INFLUENCE OF DIFFERENT KNEE MODELS ON CALCULATED MUSCLE FORCES

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A basic task in biomechanics is the precise analysis of human movements and to investigate muscle forces that are responsible for these movements. Using inverse dynamics with a focus on the lower extremities the knee model type is of major interest. It is well known that the calculated muscle forces depend on the knee model type. With this study the influence of different knee model types and femoropatellar model types were investigated.

KEY WORDS: biomechanical modelling, knee model, muscle forces

INTRODUCTION: One aim of sport biomechanics is to analyse the efficiency of training exercises, for example in force training. Therefore, it is necessary to investigate what happens inside the body depending on the external loads. One question could be: Are the inner loads comparable to the external ones? To answer this question, a neuromuscular multi body system (MBS) model was developed for the lower extremities (Roemer 2004). It is well known, that the knee model has a main influence on the results of the calculated muscle forces of the Mm. quadriceps. The aim of this study was to evaluate the coordinates of the moving joint axis and how big the influence of the model is on the calculated muscle forces.

METHODS: To model the knee joint and the patellofemoral joint with moving joint axes (MD), an individually parameterized model was used (Roemer 2004, Wank 2000). The input data for this model were extracted from MRI scans in different knee positions (Figure 1).

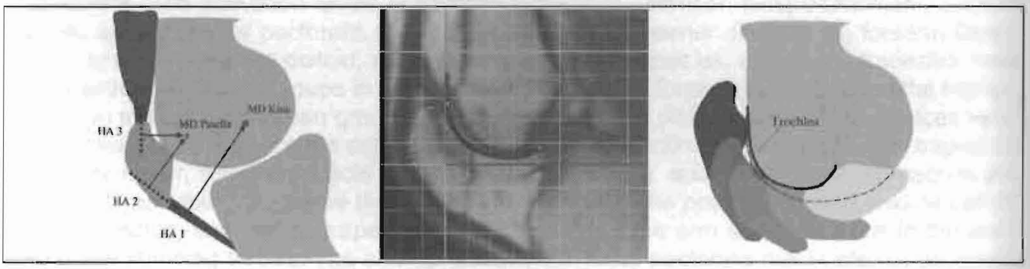

Figure 1 Knee model and MRI scans.

The outline of the condylus femoris was digitized using a high resolution. This outline was the input parameter for the knee model that was used in the MBS man model DYNAMICUS in alaska 4.1 for the calculation of the moving joint axis (Roemer 2004, Wank 2000).
To evaluate the accuracy of the coordinates of the moving joint axis the results of the knee model from WANK were compared with the velocity pole (Comparison C1).
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 centrode $P^* \sim (\xi^*, \eta^*)$ 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 centrode respectively $P^* \sim (x^*, y^*)$ are defined as:

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

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

with:

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

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

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

One problem of this approach is, that the angular velocity has to be unequal to zero, because $\dot{\varphi}$ is the denominator. MRI scans in 10° steps of a measured knee extension and flexion were the basis for the comparison (C1).

The results of different model types for the knee joint and the patellofemoral joint were used to show their effects on the calculated muscle forces.

The comparison (C2) shows the differences between two model types for the patellofemoral joint. The first model implies the simplification that the patella is moving on a circular path. For the second one the path for the patella was individually parameterized with a moving joint axis. This comparison was calculated for a knee joint modelled as a joint revolute to minimize the possibility of side effects on the results.

The third comparison (C3) shows the differences between a knee joint modelled as a joint revolute to an individually parameterized model with a moving joint axis. The model with the moving joint axis is described in ROEMER 2004. In both cases the path for the patella was calculated in the same way using the MRI scans.

The basis for (C2) and (C3) was a measured leg extension motion within a leg press machines. In addition to the calculated muscle forces, the stimulation function for the Mm. quadriceps was calculated for (C3) using a model of HATZE 1977. This result was compared with the measured EMG-activity.

RESULTS AND DISCUSSION: (C1): There are only slight differences between the coordinates of the moving joint axis of the knee model and the velocity pole, if the angular velocity is unequal to zero.

