Validation of Three Dimensional Models of the Distal Femur Created from Surgical Navigation Data

Pia Bücher, BSc¹, David A. Wilson, BENG, MASc, MD², Carl Martin Grewe, BSc¹, Valentin Mocanu, Bsc², Stefan Zachow, Phd¹, Carolyn Anglin, PhD³, Michael Dunbar, MD².
¹ZIB, Berlin, Germany, ²Dalhousie, Halifax, NS, Canada, ³University of Calgary, Calgary, AB, Canada.


Introduction: Long term satisfaction of patients with total knee arthroplasty (TKA) has lagged behind that of total hip arthroplasty (Bourne et al. 2010). One explanation for this dissatisfaction is a mismatch between the shape of the native distal femur and its shape post-operatively which could have detrimental functional implications to the joint and therefore an awkward ‘feel’ during use. The shape of the distal femur following surgery is dependent of two factors, the shape of the femoral component and its positioning when implanted. The impact of this mismatch is unknown as the three dimensional morphology of the distal femur is not measured during surgery, nor is the exact position the implant recorded in conventional knee arthroplasty surgery.

A technique that would allow for quick feedback on morphologic concordance between the native femur and implanted femur with no additional imaging requirement could potentially offer a pathway to optimize function and satisfaction.

Statistical shape models provide the ability to generate various plausible shapes of a certain anatomical structure by adjustment of just a few parameters, the so called shape modes. Commonly, they are used to segment anatomical structures in medical image data by optimizing the shape modes in order to match features extracted from the images.

The objective of this study was to develop and validate a fitting procedure for a statistical shape model of the distal femur using data collected routinely intraoperatively as part of surgical navigation total knee arthroplasty.

Methods:  A total of 20 patients who underwent navigated total knee arthroplasty also had an MRI performed within 2 months preoperatively as part of a previous study protocol. These patients data were selected to be used in this study. Of these subjects the first 3 processed cases are presented here. During surgery the standard surgical protocol was followed which included digitization of the anterior cortex of the femur, the distal and posterior femoral condyles, the medial and lateral epicondyles and the femoral center (a point roughly corresponding to the entry point for a intramedullary guide rod). Post-operatively these data were extracted from the navigation unit and imported into Matlab (Mathworks, Massachusetts, USA) and stored as point clouds. A statistical shape model adapted from previous work was optimized iteratively to approximate the shape of the distal femur from available point clouds. To overcome the challenge in fitting the statistical shape model to a sparse point cloud, a Gaussian prior with adjustable distribution parameters was used in an alternating optimization scheme to constrain the generation of femoral shapes while still allowing the flexibility to adapt to individual features. To account for measurement errors, a robust correspondence estimator was used for
optimization of the rigid transformation and shape parameters. The final statistical shape models were exported into ZibAmira (ZIB, Berlin, Germany) for further analysis.

The MRI data from the same group patients was segmented to develop 3-D models using ZibAmira. The segmented MRI data was used as the control against which the statistical shape model was compared. The quality of the statistical shape model was evaluated visually and by calculation of the mean and RMS error of the models.

**Results:** An example of the optimized statistical shape model femur with the provided surgical navigation points overlaid for a sample patient can be seen in figure 1. Comparison of the statistical shape model with the femoral models obtained from the segmented MRI data can be seen in figure 2. The error between the statistical shape model and the MRI are summarized in Table 1. The average error for the three cases was 1.21mm, 1.56 and 1.61mm.

**Discussion:** As total knee arthroplasty evolves, a patient specific approach is going to be demanded by patients. Using a image based navigation system is one option to have accurate intraoperative morphologic information. However, it relies on accurate registration of the image based model to the operative anatomy, and adds additional cost and time to acquire and input the images to the navigation system.

The results of this study show that even with the relatively sparse data set available from routine navigated total knee arthroplasty, the statistical shape model can provide an accurate approximation of the distal femur. These models can be used retrospectively to compare native anatomy with implant positioning, providing valuable insight into patient function and satisfaction. In the future these models could be incorporated into a surgical navigation unit and provide a surgeon with accurate real time feedback on the exact concordance of the proposed femoral component positioning with the native anatomy without any additional imaging.

**Significance:** This technique is an important step in the development of a patient morphology-specific TKA protocol. First it will help establish the link between distal femoral shape and patient outcomes through retrospective analysis of navigation cases. In the future, it could be used to provide surgeons with detailed morphologic information in real time in the OR to compare proposed implant shape and position with native anatomy. This could allow for optimization of implant selection and position for a given patient and potentially improve patient satisfaction and function.
Table 1: Surface distance (in mm) between automatic fitting result and manual segmentation.

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*ORIS 2015 Annual Meeting  
Poster No: 0874*