# Detailed elasto-kinematic multibody model for simulating stability tests of the human knee

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## Abstract

The knee is one of the most complex and fascinating joint of the human body. It provides at the same time the stability and the mobility of the lower limb. Due to this very crucial role, its anatomical structures are often subjected to injuries and ruptures. In order to detect the integrity of such complex, doctors often use stability tests. During these assessments, they apply forces at certain locations of the main segments of the knee and interpret the corresponding displacement and resisting strength. The main problem related to these procedures is about their variability due to the mere qualitative assessment of the results and the strong dependence from the expertise of the physiatrist. Moreover, an internal assessment of forces between bony segments and force/displacement of ligaments is not possible without the integration with other instrumented examinations.

Starting from this background, the objective of the study is the development of a detailed model of the human knee and the simulation of the most common stability tests able to assess the joint performance in a quantitative and repeatable way. Moreover, thanks to a comprehensive model, it can be possible to simulate a variety of different cases, including both healthy and injured conditions.

According to the scientific literature, the human knee is often simulated using finite elements due to the very crucial elastic and morphological characteristics (see [1] and [2] as recent examples). These simulative approaches are useful for addressing static or quasi-static simulations, but the computational effort may become very relevant if large motion and time-dependent behaviour are required. In order to overcome these limitations, multibody models can be used (see [3] as an example). In this case, the main difficulties are in the description of the compliance of the anatomical structures that characterize the elasto-kinematic behaviour of the joint (*i.e.* the kinematic of the joint is influenced by the elasticity and by the related forces) due to the intrinsic rigidity of the bodies.

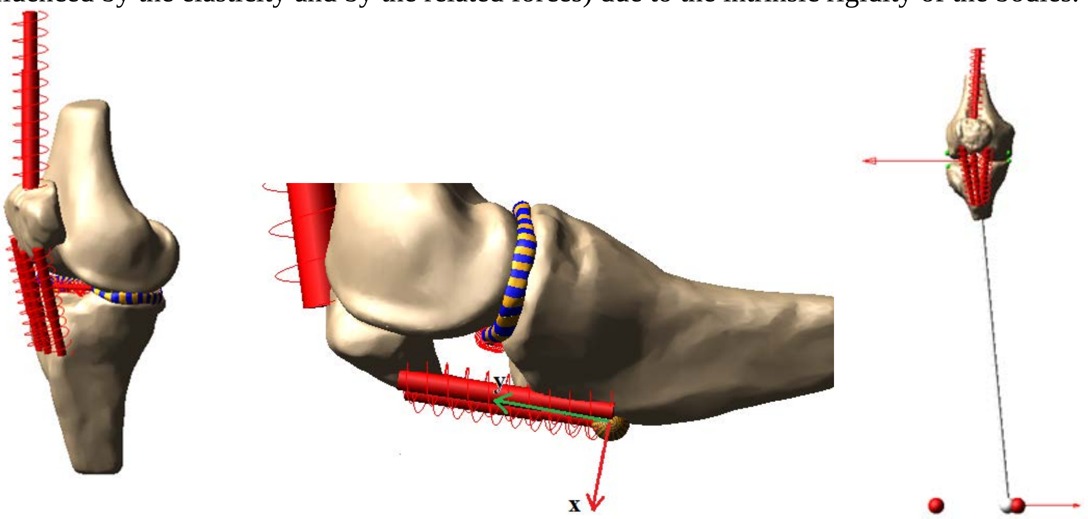


Figure 1. An overview of the multibody model used for the investigation. Bones are depicted in ocher, ligaments are in red and menisci portions in blue and yellow. Applied forces are also visible.

The knee model takes hint from that proposed in [4] and [5], is made of three main rigid bodies (femur, tibia and patella), comprises 10 ligaments and a series of 61 small rigid bodies representing the lateral and medial menisci. The model is built without the use of kinematic constraints, but only with elastic elements and 3D contact forces. The geometries have been reconstructed from MRI databases, the ligaments have been modelled using nonlinear spring-damper elements and the compliance of the

menisci using 3D bushing elements connecting the adjacent small portions. Rigid contact between bones (femur and tibia) and menisci is also considered. Views of the model are shown in Figure 1.
In order to virtually assess the stability of the knee, the model has been used for simulating three different clinical tests: the drawer test, the Lackman test and valgus stress test. The first and second ones are used to assess the functionality of the cruciate ligaments; the third one is used to assess the functionality of the lateral/collateral ligaments. In the simulations, the tests have been simulated by imposing time-dependent forces acting on specific points on both femur and tibia, able to reproduce the actions of the physiatrist. Due to the elasto-kinematic characteristics of the knee complex, all the simulations also include a preliminary phase (before the execution of the tests) in which the tibia is bent to the correct attitude. This initial positioning is very important due to the necessity of starting the simulations from congruent positions of equilibrium among ligament forces and contact reactions.
The relevant results of the simulations are about the displacement of the knee structures and the reaction forces of ligaments and contacts. Both healthy and damaged ligaments have been simulated in order to assess the difference in the displacements and in the load distribution among the elastic structures. Figure 2 shows two examples of the results with a comparison between healthy and injured conditions.

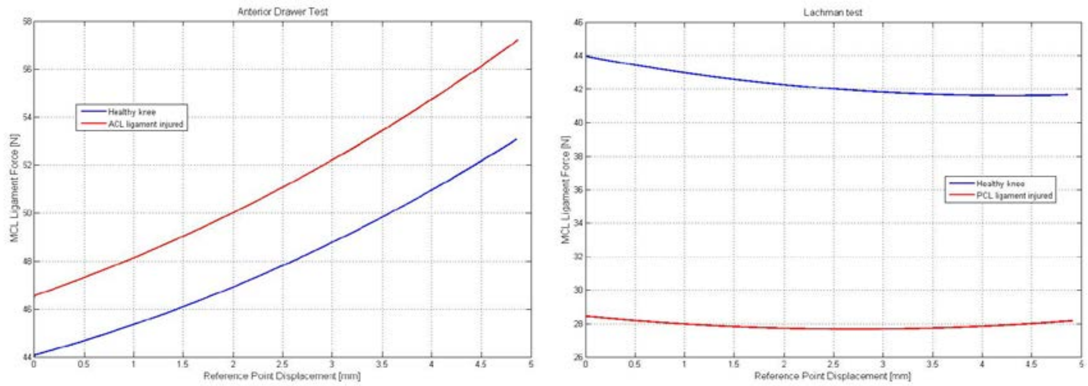


Figure 2: Examples of results: MCL Ligament forces for healthy and injured configurations for the anterior drawer test (on the left) and for the Lachman test (on the right).

The detailed multibody model of the knee complex has proven to be suitable for fast simulations and has allowed to achieve a quantitative assessment of the knee joint stability performance by numerical simulations of standard clinical tests. The authors are aware that the model and the methodology are at early stages and an experimental validation is required. On the other side, the results are promising and the potential of the proposed methodology seems relevant.

## References


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