EFFECT OF NEGLECTING PASSIVE SPINAL STRUCTURES ON ESTIMATED JOINT LOADS: A MUSCULOSKELETAL MODELLING STUDY

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Introduction

Accurate estimation of joint loading is of high significance to study the biomechanics of the spine. There are two musculoskeletal approaches typically used to determine these quantities: the forward-dynamics (FD) and the inverse-dynamics (ID) approach. While current ID models of the spine are becoming increasingly complex, they face the challenge of relying on accurate and comprehensive kinematic data, which most of the current motion capture technologies cannot provide for the spine. Furthermore, most ID spine models neglect the contribution of passive joint stiffness produced by ligaments and the intervertebral discs (IVDs). The major aim of this study was to quantitatively analyse the effect of individual passive structures (i.e., ligaments and IVDs) on the computed generalised net joint forces and torques in the spine using a combined FD and ID approach. A secondary aim of this study was to compare the model performance in two different musculoskeletal modelling environments (i.e., *demoa* and *OpenSim*).

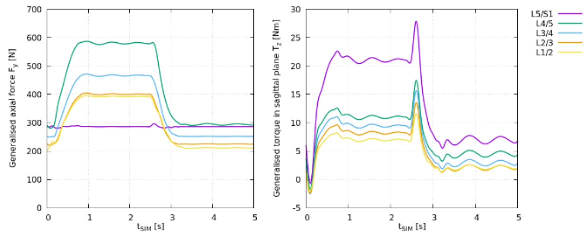
Methods

The recently published generic baseline model [1], implemented in the *demoa* software environment [2,3], was used. The thoracolumbar spine model including six degrees of freedom intervertebral joints, a detailed musculature, intersegmental ligaments and IVDs, previously used in FD simulations of a forward flexion-extension movement [1], was transferred into the *OpenSim* modelling platform. Solutions for the equivalent modelling of individual structures (i.e., muscles, ligaments and IVDs) in *OpenSim* were found. Using the full kinematic description obtained from the FD simulations, systematic ID analysis was performed in a step-wise approach increasing the model complexity by adding individual biological structures to determine their individual impact on ID analysis results. Under consideration of identical geometry and soft tissue properties, the ID model kinematics and kinetics were cross-validated against FD simulation results using the *in silico* derived motion data.

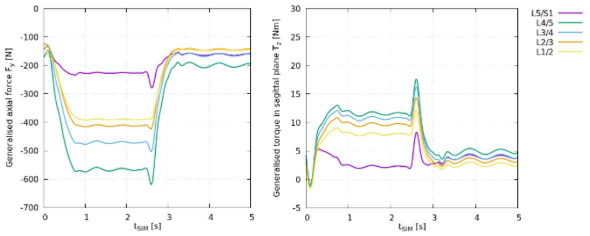
Results

Inverse-kinematics and ID analysis was performed using the generic *OpenSim* spine model with and without the contribution of individual structures. The joint kinematics complied with the joint angles obtained in the FD simulation as a result of the prescribed motion.

Results of this study have shown that the inclusion of ligaments and IVDs significantly reduces the magnitude and pattern of compressive joint loading (F_y) on average by -200% (i.e., +102% through ligaments; -302% through IVDs) and the magnitude of anterior torque (T_z) by -75% (i.e., -41% through ligaments; -34% through IVDs), respectively, between L1/2 and L4/5 (Figure 1). The individual structural contribution of ligaments and IVDs complied with the results obtained from the FD simulation in *demoa*.



(a)



(b)

Figure 1: Generalised axial force F_y (left column) and torque T_z (right column) obtained from ID analysis with ligaments implemented in (a) and IVDs in (b).

Discussion

The novelty of this work comprises the capability to use a sophisticated generic spine model [1] across two different modelling environments exploiting the strength of each environment and musculoskeletal approach, e.g., the possibility to remove biological structures under the conservation of movement in the ID approach. Moreover, in a quantitative investigation, this study has shown that neglecting passive spinal structures leads to a significant overestimation of joint loading, and consequently muscle forces.

References

1. Meszaros-Beller et al., Biomech. Model. Mechanobiol., 2023. https://doi.org/10.1007/s10237-022-01673-3
2. Schmitt S. demoa - a biophysics simulator for muscle-driven systems. University of Stuttgart, 2022.
3. http://get-demoa.com