EXPERIMENTAL VALIDATION OF FINITE ELEMENT MODELING OF CREEP BEHAVIOR OF HUMAN KNEE JOINT

M.L. Rodriguez[1], S. Uzuner[2], and L.P. Li[1]

[1]*Department of Mechanical & Manufacturing Engineering, University of Calgary, Calgary, Canada*
[2]*Duzce University, Duzce, Turkey*

E-mail: Leping.Li@ucalgary.ca

1. Introduction

The human knee joint primarily performs mechanical functions during daily life activities. The contact mechanics of the joint is predominantly influenced by the mechanical properties of articular cartilages and menisci that exhibit strong creep and relaxation behaviors, which must be understood in order to discover the mechanism of cartilage mechanobiology, joint injury and disease. While past studies investigated either the poromechanics of individual tissues or the elasticity of the whole joint, we are interested in the poromechanics of the intact knee joint. The joint functions may be better appreciated when the fluid pressure/flow and anatomically accurate knee structure are considered simultaneously. We have first developed a fibril-reinforced model of articular cartilage using multiple experimental validations. This tissue model highlights the interplay between the collagen fibril-reinforcement and fluid pressurization in the tissues. We have then implemented the constitutive model in a patient-specific knee joint model using 3-Tesla magnetic resonance imaging (MRI) in order to determine the creep, relaxation and contact mechanics of the knee joint modulated by the fluid pressurization in the tissues. This joint model was found to be able to predict the load support of the knee joint and load share between cartilages and menisci that cannot be described with an elastic model of the knee joint. The objective of the present study is to further validate and refine the previous model with dual fluoroscopic (DF) measurement of human participants (Fig. 1).

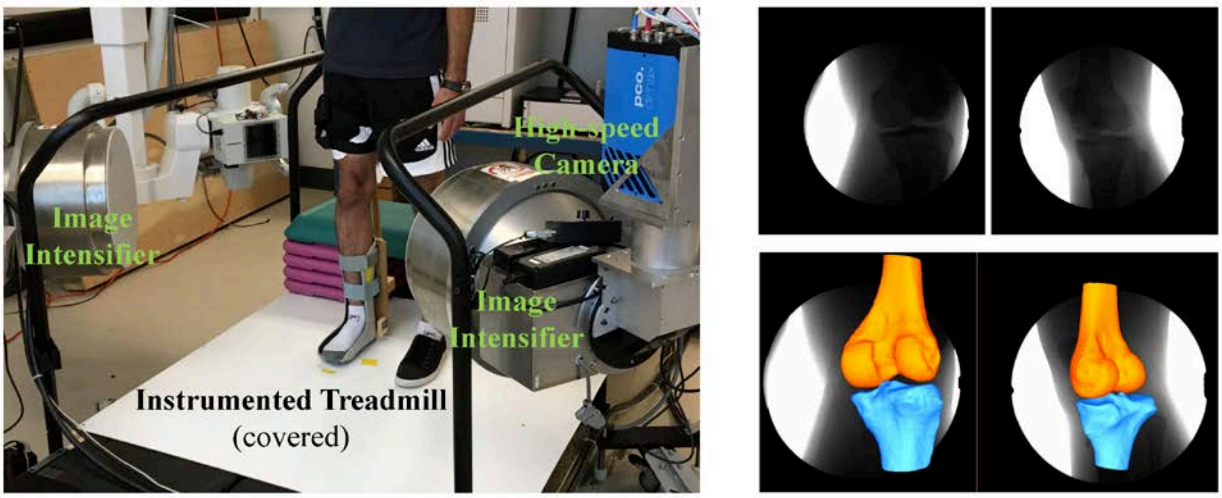

Figure 1: Experimental setup (left) and images from the two cameras of different angles (right).

2. Methods

We have so far performed 2 healthy adult knee measurements with 1 female and 1 male. Tests were done in early morning to minimize residual tissue deformation. The participants were given car rides from home and moved in wheelchairs to the test facility. The subjects further remained seated in an MRI compatible wheelchair for 30 minutes, before 3-Tesla MR images (Fiesta with GE MR750) were obtained from the unloaded knee. Afterwards, the right knee was imaged with biplanar DF while half body weight was gradually applied to the leg in approximately 5 seconds, followed by a 10-minute creep. Images were acquired from two cameras at a frame rate of 6Hz, continuously for the first minute and at 6Hz for 2 s intermittently with 30-second breaks for the rest nine minutes. The measurement was calibrated and image distortion corrected. A 2D-3D image registration approach was used to align the DF images with 3D MRI based model of the joint in order to determine the bone displacement. The ground reaction was simultaneously recorded with a Bertec instrumented treadmill. The 3D MRI model was also used for finite element analysis, whose procedure has been previously developed.

