THE VARIATION OF ORTHOTROPIC ELASTIC CONSTANTS IN THE FEMALE ANTERIOR FEMORAL MIDSHAFT: A MICRO-FINITE-ELEMENT STUDY

[1,2]P. Pankaj, [1,2]F.E. Donaldson, [3]D.M.L. Cooper, [4]C.D.L. Thomas, [4]J.G. Clement, [2]A.H.R.W. Simpson

[1] School of Engineering, The University of Edinburgh, United Kingdom;; email: Pankaj@ed.ac.uk, web: http://www.see.ed.ac.uk/orthopaedics/

[2] Edinburgh Orthopaedic Engineering Centre, The University of Edinburgh, United Kingdom

[3] Department of Anatomy & Cell Biology, University of Saskatchewan, Canada

[4] School of Dental Science, The University of Melbourne, Australia

INTRODUCTION

Computational modelling in orthopaedic biomechanics often uses continuum homogenised finite element models of the bone which require accurate definitions of its elastic properties. In this study the variation of the orthotropic elastic constants of cortical bone from the female anterior femoral midshaft were evaulated. Micro-finite-element (μFE) analysis of bone samples from 27 female donors aged between 20 – 87years were conducted to quantify the elastic constants at the periosteal and endosteal aspects. The variation of properties with age and canal volume to total volume (Ca.V/TV) were evaluated.

METHODS

The μFE process involves the conversion of high-resolution 3D images into finite-element meshes. These meshes can then be subjected to simulated mechantical tests to evaluate apparent-level elastic properties. These techniques have been used extensively for trabecular bone but not for cortical bone. The specimens considered in this study were scanned using μCT as part of a previous study [1]. Six samples were studied from each specimen creating a total of 162 samples from the periosteal and the endosteal aspects. Realistic tissue-level (lamelar bone) elastic constants were required as input to the analyses. These were derived using a simple but novel technique from micromechanical estimates for single osteonal lamella [2]. This led to a transversely isotropic material model at the tissue level. A direct mechanics approach [3] was used to analyse the samples.

RESULTS AND DISCUSSION

The variation in elastic constants correlated very well with Ca.V/TV (canal volume to total volume ratio; r^2=0.958) and significantly with age (r^2=0.391). All elastic constants were seen to reduce with increasing age and Ca.V/TV. Figure 1 shows the variation of the three Young's moduli with Ca.V/TV. A similar pattern was observed for the three shear moduli and six Poisson's ratios. The following hierarchy was observed in the elastic properties: Young's moduli E_L>E_C>E_R, shear moduli G_{CL}>G_{RL}>G_{RC}, and Poisson's ratios ν_{LC},ν_{LR}>ν_{CR}>ν_{CL},ν_{RC}>ν_{RL} (where L,C,R stand for Longitudinal, Circumferential and Radial respectively).

The elastic constants at the endosteal aspect reduced, as a function of age and Ca.V/TV, between 2 and 3 times more rapidly than those at the periosteal. This is considered to be the result of trabecularisation at the endosteal aspect, common with ageing in females. The significantly different elastic constants through the cortex, particularly at Ca.V/TV greater than 10%, are likely to affect the mechanical performance of bones. The results also shows that tissue-level anisotropy plays a far more significant role in apparent level cortical bone properties than it does for cancellous bone for which micro-architecture is the key determinant.

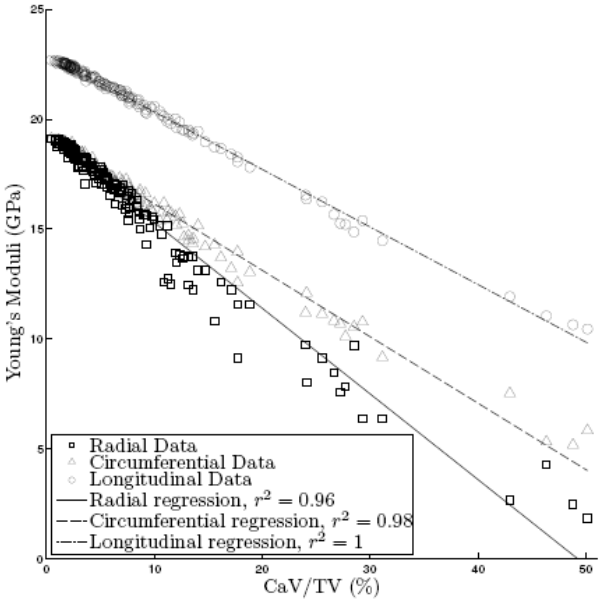

Figure 1: The variation of the three Young's moduli with the ratio of canal volume to total volume (Ca.V/TV).

CONCLUSIONS

The results of this study provide a useful source of complete orthotropic elastic constants for computational studies of bone using homogenised tissue properties. Data are available at both the periosteal and endosteal aspects enabling the significant variations through the cortex thickness to be incorporated into simulations. The elastic constants were evaluated across the full range of osteoporosis and donor age, allowing modeling parameters to be calibrated to specific patient groups.

REFERENCES

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