A Hybrid Modelling Workflow for Performing Finite Element Analyses Under In-Vivo Conditions

Camille Chartrand[1], Loïc Degueldre[2], Pierre Legay[2], Julien Clin[2], Franck LeNaveaux[2], Ryan B. Graham[1]
[1]Movement Biomechanics and Analytics Laboratory, University of Ottawa, Ottawa, Canada
[2]Numalogics Inc., Montreal, Canada
Email: cchar181@uottawa.ca

Summary

A hybrid modelling workflow was developed to build a detailed thoracolumbar spine musculoskeletal (MSK) model in a finite element (FE) modelling platform for co-simulation. Kinematic and joint load errors across models were evaluated.

Introduction

MSK and FE models are used to evaluate the mechanics of the spine. MSK models can estimate muscle forces required to produce movement, while FE models are used to evaluate structural deformations [1]. Their strengths can be combined through hybrid modelling, where a MSK model is used to estimate muscle forces that are then prescribed to the FE model as loading conditions [1]. The goal of this study was to create a framework to apply muscle forces determined from MSK modelling to a matching FE model of the whole spine.

Methods

A thoracolumbar spine and ribcage MSK model, validated for joint loads in the lumbar region, was chosen for this study [2-3]. To simplify the model for FE modelling, the following changes were made: removing the upper limbs, welding the sacrum-abdomen joint, fixing the pelvis with respect to the ground, and simplifying muscle lines of action to connect the origin and insertion points via a straight line. The model was then reconstructed in Ansys to have identical geometry; joint positions, orientations and stiffnesses; and location of muscle attachment points (Figure 1). Over 300 muscle fascicles were included and modelled by linear spring elements.

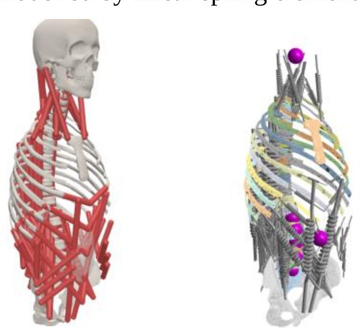

Figure 1: OpenSim (left) and Ansys (right) models.

An automated scripting workflow was developed to apply muscle forces to the FE model. In OpenSim 4.5, joint angles from a given static pose were prescribed to the MSK model and static optimization was performed to estimate muscle forces. The latter were then applied to the Ansys model by directly applying the corresponding muscle force to each spring. Joint loads created by the weight of the bodies were applied via follower loads and pure moments at each intervertebral joint. This workflow was tested by simulating symmetric static postures ranging from approximately 10 to 40° in flexion. Each pose was tested using six scaled male models, corresponding to 10th, 50th, and 90th percentiles mass and 50th and 90th percentiles for standing height. Kinematic and joint load differences and percent errors were evaluated between the OpenSim and Ansys models by taking the mean ± standard deviation (SD) over all lumbar intervertebral joints and models. Only lumbar errors were evaluated as the MSK model has yet to be validated for thoracic joint loads [3].

Results and Discussion

Errors increased with flexion angle (Table 1). On average, all errors, apart from the 40° flexion pose, were less than 10%.

Table 1: Kinematic and joint load lumbar errors between models.

Flexion Angle (°)	Kinematic Error		Joint Load Error	
	°	%	N	%
10	0.0 ± 0.0	3.8 ± 4.9	0.7 ± 0.5	0.1 ± 0.0
20	0.1 ± 0.1	4.6 ± 5.6	1.5 ± 1.1	0.3 ± 0.2
30	0.1 ± 0.1	5.8 ± 6.5	4.0 ± 2.7	0.5 ± 0.4
40	1.1 ± 0.3	39.4 ± 27.2	8.0 ± 5.6	1.2 ± 1.3

Percent errors below 10% indicate good agreement between models. While only part of the spine range of motion (ROM) was simulated, these results serve as proof of concept for producing similar simulations between MSK and FE models using this workflow. Advantages of this workflow include the modelling of the entire spine, the inclusion of over 300 muscle fascicles, and the ability to obtain similar kinematics between models without iteratively modifying stiffness properties in either model. Limitations include obtaining convergent solutions in Ansys due to the large number of articulating joints. Future work includes evaluating kinematic and joint loads in the thoracic spine, considering stability constraints in the estimation of muscle forces, incorporating pelvis rotation, simulating larger ROM poses, and tuning Ansys stiffnesses.

Conclusions

This study proposed a novel hybrid modelling approach for actuating a fully articulated FE model of the spine with over 300 muscle fascicles, with the potential of improving the applicability of FE studies to *in-vivo* conditions.

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References

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