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Research Paper

Synergistic degradation of dentin by cyclic stress and buffer agitation☆

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ABSTRACT

Secondary caries and non-carious lesions develop in regions of stress concentrations and oral fluid movement. The objective of this study was to evaluate the influence of cyclic stress and fluid movement on material loss and subsurface degradation of dentin within an acidic environment. Rectangular specimens of radicular dentin were prepared from caries-free unrestored 3rd molars. Two groups were subjected to cyclic cantilever loading within a lactic acid solution (pH=5) to achieve compressive stresses on the inner (pulpal) or outer sides of the specimens. Two additional groups were evaluated in the same solution, one subjected to movement only (no stress) and the second held stagnant (control: no stress or movement). Exterior material loss profiles and subsurface degradation were quantified on the two sides of the specimens. Results showed that under cyclic stress material loss was significantly greater ($p \le 0.0005$) on the pulpal side than on the outer side and significantly greater ($p \le 0.05$) under compression than tension. However, movement only caused significantly greater material loss ($p \le 0.0005$) than cyclic stress. Subsurface degradation was greatest at the location of highest stress, but was not influenced by stress state or movement.

1. Introduction

Resin composites have become the primary material used for tooth cavity restorations (Collins et al., 1998; Ferracane, 2011). Yet they have higher failure rates than the materials used in the past (Bernardo et al., 2007; Demarco et al., 2012). The primary mode of restoration failure is secondary caries (Dahl and Eriksen, 1978; Deligeorgi et al., 2001; Sarrett, 2005), which most commonly develop at the margins of restorations (Mjör and Toffenetti, 2000; Mjör, 2005). Secondary caries are

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potentially facilitated by the localized high cyclic stresses at the interface and fatigue (Spencer et al., 2010; Pashley et al., 2011). Cyclic stress is detrimental to the durability of resin–dentin bonds (Mutluay et al., 2013a,b). Resin composites also tend to accumulate more biofilm/plaque in the oral environment than other restoratives materials (Zalkind et al., 1998; Beyth et al., 2007). The acid production of biofilms could act in synergy with the cyclic stresses to accelerate degradation of the margins and the formation of secondary caries.

Cyclic stresses contribute to degradation at different locations of the tooth structure. For example, non-carious cervical lesions (NCCLs) at the cemento-enamel junction (CEJ) are considered multi-factorial, and attributed to a combination of erosion, abrasion, attrition and abfraction (Grippo et al., 2004; Bartlett and Shah, 2006; Ceruti et al., 2006; Michael et al., 2009; Pecie et al., 2011; Senna et al., 2012). Pioneering investigations by McCoy (1982) and Lee and Eakle (1984) identified that the CEJ experiences high stresses under non-axial loads. In fact, the term abfraction was adopted to distinguish stress-related type of lesions. Grippo (1991) suggested that stresses could foster microfracture of enamel and dentin under cyclic loading, thereby forming gaps or holes. However, the lack of direct experimental evidence of this process has led to some controversy (Litonjua et al., 2003; Michael et al., 2009; Senna et al., 2012; Grippo et al., 2012).

The effects of cyclic stresses to tooth structure are not only detrimental. Recent studies by Toledano et al. (2014a,b, 2015) report that remineralization may be achieved in demineralized regions of the hybrid layer by a period of cyclic stress. Thus, it is important to consider the contributions of cyclic stress and environment on mineralization changes in greater detail.

Both the CEJ and the margins of restored teeth experience a concentration of localized cyclic stresses and exposure to variable pH conditions. Rees (2000) suggested that the presence of acidic conditions combined with the stresses of mastication can cause more damage than either alone. But is there synergism between the cyclic stress and acidic condition that elevates the potential for degradation? Staninec et al. (2005) explored this question in an experimental study of material loss occurring to human dentin subjected to cyclic stress in an acidic environment. Results revealed that more material loss occurred when combined with mechanical stress, and that compressive stresses caused more loss than tensile stresses. Similarly, Mishra et al. (2006a) found that more material loss occurred to bovine dentin in an acidic environment when combined with static loading and that greater material loss occurred by compressive stress. The investigators also found that subsurface demineralization increased when combined with static stress (Mishra et al., 2006b). While pioneering, the aforementioned studies did not consider the potential effects of fluid movement and local dentin microstructure on the degree of material loss. Both factors could be relevant to degradation of the margins. Therefore, in the present investigation we explore the contribution of cyclic mechanical stresses and acidic buffer agitation to both surface and subsurface degradation, and assess the relative importance of dentin microstructure.

2. Materials and methods

Caries-free third molars were obtained from dental clinics in Maryland according to an approved protocol issued by the Institutional Review Board of the University of Maryland (Approval Y04DA23151). All teeth were from young donors with $17 \leq \text{age} \leq 33$ years. The teeth were kept in Hanks balanced salt solution (HBSS) with 0.2% sodium azide as an antimicrobial agent at 4 °C. Axial sections (~1 mm thick) were obtained from the central portion of the crown in the bucco-lingual plane, using a slicer/grinder (Chevalier Smart-H818II, Chevalier Machinery, Santa Fe Springs, CA, USA) with a diamond abrasive slicing wheel (#320 mesh abrasives) and water irrigation. Rectangular beams were obtained from the primary sections as depicted in Fig. 1(a). All surfaces of the specimens were lightly polished using a very-fine silicon carbide paper (SiC Paper #2000, FEPA P-2000, Struers, Cleveland, OH, USA).

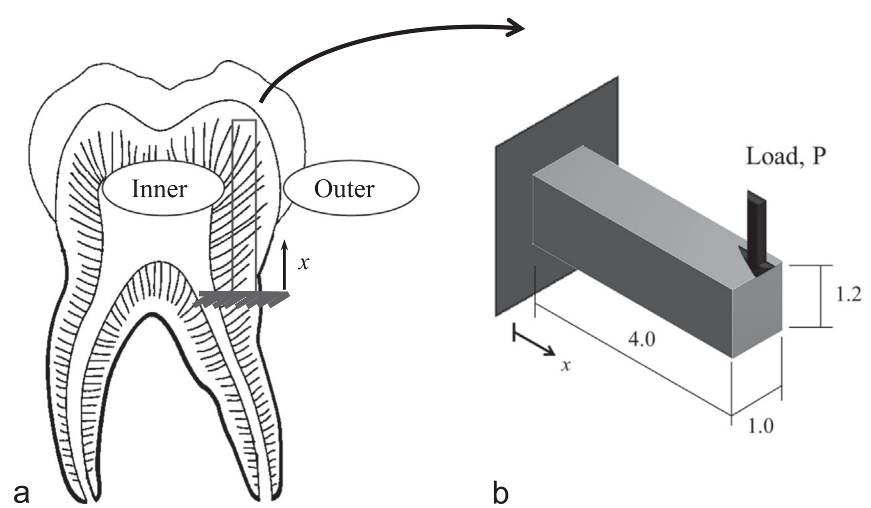

Fig. 1 – Preparation of the specimens and loading configuration. (a) View of a sectioned tooth and outline of a specimen to be sectioned, indicating the two sides of interest (i.e. inner and outer); (b) beam dimensions in millimeters and loading arrangement. The direction of loading was either from the inner to outer dentin or in the reverse direction.