A statistical shape model of bone anatomical variability for finite element assessment of bone mechanics

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Introduction

Finite element models developed from CT data are commonly used to evaluate the mechanical performance of the bone or the load transfer from implant to the bone. However, most analyses take no account either for the wide variation in material properties and geometry that may occur in natural tissues or the manufacturing imperfections in synthetic materials. Some authors recognized this limitation[1,2,3] and included uncertainties in finite element biomechanical simulations, but failed to capture bone anatomical variability. Therefore, the aim of this study is to propose a method to include bone anatomical variations for the calculation of bone performance. This statistical finite element model is illustrated with the comparison of the stiffness between male and female femoral bones.

Materials and methods

A Statistical Shape Model (SSM) of femurs was created for males and females, using 80 CT images for the first group and 57 for the second one. This compact describes the range of shape variation encountered in a set of different bones and then allows generating bone instances that represent the population. To generate it, the CT images were manually segmented and then automatically registered to a reference image in the Log-Euclidean[4] framework, to find anatomical correspondences. The obtained correspondences, in terms of velocity fields, were used to perform the principle component analysis and generate the SSM. 40 virtual CT images were then created for the male and female groups. 4 modes were chosen as they represent 77% of the shape variations for the female and 83% for the male populations; the weight of each mode was chosen randomly according to their Gaussian distribution in the PCA space. Finally from each "virtual CT" a finite element model was generated. A surface mesh was automatically produced, decimated and smoothed and converted to a volume 10-node tetrahedral FE mesh.
For the FE analysis, bone mechanical properties were assigned to each node of the mesh, based on empirical relationship between HU and Young's modulus. A load of 800N was applied on the femoral head in the direction of the intercondylar fossa. The distal part of the femur was constrained for the displacements in all directions. The displacement vector fields calculated by the non-rigid registration process, were used to "propagate" the loading condition to all the generated models.

Results and discussion

The mechanical stiffness of the femur was calculated for all the instances. Results showed that the average stiffness values were similar for the males and females generated instances (Figure 1). This indicates that the femur stiffness seems not to be gender-specific, but other parameters may be more relevant like age or ethnic groups. The present model is limited by the fact that the computed variations among bones were focused on shape and not on intensity: all instances contained the reference bone intensities. Future models including variability of both shape and mineral intensity will be proposed to clarify this issue.

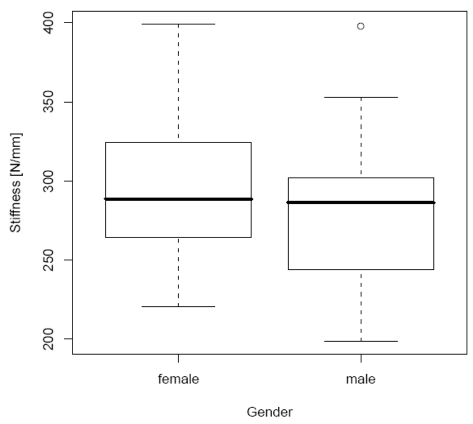

Fig. 1: Box plot of the stiffness obtained for female (left) and male (right) groups

Conclusion

An automatic pipeline was developed to build Statistical Shape Models from CT images. The developed tool enables the creation of finite element models based on instances generated with the SSM. Bone mechanical properties are automatically assigned to the FE mesh based on the HU of the "virtual CT". This method can be used to evaluate the differences between different groups of populations according to gender, ethnicity, age, body mass index, etc. In future, the method is expected to have a significant impact on population-based implant design.

Acknowledgements

This work was funded by the Swiss National Center of Competence in Research "Computer Aided and Image Guided Medical Interventions (Co-Me)"

References

[1] Taddei F., *et al.*, 2006, IEEE transactions on bio-medical engineering, vol. 53 (11), p. 2194-200.
[2] Laz, P.J., *et al.*,2007,J. Biomech, 40 (13), p.2831-6.
[3] Viceconti M., *et al.*, 2006, J. Biomech, 39 (7), p. 1169-79.
[4] Vercauteren T., *et al.*, 2008, in MICCAI, 2008, pp. 754–761.