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Can a soda-lime glass be used to demonstrate how patterns of strength dependence are influenced by pre-cementation and resin-cementation variables?

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ABSTRACT

Objectives: To determine how the variability in biaxial flexure strength of a soda-lime glass analogue for a PLV and DBC material was influenced by precementation operative variables and following resin-cement coating.

Methods: The flexural modulus of a transparent soda-lime glass was determined by longitudinally sectioning into rectangular bar-shaped specimens and the flexural moduli of three resin-based materials (Venus Flow, Rely-X Veneer and Clearfil Majesty Posterior) was also determined. Disc shaped soda-lime glass specimens ($n = 240$) were divided into ten groups and were alumina particle air abraded, hydrofluoric (HF) acid-etched and resin-cement coated prior to biaxial flexure strength testing. Sample sets were profilometrically evaluated to determine the surface texture. One-way analyses of variance (ANOVA) and *post hoc* all paired Tukey tests were performed at a significance level of $P < 0.05$. The mean biaxial flexure strengths were plotted against resin-coating thickness and a regression analysis enabled estimation of the 'actual' magnitude of strengthening.

Results: The mean three-point flexural modulus of the soda-lime glass was 40.0 (1.0) GPa and the Venus Flow, Rely-X Veneer and Clearfil Majesty Posterior were 3.0 (0.2) GPa, 6.0 (0.2) GPa and 14.8 (1.6) GPa, respectively. At a theoretical 'zero' resin-coating thickness an increase in biaxial flexure strength of 20.1% (63.2 MPa), 30.8% (68.8 MPa) and 36.3% (71.7 MPa), respectively was evident compared with the control (52.6 (5.5) MPa).

Conclusions: Disc-shaped specimens cut from round stock facilitated rapid fabrication of discs with uniform surface condition and demonstrated strength dependence was influenced by precementation parameters and resin-cementation variables.

1. Introduction

The clinical success of resin-luted porcelain laminate veneer (PLV) or dentine bonded crown (DBC) restorations is remarkable[1] and is attributed to a synergism[2] between the tooth preparation and the low strength ceramic which is conferred by the resin-based luting material. There is little doubt that the long-term comprehensive prospective clinical study of 1444 Dicor glass-ceramic crowns by Malament and Socransky[1] is the 'gold standard' in terms of identifying the effect of resin-cementation on improved clinical performance. Unfortunately, Dicor was obsolete when the 14-year results of the study were published in 1999. Given the number of new

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glass-ceramic and dispersion strengthened ceramics introduced to the dental market in the last 30 years, it would be unreasonable to perform similar long-term comprehensive prospective clinical studies on each ceramic type marketed. As a result, *in vitro* research methodologies have been devised to aid practitioners and materials scientists in assessing the appropriate ceramic material and cementation technique to improve clinical performance. When assessing the suitability of *in vitro* research methodologies a guest editorial in 1995 entitled 'The First Three Questions'[3] suggested that 'in any discipline, for any project, whatever the motivation' the fundamental questions to be asked were: What do you really want to know? What do you want to measure? and What are you going to measure?.[3]

