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# Evaluation of a geometry-based knee joint compared to a planar knee joint

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**Abstract** In this paper, we present a comparative study between two knee joint models. The two kinematical models are analyzed on a gait motion, and we evaluate their influence on the joint reaction forces. The first model is mainly based on the femoral and tibial geometries of the subject while the second one lies on statistical properties. We show that we are able to predict the lateral, anterior and longitudinal moments.

**Keywords** Knee joint · Inverse kinematics and dynamics · Joint reaction moments

## 1 Introduction

Today the field of neuromuscular simulations is used to understand the underlying dynamics of living beings movement, from gait research, treatment of patient with gait problem, to the teaching of physicians and the development of ergonomic furniture. During the last years several platforms have been developed, from commercial tools [2] to open-source based solutions [3]. The expansion of this field has also allowed the accessibility to musculoskeletal models that are capable to describe different levels of complexity [4,7]. This development of detailed models and simulation tools has given researchers and physicians powerful tools to create advanced simulations and even to execute different 'what-if' scenarios or to evaluate different simulation results before the physical treatment has even started. In this study we compare two models using two different levels of knee joint complexity.

## 2 Material and Methods

In this study a 34 year old male, weight of 89.6 kg with no recorded knee injury or other muscular or skeletal injuries where studied. Initially a MRI acquisition (resolution: 0.39 x 0.39 x 1mm) of the subject's knee was performed. Gait motions were captured using eight cameras (Qualisys) and two AMTI force platforms. The subject was also fitted with eight electromyography sensors to record muscle activation. The 3D marker trajectories were smoothed using a Kalman smoother. Two inverse kinematics (IK) processes are then performed using two different knee joints (see sections 2.1 and 2.2). The resulting angular trajectories are finally analyzed in OpenSim to get the joint reaction forces (see section 3).

### 2.1 Geometry-based knee joint

Firstly a subject-specific model was built using the AnyBody Modeling System [2]. The leg model is a seven DoFs model. The knee joint is itself defined as a three DoFs joint. Flexion-extension is driven by the subject-specific gait motion. Adduction-abduction rotation and distration-compression translation were driven thanks to the subject's knee anatomy as follow. From the MRI data both lateral and femoral knee condyles were segmented including cartilages [5]. A quadric robust-fitting approach was then used to model the condyles as ellipsoids (see Fig. 1). A constrain was set to ensure contact between the ellipsoids and two points located respectively on the lateral tibial plateau and the medial tibial plateau. To model the displacement of the contact points in the knee during the motion, the knee model also includes posterior-anterior translation and internal-external rotation given by the linear term of the equations given in [6]. The Anybody system was used to solve and export the IK solution for this knee joint.

### 2.2 Scaled planar knee joint

The second knee model that we used in this study is planar and composed of three degrees of freedom [7]. In that generic model, a pathway for the instantaneous center of rotation was chosen that gives realistic orientations of the femur relative to the tibia. Two translations (posterior-anterior and distration-compression) are described as functions of one rotational degree of freedom

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**Fig. 1** Segmented lateral, medial femoral condyles with fitted ellipsoids

(knee flexion). These two relationships give the rolling-to-sliding ratio of the motion of the femoral condyles on the tibial plateau. The effective range of rotation covers a flexion from 10° (hyper-extension) to −120°. This generic model is scaled to the subject by using common anatomical markers on the model and on the subject during motion capture. The OpenSim system was used to solve and export the IK solution for this knee joint.

## 3 Result

Fig. 2 shows the kinematical solutions (only rotational DoFs) obtained from the two models describing the same gait motion. OpenSim was then used to evaluate the knee joint reaction moments for those kinematics (see Fig. 3). The in-vivo measured values from literature [1] and the predicted simulation results follow the same trend even if there is miss-alignments which can be explained by individual factors.

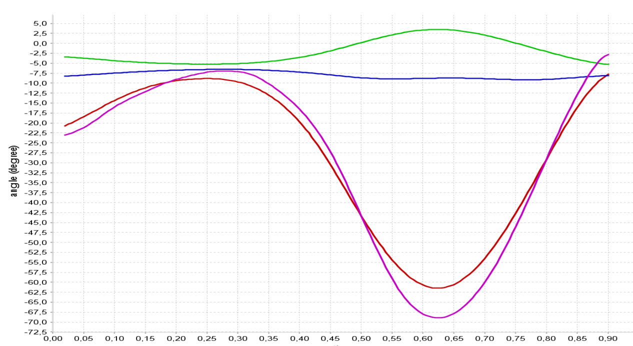


**Fig. 2** IK solution for both models. Geometry-based: red = flexion, blue = adduction, green = rotation. Planar: purple = flexion

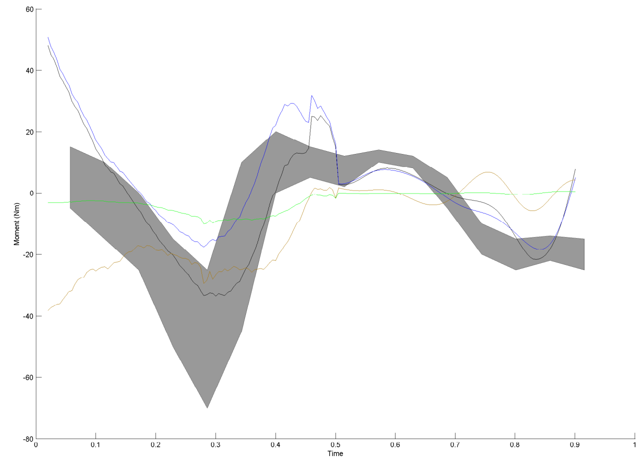


**Fig. 3** Knee joint moments. Gray area = lateral literature data [1]. Geometry-based: brown = anterior, blue = lateral, green = longitudinal. Planar: black = lateral

## 4 Conclusion

We have presented a comparative study between two different knee joint models. A gait motion was used to evaluate their influence on the joint reaction moments. The predicted simulation results followed the same trend as literature data.

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