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A novel dentin bond strength measurement technique using a composite disk in diametral compression

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ABSTRACT

New methods are needed that can predict the clinical failure of dental restorations that primarily rely on dentin bonding. Existing methods have shortcomings, e.g. severe deviation in the actual stress distribution from theory and a large standard deviation in the measured bond strength. We introduce here a novel test specimen by examining an endodontic model for dentin bonding. Specifically, we evaluated the feasibility of using the modified Brazilian disk test to measure the post–dentin interfacial bond strength. Four groups of resin composite disks which contained a slice of dentin with or without an intracanal post in the center were tested under diametral compression until fracture. Advanced nondestructive examination and imaging techniques in the form of acoustic emission (AE) and digital image correlation (DIC) were used innovatively to capture the fracture process in real time. DIC showed strain concentration first appearing at one of the lateral sides of the post–dentin interface. The appearance of the interfacial strain concentration also coincided with the first AE signal detected. Utilizing both the experimental data and finite-element analysis, the bond/tensile strengths were calculated to be: 11.2 MPa (fiber posts), 12.9 MPa (metal posts), 8.9 MPa (direct resin fillings) and 82.6 MPa for dentin. We have thus established the feasibility of using the composite disk in diametral compression to measure the bond strength between intracanal posts and dentin. The new method has the advantages of simpler specimen preparation, no premature failure, more consistent failure mode and smaller variations in the calculated bond strength.

1. Introduction

Many factors affect the prognosis of endodontically treated teeth. Among them, post loosening and root fracture are the most common reasons for failure [1]. Both events are caused by excessive forces, either at the tooth–restoration interface or in the tooth tissue itself. In fact, the two are related, with loosening of the restoration being one of the main factors causing root fracture. This has been confirmed by finite-element analysis, which shows that interfacial failure between the post and tooth will significantly increase the stress in the tooth and, hence, the risk of root fracture [2]. Following post loosening, the post–core–crown–tooth structure will no longer be able to function as a single unit in sustaining the occlusal load [3]. Therefore, ensuring adequate bond strength between the post and dentin is paramount for endodontic treatments to be successful. Interfacial debonding is also responsible for the failure of other forms of restoration, e.g. secondary caries in composite restorations due to colonization of acid-producing bacteria within the compromised interface.

Many different mechanical test methods are available for measuring the bond strength between intracanal filling materials and dentin, e.g. the microtensile bond test, the pull-out test and the push-out test [4]. The main disadvantages of the microtensile bond test, which uses extensively machined specimens with a complex shape, include a high percentage of premature specimen failure and non-uniform stress patterns. These lead to a large variability in the test results [5]. In contrast, the push-out test is reported to have a more homogeneous stress distribution and less variability in the measured data. With this method, the bond strength can be calculated by simply dividing the maximum recorded force by

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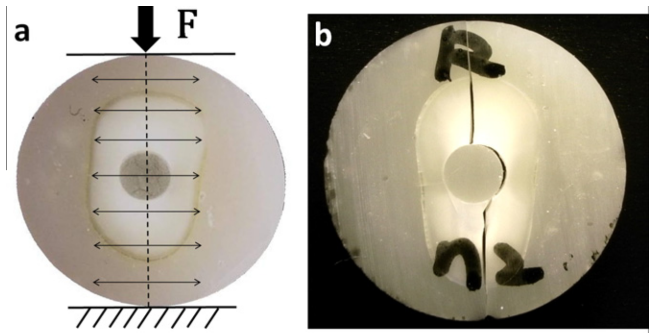

Fig. 1. (a) The modified diametral compression test. (b) A typical fracture pattern of the disk specimen after test.

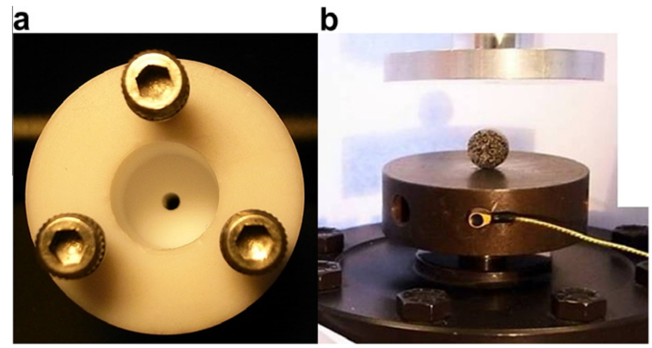

Fig. 2. (a) Customized PTFE device for sample preparation. The post was inserted into the central hole to make sure it is concentric with the outer ring. (b) Test set-up.

the area of the bonded interface [6]. Consequently, the push-out test has become a popular method for measuring the bond strength of intracanal filling materials. However, there are factors other than the bond strength that can greatly affect the force needed to push out the filling, one of them being friction between the post and dentin [7,8]. Therefore, the bond strength measured using the push-out test may be overestimated [9]. In order to measure more precisely the bond strength of intracanal filling, an alternative test method seems necessary. In an ideal test, the final failure should follow immediately the initiation of debonding at the post–dentin interface. This will allow the bond strength to be determined accurately from the well-defined final failure load.

