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Examination of ceramic/enamel interfacial debonding using acoustic emission and optical coherence tomography

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ABSTRACT

Objective. This study investigates monitored micro-crack growth and damage in the ceramic/enamel adhesive interface using the acoustic emission (AE) technique with optical coherence tomography (OCT) under fatigue shear testing.

Methods. Shear bond strength (SBS) was measured first with eight prepared ceramic/enamel adhesive specimens under static loads. The fatigue shear testing was performed with three specimens at each cyclic load according to a modified ISO14801 method, applying at 80%, 75%, 70%, and 65% of the SBS to monitor interface debonding. The number of cycles at each load was recorded until ceramic/enamel adhesive interface debonding occurred. The AE technique was used to detect micro-crack signals in static and fatigue shear bond tests.

Results. The results showed that the average SBS value in the static tests was 18.07 ± 1.72 MPa (mean ± standard deviation), expressed in Newton's at 56.77 ± 5.40 N. The average number of fatigue cycles in which ceramic/enamel interface damage was detected in 80%, 75%, 70% and 65% of the SBS were 41, 410, 8141 and 76,541, respectively. The acoustic behavior varied according to the applied load level. Events were emitted during 65% and 70% fatigue tests. A good correlation was observed between the crack location in OCT images and the number of AE signal hits.

Significance. The AE technique combined with OCT images as a pre-clinical assessment tool to determine the integrity of cemented load bearing restored ceramic material. Sustainable cyclic load stresses in ceramic/enamel bonded specimens were substantially lower than the measured SBS. Predicted S–N curve showed that the maximum endured load was 10.98 MPa (about 34.48 N) passing 10^6 fatigue cyclic.

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1. Introduction

The macro-retentive design is no longer a prerequisite if an adequate amount of tooth surface is available for bonding because adhesive resin cements have the ability to bond to both tooth structure and ceramic restoration [1–4]. Clinicians are particularly interested in restoring minimal or absent macro-retentive preparations with extensive dentin- or enamel-bonded ceramic coverage [4,5]. In recent years, tooth colored inlays, onlays, veneers and crowns can be constructed under demands for esthetic, metal-free restorations using a relatively simple approach using CAD/CAM techniques to prefabricate ceramics manufactured under controlled conditions [1,6,7].

However, challenges remain when working with extensive or total failure in large CAD/CAM ceramic restorations because of luting defects or resin cement wear between the ceramic restoration and tooth substance. Fatigue studies generally used repeated loads over many months or years as a likely mode of failure for bonds in the mouth to provide better insight into the in vivo performance and obtain more realistic sustainable stress values [4,8,9]. However, fatigue micro-crack growth in a bonded adhesive layer is difficult to monitor from in vitro studies requiring sectioning or dissolving sample dental tissues to confirm failure paths [4]. Consequently, the non-destructive acoustic emission (AE) technique has been used in dental materials to detect the fracture behavior and failure progression in structures such as ceramics [10,11], composites [12–16] and porcelain [17].

The AE technique combined with optical coherence tomography (OCT) was proven to have potential in investigating micro-crack growth and damage in the ceramic/dentin adhesive interface under fatigue shear testing in our previous study [4]. The results indicated that sustainable cyclic load stresses in ceramic/dentin bonded specimens were substantially lower than the measured shear bond strength (SBS). The predicted S–N curve showed that the maximum endured load was 4.18 MPa passing 10^6 fatigue cycles. Nevertheless, large CAD/CAM ceramic restorations usually attributed the adhesion complex to the bond formed between three different components: the tooth surface, the resin cement, and the ceramic surface [18]. While bonding to enamel is dependent on the micromechanical retention to the etched substrate; that to dentin relies on hybridization with the exposed collagen mesh [19,20]. The bond strength of ceramic to enamel is still superior compared to the bond strength of porcelain to dentin [18,21,22]. However, limited information is available regarding the ability of enamel bonds to resist fatigue cycling forces.

This study applied the AE and OCT techniques to monitor the failure process in CAD/CAM ceramic block/enamel interfaces using the total-etch adhesive system under different cyclic load stages. The SBS and S–N curve results were compared with ceramic block/dentin specimens obtained from our previous study to understand the interfacial mechanics at adhesive layers.

2. Materials and methods

2.1. Specimen preparation

Similar specimen preparation procedures were described in a previous study [4]. Specimen preparation is shown schematically in Fig. 1. The enamel bonding sites were prepared by sectioning 16 caries-free, extracted human molars mesio-distally and then sectioning the crown portion to expose the enamel surface. The exposed enamel surface was milled and polished with a grinding machine (P20FR, Holy Instrument Co., Taipei, Taiwan), followed with 0.05 mm thickness vinyl tape drilled with a hole (2 mm in diameter) to place on the sample that exposed a similar enamel surface. An etch-and-rinse Variolink II adhesive system was applied to bond the enamel and ceramic. The exposed enamel was acid etched with 35% phosphoric acid gel and air-dried. Heliobond was uniformly applied to the enamel surface. The CAD/CAM ceramic blocks (Pro-CAD, Ivoclar Vivadent Inc., Schaan, Liechtenstein) were cut using a saw machine to prepare a series of ceramic pieces (2 mm × 2 mm × 2 mm). The ceramic piece was etched for 90 s with 6% hydrofluoric acid and cleaned with water spray. Light cured cement was applied for 40 s to bond the enamel and ceramic together (Fig. 1).

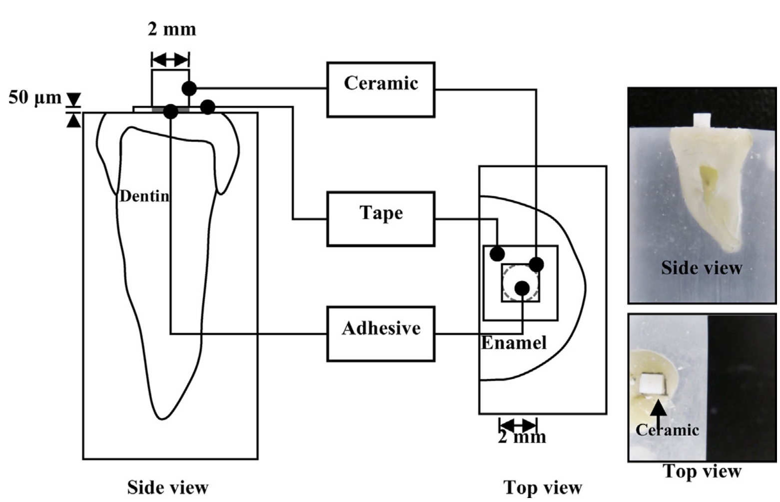

Fig. 1 – Schematic illustration of the specimen preparation procedures for the ceramic/enamel adhesive interface.