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Research paper

# Effect of aging on the transverse toughness of human cortical bone: Evaluation by R-curves

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ABSTRACT

The age-related deterioration in the quality (*e.g.*, strength and fracture resistance) and quantity (*e.g.*, bone-mineral density) of human bone, together with increased life expectancy, is responsible for increasing incidence of bone fracture in the elderly. The present study describes *ex vivo* fracture experiments to quantitatively assess the effect of aging on the fracture toughness properties of human cortical bone specifically in the transverse (breaking) orientation. Because bone exhibits rising crack-growth resistance with crack extension, the aging-related transverse toughness is evaluated in terms of resistance-curve (R-curve) behavior, measured for bone taken from a wide range of age groups (25–74 years). Using this approach, both the *ex vivo* crack-initiation and crack-growth toughness are determined and are found to deteriorate with age; however, the effect is far smaller than that reported for the longitudinal toughness of cortical bone. Whereas the longitudinal crack-growth toughness has been reported to be reduced by almost an order of magnitude for human cortical bone over this age range, the corresponding age-related decrease in transverse toughness is merely ~14%. Similar to that reported for X-ray irradiated bone, with aging cracks in the transverse direction are subjected to an increasing incidence of crack deflection, principally along the cement lines, but the deflections are smaller and result in a generally less tortuous crack path.

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## 1. Introduction

It is widely appreciated that aging-related changes to the musculoskeletal system can lead to a significantly increased susceptibility of bone fracture (Hui et al., 1988; Jennings and de Boer, 1999). In general terms, this has been traditionally attributed to issues of *bone quantity* where the loss in bone mass or bone-mineral density (BMD) from aging is used as a predictor of fracture risk. However, it is now apparent that BMD alone may not be the primary factor responsible for increased bone fractures in the elderly, and that issues associated with *bone quality* may also be important (Hui et al., 1988; Aspray et al., 1996; Heaney, 2003), a fact that has resulted in a renewed interest in how biological factors such as aging can alter the mechanical properties of bone, particularly the fracture resistance.

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