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The impact of resin-coating on sub-critical crack extension in a porcelain laminate veneer material

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ABSTRACT

Objectives. Characterisation of the interaction between crack extension, crack stabilisation and stress/strain relaxation in the polymeric matrix, the interplay between stress corrosion cracking and the mechanical response of a resin-based luting adhesive within a surface defect population could extend PLV restoration longevity by optimising cementation protocols. The aim was to investigate the influence of stress corrosion cracking and the viscoelastic behaviour of a resin-based luting adhesive independently by controlling the environmental conditions operative during test specimen fabrication.

Methods. The effects of stress corrosion at ceramic crack tips and potential viscoelastic responses to loading of the resin-coated impregnating cracks were isolated. Resin-coated feldspathic ceramic test specimens were fabricated in ambient humidity or following moisture exclusion. Bi-axial flexure strengths of groups ($n = 20$) were determined at constant loading rates of 2.5, 10, 40, 160 or 640 N/min and data was compared with uncoated controls. Fractographic analyses were performed on all fractured test specimens.

Results. Resin-cement coating resulted in significant ceramic strengthening in all conditions tested ($p < 0.01$). A two-way ANOVA demonstrated that the exclusion of moisture during resin- coating significantly increased mean BFS ($p<0.01$) but post-hoc Tukey tests identified that moisture exclusion resulted in significant increases in BFS values only at intermediate loading rates with no significant differences observed at either the fastest or slowest loading rates (640 and 2.5 N/min, respectively).

Significance. Mechanical reinforcement of PLV materials by resin-cement systems is yet to be optimized. The viscoelastic behavior of the resin-cement itself can influence the magnitude of reinforcement observed and sub-critical crack growth.

1. Introduction

Porcelain Laminate Veneers (PLVs) are a minimally invasive treatment modality used routinely by dental practitioners to modify the esthetics of the anterior dentition [1]. The brittle nature of dental ceramics can result in the fracture of PLVs in service, despite often not being directly loaded through occlusal contact during function [2]. To address the mechanical deficiencies of PLV materials, efforts have been made using

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in-vitro testing protocols to model the numerous variables that can influence PLV performance in-vivo [3–5]. Investigators have made comparisons with similar systems in the engineering literature where brittle coatings were intimately bonded to relatively compliant substrates namely, laminated glass and thermal barrier coatings [6–8]. To elucidate the key material, geometric, testing and environmental parameters that can determine the fracture pattern and associated strength values, investigators have predominantly employed methodological approaches which involve the indentation testing of ceramic materials bonded to an underlying substrate to form a bi-layered structure [6,9,10] or substrates that form multi-layered structures [10]. In indentation testing, the ceramic laminate or coating has been observed to fail due to Hertzian cone cracks propagating from the indentation contact zone (the surface in compression) or from the tensile extension of radial cracks originating at the opposite surface of the ceramic (the surface in tension) [6,11]. Radial crack extension is understood to be the dominant failure mechanism when the ceramic coating is thin and the supporting substrate is relatively compliant [6,10,11]. This failure mechanism has been demonstrated to predominate in the failure of PLVs in service [12,13].

Clinical survival data for PLV restorations identified that the highest fracture rate occur within the first year of service [14] which is often attributed to processing defects, errors in clinical decision making and/or technical execution. Despite the initial spike in early clinical failures, PLVs are routinely reported in the dental literature to have survival rates in excess of ten years [14,15]. Typically, PLVs are fabricated from amorphous glasses and glass-ceramics that are susceptible to stable crack growth, albeit over a considerable period of time, which can ultimately reduce the energetic requirement for catastrophic failure to occur [16,17]. In addition, PLVs are subject to forces of varying application rate, magnitude and frequency as part of normal masticatory function in-vivo. While the stable crack extension of defects in PLV materials is well understood, when ceramic materials are considered in isolation, it is essential to recognize that when employed clinically, the adhesive resin-based cement interacts directly with the ceramic surface defect population of the PLV restoration from which fracture originates [18]. The creation of tensile stress fields at the ceramic/resin-adhesive coating interface results in the extension of irregularities on the ceramic surface (defects, cracks or pores). This phenomenon is exacerbated in the presence of moisture by hydrolysis of the Si—O—Si bonds at the advancing crack tip, a process known as stress corrosion cracking or environmental assisted crack growth [19]. The polymeric matrix of the resin-based luting cement, which is chemically coupled to the ceramic surface by silane molecules and acts to stabilize against crack extension [20], is also simultaneously subjected to an equivalent applied tensile stress.

