Determination of the meniscal deformation under compressive loading through MR-imaging

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Introduction

Understanding the biomechanical behaviour of the meniscus can be helpful to improve meniscal repair, meniscal replacements and its surgical techniques. Although information about the biomechanical behaviour can be determined in isolated menisci, the testing of an intact knee joint is of outmost importance to clearly understand the meniscal behaviour in interaction with other tissues in an intact environment. MRI acquisition is the method of choice, as the inner parts of the knee can be assessed. The objective of this study was to determine the three dimensional (3D) meniscal deformation as well as the behaviour of its attachments under compressive loading.

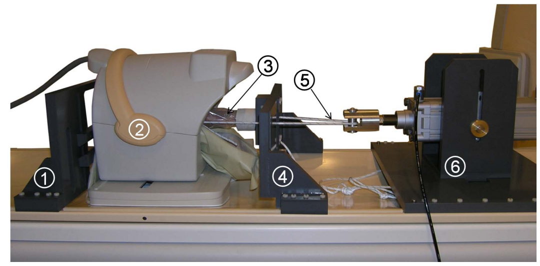

Figure 1: loading apparatus on a MRI-table, femur fixture (1), knee coil (2), specimen (3), tibia fixture (4), rope to apply load (5), pneumatic cylinder (6)

Methods

Six porcine intact knees were prepared for this study. To obtain unloaded and loaded knee joint images a loading apparatus was designed (Fig.1). It consists of a tibia fixture to securely hold the tibia, a femur fixture, which allows adjusting the flexion angle of the knee (here 30°) as well as movement of the femur through compressive loading. The load is applied via a rod in the femur and the loading is controlled by a mechanical pneumatic system. It is possible to apply compressive loads up to 1800N to a specimen with this MRI compatible pneumatic cylinder. The whole loading apparatus consists of non-ferromagnetic material to reduce local magnetic fields which generate artifacts.

The setup was placed in a 3T MRI-system (Achieva: Philips Medical Systems, Ulm, Germany) within a 8-ch sense knee coil. Image acquisition of the knee was performed in an unloaded stage and subsequently with loads equivalent to 0.5 times body-weight (BW) and 1 BW (1275N). All data were acquired with a T1-weighted 3D TSE sequence. Acquisition parameters were: TE/TR= 11.7/750ms, ETL = 5. Spatial resolution was as 0.4x0.6x0.6mm^3, pixel bandwidth 300Hz, and the scan time resulted to about 60min per scan.

In order to evaluate the 3D deformation field of the menisci an image registration was performed. First, the images were rigidly aligned to reduce motion artifacts due to the handling on the setup during loading. Afterwards the images were registered non-rigidly to obtain the 3D deformation field.

Results

The experimental setup enabled measurement of the meniscus deformation of a healthy intact knee joint by MRI. As expected all six knee joints showed plausible deformations of the menisci and their ligaments under compressive loading. Figure 2a and b picture the meniscus in an unloaded and loaded situation. Height decreases were measured in all six specimens. Figure 2c visualises a typical reconstructed 3D deformation of the meniscus and its ligaments in comparison to an unloaded case.

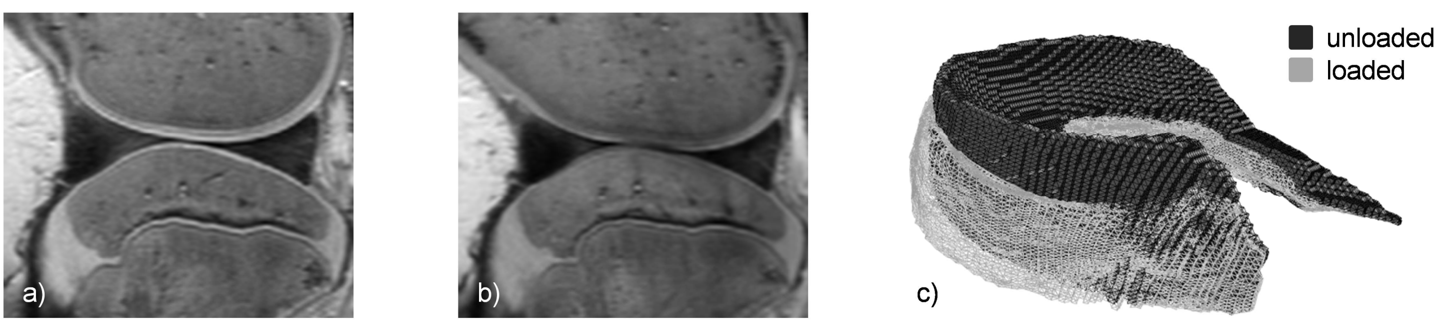

Figure 2: cross-section of an unloaded and loaded meniscus (a, b); overlayed 3D unloaded and loaded meniscus with ligaments (deformation scale factor 1.5) (c)

Discussion and Conclusion

This method can provide insights into the biomechanical behaviour of the meniscus and its ligaments in an intact knee joint. The deformation of the meniscus and its ligaments was well captured. For validation purposes the described method will be applied to a phantom. The information obtained can further be used to investigate the strains and stresses in the meniscus and its ligaments via finite element analysis. Moreover, it is possible to scan knees of different species and also in combination with pathologies like arthrosis, meniscal resections or replacements to obtain information about the deformation and strains in such situations.