To provide clinical guidance and maximise the clinical performance of resin-luted PLV or DBC restorations, axisymmetric finite-element analysis of molar crowns[4] and quantitative fractography of failed restorations[5–8] identified the failure mode to be tensile and the fracture origin to be controlled by a critical flaw on the inner surface of the crown.[4–8] Therefore the suitability of an *in vitro* research methodology to investigate the underlying resin-strengthening mechanisms of PLV or DBC restorations is the replication of the clinically observed failure mode and the fracture origin.[9–11] One test considered was the 'crunch-the-crown' testing methodology, however, failure was initiated at the loading contact zone on the external surface of the crown[5,12] and therefore the clinically observed failure mode or fracture origin were not replicated in the testing protocol. In addition, the 'crunch-the-crown' test returns only the load at which failure is deemed to have occurred which is a scalar quantity that cannot be compared and does not inform the investigator about the resultant stress state within the complex geometry of the specimen which causes fracture. As a result of these inadequacies the 'crunch-the-crown' test has essentially been made redundant from the materials science testing armamentarium.[13] Kelly et al.[14] went further recently when after criticising the appropriateness of 'crunch-the-crown' protocols the authors stated they planned to engage editors to take an 'ethical stand against the publication of studies using "crunch-the-crown" protocols in particular'.[14]Testing in biaxial flexure replicates the clinically observed failure mode and fracture origin of PLV or DBC restorations and the simplified disc-shaped specimen has a surface area to volume approximating such restorations. Using the biaxial flexure strength testing methodology, strengthening of PLV/DBC ceramic materials with resin-cement has been shown to be insensitive to defect size[9] but sensitive to macroscopic surface roughness[10] and resin-cement elasticity.[11] Therefore, the traditionally proposed theories of crack healing[15] or the crack closure stresses secondary to polymerisation shrinkage[16] have been demonstrated to incompletely explain the observed strengthening.[9–11] One limitation of all strength testing methodologies is in ceramic sample preparation where variability in the measured strength can be introduced during fabrication[17,18] through sintering or heat-pressing[19] and even CAD-CAM routes[20] which is further influenced by the technical skill of the operator.[18,21] To further understand and optimise the strengthening of PLV and DBC materials by resin-cements it would be useful to identify a substrate from which reliable, bulk-defect-free nominally identical samples may be produced. As the important effect to be observed is surface dominated,[22,23] the fracture toughness of the material is less important, however, the dependence of resin-strengthening on surface effects must be analogous to the previously reported data.[24,25]

The aim of the current study was to determine how the variability in biaxial flexure strength of an analogue for a PLV and DBC material was influenced by precementation operative variables (alumina particle air abrasion and hydrofluoric (HF) acid-etching) and following resin-cement coating. The hypothesis tested was that the analogue material would demonstrate the same patterns of strength dependence influenced by pre-cementation parameters and resin-cementation variables characterised previously with feldspathic and glass-ceramic materials.

2. Materials and methods

2.1. Soda-lime glass flexural modulus

A transparent soda-lime glass (Glass 8337B, SCHOTT-Rohrglas GmbH, Mitterteich, Germany) was received from the manufacturers in a rod form (1.5 m length, 11.6 mm diameter). The flexural modulus of the soda-lime glass was determined by longitudinally sectioning twelve rectangular bar-shaped specimens (25 mm length, 2 mm width, 2 mm thickness) using a precision circular saw (Isomet® Low Speed Saw, Buehler, Lake Bluff, IL, USA) coupled with a diamond wafering blade (15 HC Diamond, Buehler, Lake Bluff, IL, USA) rotating at 170 rpm under water irrigation. The bar-shaped specimens were visually inspected for surface defects, with any residual flash carefully removed by hand-lapping using P400 silicon carbide abrasive paper (Buehler, Lake Bluff, IL, USA) under water lubrication and light finger pressure. The bar-shaped specimens were air-dried and stored in a desiccator at 23 ± 1 °C for 24 h prior to testing and analysis.

The flexural modulus of the soda-lime glass was determined by loading the twelve rectangular bar-shaped specimens to failure in a three-point flexure testing configuration. The specimens were placed individually on a 20 mm support span and loaded centrally at 1 mm/min using a universal testing machine (Instron Model 5565, Instron Ltd., High Wycombe, UK). The slope of the linear elastic region of the load-deflection curves were determined and flexural moduli calculated using Eq. (1).

$$E_B = \frac{L^3}{4bd^3}\frac{\Delta P}{\Delta D} \tag{1}$$

where E_B is the flexural modulus, L the support span (20 mm), b the specimen width (mm), d the specimen thickness (mm) and $\Delta P/\Delta D$ is the slope of the linear elastic region of the load–deflection curve.[26]

2.2. Resin flexural modulus

The flexural moduli of the three resin-based materials (Venus Flow (Heraeus Kulzer GmbH, Hanau, Germany), Rely-X Veneer (3M ESPE, St. Paul, MN, USA) and Clearfil Majesty Posterior