Towards Developing an Integrated Framework to Predict Subject Specific Spine Mechanics

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INTRODUCTION

The current study is based on a collaboration between the University of Stuttgart (Germany) and Queensland University of Technology (Australia) combining two different types of computational models to simulate spinal movement and associated joint forces and moments .
One model is a generic neuro-musculoskeletal (NMS) model of the spine which is based on rigid body dynamics together with a forward-dynamics simulation algorithm to drive muscle activity [1]. The other model is a subject specific quasi-static finite element (FE) model of the spine including ligaments [2].
Together, these two modelling methodologies will provide a better understanding of physiological biomechanics, giving an insight into the internal dynamics of implemented tissues. The steps involved in adapting an established neuro-musculoskeletal model of the spine to include subject specific anatomical geometry and mechanical parameters in order to provide temporal data for muscle forces will be outlined.

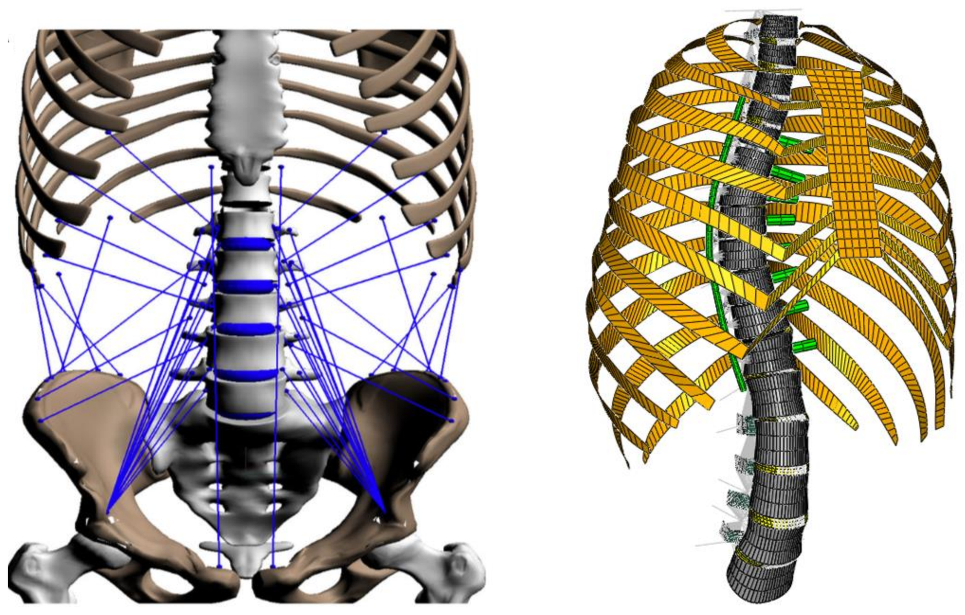


Figure 1: Different types of biomechanical models of the spine: NMS rigid body model - 2bio model [1] (left) and deformable FE model of vertebral bodies and discs – BSRG model [2] (right).

