistical analysis was performed with SPSS 15.0 (SPSS, Inc., Chicago, IL).

Results

The initial mean marginal gap core values of the three groups were different numerically in the three groups. The individual cores forming each subgroup were identified, and their mean values were calculated and measured again after veneering. This was done to test the effect of firing within each of the three-veneered groups compared to their initial baseline values.

Marginal gaps between groups after veneering

Vitadur-N showed statistically the highest mean gap values (157.8 μm). There was no statistically significant difference between the gap values of Vitadur-α and VM7, both of which showed statistically lower means (Table 1). Statistical analysis using paired t-test within each veneering group showed a statistically significant increase in mean gap in case of veneering with Vitadur-N material ($p < 0.001$); however, a significant decrease in mean gap area after veneering was evident for both Vitadur-α and VM7 ($p = 0.002$, $p < 0.001$, respectively).

Fracture resistance

When comparing the fracture resistance of the veneered crowns, Vitadur-N-veneered cores showed statistically the lowest means, followed by Vitadur-α. The highest mean values were recorded for VM7 crowns. Furthermore, when comparing the strength before and after veneering within each group, no significant change in mean fracture resistance values was evident after veneering with Vitadur-α and VM7, while a significant decrease in strength occurred after veneering with Vitadur-N (Table 2).

Fractured specimen examination

Visual examination

The In-Ceram cores and the veneered crowns fractured into multiple fragments. Delaminations were observed in the case of crowns veneered with Vitadur-N, while most fractured fragments of tested crowns veneered with VM7 and Vitadur-α

Table 2 Fracture resistance mean values of the cores and veneered crowns (N)

Material veneer	Vitadur-N		Vitadur-α		VM7		p-value
	Mean	SD	Mean	SD	Mean	SD	
Before	1089.4	127.1	1089.4	127.1	1089.4	127.1	1.000
After	740.6[c]	116.5	1038.8[b]	83.4	1147.2[a]	100.1	<0.001
p-value	<0.001		0.275		0.187		

Means with different letters are statistically significantly different according to Duncan's test.

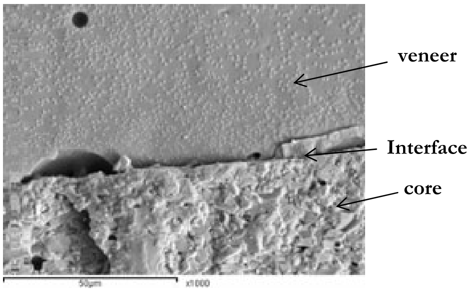

Figure 1 SEM of failed Vitadur-N-veneered crown showing the coarse, granular nature of its veneering material. In-Ceram core shows dense alumina particles of different shapes, sizes, and arrangement embedded in a nonporous matrix. Porosities and gaps are apparent at the core/veneer boundary showing incomplete adherence and debonding of the porcelain from the core surface.

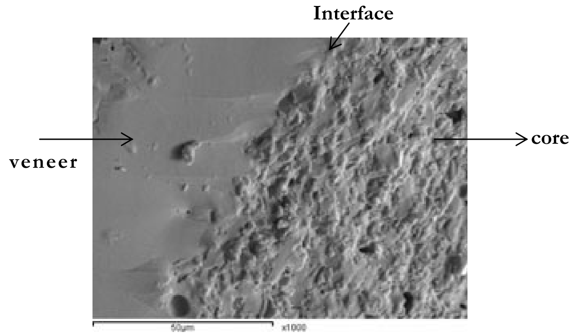

Figure 2 SEM of failed Vitadur-α-veneered crowns showing distinct morphology from the earlier generation. The particle size of the veneering material is fine textured and interlocks intimately to the alumina core. The interface appears defect-free, suggesting a good bond between the veneer and the core.

showed no delaminations. A few selected fragments from testing were selected and examined using SEM.

SEM examination of failed Vitadur-N-veneered crowns

In-Ceram cores revealed a homogenous morphology of densely packed compact alumina particles embedded in a nonporous matrix showing different shapes, sizes, and arrangement of alumina crystals. The particle size of Vitadur-N-veneering material was coarse and granular, and the boundary between the core and veneer was evident. The core/veneer interface appeared clear and evident with multiple spaces and gaps showing incomplete adherence between core and veneer after failure (Fig 1).

