Comparative Analysis on the Implications of Anterior Lumbar Interbody Fusion and Posterior Lumbar Interbody Fusion on Adjacent Segment Biomechanics: a Finite Element Study

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Disclosures: S. Asfour: None. S. Elmasry: None. L. Latta: None. J. Gjolaj: None. F. Travascio: None. F. Eismont: None.

Introduction: Low back pain is a disease of epidemic proportion in the Nation [1]. The etiology of this disease is multifactorial, and in some cases, it can be caused by disc degeneration at one or multiple spine levels (discogenic low back pain). Discogenic pain can be surgically treated via discectomy and fusion. However, longitudinal studies reported the occurrence of degeneration (e.g., disc herniation, spondylolisthesis, development of stenosis, etc.) in spinal segments adjacent to those fused [2, 3]. Such type of pathology is known as Adjacent Segment Degeneration Disease (ASDD), and its etiology is still unclear.

Recent studies have shown that fusion surgery may represent one of the factors leading to the ASDD [4, 5]. It is thus hypothesized that surgical procedures, by altering the normal physiological anatomy of the lumbar spine, elicit alterations of the adjacent segment biomechanics which contribute to disc degeneration. Several surgical techniques are currently available for performing fusion with discectomy. For instance, posterior lumbar interbody fusion (PLIF) is a traditional approach in which discectomy is performed in combination with laminectomy of the operated spine level. In contrast, anterior lumbar interbody fusion (ALIF) does not require laminectomy. Both of them, however, require the fusion of the operated spine segment. To date, the debate on which of the two approaches would provide better outcomes is still open [6].

The objective of this study was to compare the effects of PLIF and ALIF on the adjacent segment biomechanics. This was achieved deploying a realistic finite element model for lumbar spine to simulate biomechanical tests on spine constructs. The post-operative range of motion (ROM), intradiscal fluid pressure, and mechanical stress of non-operated segments were quantified. An altered ROM may be indicative of spine instability, eventually leading to spondylolisthesis and lumbar stenosis [7]. Moreover, abnormal levels of disc fluid pressure or mechanical stress may accelerate the process of intervertebral disc degeneration [8, 9]. Hence, investigating alterations in kinetic and kinematic metrics of adjacent segments may provide new insights in the etiology of ASDD, and can help answering the question on which surgical approach provides the best outcome for the patient.

Methods: Digital medical images of a healthy male subject (Visible Human Project®) were used to reconstruct a three dimensional, realistic, biomechanical finite element model of a lumbar spine (from L1 to L5). The model included lumbar vertebrae (schematized as rigid bodies), major spine ligaments (represented as non-linear tension-only elements), cartilage at facet joints (modeled as isotropic elastic material), and intervertebral discs (represented as inhomogeneous biphasic materials). For the disc, the nucleus pulposus (NP) was defined as non-linear isotropic biphasic, and the annulus fibrosus (AF) was
composed of lamellae, each of them modeled as non-linear fiber-reinforced biphasic materials. Model implementation and computations were performed via noncommercial finite element software (FEBio 1.8.0, Musculoskeletal Research Laboratory, University of Utah, Salt Lake City, UT). Simulations were executed for the ‘intact spine’ (no surgical procedure), ALIF, and PLIF. In ALIF, L4 and L5 were fused and the disc was replaced by a rigid body. Similar approach was followed in PLIF, with the additional removal of laminae at L4 and L5, together with associated ligaments. Spine constructs were mechanically loaded following a hybrid test protocol to simulate the long-term in vivo spinal behavior [10]: for all the cases investigated, a follower load of 400 N and pure bending moments were applied to spine constructs in order to attain 15° of total ROM (L1-L5) in flexion-extension. Our analysis focused on kinetics and kinematics of the adjacent segment L3-L4, and the two segments above L2-L3 and L1-L2. For each post-operative scenarios investigated, model results were normalized with respect to the ‘intact spine’ case.

Results: RESULTS
In both post-operative scenarios, changes in spinal segments range of motion were mainly observed in flexion: PLIF had a higher impact on L3-L4, whose ROM was >400% of the ‘intact spine’; in contrast, ALIF caused higher increase (~200%) in L1-L2 and L2-L3, see Figure 1. Changes in segments ROM reflected on intradiscal pressure in NP and stress in AF of the discs: PLIF produced an increase of fluid pressure larger than 200% in L3-L4; the contribution of ALIF was larger in L1-L2 and L2-L3 for both pressure and stress (>150%), see Figure 2.

Figure 1: Flexion-extension ROM of spine segments for PLIF (blue) and ALIF (red). Data are normalized with respect to ‘intact spine’ case.
Discussion: This study reports a comparative analysis on the effects of two common surgical approaches for lumbar spine fusion on the biomechanics of the non-operated spinal segments. Post-operative increase in ROM, intradiscal pressure, and stress may be detrimental for spine stability and the health of the discs [7-9]. In agreement with previous studies [11, 12], our predictions suggest that, for the spine motion explored, both PLIF and ALIF cause substantial alterations in kinetics and kinematics of non-operated segments. Fusion of L4-L5 leads to a redistribution of the relative motion of the neighboring spinal segments in order to attain the same total ROM of the ‘intact spine’. However, when compared to each other, PLIF mostly affects the immediate adjacent L3-L4, while ALIF mainly affects L1-L2 and L2-L3. In PLIF, the laminae at L4-L5, together with flavum, interspinous, and supraspinous ligaments connecting L3 to L5 are removed. Such anatomical reductions cause instability at L3-L4, and lead to increased ROM, intradiscal pressure, and stress at this level. Differently, ALIF construct is more rigid at L3-L4, and, to attain the same total ROM of PLIF, increases the motion at the above levels, causing increase in disc pressure and stress.

Significance: The ALIF may represent a better approach than PLIF for reducing potential risks of developing ASDD.

ORS 2015 Annual Meeting
Poster No: 1539