DEVELOPMENT OF A SEMI-AUTOMATED METHOD FOR GENERATION OF HEXAHEDRAL FEMORAL CARTILAGE MESHES FROM MRI

Mark A. Baldwin¹, Joseph E. Langenderfer², Peter J. Laz¹, Paul J. Rullkoetter¹*

¹Computational Biomechanics Laboratory, University of Denver, Denver, CO
²Department of Engineering and Technology, Central Michigan University, Mount Pleasant, MI
*e-mail: prullkoe@du.edu

INTRODUCTION

Patient-specific finite element (FE) models which incorporate anatomic articular surface and soft tissue geometric representations can provide important insight into knee mechanics (Li et al., 1999; Shirazi-Adl et al., 2004). However, the generation of patient-specific meshes with hexahedral elements required for an accurate contact formulation is a manual, time-consuming process (Muccini et al., 2000). Extraction of three-dimensional (3D) anatomic surfaces is accomplished with manual segmentation of medical images, but the resulting meshes are not useable for contact in FE analysis. For this reason, more efficient methods for generating patient-specific hexahedral meshes are required. Thus, this study’s objectives were: to assess the feasibility of using a semi-automated morphing method to create specimen-specific hexahedral meshes of femoral surfaces from MR images and to compare the accuracy and efficiency of meshes generated with the semi-automated method and with a traditional preprocessor-segmentation based method.

METHODS

This study adapted a previously described method of generating tibial and patellar cartilage surface meshes to generate femoral cartilage meshes (Baldwin et al. 2008). Similar to the previous study, a generic 3D hexahedral mesh for the femoral cartilage was generated in Hypermesh 7.0 (Altair, Inc., Troy MI). The mesh was aligned to the sagittal plane with three elements (~2.5 mm edge length) between the bone and articular surface and a medial-lateral width of 3 mm. Within each mesh, groups of adjacent elements were created with moveable control handles located on the group corners. Using the Hypermesh morph tool, control handle movement linearly influenced all elements' nodes within the groups, and allowed the mesh to be stretched (morphed) while element quality (i.e. shape and skewness) was maintained. Sagittal plane MR images were displayed with a graphical user interface (GUI) developed in Matlab (Mathworks, Natick, MA). The morphing process is initiated by specifying image details (e.g. field-of-view dimensions, image resolution, etc.) to scale the generic mesh in the medial-lateral (M-L) direction. Then, the most anterior, posterior, inferior and superior points are found on the femoral cartilage (not shown) to scale the generic mesh in the respective directions. Next, three points are dragged on each image to denote the anterior-posterior (A-P) and inferior-superior (I-S) femoral surface locations (Figure 1, red) and then additional points corresponding to mesh control handles (cyan) are dragged to identify the entire surface. Finally, the meshes are smoothed by fitting piecewise polynomials to handle locations in the sagittal, coronal and frontal planes. Differences between the initial generic and final control handle 3D coordinates are calculated and exported as a script to morph the meshes in Hypermesh. The morphing method was used to generate hexahedral meshes for the femoral cartilage
from MR images (CISS sequence, 512x512 pixels, 0.35 mm in-plane resolution, 1 mm slice thickness) of two healthy adult cadaver specimens. Hexahedral meshes for each femur were also generated by a combination of traditional segmentation using ScanIP (Simpleware, Exeter, UK) and manual solid mesh generation techniques in Hypermesh. Mesh differences were quantified by calculating the root mean square (RMS) difference between the 3D mesh nodal coordinates generated with each method.

**RESULTS**

The RMS differences between the GUI-morphed and manually segmented femoral surfaces for the two specimens were 0.63 and 1.24 mm, respectively (Figure 2). Meshes generated with the semi-automated method were appropriate for contact analysis and required approximately 30 minutes per femur, while generation of meshes with traditional segmentation and meshing procedures averaged 3 hours per femur.

**DISCUSSION AND CONCLUSIONS**

This study utilized a novel semi-automated GUI-based method to generate specimen-specific hexahedral meshes of femoral cartilage. Additionally, meshes generated with the semi-automated technique were compared to meshes generated with traditional segmentation, with an average RMS difference of 0.94 mm. This difference is comparable to RMS differences (0.34-0.62 mm) found for patellar and tibial cartilage mesh generation with a similar technique (Baldwin et al., 2008), and is within the reported range (0.5-4 mm) for semi-automated mesh generation of bones (Shim et al., 2007). These results imply that semi-automated mesh generation for other joints, such as the shoulder and hip, may be possible with appropriate MR scans.

**REFERENCES**

Baldwin et al. (2008) *Trans ORS* 635.

**ACKNOWLEDGEMENTS**

This research was supported in part by DePuy, a Johnson & Johnson Company.