The diametral compression or Brazilian disc test has been a popular experimental method for measuring the tensile strength of brittle materials. The stress distribution and failure mechanism have been thoroughly discussed by others [10]. There have been several modifications and extensions of this test method. For example, Tong et al. [11] used sandwiched discs to measure the interfacial fracture toughness of bone–cement interface, while the elastic stress field of a layered cylinder under diametral compression has been analyzed by Davison et al. [12].

Here, we propose a novel method based on a modified version of the diametral compression test: a disk containing an intracanal post in the center surrounded by dentin and then composite resin (Fig. 1). The purpose of this study was to evaluate the feasibility of using such a specimen under diametral compression to measure the post–dentin interfacial bond strength. The hypothesis was that we could use this test to calculate the interfacial bond strength between the post and dentin easily from the final failure force. To test this hypothesis, we used acoustic emission (AE) and digital image correlation (DIC) to detect and monitor the initiation and propagation of interfacial failure, and to establish the relationship between this and the final fracture of the disc.

2. Materials and methods

2.1. Sample preparation

Thirty-two extracted human single-canal teeth, previously stored in chloramine (0.5%) at 4 °C, were used to prepare the specimens. Any soft tissue on the root surface was removed with scaling and curettage. Teeth with caries or cracks were excluded. The crown portion above the cementum–enamel junction and 5 mm apical were cut off with a low-speed diamond saw (Isomet, Buehler, Lake Bluff, IL, USA). Root canals were prepared using a standard endodontical protocol. A 2 mm parallel post space was created with a lower-speed drill.

The teeth were divided into four groups of eight, which contained glass-fiber posts (RelyX™ Fiber Posts, 3M, St Paul, MN, USA), stainless-steel posts, direct resin fillings (Z250, 3M ESPE) and no restorations, respectively. The posts were cemented with resin cement (Adper™ Single Bond Plus, 3M; RelyX™ ARC Adhesive Resin Cement, 3M), following the manufacturer's protocol. The teeth were potted with resin (Z250, 3M ESPE) in a customized device to fabricate 10 mm diameter rods with the posts centrally located (Fig. 2a). One tooth from each group was scanned using microcomputed tomography (micro-CT) (XT H 255, X-Tek, UK) to evaluate the quality of post restoration. An additional group of composite resin rods with no teeth was used to determine the tensile strength of the composite. All the rods were sliced into 2 mm thick disks, and then stored in deionized water for 7 days before testing.

2.2. Experimental set-up for determination of failure procedure

The diametral compression test was conducted on a universal test machine (858 Mini Bionix II, MTS, USA) with two parallel horizontal planes. The load was applied under stroke-control at a rate of 0.5 mm min^{-1} until the specimen fractured. Test data, including the time histories of displacement and load, were recorded. In addition, nondestructive techniques in the form of AE and DIC were used to monitor the fracture process. The AE system (Physical Acoustics Corporation, NJ, USA) was used to detect signals produced from microcracking while the specimens were being loaded. AE sensors were attached to the lower stationary plate on which the specimen was placed. Signals detected by the sensors were passed through a preamplifier of 40 dB gain with a band pass of 100 kHz–2 MHz and a threshold set at 35 dB. Previous studies showed that setting the threshold at 35 dB could successfully eliminate the background noise from the AE signals [13,14]. The data obtained from the AE and universal test machine were used in combination to determine when cracking at the tooth–restoration interface and final failure occurred. The DIC technique was used to measure the change in strain on the surface of the specimen throughout the loading history. The system included a high-speed CCD camera and proprietary software for displacement and strain calculations (DaVis 7.0, LaVision, Germany). The surface of the specimen facing the CCD camera was sprayed with a fine layer of black paint to produce irregularly shaped speckles for ease of displacement tracking. Photographs were taken continuously at a rate of 10–20 fps throughout the test and subsequently analyzed by the DIC software. The whole test set-up is illustrated in Fig. 2b.

2.3. Bond strength and tensile strength calculation

Using finite-element (FE) analysis, the relationship between the post–dentin interfacial tensile stress and the force applied to the disk was established. The post–dentin bond strength could then