Can strength predictions of the human distal radius be improved by simulating more realistic fall-loading characteristics?

Knippels I. [1*], Wirth A. J. [2], Mueller T. L. [2], Eckstein F. [3], Müller R. [2], van Lenthe G. H. [1,2]

[1] Division of Biomechanics, K.U.Leuven, Leuven, Belgium, [*]Ingrid.Knippels@mech.kuleuven.be
[2] Institute for Biomechanics, ETH Zurich, Zurich, Switzerland
[3] Institute of Anatomy and Musculoskeletal Research, Paracelsus Medical University, Salzburg, Austria

Introduction

With the introduction of high-resolution peripheral quantitative computed tomography (HRpQCT) scanners, detailed three-dimensional *in vivo* imaging of human radii has become possible. Current recommendations for clinical measurements of the forearm are to scan a relatively small part of the radius (9-mm axial field of view). Micro-finite element (μFE) models based on the measured volume have been shown to correlate better to measured failure load than density-based parameters[1]. Current μFE modeling simulates compression testing between platens in the 9-mm slab. We hypothesized that strength prediction can be improved further when more realistic bone loading is simulated.

Materials and methods

From a collection of 100 cadaveric forearms that had been scanned with HR-pQCT (Radios, Scanco Medical AG, Brüttisellen, Switzerland) and mechanically tested in compression to failure[2], a subset of 18 bones was selected. The scans had an in-plane resolution of 89 μm with a 93 μm slice thickness.

For each of these 18 bones, three different μFE models were created. All the models were based on a direct voxel-to-element conversion. One model was made of the small region that is scanned *in-vivo* (model-A), a second one contained the distal 20% of the length of the forearm (model-B), and a third one contained this same region, but also included the scaphoid and lunate (model-C). This last model was also given a layer of cartilage on the articulating surface[3], mimicking the physiological situation (Fig 1).

All bone tissue was given a Young's modulus of 6.8 GPa and a Poisson's ratio of 0.3[4]. The cartilage of model-C was given a Young's modulus of 100 MPa and a Poisson's ratio of 0.49. All models were loaded with 1000 N in axial compression and were solved using ParFE[5]. The strength of the bone was determined as the force required to have 7.5% of the tissue volume in the region recommend for clinical scanning to be loaded above 0.7% effective strain.

Results and discussion

The strength prediction based on model-B correlated very highly with the strength prediction based on model-A (R^2=0.99), indicating that no additional information was gained by including more bone in the analyses. Model-C had a somewhat lower correlation to model-A (R^2=0.84), suggesting that load transfer through the bone is significantly altered when a cartilage layer is present. However, the R^2 values of the correlations with the measured failure load did not improve; they were 0.70, 0.72 and 0.69 for models A, B and C, respectively, indicating that, so far, no improvements relative to the measured failure load were obtained by adding cartilage and wrist bones.

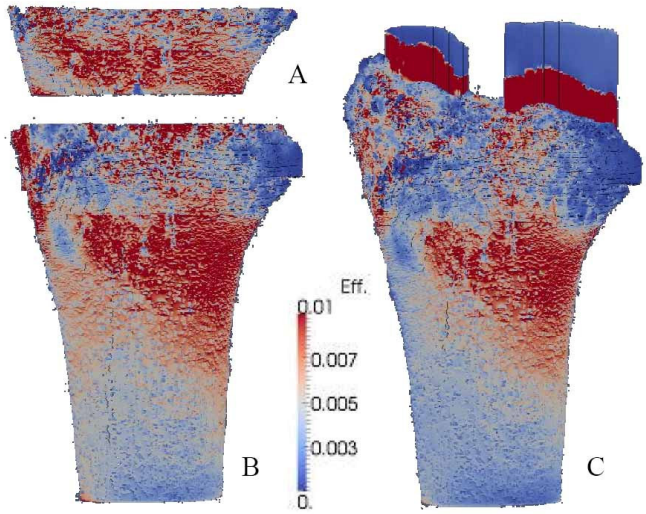

Figure 1. Effective strain for one radius; model type A, B and C

Conclusion

Strength predictions of the distal radius are affected by load application. However, for the relatively small set of samples analyzed so far, no improvements in strength prediction in comparison to actual mechanical testing were achieved by including more detailed models and more realistic boundary conditions. In-depth analyses of the load transfer differences between model-A and model-C will be performed.

Acknowledgements

Funding from the European Union for the osteoporotic virtual physiological human project (VPHOP FP7-ICT2008-223865) is acknowledged. Computation time was provided by CSCS (Switzerland).

References

[1] Pistoia W *et al*, J Clin Dens 7(2):153-160, 2004.
[2] Mueller TL *et al*, Bone 45: 882–891, 2009.
[3] Wirth AJ *et al*, Annual Meeting, Swiss Society for Biomedical Engineering, Sept. 4-5, p. 25, 2008.
[4] MacNeil JA, Boyd SK, Bone, 42(6): 1203-13, 2008.
[5] Arbenz P *et al.*, Int. J. Numer. Meth. Engng; 73: 927–947, 2008.