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HUMAN CORTICAL BONE TOUGHNESS AT TWO STRAIN RATES ON THREE PAIRED ANATOMICAL LOCATIONS

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Introduction

Most of the fractures occur at the radius or at the femoral neck after a fall, involving high strain rate ($10^{-1}.s^{-1}$) [1]. Cortical bone toughness is usually measured under quasi-static loading condition even though it is known to have viscoelastic properties [2]. A recent study on one subject actually showed that the toughness of femoral shaft specimens is lower at a strain rate representative of a fall [3]. We hypothesize this effect could be the same whatever the anatomical location. The aim of this study is thus to quantify human cortical bone toughness using paired radii and femurs (neck and shaft) considering two strain rates (quasi-static and representative of a fall).

Materials and methods

Paired specimens were taken from radius, femoral neck and femoral diaphysis of seven donors (women from 57 to 91 y.o. (73.1 ± 12.1)). Based on a previous protocol [4], 25mm long rectangular notched samples, with a section of $2 \times 1 \text{mm}^2$, were prepared. A pre-crack of $100 \mu\text{m}$ was performed with a cutter blade leading to a total notch length of 1.1mm. The notch was perpendicular to the osteon orientation. Two samples were prepared from each anatomical location to assess the effect of strain rate: one was loaded in quasi-static condition ($10^{-4}.s^{-1}$), the other was tested at a strain rate representative of a fall ($10^{-1}.s^{-1}$). The measurements of fracture toughness were performed according to ASTM E-1820. Equations used to calculate the mechanical parameters were developed in a previous study [4]. Two parameters were evaluated: K_{el} ($\text{MPa.m}^{0.5}$) which is the toughness based on linear fracture mechanics (LEFM), and K_{Jc} ($\text{MPa.m}^{0.5}$), the non-linear fracture mechanics fracture toughness, including both elastic and plastic contributions.

Results and discussion

Figure 1 shows values obtained for toughness at two strain rates and three anatomical sites. These results show that strain rate has an effect on cortical bone toughness. For strain rate representative of a fall, K_{el} is higher, whereas K_{Jc} decreases. These results are in agreement with previous studies [3–5] performed on tibial diaphysis and femoral diaphysis.

For quasi-static loading, K_{Jc} values for radius are significantly higher than the ones for the femoral neck

and femoral diaphysis ($p < 0.05$) respectively from 29% and 20%.

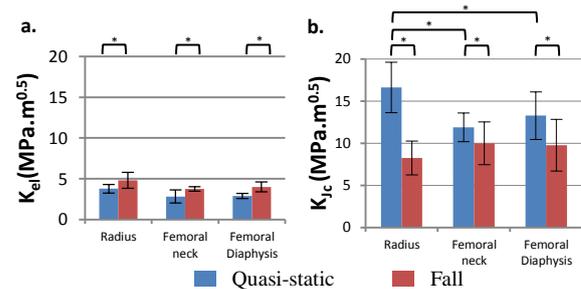


Figure 1 Quasi-static (blue) and Fall (red) response of human cortical bone for 3 anatomical locations and 2 strain rates: a) K_{el} (toughness calculated with LEFM) and b) K_{Jc} (toughness including elasticity and plasticity) (*: $p < 0.05$)

These results show that strain rate has a real effect on bone fracture behavior. Toughness base on LEFM increases significantly with the rate ($p < 0.05$, 22% for the radius, 25% and 28% for the femoral neck and shaft). Toughness including the plastic contribution is significantly reduced at high rate ($p < 0.05$, 60% for the radius, 19% and 28% for the femoral neck and shaft). The viscoelastic behavior of bone might explain the increase of K_{el} , whereas toughening mechanisms associated to the plastic component may be not entirely activated at high rate. This protocol will be extended to 30 subjects to confirm these results. Imaging experiments will also be performed to investigate bone microstructure on these different anatomical sites.

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