Optimizing Center of Rotation Placement in Musculoskeletal Models of the Scoliotic Spine: A Sensitivity Study

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Summary

This study evaluates the sensitivity of joint reaction forces to center of rotation (CoR) variations in a personalized musculoskeletal model of an AIS patient. Results suggest that optimizing CoR placement by minimizing joint reaction forces could improve model accuracy, offering a biomechanically informed approach to CoR definition.

Introduction

Joint motion in musculoskeletal (MSK) models is often constraint to rotations only, reducing vertebral joints from six degrees of freedom to three. This simplification highlights the importance of the center of rotation (CoR), as its position directly influences muscle moment arms and alters muscle and joint reaction forces [1]. In MSK models that incorporate spinal deformities such as adolescent idiopathic scoliosis (AIS), the CoR must be adapted accordingly. Typically, the CoR is determined based on geometric approaches [2, 3]. However, optimizing CoR placement by minimizing joint reaction forces could improve model accuracy and provide a biomechanically informed CoR definition. This study evaluates the sensitivity of CoR definitions and investigates the potential of an optimization algorithm to refine CoR placement by minimizing joint reaction forces.

Methods

A previously developed personalized MSK model of a 12-year-old female patient with AIS (Cobb angle: 21°) [3] was used to evaluate the sensitivity of joint reaction force predictions to variations in joint center position. The spinal shape was personalized based on biplanar radiographs, and the model was driven by motion capture data collected from a sit-to-stand task performed by the patient. A 3x3x3 grid with 10mm increments was used to systematically alter the joint center coordinates of the apical segment (T8/T9) (Fig. 1). Joint reaction forces were computed using OpenSim v4.5 and MATLAB R2023B (Mathworks, Inc., Natick, MA, USA).

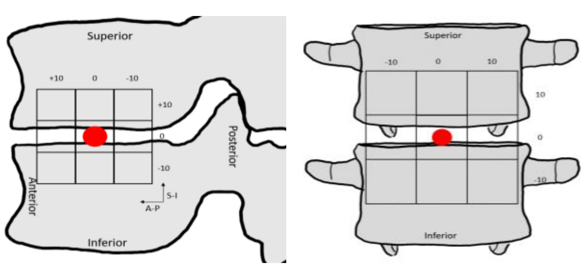

Figure 1: Joint center grid with the introduced variation. The red dot indicates the center of rotation (CoR) as previously defined. A-P: anterior-posterior, M-L: medial-lateral, S-I: superior-inferior.

Results and Discussion

Joint reaction forces varied within a range of 1-2% of body weight (BW) at 43% of the movement cycle where the peak forces were observed (Fig. 2).

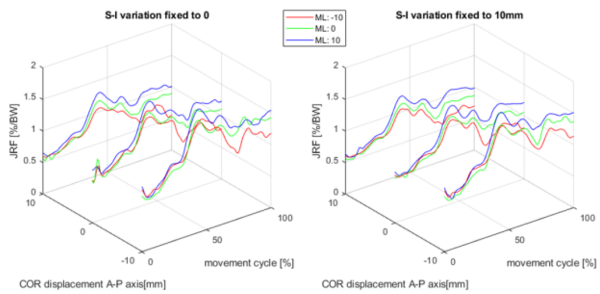

Figure *2:* Joint reaction forces (JRF), normalized to body weight (BW) for a sit-to-stand movement. Colors represent different center of rotation (CoR) positions along the medial-lateral axis, while the y-axis indicates variations in the anterior-posterior direction. Separate graphs illustrate shifts along the superior-inferior axis.

Variations in the CoR significantly influence joint reaction force computations, with a 10 mm shift in CoR position leading to deviations of up to approximately 1% of the subject's BW. The MSK model has certain limitations, as it does not account for passive structures (e.g. ligaments, fascia) that limit spinal mobility and may reduce the sensitivity of joint reaction forces to CoR variations. Additionally, static optimization appears to be only partially accurate in predicting AIS-related muscle activation patterns [3]. Future simulations should therefore integrate EMG-assisted optimization to better capture individual muscle activation dynamics.

Conclusions

Optimizing the CoR placement by minimizing joint reaction forces offers a biomechanically informed approach to defining its position during movement.

Acknowledgments

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References

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