3D DXA-BASED PATIENT-SPECIFIC FEMUR FINITE ELEMENT MODEL FOR CLASSIFICATION OF FRACTURE AND NON-FRACTURE CASES

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Introduction
Osteoporotic bone fractures lead to weighty losses of independence and quality of life, and to increased mortality in women [1]. Minimally irradiating image techniques such as dual-energy X-ray absorptiometry (DXA) provide assessment of bone loss through the bone mineral density (BMD). Yet, fracture risk predictions remain limited with 30 to 40% of error [2]. Recently, the 3D-DXA algorithm was proposed to extract the 3D geometry and analyse the trabecular and cortical BMD of the proximal femur [3]. This study hypothesizes that such technology can benefit from finite element (FE)-based biomechanical analyses to define classification criteria that integrate anatomical, bone quality and mechanical patient information.

Materials and Methods
DXA images acquired with a Prodigy scanner (GE Healthcare) were collected at CETIR Medical Centre. 49 postmenopausal women with and 37 without hip fracture (control) were included. Proximal femur 3D models were generated using the software 3D-DXA (Galgo Medical), and used to morph a generic structural mesh of the femur to automatically generate patient-specific FE models (Fig.1).

![Figure 1: Integrated workflow.](image.png)

A static peak load that depended on patient mass and height simulated side fall effects (Eq. 1). Mechanical fields were calculated through Young’s modulus (E) – BMD relationships for the cortical and trabecular bone (Eqs. 2,3) [4,5]. The power of strain, stress, and strain energy descriptors to separate fracture and non-fracture cases was tested through the ROC-AUC method.

\[
F_{\text{peak}} = \sqrt{2ghKm}
\]

\[
E_{\text{cortical}} = 10200\rho_{\text{ash}}^{2.01}
\]

\[
E_{\text{trabecular}} = 7664\rho_{\text{ash}}^{1.96}
\]

Results and discussion
The major principal stress (MPS) was the parameter with the highest ROC-AUC values (Fig. 2). For intertrochanteric fractures, it led to ROC-AUC values 28% and 18% higher than the values obtained with the volumetric BMD measured by DXA, when analysed in the trabecular and cortical bone respectively. It is worth to highlight that the MPS.

For intertrochanteric and neck fractures, the ROC-AUC values for the MPS calculated at the trabecular bone of those fracture zones were 0.93 and 0.80, respectively. The ROC-AUC values for the MPS calculated at the cortical bone of the aforementioned fracture zones were 0.73 and 0.80. These results are comparable to the results presented in the literature using CT-based FE models [6], and suggest that the trabecular bone quality is particularly critical for proximal femur osteoporotic fractures, in general.

![Figure 2: Intertrochanteric ROC-AUC curves for trabecular bone.](image.png)

Conclusion
3D-DXA-based FE models of the femur provide descriptors that integrate quantitative and qualitative variables from the 3D-DXA with good to excellent sensitivity to hip fracture occurrence. Statistical analyses by fracture type, tissue and gender are crucial to achieve accurate patient classification in the future.

References

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