# ESTIMATION OF THE MOVING JOINT AXIS IN THE KNEE JOINT BY MOTION ANALYSIS DATA

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It is essential to use individually parameterized models for the knee joint as well as for the patellofemoral joint while analyzing the correlations between external and internal loads and the efficiency of specific training exercises for the lower extremities. A new approach to estimate the moving joint axis within the knee joint using motion analysis data was evaluated. The results of this single case study show that this approach might offer a possibility to parameterize an individualized knee joint model without using MRI scans.

**Keywords:** biomechanical modelling, knee model, moving joint axis

## INTRODUCTION:

It is necessary to take the moving joint axes of the knee joint, respectively the patellofemoral joint into account for the calculation of muscle forces for the Mm. quadriceps. The consideration of changing leverages within these joints during knee motion only leads to realistic results for calculated muscle forces (Roemer 2005). An individualized knee joint model was therefore developed (Wank 2000), which was implemented into a multi body system leg model (Roemer 2004). Input data for that model were gained using MRI scans of knee flexion movement within an open MRI system. The aim of this study was to find a way to simplify data acquisition for this model.

## METHODS:

In this single case study data for the knee model were collected via MRI scans and motion analysis with a 12 camera VICON system (240Hz). The input data for this model were extracted from MRI scans in 13 different knee positions (Fig. 1). Data of the femoris condylus outline and the relative movement of the tibia plateau was the input for the multi body system (MBS) knee model.

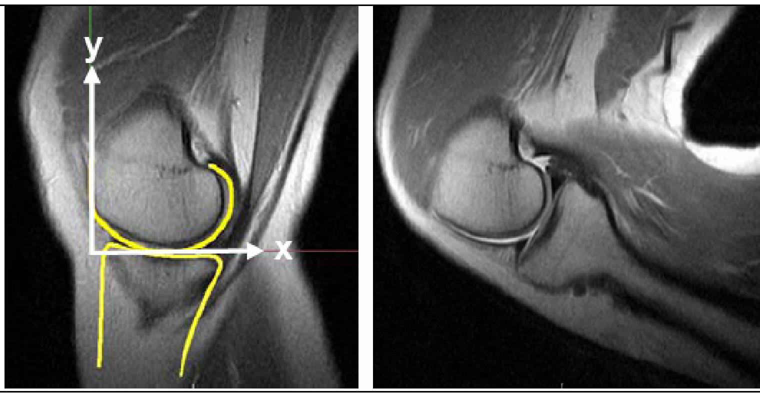


Figure 1 Knee model and MRI scans

In contrast to the above method, the coordinates of 40 markers placed around the thigh and 40 markers placed on the shank were used to reconstruct the relative motion of these two segments. The optimization method described by Andriacchi et al. (1998) was used to minimize the influence of the skin movement on the marker coordinates. Markers with the smallest amount of influence by skin movement were selected to transfer the recorded motion to the model. To connect the segments viscoelastically with referring body markers 16 markers were placed around the thigh and 12 on the shank. This leads to a dynamic adjustment of the two segments relative to the moving marker cloud. Due to the linear elasticity used for the connection of the markers this approach is equivalent to linear filtering.

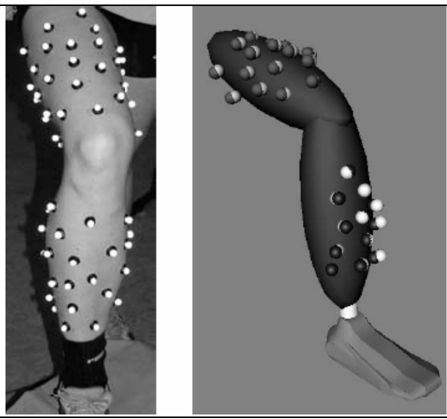

Figure 2 Leg with attached markers and leg model with body markers

Thus the relative motion of thigh *(E0)* and shank *(E1)* was transferred to the MBS leg model. This model had no kinematic coupling in the knee joint with respect to the planar flexion and extension motion. The final rotation, adduction, and abduction movements were provided within this model by kinematic constraints.
The location of the moving joint axis in this model was calculated using an approach of kinematic theory. The instantaneous pole is defined as the position at which the relative velocities are zero of two bodies rotating against each other.
The coordinates of the space centroid $P \sim (\xi, \eta)$ are defined as:

$$\xi(t) = \frac{1}{\dot{\varphi}(t)} \cdot (\dot{x}(t) \cdot \sin(\varphi(t)) + \dot{y}(t) \cdot \cos(\varphi(t)))$$

$$\eta(t) = \frac{1}{\dot{\varphi}(t)} \cdot (\dot{x}(t) \cdot \cos(\varphi(t)) + \dot{y}(t) \cdot \sin(\varphi(t)))$$

and the coordinates of the body centroid respectively $P \sim (a, b)$ are defined as:

$$a(t) = x(t) + \xi(t) \cdot \cos(\varphi(t)) - \eta(t) \cdot \sin(\varphi(t))$$

$$b(t) = y(t) + \xi(t) \cdot \sin(\varphi(t)) + \eta(t) \cdot \cos(\varphi(t))$$

*with:*

$\varphi(t)$ : *angle between* $E_0$ *and* $E_1$

$\dot{\varphi}(t)$ : *anglular velocity between* $E_0$ *and* $E_1$

$x(t)$ *and* $y(t)$ : *position vector between* $E_0$ *and* $E_1$

$\dot{x}(t)$ *and* $\dot{y}(t)$ : *relative velocity between* $E_0$ *and* $E_1$

The space centroid represents the coordinates of the joint axis with respect to a frame fixed on the thigh and the body centroid to a frame on the shank. One problem of this approach is that the angular velocity has to be unequal to zero, because $\dot{\varphi}(t)$ is the denominator. Therefore in the turning points of the flexion-extension motion, where the recorded angular velocity became zero, the results of the velocity pole showed discontinuities. A polynomial $10^{th}$ grade was being used to approximate the resulting location.

**RESULTS AND DISCUSSION:**

The results show a good fitting of the polynomial 10[th] grade with respect to raw output data of the model (Fig. 3) for one extension-flexion motion of the knee joint.

