Changes in Adjacent Segment Biomechanics After Laminectomy and Laminotomy in Lumbar Spine

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Introduction: Lumbar spinal stenosis (LSS), a disease of epidemic proportions in the Nation [1], is characterized by the constriction of the spinal canal at one or multiple spine levels. Spinal stenosis is often treated surgically by decompressing the spinal nerve. However, longitudinal studies report the occurrence of degeneration (e.g., disc herniation, spondylolisthesis, newly developed stenosis, etc.) in spinal segments adjacent to those operated [2, 3]. The etiology of the adjacent segment degeneration is still unclear. We hypothesize that surgical procedures for LSS, by altering the anatomy of the spine, elicit changes in adjacent segment biomechanics which may contribute to degeneration.

Laminectomy and laminotomy are decompressive surgeries for LSS typically performed when there are no indications of pre-operative spinal instability [4]. However, little is known about their implications on the rest of the spine [5, 6]. The objective of this study was to investigate changes in adjacent segment biomechanics due to these procedures. This was achieved by deploying a realistic computational model for lumbar spine biomechanics. The post-operative kinematics and intradiscal fluid pressure of the adjacent segments were quantified. Such metrics are especially relevant when investigating the etiology of the adjacent segment degeneration since altered range of motion of spine segments may increase spinal instability, eventually leading to spondylolisthesis and LSS [1]. Additionally, abnormal levels of disc fluid pressure may accelerate the process of intervertebral disc degeneration [7, 8].

Methods: A three dimensional nonlinear finite elements model of the lumbar spine (from L1 to L5) was reconstructed via CT scan of a healthy male subject (Visible Human Project®). Lumbar vertebrae were schematized as rigid bodies, while intervertebral discs were modeled as inhomogeneous biphasic materials. More specifically, the nucleus pulposus (NP) was defined as non-linear isotropic biphasic. In contrast, the annulus fibrosus (AF) was composed of lamellae, each of them modeled as non-linear fiber-reinforced biphasic materials. Cartilage at facet joints and major lumbar spine ligaments were also included into the model. A noncommercial finite element software (FEBio 1.8.0, Musculoskeletal Research Laboratory, University of Utah, Salt Lake City, UT) was used in this study. Four post-operative scenarios were simulated: unilateral laminotomy, bilateral laminotomy, facet-sparing laminectomy, and laminectomy with facetectomy. For each scenario, the operated segment was L4-L5, and the changes to spine anatomy associated with each surgical procedure were implemented as reported in previous studies [5, 9]. In the simulations, a follower load of 400 N, together with a pure flexion-extension bending moment (8 Nm in flexion and 6 Nm in extension) were applied to the spine. Such loading conditions were the same as those used in a previously reported in-vitro study [5], which was used for validating our model. This analysis focused on post-operative alterations of the biomechanics of the
adjacent segment L3-L4 in terms of rotational range of motion in the sagittal plane, and intradiscal pressure. For each post-operative scenarios investigated, model results were compared to those computed for the ‘intact spine’ case (no surgical operation).

**Results:** Our model was successfully validated: its predictions on spine kinematics were in good agreement with in-vitro studies on alterations of spinal range of motion as a consequence of multiple level laminectomy and laminotomy [5] (data not shown).

When investigating the post-operative alterations of L3-L4 biomechanics, it was found that laminectomy procedures caused the largest changes in the rotational range of motion of the adjacent segment: more than 100% during flexion with respect to the ‘intact spine’ case, see Figure 1. These post-operative scenarios were also characterized by the largest increases in intradiscal pressure: more than 100% in NP and more than 50% in AF when compared to the ‘intact spine’ case, see Figure 2. In contrast, after either unilateral or bilateral laminotomy, changes in adjacent spinal segment kinematics and intradiscal pressure were less than 20% and less than 2%, respectively.

![Figure 1: Post-operative changes in rotational range of motion of the adjacent segment. Data are compared to the ‘intact spine’ case.](image-url)
Discussion: Post-operative increase in spine range of motion is indicative of spine instability, which may be detrimental for the adjacent segment health [1]. In agreement with clinical studies [10], this model predicted changes in spine kinematics after laminectomies that were dramatically larger than those found after laminotomies (Figure 1). This is related to the fact that, in laminectomy procedures, interspinous and supraspinous ligaments are removed. Such ligaments withstand the highest tensile forces during spine flexion [11].

Intradiscal pressure increase may negatively affect intervertebral disc metabolism, potentially leading to disc degeneration [7, 8]. Similarly to kinematics results, our model’s predictions indicate that, after either unilateral or bilateral laminotomy, intradiscal pressure changes are expected to be negligible. In contrast, after laminectomy procedures, intradiscal pressure is expected to increase up ~100% (Figure 2). Similar trends with different magnitudes were found in an in-vitro study on calf spine [6].

Significance: Laminotomy represents a better approach than laminectomy for reducing potential risks of developing either spine instability or mechanically-accelerated disc degeneration in adjacent segments.

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