VALIDATION OF A HR-PQCT BASED FINITE ELEMENT METHOD ON MECHANICAL TESTS OF DISTAL RADIUS SLICES

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INTRODUCTION

Osteoporosis is a skeletal disease leading to increased fragility through bone loss and micro-architectural degradation. Non-invasive assessment of fracture risk becomes therefore of increasing interest. Distal radius fractures are amongst the three most common osteoporotic fractures. As they tend to occur earlier in lifetime than hip and vertebral fractures, they could be used as a warning for increased fracture risk at other sites. The emergence of high resolution peripheral quantitative computed tomography (HR-pQCT) allows detailed analysis of the bony microstructure of the distal radius *in vivo*. In the past years, HR-pQCT-based, anatomy specific micro finite element (microFE) analysis has been making substantial progresses in predicting Colles' fracture load as well as failure load of various radial slices [1,2].

The goal of this study was to validate an alternative, efficient continuum level FE approach with mechanical tests of human ultra distal radius slices extracted from the typical location of Colles' fracture.

METHODS

The left and right radii were excised from 14 fresh frozen cadavers with mean ages of 81.2 years (min/max age 59/97ys, m/f: 4/10). Twenty mm distal sections of the 28 radii were cut below the articular endplate, scanned in HR-pQCT (XtremeCT, Scanco Medical AG, Switzerland) with the standard *in vivo* protocol resulting in images with 82 µm resolution. Two samples were excluded due to pathological deformities. Twenty six specimens were tested in quasi-static compression (MiniBionix 858, MTS Systems Corp., USA) by allowing rotation of the distal plane with a ball joint. Force, displacement and inclination angles were recorded (Figure1, left).

Continuum level, smooth surface based FE models of the specimens were built in an automated way from the HR-pQCT images, distinguishing cortical and trabecular bone regions [3] (Figure 1, right). Material properties were assigned with a density and fabric based constitutive law including elasticity, plasticity and damage [4] with parameters evaluated from mechanical tests of biopsies and nanoindentation [5].

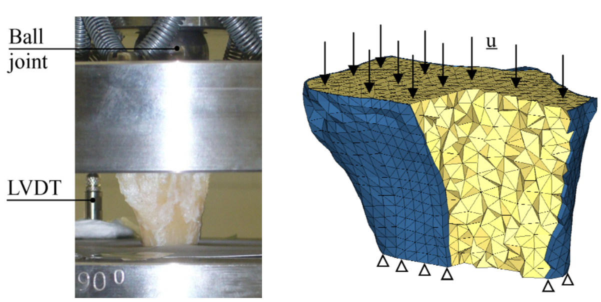

Figure 1: The experimental setup (left) and the numerical model with the corresponding boundary conditions (right).

The influence of image resolution on bone morphology was examined by scanning 6 similarly prepared radius slices (age and sex unknown) both in XtremeCT and microCT (µCT40, Scanco, 18 µm resolution) and registering the image pairs using 3D rigid image registration (ITK, Kitware Inc., USA). Relations between quantities evaluated at the low and at the high resolution images were identified for density and fabric using corresponding cubical sub-volumes (5.33^3 mm^3, N=81). Nonlinear finite element analyses of pure compression tests were performed (Abaqus 6.6, SIMULIA, USA) without allowing rotation of the distal plane.

RESULTS AND DISCUSSION

In 24 cases, the radial slices fractured in dorsal inclination with an angle < 1° until maximal load. Experimental stiffnesses ranged from 6839 to 42491N/mm (mean±SD: 23967.1±9734.6), while ultimate forces varied from 948 to 5730N (2905.4±1231.8). The correlations between experimental and FE results (Figure 2) were high for both stiffness (R^2=0.933) and strength (R^2=0.885). Despite calibration of density and fabric, the FE analyses overestimated stiffness of the osteoporotic slices up to 100% and overestimate failure load by 1.25 kN of all slices.

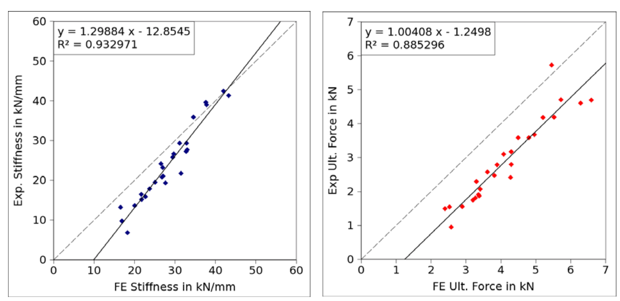

Figure 2: Linear regressions between the experimental and FE values of stiffness (left) and ultimate force (right).

CONCLUSIONS

The systematic overestimation of the mechanical properties by the FE method has to be clarified. However, the obtained results demonstrate that the proposed FE framework is capable of predicting the failure load of the distal part of the radius involved in Colles' fracture with a reasonable accuracy. This emphasizes the potential of the FE method to improve the assessment of fracture risk of the distal radius.

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