Finite Element Analysis of the Spine during Functional Activities in Patients with Adolescent Idiopathic Scoliosis

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Introduction

Adolescent idiopathic scoliosis (AIS) is a complex deformity of the spine that occurs in 80% of adolescents. It results in a lateral deformation of the spine that may require multi-level fusion surgery in severe cases. The cause of this condition is not known, but it is thought to be related to asymmetrical loads that modulate the growth of the bony endplates and cause the vertebrae to wedge. The deformed geometry of the spine leads to uneven load distribution on the endplates, further deforming the spine. This work aimed to better characterise the mechanical loads on the endplates of AIS patients during physiological activities by combining structural mechanics finite element simulations (FE) with existing moment and force predictions from musculoskeletal simulations (MSK). Patient-specific simulations were performed based on patient anatomy and typical activities recorded using motion tracking.

Materials and Methods

Patient-specific 3D spinal anatomy was derived from biplanar radiographs of two patients with AIS (EXA02: 45° Cobb angle; EXA03: 21° Cobb angle). Dual kriging was used to deform a geometric reference model to landmarks identified on the radiographic projections (Fig. 1). Based on this reconstruction, FE models of the patient's disc and ligaments were automatically created for each level of interest (Fig. 1). The mechanical properties of the disc were determined using existing experimental data collected on sheep specimens [1].

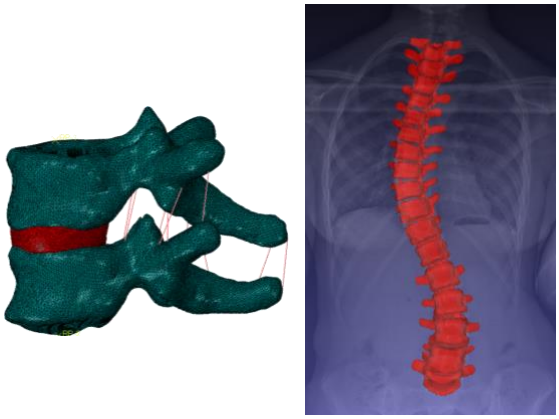

Fig. 1 FE model of a functional spinal unit (left), 3D patient-specific spine model reconstructed from orthogonal radiographic images of the patient (right)

Existing MSK simulations of the same patients were used to determine the boundary conditions of the FE model [2]; the external moments and joint reaction forces calculated with the MSK model during lifting a 5-kg-box from the ground were applied to the rigid vertebral bodies.

Results

Accurate patient-specific reconstruction of the vertebral bodies and intervertebral disc was achieved. The material parameters of the intervertebral disc showed a good identification based on experimental data. When the patients were standing with the 5-kg-box in their hands, the combined MSK / FE model showed asymmetric loading on the endplates, with the concave side of the body carrying more load than the convex (Fig. 2).

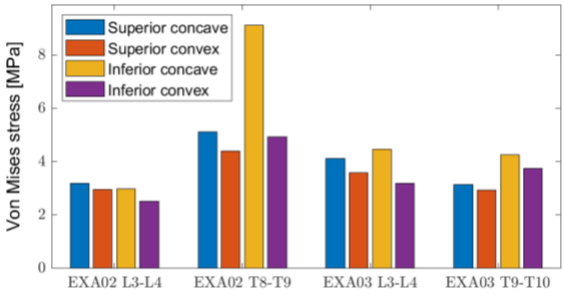

Fig. 2 Von Mises stress distribution (95% percentile) on the concave and convex sides of the superior and inferior endplates of two patients at the apex (T8-T9 level)

Discussion

This study allowed the calculation of vertebral stresses in patients suffering from AIS during functional activities. The main limitation of this initial approach concerns the material properties of the ligaments which are too stiff, limiting the flexion-extension motion. In addition, further work is needed to accurately transfer the boundary conditions from the MSK simulations to the FE model, focusing on joint reaction forces and rotational displacements. This project is a first step toward exploring conservative treatment approaches of AIS patients, with the goal of reducing or eliminating the need for surgical correction.

References

[1] PhD Thesis: Reutlinger Christoph, (2014) University of Bern
[2] Master's Thesis: Rauber Cedric, (2022) University of Bern