SUBJECT-SPECIFIC KNEE LIGAMENTS MODELING APPROACHES IN FINITE ELEMENT ANALYSIS: 1D AND 3D

Hamid Naghibi Beidokhti (1), Dennis Janssen (1), Sebastiaan van de Groes (2), Ton van den Boogaard (3), Nico Verdonschot (1)

1. Orthopaedic Research Lab, Radboud University Nijmegen Medical Centre, The Netherlands; 2.Orthopaedic Department, Radboudumc, Nijmegen, The Netherlands; 3. Department of Applied Mechanics, University of Twente, The Netherlands.

Introduction

Knee ligaments are among the most complicated structures and have a large effect on knee biomechanics. There are different approaches to model the knee ligaments in FE models. In the knee joint, ligaments have been commonly modelled as 1D spring elements; moreover, some studies modelled the ligaments as 3D constitutive elements [2].

Using springs reduces computational costs compared to constitutive models of the ligaments. In turn, constitutive models closer approximate the anatomy, and facilitate the prediction of local quantities and interactions with surrounding tissues, such as wrapping [1].

To the best of our knowledge, there is no direct/practical comparison study between two FE ligament modelling approaches. The aim of this study is to develop and compare two separate subject-specific finite element knee models in terms of ligament modelling approaches, based on cadaveric validation experiments.

Materials and Methods

Two FE knee models were developed based on MRI data of a cadaveric knee, including bones, cartilage, menisci and ligaments. In the first model all tibiofemoral ligaments were modelled using solid elements with nonlinear transversely isotropic fiberic materials using the Holzapfel–Gasser–Ogden model. In the second model, the ligaments were represented by nonlinear no-compression springs, where the cruciate and collateral ligaments were modelled as two and three bundles, each, respectively. In both models, the ligament properties, including the collagenous fiber properties and ligament pre-tension were separately optimized based on cadaveric laxity tests, starting from data in the literature. Subsequently, both models were validated according to a series of validation experiments. The joint kinematics, tibial cartilage contact pressure (on the lateral plateau) and computational costs were compared.

Results

Both optimized models could closely follow the experimental translations, in unloaded, tibial axially loaded (106N) and anteriorly loaded (100N) passive flexions. However, constitutive model revealed better agreement with the experiment in valgus-varus rotations in both loaded and unloaded flexions cases (Figure1). Contact variables are listed in Table1 for the experiment, optimized constitutive model and optimized spring model. The average computational time for each spring and constitutive models were approximately 25 and 40 minutes, respectively.

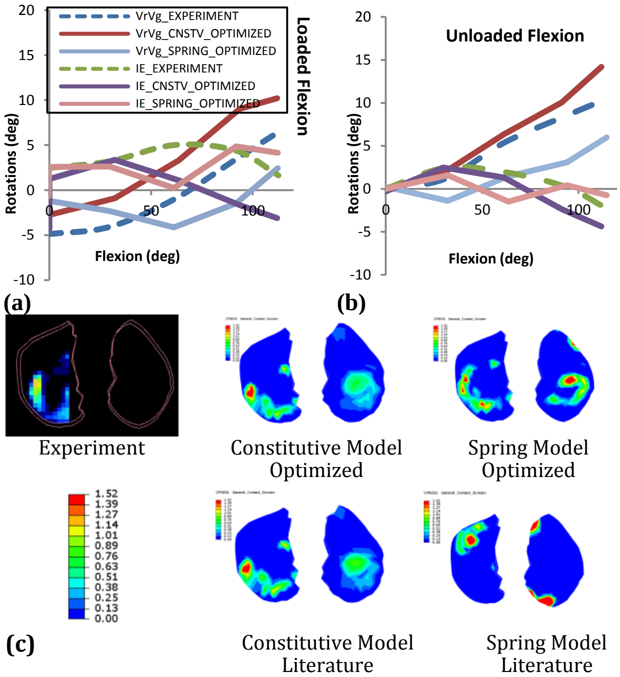

Figure 1: knee Rotations predictions of spring and constitutive models vs. experiment in loaded flexion (a), and unloaded flexion (b); contact pressure on tibial cartilage at flexion angle of 60 deg. (c).

Flexion Angle (deg)	Experiment		Constitutive Model		Spring Model	
	Peak Pressure (MPa)	Contact Area (mm2)	Peak Pressure (MPa)	Contact Area (mm2)	Peak Pressure (MPa)	Contact Area (mm2)
0	0.74	290	0.98	247	1.14	118
30	0.72	435	0.95	367	0.62	282
60	1.18	341	1.57	380	1.52	440
90	1.54	290	1.96	430	1.75	483
110	1.36	214	2.14	457	2.24	397

Table 1: contact variables at lateral tibial cartilage in tibial axially loaded (106N) passive flexion.

Conclusion

Both subject-specific knee FE models, the faster spring model and the more realistic and detailed constitutive model, could successfully predict the biomechanics of the joint. Implementing the properties from the literature can misguide the analyses to wrong solutions.

References

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2. Kazemi et al, Comput. Math. Methods Med., 2013: 1-27, 2013.

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