SEM examination of failed Vitadur-α-veneered crowns

Vitadur-α veneer and In-Ceram alumina core ceramic appeared distinct with different morphology, and the boundary between them appeared to have no gaps, that is, defect-free interface, suggesting a good bond between the veneer and the core, contrary to the first-generation veneering material. There was, however, a structural difference in the crystal structure of both ceramics. Vitadur-α appeared to possess a finer texture when compared to the coarse, granular appearance of Vitadur-N (Fig 2).

SEM examination of failed VM7-veneered crowns

The boundary between In-Ceram core and VM7 veneer appeared evident, but not clear-cut, due to some apparent interlocking between core and veneer creating a zone where the materials appeared to blend and intertwine, making them not clearly distinct from each other. This may explain the fracture pattern, where both veneer and core appeared to fracture, with less delamination (Fig 3).

Discussion

Mean values of marginal discrepancy for In-Ceram crowns ranging between 12 and 161 μm have been reported.[7,8,10,17-22,32,33] The mean gap values increased after porcelain firing in the case of Vitadur-N, recording values of 157.8 μm. These values are in agreement with those of Sulaiman et al[17] (160.6 μm). The fact that the values increased after veneering agrees with the findings of Castellani et al[10] and may be explained by numerous causes. A significant amount of shrinkage occurs during sintering; as the ceramic compacts, it lifts from the margin of the die, creating gaps.[9] It may also have been caused by the difference in the coefficient of thermal expansion (CTE) and sintering temperature of both the core and veneering materials. Another possible explanation could be the weak bond between the core and the veneering material allowing uncontrolled veneer shrinkage; however, Pera et al[19] reported dimensional stability of In-Ceram cores during firing of Vitadur-N.

Vitadur-α and VM7 groups showed numerically smaller gap values after firing (106.3 and 111.4 μm, respectively), indicating controlled firing shrinkage of the veneer and matching CTE. A decrease in In-Ceram gaps was reported after veneering (18.3 μm).[21] Balkaya et al,[20] on the other hand, reported greater gaps for the veneered crowns (Vitadur-α) compared to the copings. These findings could be due to differences in the testing conditions of both studies. Uniform core thickness in the present study, along with the chosen taper, die dimensions, and spacer, may have helped control the seating.

Yeo et al[22] reported gap values close to those in the present study (112 μm). The ideal tangential and radial tensile stress is ensured if the CTE of the ceramic is optimally matched with that of the substructure material. The CTE of In-Ceram alumina core is reported by the manufacturer to be 7.2 to 7.6 $\times$ 10^{-6}/°C, while that of Vitadur-α is approximately 6.7, and VM7 veneer is 6.9 to 7.3 $\times$ 10^{-6}/°C.[34] This change in their value may be the reason the gaps found in Vitadur-α, and VM7 were found to be within the clinically accepted range set between 40 and 120 μm.[15]

Most investigators agree that veneering porcelain dictates the ultimate strength of all-ceramic restorations.[28,35,36] A significant decrease in the mean fracture resistance of the cores was evident after veneering with Vitadur-N. Kelly et al[28,29] stated that 70% to 78% of failures were found to originate from the core/veneer interface. Moreover, the observed reduction in strength could have been due to the porosities observed at the

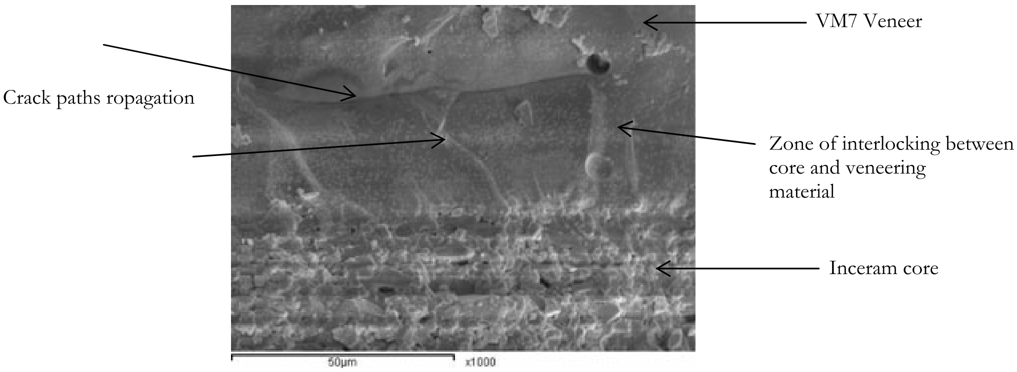

Figure 3 SEM of failed VM7 crown showing interlocking between the alumina core and veneer, creating a zone where the materials appear to blend and intertwine, making them not clearly identified from each other.

