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Value-based optimisation of adolescent scoliosis surgery planning combining predictive analytics and biomechanical modeling - Conceptual framework

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ABSTRACT

Adolescent Idiopathic Scoliosis (AIS) is a spinal deformity affecting 1–3% of young individuals, predominantly girls. In severe cases, surgical fusion and instrumentation are required to correct the spine curvature. However, surgical planning remains highly complex, as it depends on numerous patient-specific factors, and complications are still frequently reported. Currently, surgeons primarily rely on clinical observations and empirical rules, leading to variability in techniques and outcomes. Furthermore, complications are still frequently reported (5–23%), with many being biomechanical in nature (e.g., junctional kyphosis, adjacent segment degeneration) or related to instrumentation failure.

To enhance surgical planning, predictive analytics using artificial intelligence has been introduced, incorporating patient-specific anatomical data. However, these tools have significant limitations: they primarily adopt a geometric approach to spinal modeling without integrating fundamental biomechanical properties. Conversely, deterministic biomechanical models, grounded in physics-based principles, enable the simulation and optimization of the effects of specific variables on mechanical forces and constraints applied to the spine. However, their practical implementation requires a substantial amount of input data.

Given the wide variability in AIS types and severities, as well as the strengths and limitations of existing approaches, this project seeks to address the following research question: How can AIS surgery be optimized by integrating biomechanical constraints on the instrumented spine to minimize postoperative complications (e.g., junctional kyphosis, adjacent segment degeneration, and implant failure), enhance patient outcomes, and reduce both surgical costs and duration?

To explore this, we establish a conceptual framework demonstrating the feasibility of optimizing surgical planning using a multibody biomechanical model. The initial results of this study underscore the potential of this approach by incorporating the initial planning derived from predictive analysis to refine the surgical plan, thereby minimizing biomechanical loads and moments linked to postoperative complications. Moreover, the results integrate surgical efficiency (time and cost) and clinical outcomes (correction, patient mobility, and spinal balance).

By anticipating postoperative complications and optimizing overall surgical value, this tool aims to improve patient outcomes while enhancing the efficiency and reliability of AIS surgical planning.