Extraction and variability of the femur cortical thickness from Computer Tomography

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Purpose: 3D bone reconstructions from biplanar radiographies showed an increasing interest in the literature in the last decade (see e.g. Humbert *et al.*, 2009). Iterative reconstruction process consists in retroprojecting the bone surface on the X-rays and adjusting the three-dimensional (3D) surface to fit the radiographies. However, these reconstruction methods and their accuracy present limitations due to the surface representation of the 3D object. A simple enhancement of surface models can be achieved by adding cortical thickness to the reconstructed surfaces. This would allow the simulation of X-rays through it and the computation of simulated radiographs directly comparable to the original X-rays. This approach calls for the building of cortical thickness databases. In this context, our work aims to provide a method for cortical thickness reconstruction from Computer Tomography (CT) images. This method will be applied to the case of the femur and a variability study of the resulting database will be conducted.

Methods: Axial CT slices 0.75-mm-thick with an inter-slice distance of 0.5 mm were collected from 15 cadavers. The population consisted in 13 men and 2 females, with a mean age of 74.5 years, spanning from 56 to 88. 14 left and 6 right femurs without visible pathology in the images have been selected for the study.

An original method has been developed in order to reconstruct the internal and external cortical surfaces of the femur from the CT images: (1) two stereo Digitally Reconstructed Radiographs (de Bruin *et al.*, 2008) are computed from the CT scans and a first external cortical surface is computed from the stereo-radiographs, the surfaces being topologically similar for all the femurs (Chaibi *et al.*, 2011), (2) the intensity profiles of a subset of the surface vertices are computed as the grey levels of the CT bloc along the normal of the surface vertices, (3) the internal and external cortical positions along the profiles are respectively semi-automatically detected and adjusted, and (4) the 3D vertices of the surface are adjusted accordingly, the other non-processed vertices being adjusted using a krigging technique (Trochu, 1993). 20 pairs of topologically similar internal and external cortical surfaces of the femur have been reconstructed by this method and one femur has additionally been segmented by means of the software Amira® to serve as a reference for a preliminary evaluation of the method.

The cortical thicknesses have been computed as the distance between the external surface vertices and the internal surface along their normal directions. A variability study of this database of 20 sets of cortical thickness has been performed by means of principal component analysis (PCA) for the diaphysis, the head, the neck and the distal regions of the femur.

Results: The average and 2RMS reconstruction errors of the external surface reconstructed by our method with the reference were found as 0.4 mm and 1.1 mm, while 0.7 mm and 1.9 mm for the internal cortical surface.

The PCA showed a first parameter explaining 42% to 66% of the variance depending on the region. This parameter appeared related to the more proximal part for the diaphysis while rather uniform for the other regions. The correlation coefficient of the first PCA parameters for the head and the neck was as high as 0.92 while varying between 0.4 and 0.75 for the rest, meaning that the cortical thickness of the head and the neck are closely related. The second PCA parameters, all explaining less than 12%, did not appear related to meaningful variations.

A cortical thickness model has been proposed by using the first PCA parameter for the diaphysis and the average cortical thickness for the rest. This model allows to complement an external surface with cortical thickness with an average and 2RMS reconstruction errors of 0.75 mm and 1.7 mm for the diaphysis, and 0.7 mm and 1.7 mm for the rest of the femur.

Conclusion: An original method to obtain 3D internal and external cortical surfaces of the femur from CT scans has been proposed. 20 pairs of surfaces have been obtained with our method, the 2RMS reconstruction error remaining below 2 mm. A variability study of the database showed a first parameter, linked for the head and the neck, related to the general cortical thickness. Finally, a volume model has been proposed, allowing the reconstruction of the cortical thickness with a 2RMS error of 1.7 mm. In recall to the context of the study, this model allows to produce accurate simulated radiographs, as visible on the figure 1, and constitutes a good simplicity-pertinence compromise.

Figure 1 : Original (left) and simulated (right) X-ray obtained with an external surface reconstructed by the method proposed by Chaibi *et al.* (2011) and a cortical thickness computed by our model

Acknowledgements:

This work is part of the SterEOS+ project funded by the Ile-de-France region though the Medicen competitive cluster. The authors would like to thank Erwan Jolivet for his useful suggestions and support.

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