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What is the influence of strain rate on human cortical bone crack propagation mechanisms?

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Introduction

Osteoporosis remains today a major health problem. Cortical bone fracture mechanisms are well documented under quasi-static loading condition. However the influence of strain rate on fracture needs to be better understood as bone fractures mainly occur after a fall from a standing height. The fracture process in human cortical bone is complex, and involves the overall organization of the tissue. Previous results showed that the whole porosity network, from the Haversian system to the lacunar network, as well as the collagen cross-links maturation, might be involved in the crack propagation mechanisms in cortical bone. Thus, the aim of the current study is to collect biomechanical, morphometric and biochemical parameters to make an overall characterization of human cortical bone crack propagation mechanisms considering two different loading conditions.

Materials and methods

In that objective, paired human femoral diaphysis, femoral neck and radial diaphysis were extracted from 8 female donors (70 ± 14 y.o., min: 50 y.o., max: 91 y.o.). Toughness experiments were performed on cortical bone samples. Two loading rates were considered for each bone: a quasi-static standard condition, and a condition representative of a fall. The mechanically tested specimen were then used to perform synchrotron radiation micro-computed tomography imaging (voxel = $[0.7\ \mu m]^3$) in order quantify the Haversian and lacunar systems, and to evaluate the formation of micro-cracks during crack propagation. Adjacent cortical bone specimens were finally used to measure the concentration of immature and mature enzymatic cross-links by a high performance liquid chromatography. The CX ratio (CX = [Immature] / [Mature]) was analyzed as it gives information on the collagen cross-links maturation.

Results and discussion

Results showed that if collagen cross-links are involved in the elastic contribution of the fracture process, the plastic one is mainly governed by the porosity network associated with micro-cracking or crack deflection toughening mechanisms under a quasi-static loading. Under a fall-like condition, the cortical porosity is less involved in crack propagation mechanisms. Crack propagation barriers seem less efficient in this critical loading condition. This study provides new information on human cortical bone crack propagation mechanisms under quasi-static and fall-like loading condition, on different paired anatomical locations.

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