

Decoding the Impact of Thoracic Flexibility on Cervical Alignment: Advanced Predictive Modeling of Disability Outcomes in Posterior Cervical Fusion

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INTRODUCTION: Thoracic flexibility and cervical alignment are crucial factors influencing post-surgical outcomes in patients undergoing posterior cervical fusion. While prior research has emphasized the role of sagittal alignment, the complex interactions between thoracic flexibility and cervical biomechanics and their effects on pain and disability remain poorly understood. We investigated the relationship between thoracic flexibility, cervical alignment, and clinical outcomes and to evaluate whether advanced predictive models can enhance outcome prediction in posterior cervical fusion.

METHODS:

A retrospective analysis was conducted on 227 patients who underwent multi-level posterior cervical fusion. Thoracic flexibility was quantified by the difference in T1 slope between upright X-rays and supine MRI/CT scans, while cervical alignment was measured using C2-C7 lordosis and sagittal vertical axis (SVA) changes. Clinical outcomes were evaluated using the Visual Analog Scale (VAS) for pain and the Oswestry Disability Index (ODI) for disability. Analytical approaches included interaction analysis, non-linear regression, clustering (K-means), and predictive modeling (Gradient Boosting Machines [GBM], Random Forests), with model validation using cross-validation and silhouette analysis.

RESULTS: The interaction analysis revealed that the combined effect of thoracic flexibility (Δ T1 slope) and sagittal imbalance (Δ SVA) had a moderate impact on disability, though it did not explain all variability in outcomes. BMI played a significant role, with patients having higher BMI experiencing greater disability due to sagittal imbalance. Polynomial regression identified a non-linear relationship between Δ T1 slope and Δ SVA ($R^2=0.333$), indicating that thoracic flexibility has a more complex impact on cervical alignment. This suggests that small changes in thoracic flexibility can lead to disproportionately large impacts on cervical sagittal alignment in certain patients. Although the interaction of biomechanical factors like thoracic flexibility and alignment had a measurable impact on disability, their influence on pain was limited. Clustering analysis identified patient subgroups based on thoracic flexibility, sagittal imbalance, and clinical outcomes. These subgroups demonstrated varying levels of disability and pain, with patients exhibiting high thoracic flexibility and significant sagittal imbalance reporting the highest levels of disability and pain. Predictive modeling, using techniques such as GBM and Random Forest, performed poorly in predicting clinical outcomes, yielding negative R^2 values. This suggests that additional biomechanical or psychosocial variables may be required to improve the accuracy of predictive models for patient outcomes following cervical spine fusion.

DISCUSSION AND CONCLUSION: Thoracic flexibility and cervical alignment influence disability outcomes, but the predictive power of these biomechanical factors is limited when predicting pain and overall outcomes. The interaction between BMI, thoracic flexibility, and sagittal imbalance was found to exacerbate disability, but additional psychosocial and biomechanical factors may need to be incorporated for more accurate predictions. The advanced modeling techniques showed that the current set of clinical variables lacks sufficient power to predict patient outcomes accurately. Nevertheless, understanding these complex interactions provides a foundation for more personalized treatment strategies, such as tailoring interventions based on patient subgroups characterized by specific biomechanical profiles, including age, BMI, and thoracic flexibility.