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Research paper

The effect of strain rate on fracture toughness of human cortical bone: A finite element study

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ABSTRACT

Evaluating the mechanical response of bone under high loading rates is crucial to understanding fractures in traumatic accidents or falls. In the current study, a computational approach based on cohesive finite element modeling was employed to evaluate the effect of strain rate on fracture toughness of human cortical bone. Two-dimensional compact tension specimen models were simulated to evaluate the change in initiation and propagation fracture toughness with increasing strain rate (range: 0.08–18 s^{-1}). In addition, the effect of porosity in combination with strain rate was assessed using three-dimensional models of micro-computed tomography-based compact tension specimens. The simulation results showed that bone's resistance against the propagation of a crack decreased sharply with increase in strain rates up to 1 s^{-1} and attained an almost constant value for strain rates larger than 1 s^{-1}. On the other hand, initiation fracture toughness exhibited a more gradual decrease throughout the strain rates. There was a significant positive correlation between the experimentally measured number of microcracks and the fracture toughness found in the simulations. Furthermore, the simulation results showed that the amount of porosity did not affect the way initiation fracture toughness decreased with increasing strain rates, whereas it exacerbated the same strain rate effect when propagation fracture toughness was considered. These results suggest that strain rates associated with falls lead to a dramatic reduction in bone's resistance against crack propagation. The compromised fracture resistance of bone at loads exceeding normal activities indicates a sharp reduction and/or absence of toughening mechanisms in bone during high strain conditions associated with traumatic fracture.

1. Introduction

Bone is subject to a wide range of strain rates during daily activities such as walking (0.004 s^{-1}) (Lanyon et al., 1975), strenuous activities such as sprinting and downhill running (0.05 s^{-1}) (Burr et al., 1996) or traumatic fracture events such as accidents or falls (25 s^{-1}) (Hansen et al., 2008). Previous studies showed that the mechanical response of

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