METHODS

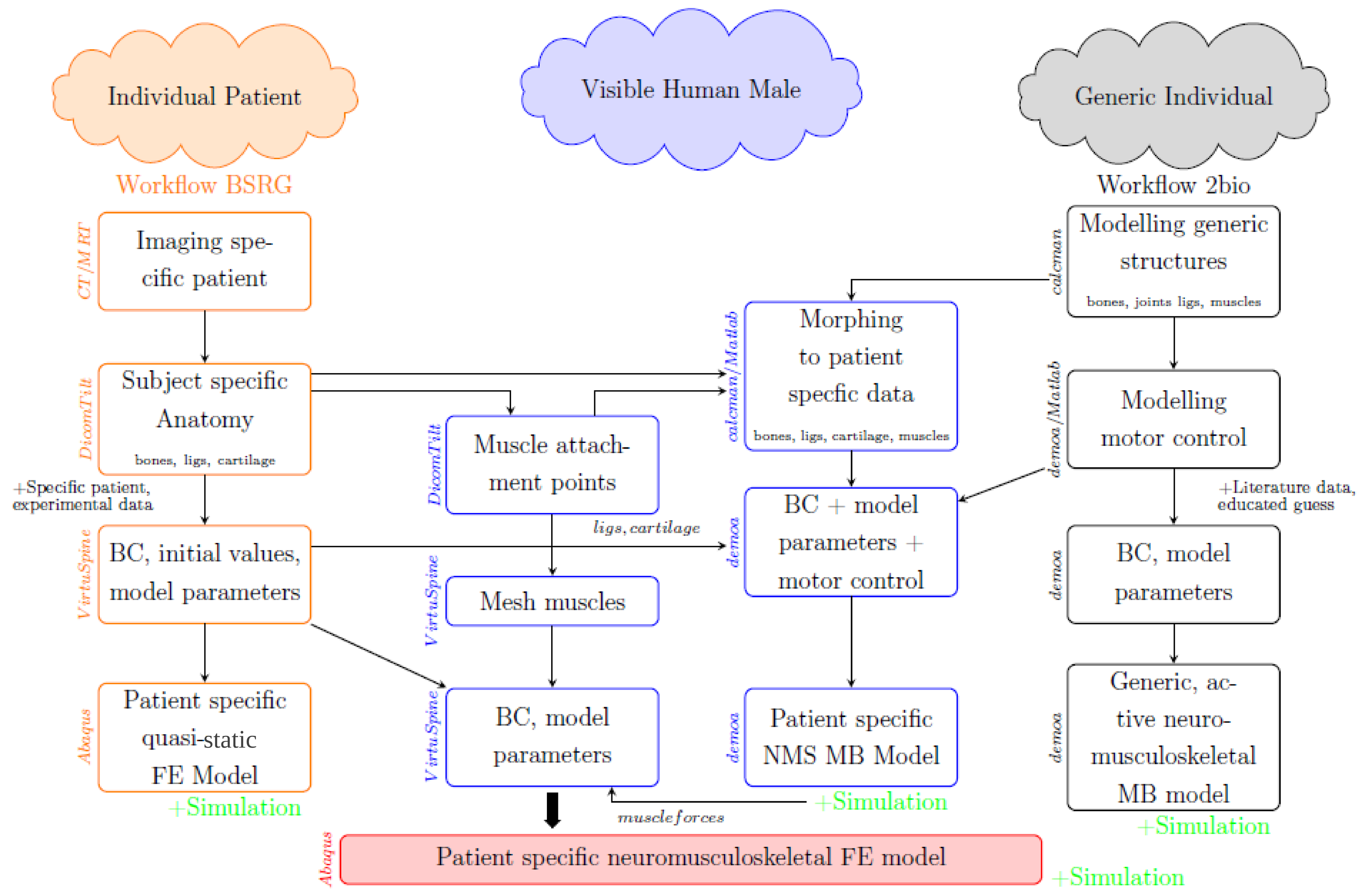
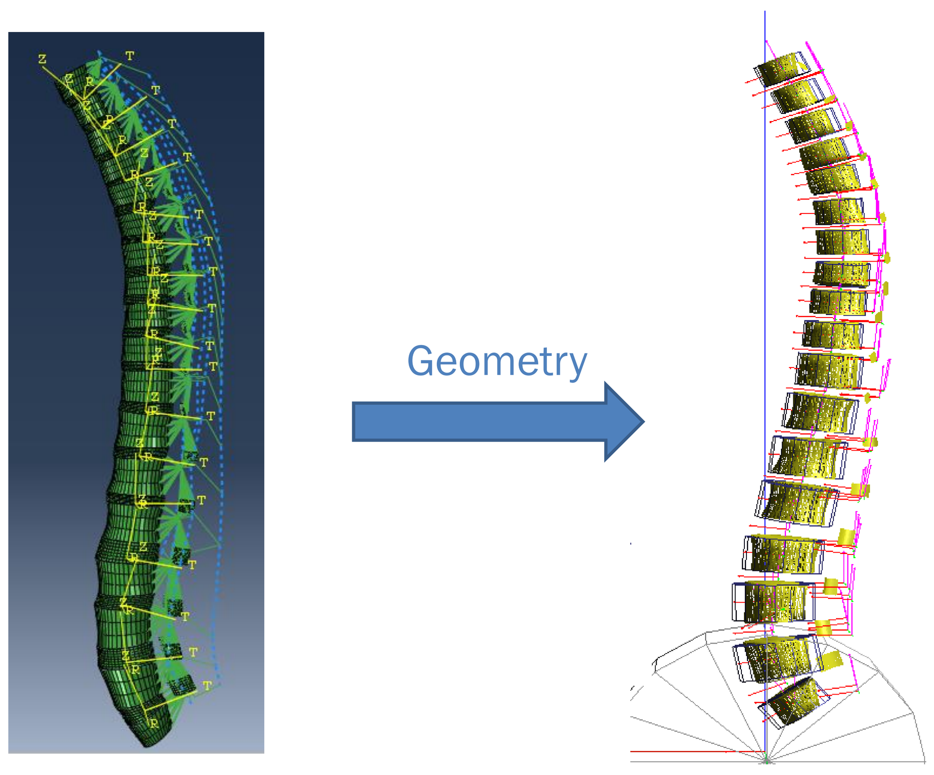


Figure 2: Flowchart of the BSRG- 2bio model project combining two different computational models. Developed integrated framework enables to evaluate and compare performances of two different models.