Polymeric materials are viscoelastic in nature, exhibiting a time-dependent plastic deformation such that during testing the mechanical properties of polymeric-based materials are sensitive to the rate of stress application [21]. The propensity for viscoelastic behavior in dental resin-based composite (RBC) materials is increased with reduced filler volume fraction and is therefore increased for flowable RBCs and resin-based luting adhesive systems compared with conventional dental RBC materials [21]. As a result, a balance between crack extension, crack stabilization and stress/strain relaxation in the polymeric matrix within the ceramic surface defect population must exist in response to the application of an applied load. Characterization of the interaction between crack extension, crack stabilization and stress/strain relaxation in the polymeric matrix, the interplay between stress corrosion cracking and the mechanical response of a resin-based luting adhesive within a surface defect population could extend PLV restoration longevity by optimizing cementation protocols. Therefore, the aim of the current study was to investigate the influence of stress corrosion cracking and the viscoelastic behavior of the resin-based luting adhesive by controlling the environmental conditions operative during test specimen fabrication. The strain-rate dependent behavior of both glassy ceramics and dental RBC materials have been previously characterized [17,22,23], thereby supporting the testing of an experimental hypothesis. The hypothesis tested was that in the absence of moisture, the strain-rate dependent behavior of a resin-based luting adhesive would dominate system strengthening.

2. Materials and methods

2.1. *Specimen manufacture*

To investigate the viscoelastic behavior of the resin-based luting adhesive, 50 resin-based adhesive (Rely-X Veneer Cement, shade A2, 3M ESPE, St. Paul MN, USA) bar-shaped specimens (25.0 ± 0.1 mm length, 2.0 ± 0.1 mm width, 2.0 ± 0.1 mm height) were fabricated by condensing the material into a Teflon mold. Following condensation of the adhesive, the mold was covered with an acetate strip, then a glass slide and finally a 1 kg weight were applied to ensure consistent specimen packing. The resin-based adhesive was light-irradiated with an overlapping irradiation protocol [24]. Firstly, the center of the specimen was irradiated through a 13 mm light curing unit (LCU) tip diameter, connected to an Optilux 501 (SDS Kerr, Danbury, CT, USA) LCU operating at an output intensity of 740 ± 38 mW/cm^2 for 20 s. The LCU tip diameter was moved such that the next irradiated area overlapped the previously exposed area by a quarter of the diameter of the exit window [24] and repeated until the entire specimen had been irradiated (three irradiations). To ensure consistency in the irradiation of the bar-shaped specimens the process was facilitated by pre-marking the acetate strip so that the LCU tip could be placed accurately. Following irradiation, the specimens were removed from the mold, checked for surface imperfections and any evidently defective specimens were replaced before light-irradiating the opposing surface using the overlapping protocol. All bar-shaped specimens were storage in a light excluding container for one week prior to flexural modulus determination.

A feldspathic dental ceramic (VITA VM7, Vita, Bad Säckingen, Germany) advocated for the manufacture of PLV restorations was used to produce 300 nominally identical disc-shaped specimens. A slurry mix consisting of 0.6 g of VITA VM7 base dentin powder (Lot 7433) and 0.22 mL of Vita Modelling Fluid (Lot 4209R) was manipulated and transferred to a Nylon ring mold (15.0 ± 0.1 mm diameter and 0.9 ± 0.1 mm