Identification of Subject-specific Dynamic Laxity Tests to Stretch Individual Parts of Knee Ligaments

Michael S. Andersen[1], Ilias Theodorakos[1]
[1]Center for Mathematical Modeling of Knee Osteoarthritis, Department of Materials and Production, Aalborg University, Denmark
Email: msa@mp.aau.dk

Summary

We developed an approach to identify optimal, dynamic knee laxity tests to stretch individual parts of knee ligaments. For most ligaments, we found novel laxity tests that better isolate the stretch in each ligament compared to standard laxity tests. Our results can be applied to develop better laxity testing protocols than currently applied to diagnose ligament injuries or identify ligament properties from laxity tests.

Introduction

Knee instability can lead to pain, joint degradation and an overall reduced quality-of-life [1]. As ligaments are among the elements that ensure the passive joint stability, it is important to gain a deeper insight of their mechanical properties *in vivo*, which cannot be measured directly.

Recently, we developed a 3D laxity measurement technology [2] that enables applying any load case. This provides an opportunity to design laxity tests that target the stretch of some ligaments relatively more to others. Identification of such laxity tests were the aim of this study.

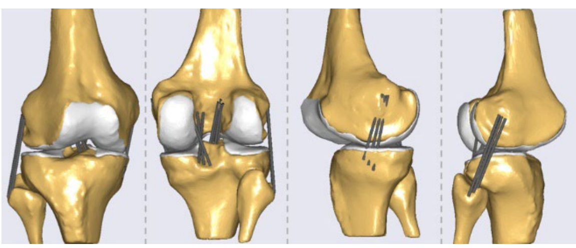

Figure 1: Illustration of the applied knee model.

Methods

A knee model (Fig. 1) based on MRI scans of a female subject (27 year-old, 1.72 m, 61 kg) was developed in the AnyBody Modeling System (AnyBody Technology, Denmark) using the Force-dependent Kinematics (FDK) approach [3], simultaneously solving for knee kinematics and quasi-static force-equilibrium. The model included contact between the tibial and femoral cartilage and the four major ligaments (ACL, PCL, MCL and LCL). The inputs to the model were the knee flexion angle and applied force and moment to tibia.

We generated ~100.000 random combinations of applied forces (0 – 150 N), moments (0 – 10 Nm) and knee flexion angles (0 – 90°). Then, for each ligament bundle, we identified ten "optimal laxity tests": the one that led to the highest ligament force and then nine others that were evenly distributed between zero force and the identified maximal force within 10 N and which also minimized the maximum force in all other ligament bundles.

For comparison to the optimal laxity tests, we also computed the ligament forces with the standard varus/valgus and internal/external laxity tests for 0, 30, 60 and 90 degrees of knee flexion and denote these as the "standard tests".

To assess how well each load case isolated the stretch in the ligament bundle of interest, we defined an "isolation metric" based on the areas under the force-strain curve from zero up to the maximal strain. The isolation metric was defined as the ratio of the area under the force-strain curve for the ligament bundle of interest divided by the maximum area of all other ligament bundles.

Results and Discussion

The optimal laxity tests improved the isolation metric for all ligament bundles (Table 1) except the posterior bundle of PCL, which showed a slight decrease of 32%. We found improvements of up to 450% (for pMCL) among the other ligament bundles. Neither the standard nor optimal laxity tests were able to stretch the anterior bundles of the PCL and LCL.

Conclusions

In this study, we presented a method to identify optimal dynamic laxity tests to stretch individual ligament bundles. This approach, and the obtained results, can be applied to develop future measurement protocols, ultimately leading to a better estimation of knee ligament properties *in vivo*.

References

[1] Nevill MC, et al., *Arthritis Care Res,* **68**:1089-1097, 2016.
[2] Pedersen et al., *J Biomech*, **82**:62-69, 2019.
[3] Andersen et al., *J Biomech Eng*, **139**: 091001, 2017.

Table 1: 1 Isolation metric for each of the ligament bundles with the optimized and standard test.

Ligament bundle	amACL	alACL	pmACL	plACL	aPCL	mPCL	pPCL	aLCL	mLCL	pLCL	aMCL	mMCL	pMCL
Isolation metric [] (optimized tests)	0.228	0.240	0.406	0.426	0.000	0.212	1.227	0.000	0.154	1.141	0.427	0.413	0.061
Isolation metric [] (standard tests)	0.125	0.120	0.318	0.302	0.000	0.042	1.797	0.000	0.040	0.557	0.310	0.208	0.011
Improvements in isolation metric [%]	83	101	28	41	-	405	-32	-	281	105	38	99	450