One biomechanical indicator improves femoral neck fracture prediction

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Introduction

World-wide femoral neck fractures are an increasing clinical and social problem because of their correlation to the population aging (Cooper, 1999). The hip fracture prevention was found to be more effective than its treatment. For this reason, the attention was focused on the definition of a classification criterion of at-risk patients. A threshold on the Bone Mineral Density (BMD) was defined and used in the daily clinical practice (Genant et al., 1999). However, the density distributions of at-risk patients and controls present a large overlap reducing the classification accuracy (Chevalley et al., 1991). Many attempts were carried out to improve the classification accuracy by adding new indicators. Among them, Finite Element (FE) model results were used to obtain deterministic indicators of the proximal femur strength (Testi et al., 1999). Aim of this work was to evaluate the improvement obtained by including geometric and FE parameters to the standard clinical protocol.

Methods

The densitometric DXA scans of 200 elder Caucasian women were collected. About half of them reported a hip fracture. Inquiring the subject or a relative, the cause of fracture was determined and the absence of bone affecting diseases verified. All fractures were confirmed on X-ray by an expert radiologist.

All densitometric and geometric parameters collected in the daily clinical practice were considered. The BMD was measured in three different regions of interest: the femoral neck, the Ward's triangle, and the L2-L4 vertebral group. On the DXA image, the clinician evaluated the neck-shaft angle, the femoral neck length, and the diameter of femoral diaphysis and neck. Furthermore, for each patient a FE model of the proximal femur was developed where the material properties were obtained from the DXA information (Testi et al., 1999). From the FE model, biomechanical indicators were extracted to describe the proximal femur strength in the patient's fall on a side. The applied loading condition is described in Figure 1.

![Figure 1: Loading condition simulating a fall on a side from standing height. The impact force was a function of patient's height and weight.](image-url)
All the parameters were used to design Bayes linear classifiers. The classifier performances were evaluated by a leave-one-out method.

**Results & Discussion**

The femoral neck BMD alone had an accuracy in the classification of about 65%, while the best classification model achieved an accuracy of 81%. In this model, the densitometric parameter contributing to the classification was the femoral neck BMD. Adding the subject's height, the two-parameter model achieved an accuracy of about 70%. Then, the neck-shaft angle and femoral neck length and diameter were improving the classification to 77%. The last statistically significant parameter was the maximum FE principal tensile strain. This FE-determined indicator increased the classification accuracy to 81% and was located for all patients in the femoral neck region that is common site for fracture in the elderly. An example of the principal tensile strain pattern is reported in Figure 2.

![Figure 2: Example of principal tensile strain distribution. The arrow indicates the location of the peak strain.](image)

The role of the well-known influencing factors in the hip fracture was confirmed. In particular, as expected the BMD at the femoral neck region was dominating. Both the height and the neck-shaft angle are reported in the literature to be important variables in the fracture prediction.

This study has demonstrated that adding one biomechanical indicator, the maximum principle tensile strain, significantly improves the accuracy in the classification of at-risk patients. This confirms that FE results may increase the predictive power with respect to the standard protocol considering together bone density distribution, proximal femur anatomy, and fall-related trauma loading.

**References**

Cooper C. *Osteoporos Int*, 9, S2-5, 1999.