interface, which were not evident with the two other veneering materials (Figs 1-3). Consideration should also be given to the roles of the interface strength and residual thermal mismatch stresses.[37,38]

The magnitude of the recorded mean fracture strength values for the Vitadur-α and VM7 crowns (1038, 1147 N, respectively) were close to those reported by Yoshinari and Derand[2] (1276 N). This value predicts better clinical performance and longer survival rates for these restorations in service, as they are well above the average biting force in the molar region (400 to 890 N).[1] Moreover, Guazzato et al[39,40] concluded that the material that underwent tensile stress dictated the ultimate strength of all-ceramic restorations. Regarding the strength before and after veneering, no significant change was evident compared to the core. This agrees with the findings of Thompson,[35] who concluded that bilayered materials were not stronger than core materials, and that the less-core component there was, the weaker the material. Wakabayashi and Anusavice[41] declared that the fracture resistance of alumina cores increased, and that crack initiation shifted from veneer to core as the core-to-veneer thickness ratio increased, but it never exceeded it.

Even thickness of the core is of particular importance, as the latter influences the deformation to the third power; this is why even core thicknesses of 0.7 mm were chosen in the present study. Small variations in core thicknesses have considerable effects on the overall fracture resistance of a restoration.[28,41,42] The results of the present study could also be attributed to different conditions of mechanical testing, processing variables such as different elastic modulus of the supporting dies, geometry of the preparation, direction of load application, applicator diameter, bonding, core thickness porosity, substructure design, and the fact that the alumina cores in this study were veneered with different veneering materials.[37,38,41,43] The values obtained may thus differ from those of other studies and can only be used for comparison among the specimens tested.

The particle size of Vitadur-N-veneering material was coarse and granular, while Vitadur-α appeared to possess a finer texture in comparison. This agrees with the manufacturer's reported grain size of 30 μm and 18 μm; however, the finest texture was evident in case of VM7 material, which was reported to possess a size of 0.7 μm free of any crystal phase.[34] This probably contributed to better wetting and bonding to the sandblasted core surface, explaining the higher fracture resistance values recorded.

The fracture patterns differed in the three groups. Delaminations were observed in case of crowns veneered with Vitadur-N, while in the other groups, complete failure was predominant, involving both core and veneer. Many factors, such as the modulus, thickness, porosity, and geometry of the materials, influence fracture behavior.[44] Spaces and gaps were apparent at the interface of Vitadur-N-veneered cores, showing incomplete adherence between core and veneer in some areas, and debonding of the porcelain from the coping surface as a result of the testing. This explains the delaminations of some failed specimens (Fig 1). Successful performance and reliability of veneered ceramic restorations may be limited by adhesion of the veneering porcelain to the substrate.[45] Kelly et al[28] observed porous defects at the core/veneer interface. They reported that cracks started in the more porous layer and extended from there to the entire thickness. This explains the significant decrease in fracture strength after core veneering with Vitadur-N. On the other hand, Vitadur-α and VM7 veneer appeared to possess distinct fine texture, and the interface appeared intimate with no gaps, suggesting a better interfacial bond.

The hypothesis that veneering materials may alter the properties of In-Ceram alumina cores has been confirmed. Further investigation comparing the bond strength between the alumina core and its veneering materials is currently in press.

The improvement in marginal fit and strength of In-Ceram restorations observed in this study with VM7-veneering material should increase the survival rate of these restorations, contrary to the initially developed systems. This study involved in vitro testing, thus giving an idea about clinical expectations; however, clinical trials are the final determinant to the performance of these new all-ceramic systems.

Conclusions

(1) After veneering, Vitadur-N showed statistically the highest mean vertical gap of 157.8 μm. No significant difference was evident between the marginal fits of Vitadur-α and

VM7 (106.3, 111.4 μm, respectively), both clinically acceptable.

(2) Regarding the strength before and after veneering, no statistically significant change in mean fracture resistance values of Vitadur-α and VM7 was evident compared to the alumina core strength; however, a significant decrease was found after veneering with Vitadur-N.

(3) VM7-veneered crowns showed statistically higher fracture resistance values than those recorded by Vitadur-α crowns.

(4) The best interface quality and finest texture of ceramic was evident with VM7.

(5) Both Vitadur-α- and VM7-veneering materials seem to possess superior properties compared to Vitadur-N; however, VM7, with its ultra-fine texture, combines greater strength and better fit while providing predictions of superior optical properties and bonding to the alumina core.

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