PREDICTING FEMORAL STRENGTH FROM 2D-3D DXA FINITE ELEMENT MODELS ACROSS AGE AND ETHNICITES

Vee San Cheong (1,2), Dheeraj Jha (1,2), Alexander Baker (2), Lorenzo Grassi (3), Namki Hong (4), Katelyn A. Greene (5), Ashley A. Weaver (5), Sami Väänänen (6), Yumie Rhee (4), Hanna Isaksson (3), Stephen J. Ferguson (1,2), Benedikt Helgason (1,2)

1. Singapore-ETH Centre, Singapore; 2. Institute for Biomechanics, ETH Zürich, Switzerland; 3. Department of Biomedical Engineering, Lund University, Sweden; 4. Department of Internal Medicine, Yonsei University College of Medicine, South Korea; 5. Department of Biomedical Engineering, Wake Forest University School of Medicine, USA; 6. Department of Technical Physics, University of Eastern Finland, Finland

Introduction

Femur strength derived using quantitative computed tomography (QCT)-based finite element analysis (FEA) has been shown to be a better predictor of fracture risk than areal bone mineral density (aBMD) in a Caucasian cohort [1]. However, its adoption in clinical practice has been limited, as these models rely on the acquisition of 3D QCT images, which have higher costs and radiation exposure compared to 2D imaging methods such as dual-energy X-ray absorptiometry (DXA). Recent studies have utilised 2D-to-3D reconstruction of shape and BMD distribution (3D-DXA) to predict femoral strength [2, 3], but are limited in terms of sample size, or have been performed using *ex vivo* scans. This work validates and improves the prediction of femoral strength from 3D-DXA against QCT-based FE models, acquired from *in vivo* scans in a multi-centre study.

Methods

112 paired 3D-DXA and QCT images from five cohorts (age 20-88; absence of bone disease treatment) were included in this study. 3D-DXA images were estimated from 2D-DXA images using statistical shape and density modelling (3D-Shaper, Galgo Medical). A validated approach for sideways fall simulation was used [1, 2]. The bone anatomies were converted into smooth, continuum models with 10-node tetrahedral elements. Bone elastic moduli were mapped from Hounsfield units (K_2HPO_4 phantom, QCT Pro). Non-linear material properties (compression-tension asymmetry, strain-rate dependency) were assigned. Boundary and loading conditions used are indicated in Figure 1. Femur strength was calculated as the maximum force experienced in the femoral neck during loading.

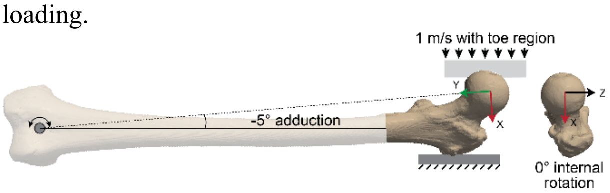

Figure 1: Boundary condition and loading conditions for sideways fall simulations

Densitometric and volumetric analyses were also performed to understand the differences between the 3D-DXA and CT models, and to develop a data-driven model that uses 3D-DXA greystack images as input, to improve the prediction of femoral strength.

Results

Bone volumes and femoral strength from 3D-DXA models were under-predicted (Figure 2A). Linear regression between 3D-DXA and CT volumetric BMD (vBMD) was y = 0.88x + 24.8 mg/cm³, R^2 = 0.72). New geometries created by 1) binarising and eroding the 3D-DXA greystack volumes, and 2) calibrating vBMD within the modified 3D-DXA surfaces to obtain a 1:1 regression with CT vBMD, improved femoral strength prediction (slope: 0.97, offset: 0.68 kN; Figure 2B).

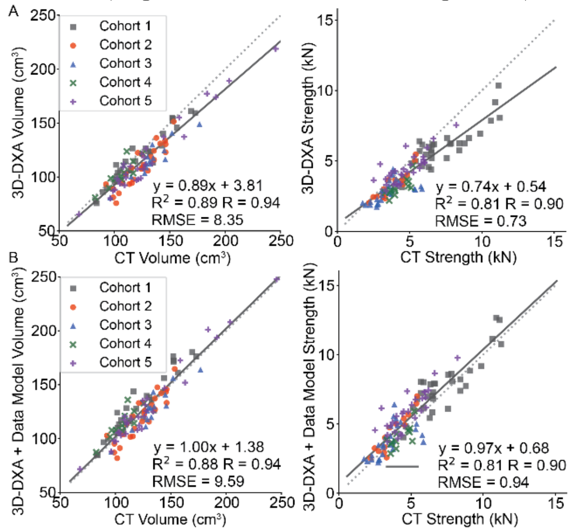

Figure 2: Differences in volume and femoral strength prediction using (A) 3D-DXA models, and (B) proposed data-driven model.

Discussion

The improvement in the coefficient of determination of vBMD from R^2 = 0.72 to R^2 = 0.79 was not reflected in the change in correlation for femoral strength. This suggests that optimisation of the bone distribution in the 2D-to-3D reconstructions of DXA scans may further improve the prediction of femoral strength.

References

1. Fleps et al, Bone, 154:116219, 2022
2. Grassi et al, Bone, 142:115678, 2021
3. Steiner et al, Med Eng Phys, 93:72-82, 2021

Acknowledgements

This work was supported by grants from the National Research Foundation Singapore (Future Health Technologies programme), the ETH focus area (PHRT #325, #430), the Korea Health Industry Development Institute (HI22C0916), Hanmi Pharmaceutical Co. Ltd. (4-2018-0845) and the NIH (R01AG050656, K25AG058804, F31AG069414).