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Scaling musculoskeletal models from dynamic motion capture trials

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INTRODUCTION

Model validation is a crucial issue if patient-specific musculoskeletal models should assist in clinical problems. Although focus on validation has increased in the last years, the influence of modeller decisions on the modelling process has received little attention [1]. This, in spite of the fact that implicit assumptions, and manual adjustments in the modelling process, can have a major influence on the outcome of a model [2]. In an exercise at a recent PhD course in musculoskeletal biomechanics at Aalborg University in Denmark, the participants were asked to use a musculoskeletal model to predict the hip reaction force. Even though the participants used a general musculoskeletal modelling package and the same musculoskeletal model, the differences in the predictions varied by more than one body weight. The variability was introduced due to modeller choses on model scaling and manual placement of skin markers on the model.

To address the problems of modeller dependence and simplistic scaling laws, we present a kinematically-based method to scale template musculoskeletal models to match both segment lengths and joint parameters to a specific patient. This work provides an overview of the method compared to a simpler approach using linear segment-wise scaling of musculoskeletal models.

METHODS

The first step of the *kinematically scaled model* is the creation of a patient-specific representation of the patient kinematics and joint parameters. The model is built by creating segments with coordinate systems aligned to a standing reference, as shown in figure 2. Joint positions and orientations are treated as design variables in an optimization problem, and patient-specific parameters are found based on functional trials similar to the method proposed by Reinbolt et al. [3].

The kinematic representation of the patient is then registered to a template (cadaver-based) dataset to create a non-linear transformation (scaling) by which the template dataset can be transformed to match the patient-specific joint parameters.

The modelling procedure was implemented in the AnyBody Modeling System (AMS) (AnyBody Technology A/S, Denmark), a multi-body environment for biomechanics. Figure 1A outlines the modelling procedure and shows the main differences to a linearly scaled model (figure 1B), which is currently the default way of scaling motion capture based gait models in the AMS.

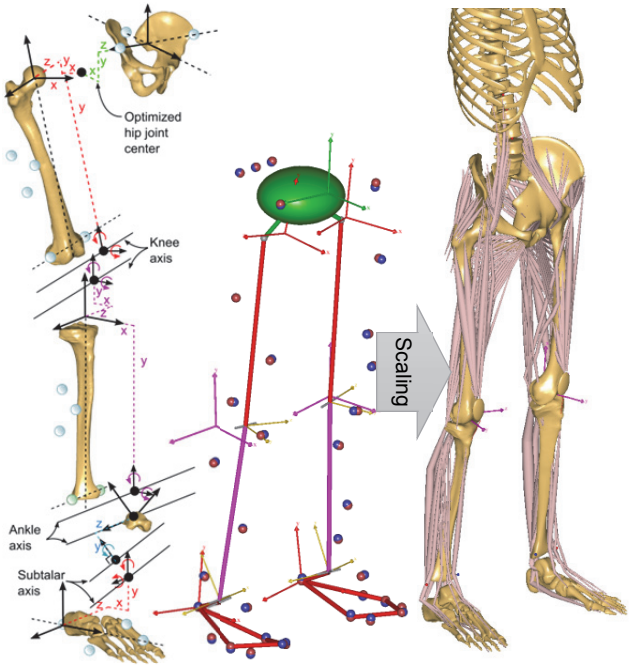

Figure 2: The patient-specific kinematic stick-figure model specifies the scaling/transformation of the musculoskeletal template geometry.

To exemplify the procedure, the two methods were applied to the same five normal gait trials from a dataset made public for the ASME 2012 Summer Bioengineering Conference as part of the third "Grand Challenge Competition to predict In-Vivo Knee Loads" [2].

RESULTS AND DISCUSSION

The models ability to track the motion capture data is illustrated on figure 3. A smaller average marker error is observed for the new approach during the whole gait cycle. However, since this could be caused by over fitting the model to soft tissue artefacts, it cannot be concluded that the *kinematically scaled model* is better at capturing the underlying patient-specific kinematics. This is a question which is best answered using more invasive bone pin studies or fluoroscopic imaging.

