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Contributions of aging to the fatigue crack growth resistance of human dentin

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ABSTRACT

An evaluation of the fatigue crack resistance of human dentin was conducted to identify the degree of degradation that arises with aging and the dependency on tubule orientation. Fatigue crack growth was achieved in specimens of coronal dentin through application of Mode I cyclic loading and over clinically relevant lengths ($0 \leqslant a \leqslant 2$ mm). The study considered two directions of cyclic crack growth in which the crack was either in-plane (0°) or perpendicular (90°) to the dentin tubules. Results showed that regardless of tubule orientation, aging of dentin is accompanied by a significant reduction in the resistance to the initiation of fatigue crack growth, as well as a significant increase in the rate of incremental extension. Perpendicular to the tubules, the fatigue crack exponent increased significantly (from $m = 14.2 \pm 1.5$ to 24.1 ± 5.0), suggesting an increase in brittleness of the tissue with age. For cracks extending in-plane with the tubules, the fatigue crack growth exponent does not change significantly with patient age (from $m = 25.4 \pm 3.03$ to 22.9 ± 5.3), but there is a significant increase in the incremental crack growth rate. Regardless of age, coronal dentin exhibits the lowest resistance to fatigue crack growth perpendicular to the tubules. While there are changes in the cyclic crack growth rate and mechanisms of cyclic extension with aging, this tissue maintains its anisotropy.

1. Introduction

Dentin, the hard tissue occupying the majority of the human tooth, is an interesting structural material. This tissue is ~45% mineral, 33% organic material (primarily type I collagen) and 22% fluid by volume [1], a composition similar to that of cortical bone. Perhaps the most distinct feature of the microstructure is the network of microscopic channels (i.e. tubules) that extend outward from the pulp towards the dentin–enamel junction (DEJ) and cementum. The tubule geometry is dependent on location within the tooth and distance from the pulp chamber. Overall, the lumens exhibit an average diameter exceeding one micrometer (ranging from ~1 to 2.5 μm) and a density from ~10,000 to 60,000 mm^{-2} [2,3]. Each tubule lumen is bordered by a highly mineralized cuff of peritubular dentin having thickness ranging from 0.5 to 1 μm. The region between the tubules, regarded as intertubular dentin, consists of a collagen fibril mesh that is supported by both inter- and intrafibrilar apatite crystallites [4,5].

Both cortical bone and dentin are commonly regarded as hierarchical structural materials, a characterization that originates from the constituents, the multiplicity in scale and their complex integrated relationship [6–9]. Nevertheless, microscopic evaluations of dentin are dominated by the dentin tubules and their arrangement. Due to their appearance as reinforcing fibers, dentin is often perceived to possess mechanical anisotropy. Surprisingly, dentin exhibits only a small degree of elastic anisotropy, with the largest elastic modulus obtained for loading perpendicular to the tubules [10–12]. The tensile strength of human dentin exhibits a greater degree of orientation dependence, with the largest strength obtained in the direction perpendicular to the tubules [13–15]; the root exhibits the greatest degree of anisotropy [16,17]. Though the tubules and the peritubular cuffs are the most obvious structural components, the differences in strength have been perceived to result from the collagen fibril orientation rather than the tubules [5].

Due to the cyclic loading that develops during mastication and the potential for flaws to be introduced within teeth via the practice of restorative dentistry, the fatigue and fracture properties of dentin are critically important. The importance of tubule orientation on these measures of mechanical behavior and apparent anisotropy has been explored to some extent. In response to cyclic loading, the lowest fatigue strength is obtained for loads applied parallel to the tubules [18], and cracks prefer to grow perpendicular to

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