LIGAMENT ESTIMATION FROM *IN VIVO* KNEE MOTION: AN INVERSE-KINEMATICS MODEL

[1]Elvis C.S. Chen and [1,2]Randy E. Ellis
[1]School of Computing, Queen's University, Canada, [2]Harvard Medical School, U.S.A.
email: chene@cs.queensu.ca, ellis@bwh.harvard.edu

INTRODUCTION

A forward-kinematics knee (FKK) model was previously introduced [1]: given a joint angle, the precise knowledge of the articular geometry plus mechanical properties of knee ligaments, the FKK model predicted where the femoro-tibial contacts were based on the principle of ligament energy-minimization. Knee motion was simulated by finding successive contacts from full extension to full flexion. We now introduce an inverse-kinematics knee (IKK) model that performs the opposite: given an observed knee motion, determine the joint angle and the *in vivo* femoro-tibial contact. The *in vivo* contacts were validated using Fuji-films. Together, the FKK/IKK pair form a *predictor-corrector* loop that can then be used in a parameter-estimation algorithm to find the ligament insertion locations and neutral length of the individual patient.

METHODS

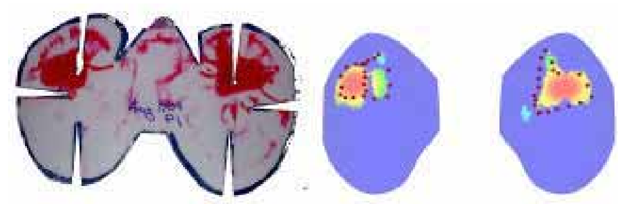
Articular surfaces of aTotal Knee Replacement (TKR) prosthesis were laser-scanned at 0.25mm resolution and computer models of the surfaces, in the form of point clouds with surface normals, were reconstructed. TKR components were mounted to a knee-jig in which they were held in contact by tensile forces of 6 springs: 3 mimicking MCL, 3 mimicking LCL. The mechanical properties of each of the 6 springs, including length, spring constant, and insertion location relative to TKR components, were previously measured.

TKR components were attached with Dynamic Reference Bodies and their motion, while in contact with each other, were tracked by a 3D optical tracker. An image-free contact-determination algorithm was developed to find the *in vivo* femoro-tibial contacts. Based on proximity search and facilitated by a KD-tree, this algorithm was able to find the femoro-tibial contact under 1sec for each joint pose. For experiments involving Fuji-films, the entire knee jig was mounted to a FORCE5 manipulator that applied 100lb of downward force to produce imprints on Fuji-films

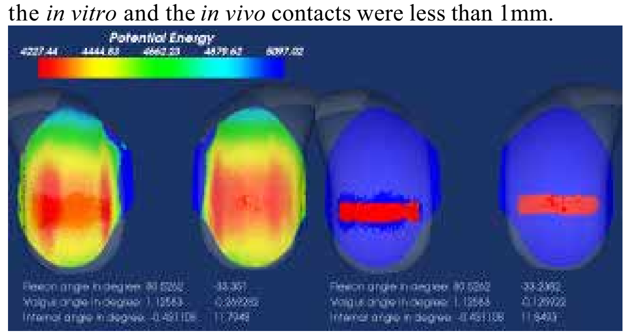
Two sets of contact locations were determined for each joint angle: one *predicted* from the FKK model and the other *observed* from the contact-determination algorithm. Together, they form a *predictor-corrector* pair that can then be fed into a parameter-estimation algorithm, in which the parameters to be estimated were the ligament mechanical properties (neutral length, insertion locations, and spring constant) that would produce the observed knee motion.

RESULTS AND DISCUSSION

A size-3 Sigma Knee (Johnson & Johnson), represented by approximately 31,000 and 19,000 points for the femoral and tibial components respectively, was used for this study. The contact-determination algorithm was first validated using Fuji-films: the perimeter of the Fuji-film contacts were digitized and superimposed to those found by our algorithm. They showed high degree of conformity.



For each recorded joint pose, the joint angle (without translation), along with known ligament information, were fed to the FKK model. The FKK model produced an *energy map* and regions with the lowest energy were selected as the *in vitro* contact. The same pose was also fed into the contact-determination algorithm and the *in vivo* contact was produced. Numerically, the difference in the translations found between the *in vitro* and the *in vivo* contacts were less than 1mm.



These sets of predicted *in vitro* and observed *in vivo* contacts were then used in a parameter-estimation algorithm in which the ligament information was treated as the unknown. Our implementation was able to correctly estimate the ligament insertions that were intentionally and erroneously guessed at 10mm away from the correct location. The *predictor-corrector* paradigm can also be used to test different hypotheses of ligament model: simulations suggested that a single-fibre ligament model could produce kinematics that was similar to a multi-fibres (3) ligament model in Sigma Knee.

CONCLUSIONS

We proposed an inverse-kinematics knee model. Combined with a forward-kinematics model, this *predictor-corrector* pair can be used to estimate ligament parameters such as ligament insertions. Furthermore, it can be used to test different hypotheses of the ligament model, based solely from a sequence of *in vivo* knee motion. We also introduced an image-free, nearly real-time contact-determination algorithm. Application includes, but not limited to, post-TKR assessment.

REFERENCES

1. Chen *et al* (2001). *Medical Image Analysis* **5**(3), 317-330

ACKNOWLEDGEMENTS

Joel Lanovaz assisted in the development of the knee jig.
Support in part was provided by NSERC, CITO, and ORDCF.