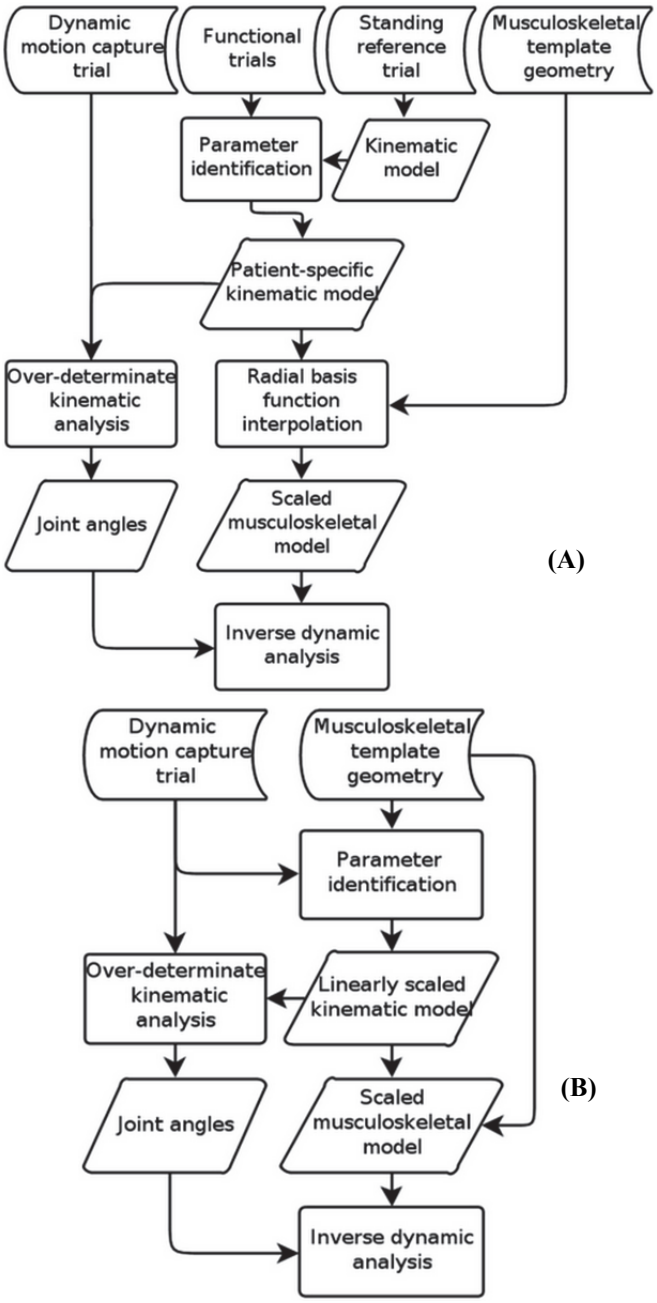

Figure 1: Schematic overview of the models. A) The *Kinematically scaled model* uses a standing reference and functional trials to obtain a patient-specific kinematic model. B) The *Linearly scaled model* relies on the dynamic trial only to linearly scale the model.

Table 1: Example of left side joint parameters for selected joints. The coordinates are given in the frames defined by the markers in the standing reference. **x**: anterior/posterior, **y** superior/inferior, **z** medial/lateral.

	Joint Parameter	Kin. scaled			Lin. scaled		
		x	y	z	x	y	z
Pelvis	Hip position (mm)	-77	-99	107	-86	-96	87
Thigh	Hip position (mm)	-4	-2	10	-28	-10	33
	Knee position (mm)	2	-431	0	9	-437	-8
	Knee orientation (deg)	7	-8	.	2	-3	.
Shank	Knee position (mm)	0	0	-61	-26	6.5	-52
	Knee orientation (deg)	-11	17	.	-8.0	24	.
	Ankle position (mm)	4	-420	0	-2	-430	-14
	Ankle orientation (deg)	-1	-18	.	-9	14	.

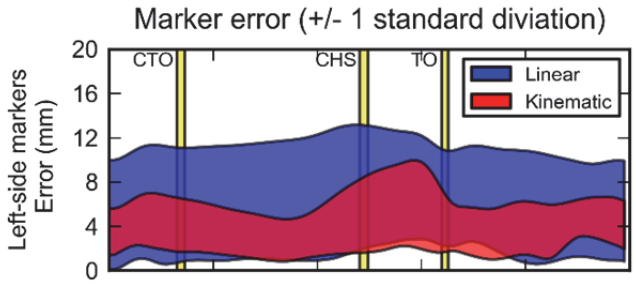

Figure 3: Marker error (+/- 1 std.div) for all five gait trials.

Table 1 shows a few examples of joint parameters from the two methods. The data is represented in the anatomical frames defined by the markers of the standing reference. There is a clear difference between joint parameters of the two approaches. Also, while the joint parameters of the *kinematically scaled model* depends only on the input data, the joint parameters of the *linear scaled model* is likely to vary with the operator due to the manual adjustments necessary.

The proposed scaling procedure incorporates methodology from traditional kinematic gait analysis, moving musculoskeletal models beyond linear segment-wise scaling and eliminating some manual adjustments necessary in current linear scaling techniques. Automation of the modelling process, however, comes at a price; the requirement for extra data. The approach requires a standing reference and some additional functional trials

CONCLUSIONS

It is beyond the scope of this work to claim the superiority of one scaling approach over the other. Achieving such a goal requires additional studies, focusing on the reliability and validity of each of the steps in the modelling procedure. Some parts of the validation puzzle already exist in the literature, but there still is much to do.

If multi-body musculoskeletal modelling is to gain similar clinical acceptance as clinical gait analysis, a consensus on the modelling processes and assumptions is necessary to ensure validity of the results and allow comparisons between studies. Stated shortly, reliability is a prerequisite for validity. Since the *linearly scaled model* is influenced by modeller decisions for every subject and trial, and no modelling consensus exists, the results are not reliable. It is likely that such a consensus will eventually evolve, given sufficient time and published research. The challenge then remains to construct modelling procedures and tools sufficiently robust to create consistent results regardless of the operator.

REFERENCES

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