VALIDATED FINITE ELEMENT MODEL OF A COMPOSITE TIBIA

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INTRODUCTION

Composite bones are synthetic bones made of a hard glass-fibre reinforced epoxy shell (representing cortical bone) with a foam centre (representing trabecular bone). They are useful tools for experimental studies on orthopaedic implants as they have little variability between them, are more convenient to handle and store than cadaveric bones, and are cheaper and easier to source. Finite element (FE) models of composite bone can be used to evaluate new and modified designs of joint prostheses and fixation devices. Although FE models of the composite femur have been created and validated [1,2], no validated FE models of the composite tibia yet exist.

The aim of this study is to create an FE model of the composite tibia (Mod. 3101 Pacific Research Laboratories, WA, USA) and validate it against experimental results. As an initial step, the FE model was validated against the results obtained by Cristofolini and Viceconti [3], who measured deflections in the bone due to simple loading conditions.

METHODS

CT (HiSpeed CT/i, GE Medical Systems, USA) images of a composite tibia taken at 2 mm intervals in the transverse plane were segmented, and 3D models of the outer surface geometry of the bone and the geometry of the surface between the epoxy shell and the foam were created (sliceOmatic, TomoVision, Virtual Magic Inc., Montreal, Canada). These two surface geometries are now available at the BEL Repository, http://www.tecno.ior.it/VRLAB/. The surface geometries were used to create a 10-node tetrahedral solid mesh of the tibia (MSC.Patran, 2004 r2, MSC.Software Corporation, USA). Five different meshes consisting of 64349 to 110363 nodes were created; convergence of the results was checked. The reinforced material and the foam were both assumed to be isotropic with Poison's ratios of 0.3 and with Young's moduli of 14200 MPa and 69 MPa, respectively [3].

In the reported experimental study [3], the bending stiffnesses of eight composite tibiae were estimated by bending them in the latero-medial and antero-posterior planes. A four-point bending jig was used for load application (up to 500 N), while an extensometer was used to measure the mid-diaphysial deflection. The average results of five tests done on each bone, as well as the overall average, were presented. The experiments were simulated on the FE model (MSC.Marc, MSC. Software Corporation, USA) and model deflection and stiffness results compared to experiment.

In the reported experimental study [3], the torsional stiffness of the eight composite tibiae were estimated by applying a 5 Nm moment to the proximal end and measuring the angle of twist. The average torsional stiffness for each specimen, as well as the total average, was presented. To simulate the experiments on the FE model, two forces, parallel to each other and to the transverse plane, were applied to the proximal tibia. The surface nodes in the distal 30 mm of the tibia were fixed. Model displacements were used to calculate the angle of twist and torsional stiffness and compared to experimental results.

RESULTS AND DISCUSSION

For anterior-posterior bending, the FE analysis gave a deflection of 0.266 mm and a bending stiffness of 1880 N/mm. This stiffness is within 1% of the average experimental value and is well within the reported range of values [1]. For latero-medial bending, the FE analysis gave a deflection of 0.553 mm and a bending stiffness of 904 N/mm. This stiffness is within 4% of the average measured value and within the range reported [1].

For torsion, the FE analysis gave an angle of rotation of the proximal tibia with respect to the distal tibia of 0.762^o and a torsional stiffness of 6.56 Nm/degree. This stiffness is just over 20% higher than the measured average and outside the maximum measured value as well [1]. While the reasons for this large discrepancy are not clearly understood, it is possible that simplified boundary conditions in the FE model which ignored the two end mounting pots in the experiment may have led to slight, yet unwanted, deflections in the model. The assumption that the material properties of the composite bone were isotropic may also have contributed to the error.

It is of interest to note that only the bending stiffness and torsional stiffness were compared between the experimental results and the FE model, as this was the only information reported on the experimented tibiae. The surface strains generated due to these types of loading were not measured in the reported study. Therefore, while the model can be used reasonably accurately in cases where deformations are concerned, it may not yield accurate results if stresses or strains are analysed. Further experiments using more comprehensive loading conditions have been done on a strain gauged composite tibia. These results are now being compared against FE results. Additional attention is being dedicated to the proximal epiphysis.

CONCLUSIONS

This study has used the only reported experimental data on the second generation composite tibia (Mod. 3101 Pacific Research Laboratories, WA, USA) to validate an FE model of the same. The FE model can be used to evaluate conditions where bending predominates and should generate accurate results. However, for loading situations where torsion is predominant, less accurate results may be generated.

REFERENCES

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