The Impact of Spinal Alignment Individualization on Musculoskeletal Loads Predictions in Adult Spinal Deformity

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Summary

This study highlights the sensitivity of individualized alignment modeling on spinal loads in an adult spinal deformity cohort. Simulating progressively detailed sagittal and coronal alignment representations revealed substantial differences in spinal load predictions. These findings emphasize that oversimplifying alignment or neglecting coronal deformities leads to significant spatial and biomechanical errors.

Introduction

Spinal alignment is a critical biomechanical factor influencing the risk of mechanical complication after spine surgery [1]. While it significantly impacts spinal loads, musculoskeletal (MSK) models often simplify body posture by evenly distributing postural angles across segments, leading to inaccuracies in alignment representations. This study aims to evaluate the effect of spinal alignment modeling methods, with increasing level of individualization, on spinal load predictions in patients with adult spinal deformity (ASD).

Methods

Thoracolumbar spinal loads of 598 ASD patients (ESSG cohort, 52.6±21.0 years, M/F: 0.23) were predicted using a novel articulated MSK model of the spine (AnyBody v.8). For each patient, four upright-standing models were reconstructed with progressively detailed sagittal (S1-S3) and sagittal-coronal (SC3) alignment representations derived from (bi-) planar radiographs (Figure 1). S1 used clinical measurement angles, S2 incorporated individual vertebral inclinations, and S3 added vertebral centroid positions. SC3 further included the coronal deformity. Spinal loads in compression (CMP), antero-posterior (AP) and medio-lateral (ML) shear were estimated by inverse-static simulations. The relative force variation (RFV), calculated as the median % difference in loads across all spinal levels, was evaluated with respect to S3. Reconstruction errors in vertebral rotations and positions were analyzed.

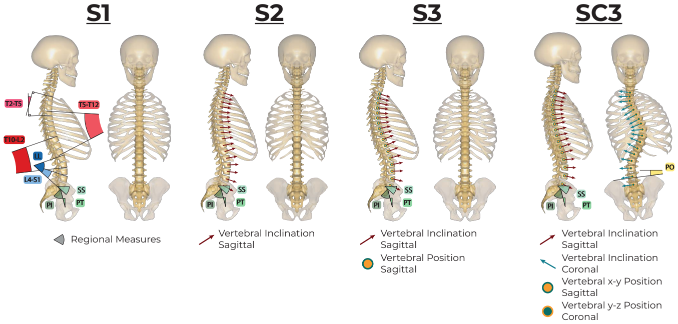

Figure 1: Patient-specific spinal alignment modeling methods with increasing level of radiographical conformity.

Results and Discussion

Statistical differences (p<.05) were found in 125/153 evaluated segmental loads (CMP, AP and ML shear) across all scenarios (Figure 2). Median RFVs in CMP compared to S3 were 10.64% (S1), and 15.06% (S2) higher in the sagittal plane and 45.88% (SC3) in the biplanar posture representations. For AP shear loads, higher median RFVs were observed: 41.45% (S1), 63.26% (S2) in the sagittal plane, and 36.57% (SC3) for coronal deformities. Vertebral inclinations related to S1 postures deviated by ±20° across all spinal levels, while centroid positions varied ±6cm (AP), -13cm to 7cm (cranial-caudal) and -17cm to 12cm (ML), compared to radiographical data.

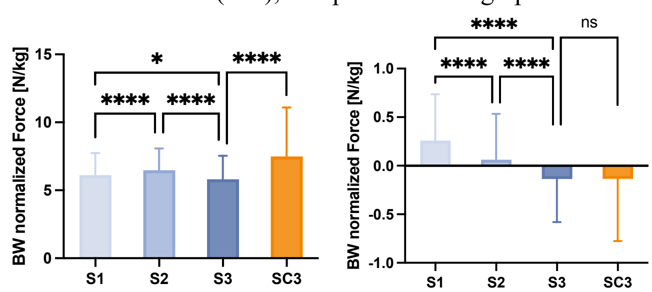

Figure 2: Body weight (BW) normalized T10T11 CMP (*left*) and AP shear (*right*) in progressively biofidelic postures, analyzed with non-parametric (Shapiro-Wilk p<.0001), paired Friedman test.

The findings of this study demonstrate that the level of individualization in patient-specific alignment modeling significantly influences spinal load predictions. Simplified alignment reconstructions (S1-S3) resulted in substantial spatial deviations in vertebral positions and inclinations compared to the radiographic ground truth data, which may explain the observed discrepancies in load predictions. Additionally, spinal loads were significantly underestimated when coronal deformities were not incorporated into the model [2].

Conclusions

The level of individualization in posture reconstruction significantly impacts spinal load predictions. Therefore, it is crucial to fully incorporate radiographic information to accurately represent patient-specific vertebral alignment and ensure more reliable spinal load predictions.

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References

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