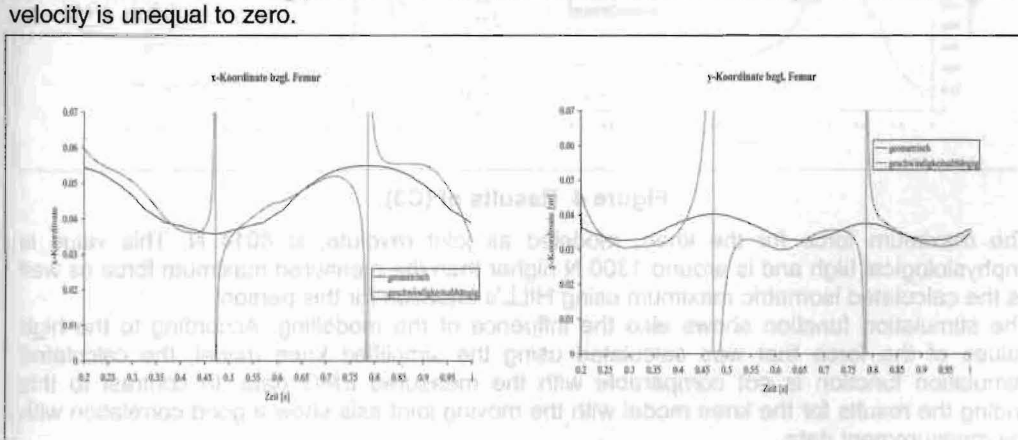

Figure 2 Results of (C1).

The calculated coordinates of the velocity pole show discontinuity as it was expected for the turning points of the motion. The reason for the differences between the two models during the motion might be the approximation of the relative velocities for the calculation of the velocity pole.
The accurate measurement of relative velocities concerning the knee joint was not possible within this study, because these measurements are costly and invasive (see SHEEHAN/ZAJAC/DRACE 1998).
(C2): The results of this comparison show differences in the calculated muscle forces depending on modified leverages of the patella for the leg extension. The differences scale up with an increasing knee angle. The calculated force of the Mm. Quadriceps increases up to 500 N for the model with the patella moving on a circular path.

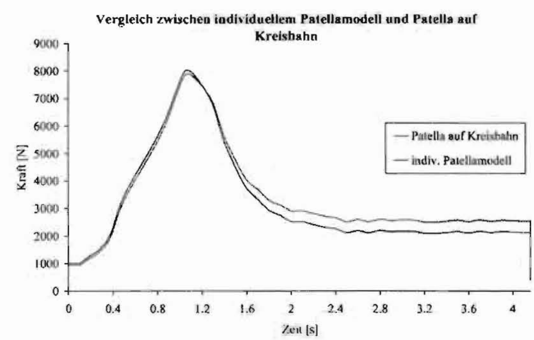

Figure 3 Results of (C2).

(C3): Depending on the type of the knee model the leverages change significantly. The following figures show the calculated muscle forces for Mm. Quadriceps and the stimulation functions respectively.

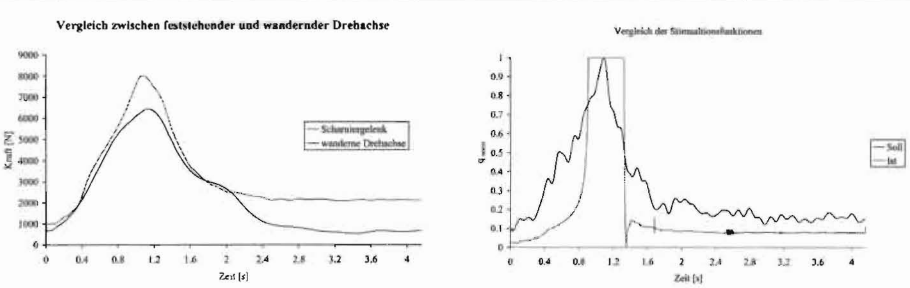

Figure 4 Results of (C3).

The maximum force for the knee, modeled as joint revolute, is 8014 N. This value is unphysiological high and is around 1300 N higher than the measured maximum force as well as the calculated isometric maximum using HILL's equation for this person.
The stimulation function shows also the influence of the modelling. According to the high values of the force that was calculated using the simplified knee model, the calculated stimulation function is not comparable with the measured EMG data. In contrast to this finding the results for the knee model with the moving joint axis show a good correlation with the measurement data.

CONCLUSION: The results of these comparisons indicate that it is necessary to take the moving joint axes of the knee joint and the femoropatellar joint respectively into account for

the calculation of muscle forces for the Mm. Quadriceps. The consideration of the changing leverages within these joints during knee motion only leads to physiological results for calculated muscle forces. Otherwise it was not possible to calculate stimulation functions that were comparable with measured data.
This leads to the conclusion, that it is essential to use individual 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.

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