PRE-PLANNING OF HIGH TIBIAL OSTEOTOMY: THE EFFECT OF LIGAMENTOUS TISSUES

M. Iravani MSc[1], F. Farahmand PhD[1,2*], S. Medhipour MD[3,] M. Hovittalab MSc[1]

[1] Mechanical Engineering Department, Sharif University of Technology, Tehran, Iran

[2*]RCBTR, Tehran University of Medical Sciences, Tehran, Iran, farahmand@shairf.edu

[3] Orthopaedics Department, Tehran Clinic, Tehran, Iran

INTRODUCTION

High tibial osteotomy (HTO) is a common surgical procedure for treatment of patients with varus malalignment. Relatively good short- and mid-term results have been reported for this procedure in clinical literature [1,2]. However, the success rate seems to be strongly dependent on the quality of the correction It has been reported that undercorrection and overcorrection can both lead to poor results, due to the persisting high loads on the medial compartment of the knee, or overloading of its lateral compartment, respectively [3,4] .
An accurate pre-planning is thus essential to ensure that the precise amount of alignment is achieved postoperatively. The idea is to find the osteotomy wedge angle such that the mechanical axis, which runs from the centre of the hip to the centre of the ankle, passes through the middle of the knee joint. In the current geometric approach, the appropriate wedge angle is found based on the measurements performed on the pre-operative radiographs or CT scans of the patient. However, such method does not consider the post-operative changes in the knee joint configuration, caused due to the deformation of the soft ligamentous tissues.
Previous biomechanical studies on the HTO, on the other hand, have often neglected the relationship between the anatomical correction, applied during surgery, and the resulting alteration of the loading axis. Mostly, the effect of HTO has been modelled as a change in the knee varus moment without any explicit relationship with the wedge angle [5,6]. Some others [7,8] have prevented the knee joint abduction-adduction reconfiguration by restricting the joint's degrees of freedom to only in the line with the mechanical axis.
The purpose of the present study was to simulate the HTO in a patient with varus deformity in order to explore the interactions between the wedge angle, the mechanical axis, and the knee joint configuration.

MATERIALS AND METHODS

A finite element model of the knee joint of a 19-year-old male patient with 5 degrees varus deformity was developed in ABAQUS. The geometry of the model was obtained using CT scans of the whole lower limb, as well as the MRI of the knee joint. The model included the distal femur, coupled with the centre of the hip, and the proximal tibia, coupled with the centre of the ankle, both assumed as rigid bodies. The articular cartilage, over the femoral and tibial articular surfaces, and knee meniscus were modelled as homogenous, isotropic, and linearly elastic solids. The ligamentous tissues, including the ACL and PCL (each having 2 bundles), and the MCL and LCL (each having 3 bundles), were represented by nonlinear springs (Fig 1-left). All mechanical properties were obtained from the literature.
The contact between femur, tibia and meniscus was modelled as frictionless general contact. The tibia was considered completely fixed and the femur free to rotate and translate in all degrees of freedom, except for flexion-extension that was fixed around the transepicondylar

axis at full extension. A 600N body force was applied at the femoral head in the line of the mechanical axis (Fig 1-right), and the resulting knee joint configuration, as well as the tensions in the ligament bundles and the contact stresses at the femoral and tibial articular cartilage and meniscus were studied.
The HTO was simulated assuming insertion of wedges with different angles at 35 mm beneath the tibial platue and applying the resulting alteration of the loading axis to the model. The effect of the knee ligaments' stiffness on the results was also investigated by reducing their stiffness to half the original values.

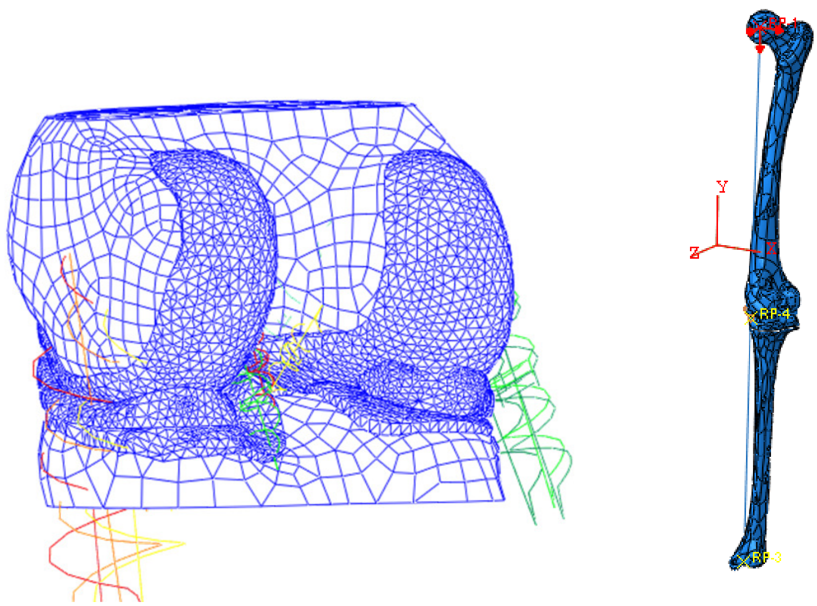

Figure 1: The finite element model of the knee (left) loaded in the line of the mechanical axis (right).

