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The strength of sintered and adhesively bonded zirconia/veneer-ceramic bilayers

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ABSTRACT

Objectives: Recently all-ceramic restorative systems have been introduced that use CAD/CAM technology to fabricate both the Y-TZP core and veneer-ceramic layers. The aim was to identify whether the CAD/CAM approach resulted in more favourable stressing patterns in the veneer-ceramic when compared with a conventionally sintered Y-TZP core/veneer-ceramic.
Methods: Nominally identical Vita VM9 veneer-ceramic disc-shaped specimens (0.7 mm thickness, 12 mm diameter) were fabricated. 20 specimens received a surface coating of resin-cement (Panavia 21); 20 specimens were bonded with the resin-cement to fully sintered Y-TZP (YZ Vita Inceram Vita) discs (0.27 mm thickness, 12 mm diameter). A final series of 20 Y-TZP core/veneer-ceramic specimens were manufactured using a conventional sintering route. Biaxial flexure strength was determined in a ball-on-ring configuration and stress at the fracture origin calculated using multilayer closed-form analytical solutions. Fractography was undertaken using scanning electron microscopy. The experimental test was simulated using Finite Element Analysis. Group mean BFS were compared using a one-way ANOVA and post hoc Tukey tests at a 95% significance level.
Results: Resin cement application resulted in significant strengthening of the veneer-ceramic and further significant strengthening of the veneer-ceramic ($p < 0.01$) occurred following bonding to the Y-TZP core. The BFS calculated at the failure origin for conventionally sintered specimens was significantly reduced when compared with the adhesively bonded Y-TZP/veneer-ceramic.
Conclusions: Under the test conditions employed adhesive cementation between CAD/CAM produced Y-TZP/veneer-ceramic layers appears to offer the potential to induce more favourable stress states within the veneer-ceramic when compared with conventional sintered manufacturing routes.
Clinical significance: The current investigation suggests that the stressing patterns that arise in all-ceramic restorations fabricated using CAD/CAM for both the core and veneer-ceramic layers differ from those that occur in conventionally sintered bilayer restorations. Further work is required to ascertain whether such differences will translate into improved clinical outcomes.

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1. Introduction

Fractographic analysis of failed clinical restorations[1,2] and in vitro simulations have demonstrated that fracture in Y-TZP/veneer-ceramic systems occurs predominantly due to chipping within the veneer-ceramic and/or delamination from the underlying Y-TZP core.[3–8] It has been further shown that the initial flaw can extend sub-critically in areas of high stress concentration which are often in the proximity of a contact load.[9] Sub-critical crack growth in veneer-ceramics is well characterised[10] and is likely to be influenced by the mechanical variables of the masticatory challenge and by the physiochemical characteristics of the oral environment. The rate of crack-extension and to some extent the crack direction will however be modified by the presence and characteristics of residual stress states that exist within the ceramic body.[11] Residual stress states in Y-TZP/veneer-ceramic systems may be introduced during veneer-ceramic sintering as a consequence of the thermal expansion mismatch between the two materials[1,12,13] and as tempering stresses associated with temperature gradients during cooling.[14–16] Residual stresses have the capacity to be both beneficial when manifested as compressive stress states and deleterious as tensile stress states, particularly when located in a region of stress concentration that occurs on application of external load.[17] Consequently considerable focus exists on the development of material, design and processing solutions to optimise residual stress states within Y-TZP/veneer-ceramic systems with the overall aim of decreasing the incidence of fatigue related fracture events.

Traditionally Y-TZP cores are milled in either partially or fully sintered states prior to manual application of an aesthetic veneer-ceramic through a conventional powder condensation and sintering route. To reduce operator variability associated with the manual application/condensation of the veneer-ceramic, commercial Computer-Aided Design/Computer-Aided Manufacture (CAD/CAM) systems have been introduced which fabricate both the core and veneer layers individually – a process which has been described as Rapid Layer Manufacture (RLM).[18] The two RLM layers are subsequently joined using an interface adhesive comprised of either a low-fusing glass ceramic[19,20] or a resin-cement.[18,21] The technique has a number of proposed advantages which include a reduced need to match the coefficients of thermal expansion of the two layers which is essential in traditional ceramic fusion manufacture.

