COMPUTATIONAL BONE MECHANICS TO DETERMINE BONE STRENGTH OF THE HUMAN RADIUS

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Introduction

Fractures in the distal radius are amongst the most common in humans. Their incidence is increasing due to an aging population leading to a higher percentage of osteoporotic patients with an increased risk of forearm fractures. Hence, an accurate prediction of bone strength in the human radius is of major interest. Bone strength depends on bone geometry and internal architecture. With the recent introduction of a new generation of high-resolution 3D peripheral quantitative computed tomography (HR-pQCT) systems, direct quantification of structural bone parameters has become feasible. Furthermore, it was recently demonstrated that bone mechanical competence can be derived from HR-pQCT based micro-finite element modelling (µFE) [Pistoia *et al*, 2002].

The goal in this study was to gain more insight into bone mechanical competence at the human distal forearm in an elderly population. Specifically, our aim was to find the optimal region for assessing fracture prediction based on µFE bone mechanics.

Methods

Two age-matched groups of 50 male (age 79.9 ± 8.76 years) and 50 female (age 81.6 ± 8.86 years) right forearms were harvested from formalin-fixed cadavers. The forearms were imaged with a new generation pQCT scanner (Radios, Scanco Medical AG, Bassersdorf, Switzerland) providing a nominal resolution of 93 µm enabling to assess bone microstructure. Measurements were acquired for five consecutive regions, covering 20% of the forearm length; region 1 started just below the distal joint space. An additional region of interest was defined based on the recommendations of the manufacturer for *in vivo* measurements (Figure 1A). Subsequently, failure load was assessed by experimental uniaxial compression testing.

µFE models of the six regions were created by a direct conversion of bone voxels to hexahedral elements. A new PCG based parallel solver [Arbenz *et al*, 2007] was used to solve these large problems with up to 16 million degrees of freedom using a CRAY XT3 system. The force required to reach 1% apparent strain as well as the tissue-level stresses and strains were calculated (Figure 1B). Apparent stiffness was derived by dividing the µFE-calculated force in axial direction with the axial displacement.

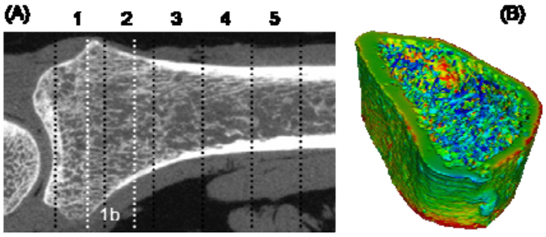

Figure 1: (A) Analyzed regions and (B) µFE.

Results

The best linear prediction of the failure load using bone apparent stiffness was obtained at the most distal region (R^2=0.73, p<0.001) with predictions decreasing towards more proximal regions (region 4, R^2=0.64, p<0.001). These findings are in line with previous work on estimating bone failure load from structural parameters [Mueller *et al*, 2006], where we showed that bone strength was best predicted from structural parameters from the most distal region of the radius.

Discussion

We demonstrated good correlations of µFE derived bone stiffness with measured failure load. Furthermore, we found that the most relevant region to determine failure load is located just below the growth plate. These findings are also of major clinical interest. Investigations in failure load criterions to derive bone strength from µFE analysis [Pistoia *et al*, 2002] and the analysis of the whole 20% of the forearm length including accurate modelling of the metacarpal bones will show if an additional improvement of the measured failure load prediction can be achieved.

References

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