Musculoskeletal Modelling of the Spine during Functional Activities in Patients with Adolescent Idiopathic Scoliosis

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Introduction

The spine is the central support structure of the body, connecting different parts of the musculoskeletal system, providing movement and stabilisation. Adolescent Idiopathic Scoliosis (AIS), a three-dimensional deformity of the spine, is the most common form of scoliosis in adolescents, affecting 4% of this population[1]. The aim of this study was to use biplanar EOS images to implement a spinal deformity into musculoskeletal (MSK) modelling software and perform simulations to determine joint reaction loads during functional activities. In combination with finite element simulations, this will lead to a better understanding of the pathomechanism of the disease.

Materials and Methods

EOS images from AIS patients were used to predict landmarks of the thoracic and lumbar vertebrae, which were then used to derive orientation and virtual joint positions to create OpenSim-based patient-specific MSK models (Fig.1). After model creation, a model validation and sensitivity study was performed to determine the optimal model parameters in terms of maximum isometric muscle force and the optimal actuator force to support movement in the spinal joints. Parameter evaluation was performed for a subject with a Cobb angle of 45°. External moments as well as joint reaction loads during the lifting of a box lifting task with a weight of 5kg were predicted for the first time by an OpenSim analysis.

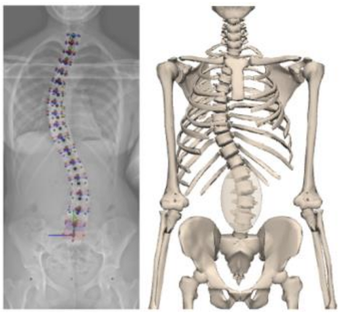

Fig. 1 Radiographic EOS images with predicted landmarks on the vertebrae (left) and derived OpenSim model with a spinal deformation (right) of a patient suffering from AIS.

Results

The difference in the locations of the joint centres between the EOS model and the OpenSim model showed a maximum error of 3.1mm in the laterolateral direction. The sensitivity study of the model parameters showed that, in principle, increasing the optimal force of the supporting actuator leads to fewer failed frames in the static optimisation, whereas a decrease leads to less smooth curves for all tested scale factors for the maximal isometric muscle force. External moments and joint reaction loads for flexion/extension (FE), lateral bending (LB) and axial rotation (AR) were predicted (Fig.2). Moreover, the muscle activity ratios of the model in standing position were compared with experimental data as well as with other studies, including predictions by different MSK models [2, 3] and in vivo experiments. Trends similar to those reported in literature were observed.

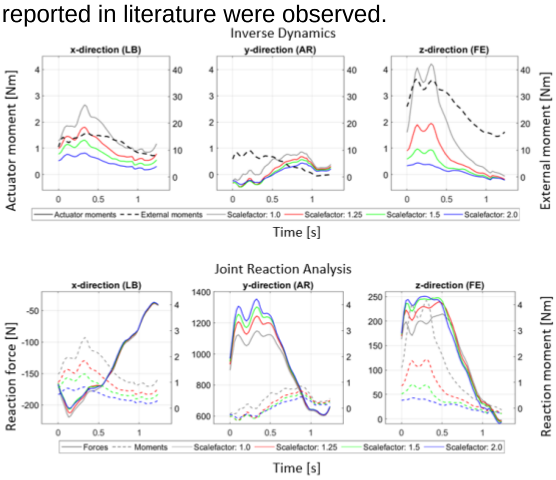

Fig. 2 External moments are reasonably higher for FE-direction and increasing the muscle scale factor increases the joint reaction forces but lower the reaction moment.

Discussion

This study provides a method capable of predicting joint reaction forces and external moments of AIS patients during functional activities. Main limitations in the model building process such as centre of mass, rib deformation and muscle properties could be further improved, and some MSK model components, such as passive elements, could be implemented to better match the mechanics of the model to reality. This model can be used to perform finite element simulations to better understand the biomechanical factors affecting the progression of the curvature.

References

[1] Scoliosis Research Society, *2022 (www.srs.org)*
[2] Barba et al. *J Biomech*. 2021; 114:110154.
[3] Schmid et al. *Front Bioeng Biotech*. 2020; 8:159.