ESTIMATION OF FEMORAL TRABECULAR BONE FABRIC FROM QCT IMAGES DEPENDS ON THE SIZE OF THE REGION OF INTEREST

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Introduction

Quantitative computed tomography (QCT)-based patient specific finite element (FE) models have proven to be a useful tool in evaluating bone strength. The accuracy in this prediction seems to depend on the loading scenario [Dall'Ara, 2013], but may be improved by including directional anisotropy [Lenaerts, 2009]. The mean intercept length (MIL) method is the gold standard when assessing anisotropy from segmented high-resolution images, but this method cannot be applied to QCT images of trabecular bone. The gradient structure tensor (GST) is a viable method for evaluating anisotropy of trabecular bone from QCT [Wolfram, 2009], but the accuracy has yet to be clearly delineated. The goal of this study was to develop a reliable method for evaluating femoral trabecular bone anisotropy from QCT images using the GST.

Methods

Twelve human proximal femora were scanned using QCT and high resolution peripheral QCT (HR-pQCT) scanners. Two registered data sets were created at two different isotropic voxel sizes (0.33 and 0.082mm). Thousands of cubical regions of interests (ROIs) of different sizes (5, 7.5, 10, 15mm) were cropped in the trabecular region of the QCT datasets and a GST fabric tensor $\widehat{\boldsymbol{G}}$ was computed (Fig 1., left). Cubes were cropped at the same location from the HR-pQCT dataset to obtain the normalized MIL fabric tensor $\widehat{\boldsymbol{M}}$ (Fig 1., right). A power transformation was proposed to relate the MIL tensor $\widehat{\boldsymbol{M}}$ with the GST tensor $\widehat{\boldsymbol{G}}$:

$$\widehat{\boldsymbol{M}} \leftrightarrow {}^{GST}\widehat{\boldsymbol{M}} = \frac{3\widehat{\boldsymbol{G}}^n}{tr(\widehat{\boldsymbol{G}}^n)} \quad (1)$$

As a good correspondence between the main eigenvectors of $\widehat{\boldsymbol{M}}$ and $\widehat{\boldsymbol{G}}$ was found for high degrees of transverse anisotropy (DTI), a threshold DTI_{thres} was defined with the eigenvalues ${}^{GST}\widehat{m}_i$ such that 95% of all ROIs had an angular difference of 30° or less:

$$DTI_{thres} = \frac{2\,{}^{GST}\widehat{m}_1}{{}^{GST}\widehat{m}_2 + {}^{GST}\widehat{m}_3} \quad (2)$$

Results

For ROIs above DTI_{thres}, significant power relationships were obtained between the GST and MIL DTI for all sizes (R^2>0.72). The DTI_{thres} and the coefficient n are plotted for a range of ROI sizes (Fig. 2). Results define the DTI_{thres} and n required for GST-based anisotropy predictions for a given ROI size.

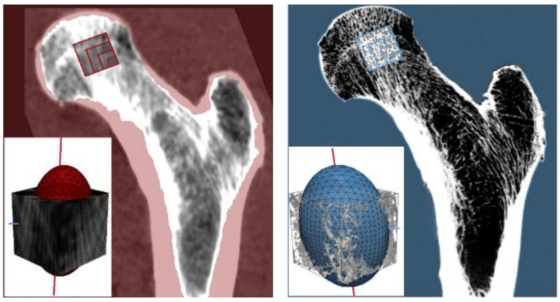

Figure 1: Cut section of QCT and HR-pQCT images used for computing GST (left) and MIL (right) tensors. ROI sizes are indicated in the femoral heads and the fabric tensors are shown in the bottom left corners.

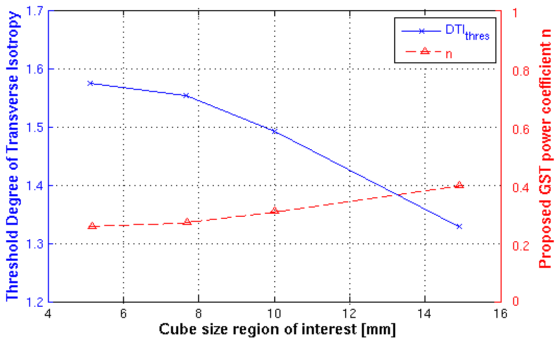

Figure 2: Continuous line shows the relation between DTI_{thres} and ROI size. Dashed line reports the relation between n and ROI size (0.957≤ R^2 ≤0.961).

Discussion

Regions with a high DTI also exhibit a high BV/TV, predominantly contributing to the femoral stiffness and strength. This method may be used to improve QCT-based FE models for the prediction of femoral strength.

References

Dall'Ara *et al*, Bone, 52:27-38, 2013
Lenaerts *et al*, Phil.Trans, 367:2079-93, 2009
Wolfram *et al*, JBiomech, 42:1390-1396, 2009