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Tensile properties of rat femoral bone as functions of bone volume fraction, apparent density and volumetric bone mineral density

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ABSTRACT

Mechanical testing has been regarded as the gold standard to investigate the effects of pathologies on the structure–function properties of the skeleton. Tensile properties of cancellous and cortical bone have been reported previously; however, no relationships describing these properties for rat bone as a function of volumetric bone mineral density (ρ_{MIN}), apparent density or bone volume fraction (BV/TV) have been reported in the literature.

We have shown that at macro level, compression and torsion properties of rat cortical and cancellous bone can be well described as a function of BV/TV, apparent density or ρ_{MIN} using non-destructive micro-computed tomographic imaging and mechanical testing to failure. Therefore, the aim of this study is to derive a relationship expressing the tensile properties of rat cortical bone as a function of BV/TV, apparent density or ρ_{MIN} over a range of normal and pathologic bones.

We used bones from normal, ovariectomized and osteomalacic animals. All specimens underwent micro-computed tomographic imaging to assess bone morphometric and densitometric indices and uniaxial tension to failure.

We obtained univariate relationships describing 74–77% of the tensile properties of rat cortical bone as a function of BV/TV, apparent density or ρ_{MIN} over a range of density and common skeletal pathologies. The relationships reported in this study can be used in the structural rigidity to provide a non-invasive method to assess the tensile behavior of bones affected by pathology and/or treatment options.

1. Introduction

Conventional mechanical testing has historically been regarded as the gold standard for investigating the effects of various interventions and pathologies on the structure–function properties of the skeleton (Danielsen et al., 1993; Turner and Burr, 1993). Recent advances in speed, resolution and reduction of artifacts in medical imaging (Genant et al., 2000) and the increasing computing power of personal computers (Moore, 1965) have made virtual alternatives to conventional and invasive procedures increasingly feasible (Bagi et al., 1992; Ferretti et al., 1995; van Rietbergen et al., 2002; Martin et al., 2004). The assessment of mechanical strength of skeletal tissue through alternative non-destructive means, virtual biomechanics, enable us to perform longitudinal in-vivo assessment of bone strength, facilitate the evaluation of multiple skeletal sites from the same subject, reduce the number of subjects and consequently the costs associated with a study. Additionally, the large experimental errors linked to operator dependent procedures such as specimen preparation and gripping (Odgaard and Linde, 1991; Keaveny et al., 1997) and inter-laboratory testing protocol differences can be reduced (Turner, 1989).

Both tissue material and geometric properties are considered in the analysis of bone strength. Currently, virtual biomechanics methods can be categorized into patient-specific finite element analysis (FEA) (Martin, 1991; Bessho et al., 2007), direct strength assessment such as dual-energy X-ray absorptiometry (DXA) (Kanis et al., 2000) or quantitative computed tomography (QCT) (Lochmuller et al., 2002; Buckley et al., 2007). Patient-specific FEA accounts for changes in the tissue material and geometric properties, but it is costly (Guldberg et al., 1998). Fracture predictions using DXA, as relatively crude 2D projection of 3D structures, are more cost-effective. However, it is neither sensitive nor specific, as it does not consider changes in material or geometric properties of bone (Riggs and Melton, 2002; Heaney, 2003; Schuit et al., 2004). QCT imaging (Faulkner et al., 1991; Lang et al., 1997; Lang

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