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TRABECULAR BONE TISSUE STRAIN DISTRIBUTIONS IN THE HEALTHY AND OSTEOPOROTIC PROXIMAL HUMAN FEMUR DURING A FALL TO THE SIDE

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INTRODUCTION

Failure of bones is initiated at the bone tissue level, when local stresses exceed the strength. Information about bone-tissue stresses could lead to a better understanding of bone-fracture etiology. Evaluation of tissue-level stresses and strains due to externally applied forces is possible with micro-finite element analysis. In an earlier study, we used this approach to determine tissue-level stresses and strains in a normal and an osteoporotic femur for normal activities (van Rietbergen, 2003). In this study we evaluated tissue-level stresses and strains during a fall. A specific purpose of this study was to determine the safety factors for a healthy and an osteoporotic proximal femur.

MATERIALS AND METHODS

Based on close matched age, body weight and length, a healthy (T-score: -0.5, neck BMD 0.917 g/cm^2) and an osteoporotic (T-score: -4.0, neck BMD 0.496 g/cm^2) human proximal femur were selected for the creation of two large-scale micro-finite element models (van Rietbergen, 2003).

Boundary conditions were applied to simulate a fall with impact on the lateral aspect of the greater trochanter. The femoral shaft was placed at a 10º angle with respect to the horizontal and the femoral head was rotated internally by 15º. Nodes on the surface of the trochanter and distal end were fixed against vertical and horizontal displacements, respectively. An arbitrary resultant hip force of 1000 N was used.

Stresses and strains were calculated in each element. The safety factors were estimated based on the strains found in a volume of 1 mm^3, located in the area where the highest tensile strains in the cortex occurred. The safety factors were evaluated as the ratios between the average strain in the selected volume and the cortical tensile yield strain (0.57 %; Burstein, 1975).

RESULTS

The principal strains were higher in the osteoporotic femur than in the healthy one (Fig. 1), with safety factors against fracture of 3.96 and 6.10, respectively. Compared to the earlier study of physiological loading effects, the loading conditions simulating a fall resulted in more symmetric strain distributions between the medial and lateral corteces.

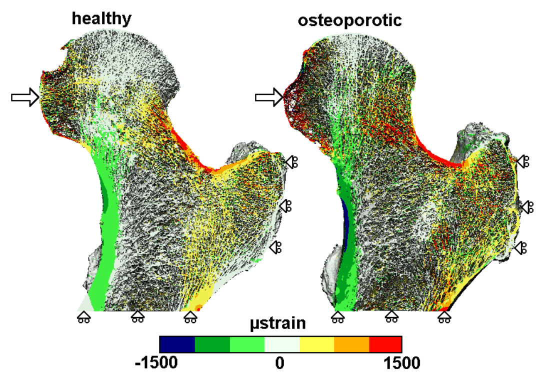

Fig. 1. Absolute maximum principal strains in the healthy and osteoporotic proximal femur. The posterior halves of the micro-finite element models are shown.

DISCUSSION

The estimated safety factors correspond to ultimate loads of 6100 N for the healthy femur and 3960 N for the osteoporotic femur. These values agree well with ultimate loads measured, and correlated with femoral-neck BMD (Cheng, 1997; Courtney, 1994).

Obviously, the failure mechanism of the proximal femur in a fall involves excessive tensile strains in the medial cortex. However, it is not impossible, in view of the high compressive strains in the lateral cortex, that buckling occurs as well. Although osteoporosis is basically an affection of trabecular bone, it seems to have its effects on fracture risk indirectly, by increasing cortical strain values.

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