RESULTS AND DISCUSSION

The results of the model in pre-operative condition indicated larger contact areas and higher contact stresses at the knee medial compartment. The maximum stresses were 4.1 MPa in the medial and 1.8 MPa in the lateral sides, similar to the reports in the literature. A higher tension, up to 330 N, was also observed in the LCL in comparison with the other ligaments. The change of the ligaments' stiffnesses did not change the results considerably except for the LCL.
When the HTO was simulated, the model predicted larger contact areas and stresses at the lateral side. With the stresses redistributed, lower maximum stresses were observed as small as 2.5 MPa at the medial and 2.5 MPa at the lateral compartments for a wedge angle of 8 degrees.
Figure 2 depicts the predictions of the model for the relationship between the wedge angle and the change of the mechanical axis following HTO. The dashed line indicates the resulting alteration of the mechanical axis for each wedge angle, based on the geometric pre-planning approach that does not consider the post-operative change of the knee joint configuration. The actual change of the mechanical axis, however, is always smaller and depends on the stiffness of the ligaments. For instance, while a 24 degrees wedge changes the mechanical axes by 10 degrees, based on the geometric approach, the actual postoperative change is predicted by the model to be only 7 degrees for a knee with normal ligaments and much smaller if the ligaments are of low stiffness. Considering the sensitivity of the HTO to the

correct amount of alignment [3,4], poor clinical results would not be unexpected with the current setting for pre-planning.

Our results, in general, suggest that the subject-specific models are needed to simulate the HTO in patients before surgery and determine the appropriate wedge angle that locates the mechanical axis in the middle of the knee. The present study is the first step towards developing such a model and suffers from several limitations and simplifications that necessitate further investigations.

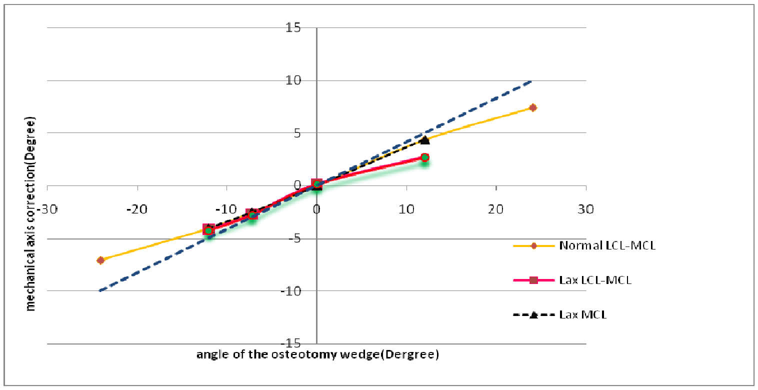

Figure 2: The relationship between the wedge angle and the mechanical axis correction predicted by the model for different ligaments' stiffnessess in comparison with that of the geometric approach (dashed line).

REFERENCES

[1] J. D. Agneskirchner, C. Hurschler, C. D. Wrann, and P. Lobenhoffer, "The effects of valgus medial opening wedge high tibial osteotomy on articular cartilage pressure of the knee: a biomechanical study," *Arthroscopy: The Journal of Arthroscopic & Related Surgery,* vol. 23, pp. 852-861, 2007.

[2] P. Hernigou, D. Medevielle, J. Debeyre, and D. Goutallier, "Proximal tibial osteotomy for osteoarthritis with varus deformity. A ten to thirteen-year follow-up study," *The Journal of bone and joint surgery. American volume,* vol. 69, pp. 332-354, 1987.

[3] S. Odenbring, N. Egund, K. Knutson, A. Lindstrand, and S. T. Larsen, "Revision after osteotomy for gonarthrosis: a 10-19-year follow-up of 314 cases," *Acta Orthopaedica,* vol. 61, pp. 128-130, 1990.

[4] T. W. Dugdale, F. R. Noyes, and D. Styer, "Preoperative Planning for High Tibial Osteotomy: The Effect of Lateral Tibiofemoral Separation and Tibiofemoral Length," *Clinical orthopaedics and related research,* vol. 274, pp. 248-264, 1992.

[5] T. Bhatnagar and T. R. Jenkyn, "Internal kinetic changes in the knee due to high tibial osteotomy are well-correlated with change in external adduction moment: an osteoarthritic knee model," *Journal of Biomechanics,* 43: 2261-2266, 2010.

[6] E. Chao and F. H. Sim, "Computer-aided preoperative planning in knee osteotomy," *The Iowa orthopaedic journal,* 15: 4-18, 1995.

[7] H. Atmaca, A. Özkan, İ. Mutlu, T. Çelik, L. Ugur, and Y. Kisioglu, "The effect of proximal tibial corrective osteotomy on menisci, tibia and tarsal bones: a finite

element model study of tibia vara," *The International Journal of Medical Robotics and Computer Assisted Surgery,* vol. 10, pp. 93-97, 2014.

[8] A. Özkan, H. Atmaca, İ. Mutlu, T. Celik, L. Uğur, and Y. Kişioğlu, "Stress distribution comparisons of foot bones in patient with tibia vara: a finite element study," *Acta of bioengineering and biomechanics/Wrocław University of Technology,* vol. 15, p. 67, 2013.