# DEVELOPMENT OF SCALABLE FINITE ELEMENT MODELS BASED ON KNEE LAXITY TESTS ON CADAVERS

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## Introduction

The aim of the project was to use the results of laxity tests on cadaver knees to create scalable, subject-specific finite element (FE) models. The models should also be able to test different unicompartmental knee prostheses and compare them to the native knee.

## Methods

For the experimental test with a robot, the alignment of the knee and the robot to each other must be known. This was solved by inserting carbon rods with metal beads in the middle of the femur and the middle of the tibia, where the attachment point for the robot was provided. This was then used to design a bone- and subject-specific 3D print that enclosed the bone and connected the two parts via the drilled channels of the rods. The 3D print could then be connected to an aluminum cylinder into which the bone was cemented, and which could be connected to the robot. The robot-knee alignment was hence defined and used to determine the position of the knee replacement using a 3D scanner (EinScan-Pro, Shining 3D).

In addition, the CT scan was used to determine the tibial and femoral knee coordinate system using the STAPLE MATLAB Toolbox [1]. Using the coordinate systems, it was possible to calculate the knee flexion angle during CT and correct the offset during the experiments. The femoral coordinate system was later assigned to the FE model as the knee coordinate system.

The experiments themselves were laxity tests consisting of anterior/posterior translations (134 N), varus/valgus rotations (10 Nm), and internal/external rotations (5 Nm). These were performed at different test angles covering the range from 5° extension to 120° flexion.

The FE model was built using Ansys® Academic Research Mechanical (Release 21.1, ANSYS Inc.). The level of detail was chosen so that the model included the femur and tibia including their cartilages, both menisci, and the cruciate and collateral ligaments, modelled as 3D geometry. Therefore, the segmentation of an MRI scan using Mimics (Release 23.0, Materialise NV) was necessary.

A multilinear elastic material model was chosen as the material model for the ligaments with a uniaxial tensile test of a lateral collateral ligament as input. An initial area and length were assigned to calculate a stress-strain curve. In addition, a strain offset parameter was introduced to handle different initial strains. An additional internal/external stiffness was added to be able to calibrate their laxities.

An important feature of the FE model was to assign an initial strain to the ligaments, so that the ligaments were already assigned a notional strain. This maintains the actual geometry segmented from the MRI and helps that the ligament remains in tension.

With the level of detail chosen for the model, there is also only one principal component per laxity test, which prevents an over-constrained system.

Since the FE model is based on the MRI images and the experiments are based on the CT images, their positions are different. Therefore, the transformation matrix had to be known to correct the offset of the FE model. MeshLab [2] was used to align the bones, and the position offsets could then be calculated and accounted for.

## Results

This scalable knee FE model build was applied to six knees that had a native geometry and three different unicompartmental knee joint replacement geometries. The difference in position between the experiments and the FE model could be offset. It was also possible to transfer the femoral coordinate system, defined by the entire femur to the FE model which only has the distal femur. With knowledge of the transformation matrix, the FE model could include the same implant position as implanted by the surgeon.

## Discussion

A reliable framework for the development of knee FE models based on cadaver laxity testing was demonstrated. An improvement for future FE models would be to provide fixation so that the MRI and CT scans are taken at the same position. Otherwise, alignment between MRI and CT bones could also be improved by using fixed bone markers in each scan without compromising the integrity of the knee. In addition, the internal/external rotation during CT could not be accounted for because the STAPLE algorithm [1] was flawed. Finally, initial stretching could be fixed to a certain strain value; however, the challenge is whether this solution remains scalable.

## References

1. Modenese, L. and J.-B. Renault, J Biomech, 116, 110186, 2021.
2. Cignoni et al, Sixth Eurographics Italian Chapter Conference, 129-136, 2008.

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