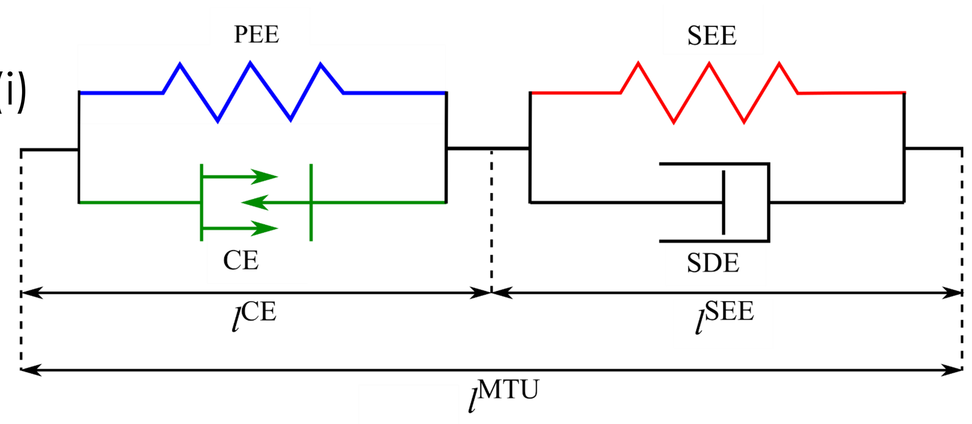
RESULTS

Steps Involved in Integrating two Complementary Modelling Methodologies

Anatomy
Adaptation of the patient specific geometry of the BSRG model to the 2bio model



(i)



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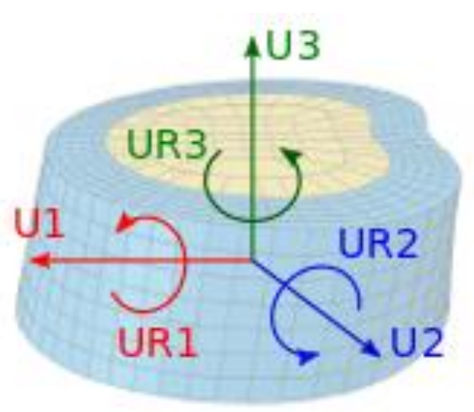

Muscles
In the 2bio model muscles are implemented as straight line elements between attachment points. A modified Hill-type model according to Haeufle et al. is used to perform forward-dynamic movements [3].

Ligaments
Optimisation applying the "Method of Least Squares" is used to adapt the ligament structures in the BSRG model and to receive appropriate parameters for the nonlinear modelling algorithm of the 2bio model.

Intervertebral Discs (IVD)
Measurements in ABAQUS are performed for given translational and rotational loads (9 different scenarios) to obtain the stiffness matrix of the IVD at each level from the BSRG model's IVD model. Based on this information a Kernel model representing the stiffness at each spinal level is implemented in the 2bio model.

Facet Joints
The 2bio model uses coordinates of the BSRG's Capsular ligament to define position of facet joints.

(ii)

