Higher Adjacent Segment Shear Forces after Simulated Lumbar Fusions with Reduced Lordosis

Marco Senteler¹, Bernhard Weisse², Dominique Rothenfluh³, Jess Snedeker¹.

¹ETH and University, Zürich, Switzerland, ²EMPA, Dübendorf, Switzerland, ³Queens Medical Centre, Nottingham, United Kingdom.


Introduction: Sagittal spinopelvic alignment has been shown to affect loads at the intervertebral joints and has been linked to spine health. Furthermore, the link between degenerative changes and loading of the IVD seems evident with pathophysiological loading widely thought to detrimentally affect the intervertebral disc. If changes in lumbosacral anatomy and kinematics are induced by lumbar fusion, a shift in loads may occur too rapidly for the disc to adequately adapt. Instead it may become prone to microstructural damage, potentially triggering a vicious degenerative cycle eventually leading to a degenerated disc at the adjacent segment. Previous biomechanical studies have experimentally investigated and characterized the effects of fusion. Significant differences in adjacent segment motion have been reported when segmental lordosis at the fusion level is not maintained [1]. On this basis we hypothesized that fusion angle also affects joint reaction loads. Employing a musculoskeletal model of the spine and using data from experimental studies, post-operative loads were quantified and are presented in relation to joint loads in a simulated configuration prior to fusion.

Methods: A publicly available musculoskeletal model of the lumbar spine and torso [2] for OpenSim [3] was adopted, substantially refined, and benchmarked against experimental data. This model was consistently used throughout the study. Intervertebral joints were equipped with stiffness and body specific coordinate systems were changed, allowing a straightforward modification of spinopelvic sagittal profile. Corrections to establish symmetry with respect to the sagittal plane were carried out and adjustments to mass properties of trunk segments reflected population mean values. Eight distinctive spinopelvic configurations were selected from clinical subjects of a previous study, covering the range of observed alignments in patients. Subsequently, a model was fitted onto each sagittal spinopelvic anatomy while maintaining total body height, mass assignments and sagittal plane symmetry. Results therefore capture the influence of sagittal profile yet are independent of other parameters and are therefore directly comparable. Simulation of a sinusoidal forward/backward bending motion from upright standing to 45° forward flexion and back in 5s was performed for each of the alignment-specific models in its pre- and post-op state. Different fusion configurations were modeled analogously to a previous experimental study [1], with segmental lordosis at the fusion level being maintained (in-situ), increased (hyperlordotic) and decreased (hypolordotic). The same study provided information on vertebrae kinematics, being used to control the simulation. Mean predicted post-fusion joint loads were then contrasted with corresponding results prior to fusion. Furthermore, the effect of fusion angle on joint loads was statistically analyzed at 0°, 15°, 30° and 45° flexion angle, employing a one-sided Wilcoxon signed-rank test. A p-value < 0.01 was considered to indicate statistical significance.

Results: Loads at the L3-L4 intervertebral joint directly superior to the fixation depend on fusion angle and vertebrae motion. Shear forces after hypolordotic and in-situ fusion were significantly higher than prior to fusion in all but the upright standing position (Fig.). The same postures resulted in significantly lowered forces in case of a hyperlordotic fusion. When considering flexion angles > 15° and in contrast to the intact spine, average shear forces were 34% higher (+25 N) after performing hypolordotic fusion and 17% higher (+12 N) after in-situ fusion. In contrast, artificially increased lordosis (hyperlordotic fusion) reduced shear loads by 48% (-34 N) within the same range of motion. Compression forces were affected by a 1% and 6% average increase (+6 N and +46 N) for fusions performed in in-situ and hyperlordotic fashion, respectively. If lordosis was decreased (hypolordotic fusion) compressive forces were reduced by 1% (-7 N). However, differences in compression were only significant after hyperlordotic fusion and only in flexed postures.
forces from 8 subjects during simulated forward-backward flexion (0°-45°-0°). Results are given in the state prior to fusion (intact) and for L4-L5 fusions performed at three different lordosis angles (in-situ, increased, decreased). Bottom: Bars representing average shear loads at four distinctive forward flexed postures (0°, 15°, 30°, 45°). Markers indicate the distribution of shear force values for all 8 subjects.

Discussion: In conclusion, the results of the present modeling study show that hypolordotic fusion accompanied by increased motion at the adjacent segment leads to significantly increased shear forces while compression forces were only marginally reduced compared to the intact state. The high relative increase in shear forces could place the intervertebral disc at increased risk for degeneration in the long term. These findings provide a mechanistic explanation for the reported increased incidence of symptomatic low back pain and more frequently observed degenerative changes at the adjacent segment after loss in lumbar lordosis. Major limitations of the present study are assumptions and simplifications made during modeling and simulation, in particular the considerable variability among real subjects that cannot be fully captured by any numerical model. However, in order to account for normal variations of sagittal profiles, which are known to influence intervertebral joint loads, all simulations were performed for a small representative population with normalized body height and weight. Qualitative consistency in joint loading differences throughout all 8 subjects demonstrates that computed differences in joint loads can be confidently tied to variations in fusion angle and involved changes in kinematics.

Significance: The current study mechanistically demonstrates for the first time that surgically decreased lordosis after fusion is likely to increase adjacent segment motion with higher shear forces in the intervertebral disc above the fixation. As a possible explanation of adjacent segment degeneration these results suggest that lordosis should be maintained or even increased when lumbar fusion is performed.

Acknowledgments: none

References: