Implementing bidirectional coupling in a combined MSK-FE modeling approach for assessing spinal loading in scoliosis patients

Background Adolescent idiopathic scoliosis (AIS) is a complex 3D spinal deformity, in which vertebral growth is altered by pathologic biomechanical forces acting on the vertebral growth plates. When the scoliosis deformity progresses to a cobb-angle beyond 45°-50°, surgical spinal fusion is required, which results in a stiffer spine and is associated with various complications. To avoid such invasive procedures, it is important to stop the progression of the curve as early as possible through conservative treatments such as scoliosis-specific exercises (SSE).

The effectiveness of currently practiced SSE is low, and new approaches should be considered. Before conducting complex clinical trials, however, new exercise concepts should be evaluated using biomechanical simulations. For this reason, we previously developed a combined musculoskeletal (MSK) and finite element (FE) modeling approach using unidirectional coupling and applied it to simulate spinal loading during static activities. To improve simulation accuracy and to allow adequate simulations of dynamic activities, a bidirectional approach should be implemented. Bidirectional simulations benefit from an iterative data exchange that accounts more accurately for large deformations[1] and allows to optimize spinal parameters such as intervertebral joint centers by minimizing the joint reaction loads or muscle activation.

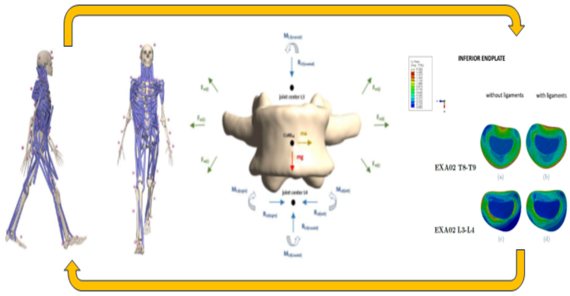

Figure 1 Individual steps of the combined simulation approach. Starting with a multi-body simulation with an MSK model, extracting the forces acting on the rigid bodies and assessing resulting forces acting on the endplates with FE modeling.

Aims 1) To implement bidirectional coupling to iteratively optimize model parameters e.g., joint centers of the intervertebral joints to minimize muscle force or loading. 2) To simulate spinal loading during dynamic activities.

Materials and Methods A generic musculoskeletal (MSK) full-body model based on Opensim[2] is personalized using patient data from children with adolescent idiopathic scoliosis. The outputs from OpenSim-based simulations, including muscle forces and acceleration forces, are applied as boundary conditions to a personalized finite element (FE) model of the spine. The FE simulations are performed using Abaqus. The center of rotation and stiffness of the targeted motion segments are calculated from the FE model and will be used to adjust the MSK model. The implementation of a bidirectional approach for these adaptations can be carried out using MATLAB or Python.

References

1. Nispel K, Lerchl T, Senner V, Kirschke JS. Recent Advances in Coupled MBS and FEM Models of the Spine—A Review. *Bioengineering*. 2023;10(3):315. doi:10.3390/bioengineering10030315
2. Delp SL, Anderson FC, Arnold AS, et al. OpenSim: Open-Source Software to Create and Analyze Dynamic Simulations of Movement. *IEEE Trans Biomed Eng*. 2007;54(11):1940-1950. doi:10.1109/TBME.2007.901024

Nature of the Thesis:
Literature reviews: 10%
MSK modeling: 30%
FE modeling: 30%
Model validation: 20%
Documentation: 10%

Requirements:

- Motivation to work in multidisciplinary team
- Interest in movement biomechanics, and basic musculoskeletal anatomy knowledge
- Programming skills in MATLAB/Python, and experience with Abaqus

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