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Human cortical bone crack propagation mechanisms: what about the influence of loading rate?

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Introduction:

A fracture is estimated every three seconds in the world, leading to an increased risk of impairment or even mortality in the elderly. Cortical bone biomarker for fracture mechanisms are well documented under quasi-static loading condition. It has been showed that, under a quasi-static condition, structural features such as the porosity network from the lacunar to the Haversian system, or even collagen remodeling properties are involved in bone crack propagation. However the biomechanical knowledge of bone fracture in a fall configuration remains poorly documented. The aim of the current study is thus to collect biomechanical, morphometric and biochemical parameters to investigate human cortical bone crack propagation mechanisms considering different loading conditions and different anatomical locations.

Materials and methods:

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 considering two loading rates: 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 μm]³) in order to quantify the Haversian and lacunar systems. Microcracking mechanism during crack propagation was also investigated. 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:

Under quasi-static loading, collagen maturation appears to have an influence on the elastic contribution of bone behavior whereas the lacunar and Haversian systems are involved on the non-linear contribution, which represents the main contribution of bone global mechanical response. If bone porosity appears to be a major determinant under a standard loading condition, it is less involved in crack propagation mechanisms under fall-like condition. Crack propagation barriers seem less efficient in this critical loading condition. Moreover bone is less able to undergo microcracking in the case of a fall, meaning that this toughening mechanism is also less efficient. This study provides new information on human cortical bone crack propagation mechanisms under quasi-static and fall-like loading condition at different length scale, on different paired anatomical locations considering both weight- and non-weight bearing bones.

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