Prediction of Hip Fracture Can Be Significantly Improved by a Single Biomedical Indicator

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Abstract—Femoral neck fractures are a relevant clinical and social problem. The aim of this study was to improve the prediction of patients at-risk of femoral neck fracture with respect to the current densitometric-based methods. In particular, finite element models were used to assess the prediction accuracy obtained by combining together data from the bone density distribution, the proximal femur anatomy, and the fall-related loading conditions. Two-dimensional finite element models were developed based on dual energy x-ray absorptiometry data. A population of 93 elder Caucasian women (half of them reporting a femoral neck fracture) were retrospectively classified both using the standard clinical protocol and Bayes’ linear classifiers. This study showed that the bone mineral density in the femoral neck region dominated the fracture event (65% accuracy). Adding the subject’s height and the neck-shaft angle to the bone density increased the accuracy to 77%. The classification accuracy was further improved to 82% by including the peak principal tensile strain obtained from the finite element analyses. This research demonstrated that adding one single biomechanical indicator to the standard clinical measurements improves the identification of patients at-risk of femoral neck fracture. © 2002 Biomedical Engineering Society. [DOI: 10.1114/1.1495866]

Keywords—Aging, Bayesian prediction, Femoral neck fractures prevention and control, Finite element analysis, Risk factors.

INTRODUCTION

Femoral neck fractures are becoming an alarming clinical and social problem worldwide.4 They are increasing due to an increase in the aging population and the exponential correlation between fracture occurrence and age.5 Furthermore, hip fracture is associated with a high level of patient morbidity and mortality. It is reported that about 25% of subjects die within one year after the fracture event,3,27 and that only about 60% of subjects completely regain normal physical activity.12,27 Therefore, much clinical attention has been centered on the prevention of femoral neck fractures.29 Prevention therapies, based on hormone or bisphosphonate intake, have been shown to be effective.2,15 However these remain expensive and have associated side effects.2,15 Subsequently, efforts have been made to identify those subjects at high risk of fracture and, consequently, in need of secondary prophylaxis. The primary cause of hip fracture is osteoporosis, a disease that reduces bone density below that level needed for the mechanical support of normal activities.38 Attempts at identifying individuals at risk of hip fracture have involved identifying those with critically reduced levels of bone density. This is the current daily medical practice that is based on a protocol proposed by the World Health Organization (WHO).38 The procedure requires that the clinician obtains a dual energy x-ray absorptiometry (DXA) scan of the patient’s proximal femur. Bone mineral density (BMD) is measured at various regions of interest and compared with the mean femoral BMD of a healthy population (chosen as the reference level). However, the two density distributions, of at-risk patients and age-matched controls, have been found to overlap by large amounts, reducing the accuracy of classification to about 65%.1

These problems have led many to attempt to improve patient classification by considering other parameters besides the bone density. Important factors, such as subject’s life-style, coordination, and proximal femur anatomy, have been identified as being influential in the occurrence of femoral neck fracture.1,12 In particular, the effect of various proximal femur geometric measurements has been investigated14,17,19 Nevertheless, even though the femoral anatomy has been demonstrated to be important in the prediction of fractures, the relative role of each geometric measurement remains controversial.

Many finite element (FE) models have been developed, based on a computer tomography (CT) scan of the proximal femur, that consider the density distribution together with the proximal femur geometry and architecture.6,22,25 These approaches are effective and ac-
curate in estimating proximal femur strength, but their application in the clinical evaluation of osteoporosis is limited because of the higher radiation dose and the higher costs associated with the CT scan. Therefore, others have proposed models of the proximal femur from DXA datasets. Starting from this rationale, the authors previously developed a FE model using only data from DXA scans.

The aim of this retrospective study was to evaluate the possible improvement provided by FE-based biomechanical indicators over the standard DXA-based method in the classification accuracy when trying to separate femoral neck fractured patients from age-matched controls.

MATERIALS AND METHODS

Data Collection

DXA scans (Norland Medical Systems Inc., USA) of 93 Italian women were randomly selected from the medical records of elderly patients routinely screened for osteoporosis. About half of these subjects had reported a femoral neck fracture \((n=42)\), while the others presented no fracture at the last date of scanning \((n=51)\). All fractures were caused by a minor trauma (a fall from standing height or walking) as reported by the patient or a relative. The fractures were diagnosed from x-rays by an expert radiologist blinded to the subjects’ status. For the fractured patients, the DXA scan was performed on the contralateral femur with respect to the fracture side on admission to hospital. Control subjects were always scanned on the left side. All patients were diagnosed as having no conditions affecting the bone tissue, such as endocrine disease, Paget’s disease, rheumatoid arthritis, chronic kidney or lung disease, hyperparathyroidism, long-term immobilization, hip prosthesis, or malignancy.

Age, height, and weight were recorded for every patient. Body mass index was evaluated as the height divided by the weight squared. The clinician measured the BMD at three regions of interest of the DXA scan: (i) Ward’s triangle (WRDT), (ii) the L2–L4 group of vertebral bodies (SPINE), and (iii) the femoral neck (FNECK).

The clinician extracted geometric parameters of the proximal femur (Fig. 1) from the DXA image. The parameter ANGLE was automatically measured as the neck-shaft angle less 90°. The hip axis length (LHIP) was manually evaluated as the distance from the inner acetabular line to the lateral side of the greater trochanter. The diameter of the femoral neck (DNECK) was measured as the cortex surface-to-surface distance along a line perpendicular to the hip axis at the narrowest part of the neck. The femoral diaphysis diameter (DFEM) was estimated as the cortex surface-to-surface distance at two centimeters below the lesser trochanter. In a previous study, the repeatability error of the geometric measurements on the DXA image was evaluated to be 2.17%.19

FE Procedure

A FE model of each femur was developed from the DXA scan of the patient’s proximal femur. The FE procedure is briefly described here, with further details concerning its validation to be found elsewhere. First, the DXA gray scale image was outlined using a thresholding operation (NIH-Image, NIMH, USA). The contour was then imported in the MatLab programming environment (The MathWorks Inc., USA) where all analyses were performed. An automatic Delaunay mesh initialization was executed (standard six degrees of freedom triangular elements), and an adaptive mesh solution was used to calculate the FE model results.

Material properties were assigned to each mesh element based on the BMD values obtained from the DXA scanning. The value for Poisson’s ratio was assumed constant, while the value for Young’s modulus was derived from the DXA BMD values. Often a bilinear relationship has been used to account for the different mechanical properties of cortical and trabecular bone. Nevertheless, preliminary analyses on a simplified cylindrical geometry demonstrated that using a linear relationship, instead of the bilinear one, only resulted in a difference of less than 5% in the FE-based principle strain. Therefore, a unique linear relationship was considered.

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E = \frac{1}{A} \int_{\text{element}} \text{constant} \times \text{BMD}(P) dA,
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