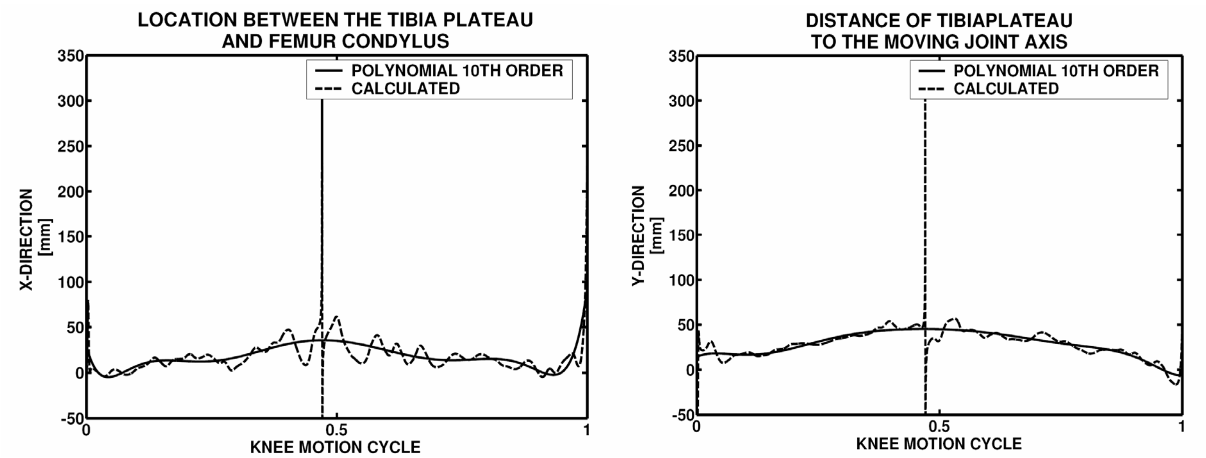


Figure 3 Calculated location of the moving joint axis with respect to the Tibia

Discontinuities of the data at the begin (110° flexion), the middle (0° flexion) and the end (110° flexion) of the motion cycle result in an angular velocity ≤1°/s. That leads to oscillations and for $\dot{\varphi}(t) = 0$ the equation is unsolvable. This effect exerts more influence on time histories of the x-coordinate with respect to the Tibia frame than on the y-coordinate respectively.
Comparison of those results with time histories of the MRI based knee model lead to the same findings (Fig. 4).

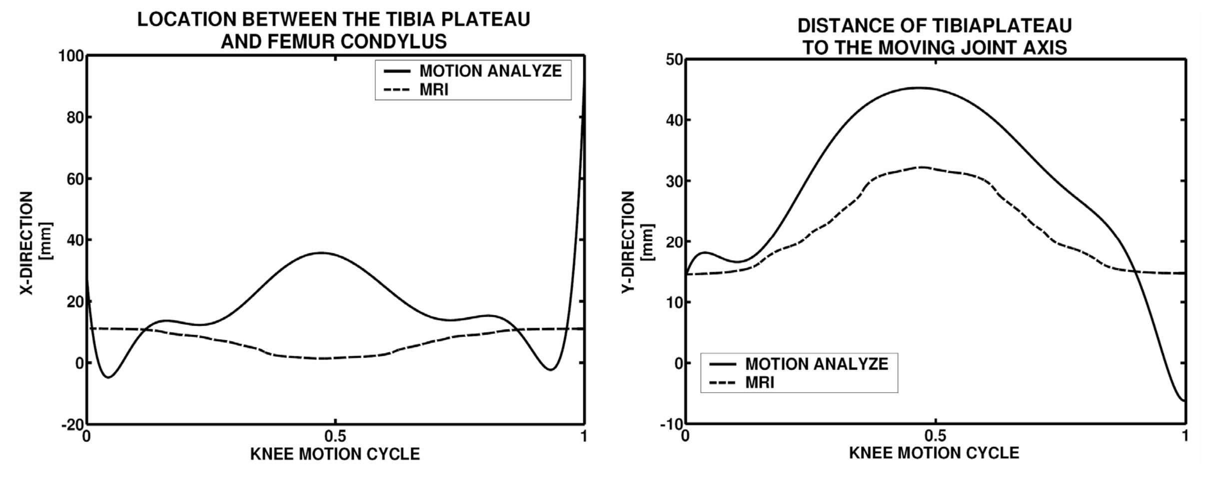


Figure 4 Location of the moving joint axis with respect to the Tibia, computed with the MRI based model and Motion Analysis respectively

For knee extension (0.5 Motion cycle) the displacement in x-direction is defined as zero and the largest displacement should occur in full knee flexion (Roemer 2005). The MRI results represent this definition. But results from Motion Analysis show large displacement for knee extension. Same consequences can be found for the y-coordinate. Main reasons for this purpose are the shown discontinuities in the results for the body centroid.
Further studies have to be conducted, to solve the mentioned problems. Therefore some boundary values should be used for calculating the moving joint axis as long as angular velocity is ≤1°/s. Also, the knee flexion-extension movement should be performed with higher

angular velocities to minimize this problem. Another possibility may be to use isokinetic devices to enhance and control the angular velocity.

**CONCLUSION:**

Individualized models are needed to analyze the correlations between external and internal loads for the lower extremities. A new approach was shown to individualize the input parameters for a knee joint model taking the moving joint axis into account. The results have shown that the MRI based model is more accurate than using Motion Analysis. It may be concluded, that further studies have to be carried out to improve the quality of the input data gained by motion analysis.

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