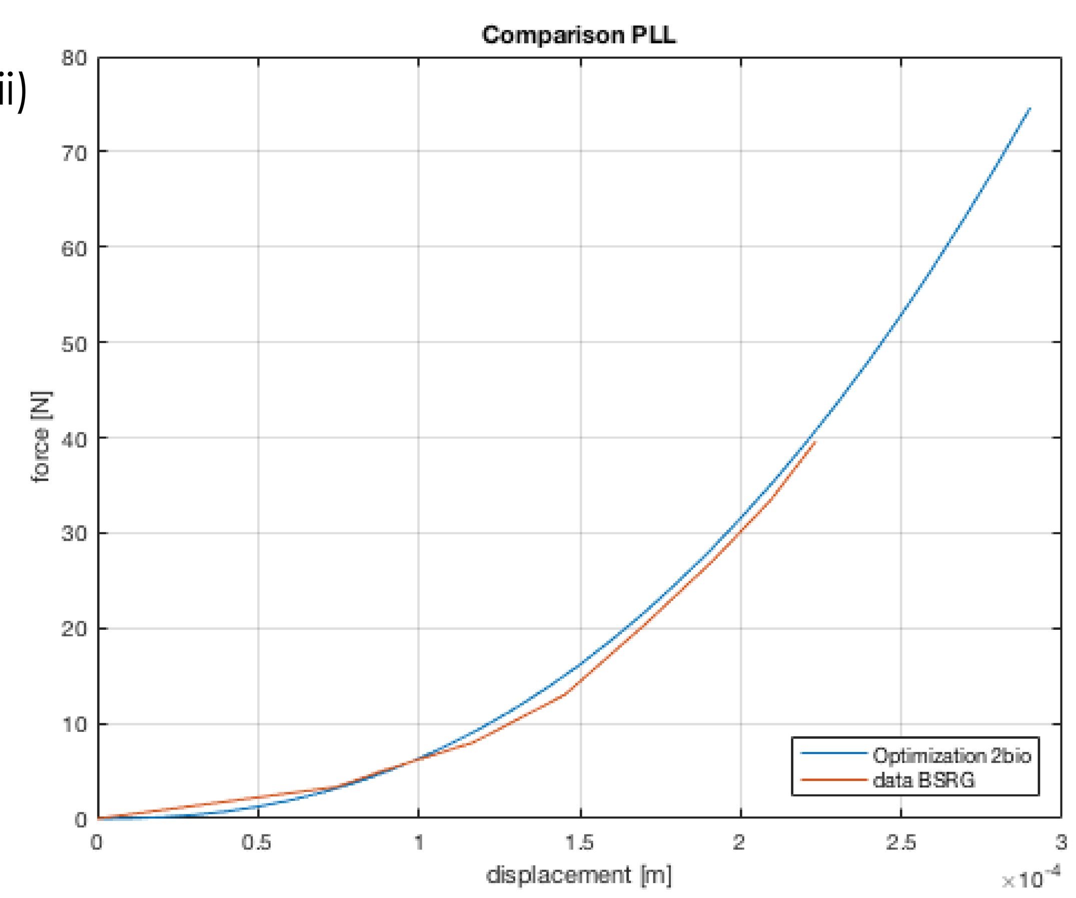

Figure 3: Detailed illustrations of various model components. (i) modified Hill-type model by Haeufle et al. which includes an additional damping element SDE to calculate muscle forces [3]. (ii) comparison of the original ligament curve of the BSRG model and the adapted curve for the posterior longitudinal ligament to make it suitable for 2bio. (iii) measurements and combinations of these on the BSRG's FEM IVD model to receive characteristic data and build a kernel model.

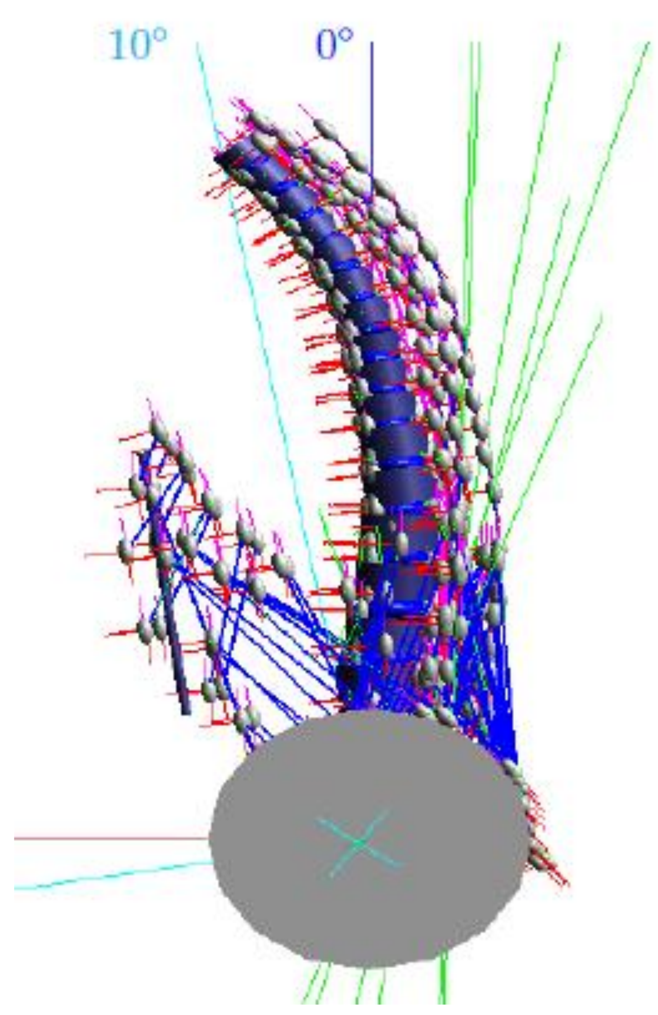

Figure 4: Forward-dynamics simulation. Simulation of forward bending using the 2bio model with patient-specific geometry in order to extract muscle forces.

DISCUSSION & CONCLUSIONS

A first drafting of the project framework that is supposed to couple two different numerical models but maintaining their modelling workflows is introduced. Spinal geometry and force laws of all biological soft tissues except the IVDs were adapted to date and implemented into the 2bio model. First goals were achieved in moving the FEM model of the BSRG forward dynamically by transferring muscle forces calculated by the kinematic model of 2bio.

References
[1] T. K. Rupp et al. (2015) In: Biomech Model Mechanobiol 14(5),1-25
[2] J. P. Little and C. Adam. (2010) In: Int Journal for Numerical Methods in Biomedical Eng 27(3), 347 -356
[3] D.F.B. Haeufle et al. (2014) In: Journal of Biomechanics 47.6, 1531–1536