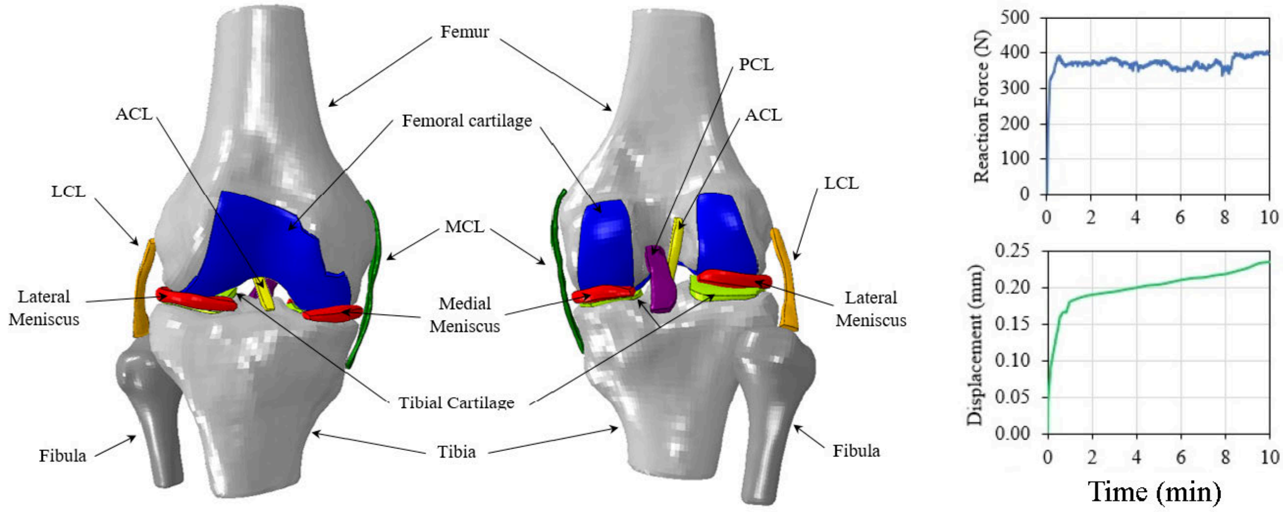

Figure 2: Knee joint model reconstructed from MRI in anterior (left) and posterior (middle) views (patellar not included), showing also the vertical reaction force measured by a force plate (upper right) and knee compression determined from DF images (lower right).

3. Results

Although there was no lab control on the weight applied on the knee in observation, a creep loading was followed pretty well in both measurements; only small fluctuations were observed (Fig. 2). The displacement found in the vertical direction of distal femur and proximal tibia indicates a nearly standard creep deformation in the joint (Fig. 2), although 3D displacement/rotation actually occurred with a maximum rotation of 4^{o} and a maximum horizontal displacement of 1.5mm. A preliminary finite element analysis on the first measurement indicated a stiffer than expected knee. The data processing and modeling on the second measurement are still ongoing.

4. Discussion

The human knee measurements indeed demonstrated creep response, as predicted in our finite element modeling, and comparable with our lab tests of fresh porcine joint specimens. In particular, significant creep deformation can be developed in a minute, which indicates the necessity of considering creep response in the joint modeling that has not drawn sufficient attention in the area.

Live human measurement appears to be complicated, but a creep loading protocol can still be performed with satisfaction. In addition to model validation, our combined measurement and modelling approach will further determine the stress and pressure in the joint using measured displacements, which may be used to evaluate cartilage health state in vivo.

Acknowledgments The authors appreciate the use of Dr. Janet Ronsky lab and great help from her team. We also acknowledge the financial support of the Natural Sciences and Engineering Research Council of Canada. Human measurements were performed with research ethics REB15-1165_REN3 at the University of Calgary.