IN VIVO ANALYSIS OF MENISCAL AND TIBIOFEMORAL KINEMATICS IN CRUCIATE LIGAMENT-DEFICIENT KNEES USING KINEMATIC MAGNETIC RESONANCE IMAGING

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INTRODUCTION

Deficiency of the anterior or posterior cruciate ligaments (ACL & PCL) can lead to altered knee and meniscal kinematics. Although cadaveric studies have demonstrated that cruciate ligament deficiencies can cause abnormal meniscal load, no studies have evaluated the changes in in vivo meniscal kinematics. Recently, kinematic magnetic resonance imaging (MRI) has been utilized for non-invasive analysis of knee kinematics under axial load. In this study, a method using kinematic MRI is developed to explore the feasibility of assessing abnormal meniscal and TF kinematics in cruciate ligament deficient knees.

METHODS

One chronic ACL-deficient patient (29 y.o. male, 6 yrs post-injury) and one subacute PCL-deficient patient (30 y.o. female, 8 months post-injury) were studied. Both patients have clinically apparent ligament insufficiency when compared with the contralateral uninjured knee. Sagittal MR images were acquired with a SIGNA 1.5T scanner (GE Medical Systems, Waukesha, WI) and a dual phased-array coil (USA Instruments, Cleveland, OH), using a fast spin echo sequence (3000/9.1 ms, 16 cm FOV and $0.31\times0.31\times1.5$ mm^3 voxel size). Each knee was imaged in extension (~−10°) and flexion (~45°) with 12.7 kg of axial load. A custom-made knee holder was used to constrain the knee. Three-dimensional image reconstruction [1] was used to quantitate knee flexion angle (FA), internal tibial rotation (ITR) and anterior and medial tibial translation (ATT & MTT) of tibiofemoral kinematics. Menisci shape and positions on the tibial plateau were also reconstructed. The centroids of the contact areas of the medial and lateral compartments were also determined.

RESULTS

Changes in TF kinematics between different knee and knee flexion angles are listed in Table 1. A negative value indicates translation in the opposite direction. For the ACL-def patient, the clinical examination is significant for a 1A lachman, 3mm side-to-side ATT difference with a good endpoint. Kinematic MRI revealed a 2.41 mm and 1.09 mm difference in ATT between the contralateral intact knee and the ACL deficient knee in extension and flexion respectively. The centroid of the medial compartment shifted posteriorly and the corresponding medial meniscus excursion also decreased between flexion and extension by 4mm. For the PCL deficient patient, the clinical examination is significant for a 2B posterior drawer, 5-10 mm posterior tibial translation with no solid endpoint. Kinematic MRI revealed a -1.16 mm and -7.13 mm difference in ATT between the contralateral intact and PCL deficient knee. Both the medial and lateral menisci has decrease excursion between flexion and extension while the centroid of the contact area shifted anteriorly.

Table 1 Changes in TF kinematics between various knee conditions for the ACL-def and PCL-def patients. ITR – internal tibial rotation (°), ATT – anterior tibial translation (mm), MTT – medial tibial translation (mm)

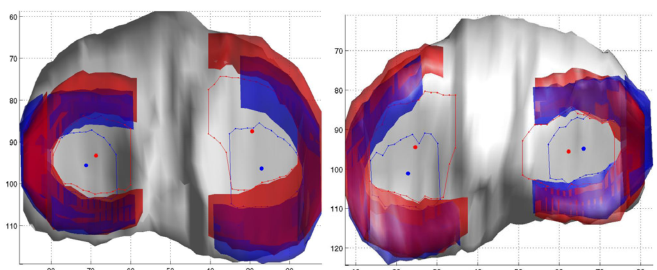
Table 1A Changes of TF kinematics in ACL-def patient

Changes in Knee Conditions	ITR	ATT	MTT
LT/Ext†→ LT/Flx	3.49°	6.31 mm	1.20 mm
RT/Ext → RT/Flx	2.04°	3.35 mm	1.39 mm
LT/Ext → RT/Ext	-1.41°	2.41 mm	-0.32 mm
LT/Flx → RT/Flx	-1.38°	1.09 mm	1.24 mm

†LT/Ext: left knee in extension. RT/Flx: right knee in flexion.

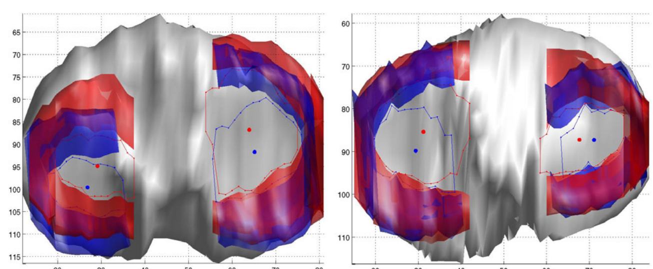
Table 1B Changes of TF kinematics in PCL-def patient

Changes in Knee Conditions	ITR	ATT	MTT
LT/Ext → LT/Flx	8.00°	7.80 mm	0.46 mm
RT/Ext → RT/Flx	6.86°	2.14 mm	3.02 mm
LT/Ext → RT/Ext	-0.68°	-1.16 mm	-2.44 mm
LT/Flx → RT/Flx	-0.72°	-7.13 mm	0.50 mm



Contralateral intact knee ACL deficient knee

Fig. 1A Menisci kinematics for the ACL deficient patient.



Contralateral intact knee PCL deficient knee

Fig. 1B Menisci kinematics for the PCL-deficient patient.

Figure 1 Menisci positions in extension are represented in red while in flexion are represented in blue. The centroids of the contact area for the medial and lateral compartments are also illustrated by the red (extension) and blue (flexion) dots on the respective tibial plateau.

DISCUSSION

Kinematic MRI demonstrated that significant changes are present between in vivo TF and meniscal kinematics following cruciate ligament deficiencies. The ATT results from the axial loaded knee are comparable with the results from clinical examinations. The study has demonstrated that cruciate ligament deficiency can lead to changes in the contact area and meniscal kinematics. More specifically, the meniscus position of the tibial plateau and its excursion can be significantly altered between flexion and extension and competency of the cruciate ligaments. Abnormal meniscal kinematics may lead to abnormal load and stress under weight-bearing conditions.

This study provides the foundation for further work in evaluating meniscal and tibiofemoral kinematics in cruciate ligament-deficient knees. This non-invasive analysis on in vivo biomechanics for simulated weight-bearing conditions may allow us to predict meniscus injuries and premature osteoarthritis. We are currently evaluating patients with symptomatic cruciate ligament insufficiencies pre- and post- ligament reconstruction to determine whether intact TF and meniscal kinematics can be restored following ligament reconstructions.

REFERENCE

[1] Slavinsky JP, et al. A Combination of Rigid and Elastic Registration Methods for a Standard Atlas of the Knee. Proc. ISMRM 11th Scientific Meeting, Toronto, ON, Canada, 2003.