When a resin-cement interface adhesive is used the residual stresses introduced by the volumetric shrinkage of the resin-cement would be expected to be insignificant when compared with the thermally introduced stresses associated with conventionally sintered Y-TZP/veneer-ceramic systems.[9] In addition the presence of a thin intermediate layer of resin-cement has also been proposed to provide an internal barrier to crack propagation across and between layers at the interface thereby preventing delamination.[22] Resin-cements have also been shown to have a highly significant interaction with veneer-ceramic surface defects, potentially conferring reinforcements in excess of 100% of the measured system strength.[23,24] Studies on resin-cementation of monolithic dental ceramics have shown that the reinforcement is sensitive to cement thickness and elastic modulus which can lead to a variation in the critical load for veneer fracture.[23,24]

Investigations into the benefits of RLM when compared with traditional veneer-ceramic sintering routes are limited. Finite Element Analysis (FEA) approaches offer insight into the effect of design variables on stress distributions and fractographic studies can identify fracture origins and patterns. However, it is also important to understand how strength limiting defect populations; thermally introduced stresses and interface variables impact on the system strength. Discerning the contribution of individual components is extremely complex, however, the combined influence may be indirectly assessed by calculating differences in the stress required to initiate fracture at regions within the veneer-ceramic layer where strength modifying variables exist. The current study uses multilayer analytical solutions in combination with bi-axial flexure testing of idealised specimen geometries designed to initiate tensile crack extension in regions of the veneer-ceramic influenced by interfacial and residual stress variables. Given the limited evidence regarding RLM and its potential advantages, the null hypothesis that there would be no difference between the failure stresses in adhesively bonded or sintered veneer-ceramic layers was tested.

2. Materials and methods

2.1. *Veneer-ceramic sample preparation*

0.6 g of Vita VM9 veneer-ceramic dentine powder was proportioned and manipulated with 0.22 mL of Vita Modelling Fluid (Vita, Bad Sackingen, Germany) to form a reproducible slurry. The slurry was transferred into a plastic ring mould (14 mm diameter $\times$ 0.9 mm thickness) which was firmly secured to a flat aluminium base-plate. The slurry was condensed using a vibrating plate and absorbent tissue to remove excess Modelling Fluid. The condensed disc-shaped specimens were then vacuum-fired (Vita Vacumat 40T, Vita Zahnfabrik, Bad Sackingen, Germany) (pre-heated to dry the specimen at 500 °C for 360 s before the temperature was increased at 55 °C/min to 910 °C under vacuum) and air-cooled to room temperature. Following firing the resultant discs with final dimensions of 13 mm diameter $\times$ 0.70 $\pm$ 0.03 mm thickness were visually inspected and then stored in a desiccator prior to usage.

2.2. *Y-TZP core-ceramic preparation*

Partially sintered Y-TZP CAD/CAM blocs (55 mm $\times$ 19 mm $\times$ 15.5 mm, YZ Vita Inceram Vita, Bad Sackingen, Germany) were rounded to a 15 mm diameter cylinder using a core drill and copious lubricant. The cylinders were then sectioned using a low-speed saw to produce discs. The discs were then manually polished on one surface using a P320 grit silicon carbide abrasive followed by a P500 grit to produce a final pre-sintered thickness of 0.30 $\pm$ 0.01 mm. The discs were sintered in Vita ZYRCOMAT 6000 MS Sintering Furnace (Vita Zahnfabrik, Bad Sackingen, Germany) resulting in a final diameter and thickness of 12 mm and 0.27 $\pm$ 0.02 mm, respectively. One