Aging Contributes to the Fatigue Crack Growth Resistance of Dentin

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INTRODUCTION

Tooth fracture is one of the most common causes of restored tooth failure and is most common in seniors [1]. With the progressive rise in number of partially and fully dentate seniors, it is becoming increasingly important to understand the changes in structure of hard tissues of the tooth with age and the corresponding influence of these changes on mechanical behavior. The objective of this research was to quantify the influence of patient age on the fatigue crack growth properties of human dentin.

MATERIALS AND METHODS

Compact Tension (CT) fatigue specimens were sectioned from the coronal dentin of extracted molars (Fig. 1) and subjected to high cycle fatigue loading (10⁶ N=19) while fully hydrated (HBSS) at 37°C (Fig. 2). The specimens were categorized as young (18 ≤ Age ≤ 35; N=9) or old (50 ≤ Age; N=11). All specimens were prepared to achieve crack growth perpendicular to the dentin tubules and then were subjected to Mode I loads (Fig. 2) with stress ratio (R) and frequency of 0.1 and 5 Hz, respectively. Fatigue crack growth rates corresponding to steady-state growth were quantified according to the Paris Law (Eqn. 1) in terms of the crack growth exponent (m) and coefficient (C). In addition, Energy Dispersive X-ray Analysis (EDXA) was performed to study the changes in chemistry and structure of dentin with age.

\[
\frac{dd}{dN} = C(ΔK)^m \tag{1}
\]

The quantities C and m are the fatigue crack growth coefficient and crack growth exponent, respectively. The stress intensity range (\( ΔK \)) was determined from the difference in stress intensity at the minimum and maximum loads. A 3-D finite element model (Fig. 3) was developed for the CT specimens (Fig. 1(b)) to determine the stress intensity distribution in terms of the energy release rate with crack extension [2].

RESULTS AND DISCUSSION

The stress intensity distribution with crack extension for all three modes (i.e. I, II, III) is shown in Fig. 4. The stress intensity at the crack tip (\( K_c \)) for an opening mode load (P) was modeled using Eqn. 2 with B, B* and W defined in Fig 1(b), and \( α = w/W \).

\[
K_c = \frac{P}{B^\alpha} \sqrt{\frac{B^\alpha + 1}{B + 1}} \left(0.131 + 0.320\alpha + 0.21\alpha^2\right) \tag{2}
\]

Overall, the fatigue crack growth rates ranged from 0.6 to 1.2 MPa•m⁰.⁵ (Fig. 5). The average fatigue crack growth exponent for the young dentin (m=13.3±1.1) was significantly lower than that of the old dentin (m = 21.6±5.2; p<0.003) [2]. The average responses are shown in Figure 6. There was a distinct increase in the crack growth exponent of the hydrated dentin with respect to age (Fig. 7). A SEM evaluation of the fracture surfaces showed microcracks and evidence of debonding between the peritubular and intertubular dentin in the old hydrated dentin (Fig. 8a). In contrast, there was no evidence of debonding between the peritubular and intertubular dentin in the old hydrated specimens (Fig. 8b). Results from the EDXA showed that the Ca/P ratio in young dentin was 3.14 ± 0.053 whereas in old dentin was 2.55 ± 0.072. Further work is underway to understand the influence of chemical changes on mechanical behavior.

CONCLUSION

Fatigue cracks in the old dentin underwent initiation and propagation at a much lower stress intensity range than that for the young dentin. Fatigue crack growth extension in old dentin is over 100 x greater than that in young dentin. This suggests that a special restorative practices may be warranted in the treatment of senior patients to reduce the risk of tooth fracture.

REFERENCES


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