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PROXIMAL FEMUR BIOMECHANICS IN DAILY ACTIVITIES: A TWO-SCALE COMPUTATIONAL STUDY.

Fulvia Taddei[1], Ilaria Palmadori[1], Markus O. Heller[2], William R. Taylor[3], Enrico Schileo[1]

[1] Istituto Ortopedico Rizzoli, Via di Barbiano 1/10 40136 Bologna, taddei@tecno.ior.it
[2] University of Southampton, University of Southampton, Highfield SO17 1BJ, M.O.Heller@soton.ac.uk
[3] ETH Zurich, Wolfgang-Pauli-Str. 10 8093 Zuerich, taylorb@ethz.ch

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Introduction

Clinically relevant bone fractures are events that occur at the organ level but are intrinsically multiscale in nature since they are caused by an unbalanced situation between external determinants (i.e. loads that are determined at the organism level) and intrinsic determinants that influence the bone strength (i.e. bone shape and distribution of mineral density at the organ level). External and intrinsic determinants are linked with the structure and the mechanical properties of bone at the tissue level, that are in turn determined by constituents distribution and interaction at the sub-tissue level.
Among all fractures, hip fractures due to an increased skeletal fragility are of main importance and represent a social burden due to increased aging of the population [1]. A lot of work has been devoted to the study of the proximal femur biomechanics to understand the determinants of proximal femur strength and its change with aging.
Aim of the present work is to describe a computational model, spanning two dimensional scales (organism-organ), that has been used to investigate the biomechanics of the human proximal femur during daily activities and in particular to understand how its safety factor changes during life in men and women, in a population based study.

Materials and Methods

200 CT datasets of femurs were obtained from a repository of pre-operative (Total Hip Replacement surgery) scans available at the Istituto Ortopedico Rizzoli. Patients with unilateral hip osteoarthritis (OA) where the contralateral femur, used for the present study, showed no sign of the disease and a normal anatomy, were selected by an expert anatomist. The extracted group consisted of 116 females and 84 males.

Personalised loading conditions: the organism scale

To model the possible loading variations associated with two frequent motor tasks (normal walking; NW and stair climbing; SC) an indexed and searchable database of joint and muscle loads was obtained from the results of musculoskeletal models on 90 patients. A personalised joint and muscle loading spectrum (comprising all major muscles acting directly on the proximal femur) for NW and SC was associated to each femur by querying the database with individual characteristics (height, weight, femoral antetorsion, CCD angle and neck length). 78 possible loading combinations for NW and 50 for SC were defined for each subject.

Personalised Finite Element model of the femur: the organ scale.

Finite Element models were built for each femur from the CT data according to a validated subject-specific procedure [2]. From the segmented bone surface, an iso-topological FE mesh (10-noded tetrahedra) was obtained using a morphing procedure based on the identification of a small number of skeletal landmarks on the femoral surface. The Bonemat© v3 algorithm [3] was used to compute the module of elasticity to be assigned to each finite element of the mesh from the local values of radiological density of the calibrated CT dataset. A Safety Factor was calculated for each femur under each loading condition as the ratio $\varepsilon_{LIM}/\varepsilon_{MAX}$, where ε_{MAX} is the maximum principal strain reached on the femoral neck surface (Figure 2), excluding the regions of the muscle force applications, and ε_{LIM} is the limit strain (ε_{LIM} = 1.04% compressive, 0.73% tensile) [4].

Results

No fracture was predicted over the whole population studied. An average SF close to five was found for both men and women (4.94 and 4.96 respectively), suggesting a globally gender-equivalent bone response to physiological loads. The correlation of SF with bone mineral density and age was, on the contrary, different between genders. In women a significant correlation of SF with both bone mineral density and age was found, but not in men, highlighting a possible gender issue that needs further investigation.

Discussion

The presented study allowed for the first time the investigation of the safety factor of the human femur during daily activities over a real population and showed its correlation with the level of mineralisation of the bone and with age, spotting out a different behaviour of men and women. Further elaboration of the results, currently on-going, may elucidate the average strain distribution in the proximal femur of stresses and strains and their variance. These results could constitute a valuable input for tissue level models that can be used for the prediction of tissue-level phenomena such as bone remodelling.

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