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Strain rate influence on human cortical bone toughness: a comparative study of four paired anatomical sites

Rémy Gauthier[1], Hélène Follet[2], Max Langer[3], Sylvain Meille[4], Jérôme Chevalier[4], Frédéric Rongiéras[1,5], Françoise Peyrin[3] and David Mitton[1,]*

[1] Univ Lyon, Université Claude Bernard Lyon 1, IFSTTAR, LBMC UMR_T9406, F69622, Lyon, France;
[2] Univ Lyon, Université Claude Bernard Lyon 1, INSERM, LYOS UMR1033, F69008, Lyon, France ;
[3] Univ Lyon, CNRS UMR 5220, Inserm U1206, INSA Lyon, Université Claude Bernard Lyon 1, Creatis, F69621 Villeurbanne Cedex, France;
[4] Univ Lyon, INSA-LYON, MATEIS, UMR CNRS 5510, F69621, Villeurbanne, France ;
[5] Service Chirurgie Orthopédique et Traumatologie - Hôpital Desgenettes, 69003, Lyon, France;

***** Correspondence: david.mitton@ifsttar.fr

Abstract: Bone fracture is a major health issue worldwide and consequently there have been extensive investigations into the fracture behavior of human cortical bone. However, the fracture properties of human cortical bone under fall-like loading conditions remains poorly documented. Further, most published research has been performed on femoral diaphyseal bone, whereas it is known that the femoral neck and the radius are the most vulnerable sites to fracture. Hence, the aim of this study is to provide information on human cortical bone fracture behavior by comparing different anatomical sites including the radius and the femoral neck acquired from 32 elderly subjects (50 – 98 y.o.). In order to investigate the intrinsic fracture behavior of human cortical bone, toughness experiments were performed at two different strain rates: standard quasi-static conditions, and a higher strain rate representative of a fall from a standing position. The tests were performed on paired femoral neck, femoral, tibial and radius diaphyseal samples. Linear elastic fracture toughness and the non-linear J-integral method were used to take into account both the elastic and non-elastic behavior of cortical bone. Under quasi-static conditions, the radius presents a significantly higher toughness than the other sites. At the higher strain rate, all sites showed a significantly lower toughness. Also, at the high strain rate, there is no significant difference in fracture properties between the four anatomical sites. These results suggest that regardless of the anatomical site (femur, femoral neck, tibia and radius), the bone has the same fracture properties under fall loading conditions. This should be considered in biomechanical models under fall-like loading conditions.

Keywords: Human cortical bone, fracture toughness, strain rate, fall, inter-sites

1. Introduction

The aging of human biological tissues is often synonymous with increased vulnerability to traumatic injuries. In the elderly, a fall from a standing position may cause a hip fracture (Court-Brown and Caesar, 2006; Gryfe et al., 1977; World Health Organization, 2007), leading to important disability and sometimes increased risk of mortality (Johnell and Kanis, 2006). From results presented in the literature, this increased vulnerability might be due to a change in structural properties such as increased porosity (Perilli et al., 2015).

Measurements of bone mineral density is currently the gold standard clinical diagnostic method for osteoporosis (Genant et al., 1999, 1996). It has been shown that bone mineral density decreases in osteoporosis (Nanes and Kallen, 2014), and that this loss of bone mass is correlated with its structural strength (Ammann and Rizzoli, 2003; Duchemin et al., 2008).

It appears, however, that the assessment of this single parameter cannot fully discriminate whether a given patient presents an increased risk of fracture (Siris et al., 2014, 2004). Other structural and mechanical parameters have to be considered in order to describe the overall fracture behavior of human bone (Griffith et al., 2010). Subject-specific finite element models are under development in order to improve fracture risk prediction (Pistoia et al., 2002). Even if these methods can give good estimations of bone structural strength, the