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MODEL DEPENDENCE OF KNEE JOINT ROTATION ANGLES

[1] Irene Reichl*, [2] Winfried Auzinger, [3] Heinz-Bodo Schmiedmayer and [2] Ewa Weinmüller
[1] University of Vienna, Institute of Sports Science, A-1150 Vienna, Austria,
[2] Vienna University of Technology, Institute for Analysis and Scientific Computing, A-1040 Vienna, Austria;
[3] Vienna University of Technology, Institute of Mechanics and Mechatronics, A-1040 Vienna, Austria

SUMMARY
Two optimization models for the analysis of kinematics data of the human tibio-femoral joint are presented. It is assumed that the intact joint can be approximated by two rotational axes, only. Model 1 allows for an arbitrary angle between the two axes, model 2 demands an orthogonal constraint. The two alternative optimizations were applied to kinematics data due to a computer simulation. It turned out that model 2 was more robust with respect to noise and is, thus, to be preferred in case of noise typically present in motion capturing with skin-mounted markers. Model 1 may possibly lead to more accurate results for medical imaging data.

INTRODUCTION
In a number of clinical applications such as ligament repair, joint replacement or prosthesis' design the understanding of knee kinematics is of fundamental importance. A crucial point is the determination of the joint rotation axes and joint displacements. On one hand, concurring definitions of knee joint axes based on anatomic landmarks are in use. On the other hand, regarding only one definition, there is a large variability between observers and different sessions or trials.

In order to reduce the observer dependence mathematical procedures based on movement analysis, have been developed. Presently a number of alternative concepts exist allowing for the determination of joint rotation axes [1]. The finite helical axis (FHA) as an invariant description of joint displacements is a powerful tool; however, the FHA is not easy to interpret clinically [2]. Other approaches model the intact human tibio femoral joint as a compound hinge joint exhibiting only two rotational axes, *flexion/extension* (FE) and *tibial rotation* (TR or internal/external rotation). Most optimization procedures assume that the FE axis and the TR axis are orthogonal and intersect [3-7]. Despite to this assumption, [8] state that the TR axis is anterior to the FE axis (i.e., there is no intersection) and not perpendicular to it.
A kinematic model that does not match the natural geometry of the joint is expected to yield displacements deviating from the original displacements. It was, thus, the aim of this contribution to quantify the effect of an orthogonality constraint when applied to data from a knee exhibiting an arbitrary angle between the two rotational axes.

METHODS
Kinematics data of the human tibio-femoral joint was generated by a computer simulation. It was assumed that two rotational axes satisfyingly approximate the human knee joint [3-7]. [8] state that the TR *axis* and the FE *axis* are not perpendicular and do not intersect whereas [9] speak about an intersection. The approach within this contribution allows for an arbitrary angle between the two axes, assuming an intersection. In the computer model, the FE axis was femur fixed and the TR axis tibia fixed. In a coordinate system with the intersection coinciding with the origin and the FE axis coinciding with the z-axis, the orientation of the TR axis may be represented by an inclination angle α and the azimuth γ, see Figure 1. The time sequence of the FE angle $\theta(t)$ and the TR angle $\phi(t)$ is task dependent. In order to include realistic rotation profiles, two examples for $\theta(t)$ and $\phi(t)$ were implemented in the computer model [10,11].

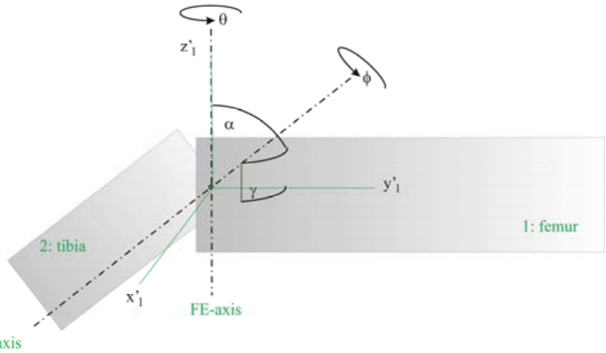

Figure 1: The inclination angle α and the azimuth γ measure the relative orientation of the TR axis with respect to the FE axis. The joint rotation is given in terms of the FE angle $\theta(t)$ and the TR angle $\phi(t)$.

The simulated kinematics data was subsequently analysed. $\theta(t)$ and $\phi(t)$ were approximated by a polynomial function in order to decrease the number of unknown parameters. $\theta(t)$ and $\phi(t)$ are modeled as an amplitude *a* times a shape function *S*, $\theta(t)= a_\theta S_\theta(t)$ and $\phi(a_\phi,t) = a_\phi S_\phi(t)$, respectively. Model 1 simultaneously optimized the parameters (α, γ, a_θ, a_ϕ), model 2 set α to 90° and optimized (γ, a_θ, a_ϕ), i.e., the FE and the TR axis are orthogonal, an approach already successfully applied to the knee joint [3-7].

Summarizing, kinematics data was simulated for two different joint rotation profiles, fixed γ and varying inclination α, see Table 1. Additionally, normally distributed Gaußian noise of different size was taken into account. Then the optimization models 1 and 2 are applied.

Table 1: Variation of input data

α	γ	$\theta(t)$	$\phi(t)$
60°	75°	modeled according to [10]	
120°		modeled according to [11]	

RESULTS AND DISCUSSION

In the noise-free case model 1 recovered the true input parameters (α, γ,a_θ,a_ϕ) of the computer simulation. For model 2 the input parameters deviate from the true values, unless for the input parameter α=90°. Figure 2 depicts the influence of noisy data. It turned out that for small noise the difference between true and optimized parameters is larger for model 2. However, model 2 is more robust with respect to larger noise typically present in skin-mounted markers. This is observed for both implemented rotation profiles [10,11]. This behavior can be attributed to the fact that the objective function of model 1 has no sharply pronounced minimum in α. Noise deforms the objective function, rendering it even more difficult to determine the minimum.
In a next step the in here discussed models will be applied to experimental data. The influence of different type of noise can be achieved comparing motion capturing with medical imaging techniques and skin mounted-markers.

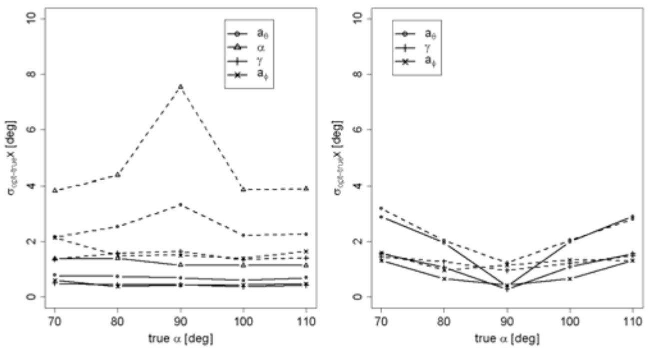

Figure 2: Results due to model 1 (left) and model 2 (right) and a rotation profile due to [10]: difference of input parameters in the simulation and optimized parameters. The Gaussian noise of the input data was σ=0.29 (solid lines) and σ=2.9 (dashed lines).

CONCLUSIONS

This contribution compared the effect of two models with a different number of constraints. The results of the simulation indicate that model 2 has to be preferred for large noise typically present in opto-electronic motion tracking of skin mounted markers. For medical imaging data, model 1 could possibly lead to more accurate results.

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