A Finite Element study of Alternative Laminectomy Procedures

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DISCLOSURES: Almeida (N), Seidenstein (N), Jain (3B – DePuy Spine, Globus Spine, Stryker Spine), Middendorf (N)

INTRODUCTION: Lumbar stenosis is a common problem arising in the elderly causing low back pain. Common treatments include laminectomy procedures. However, iatrogenic conditions like spondylolisthesis and pars interarticularis (PI) fracture due to the increased stress in the PI and intervertebral disc degeneration can occur. Recently, unilateral procedures and laminotomy procedures, which remove lesser bone from the lamina than a full laminectomy, have been proposed as potential solutions to reduce PI stress and prevent some of these iatrogenic conditions [1]. Finite element modelling can show the potential of PI fracture by identifying the stress in the PI after laminectomy procedures [2]. The current finite element models of laminectomies typically focus on full lamina removals [2] and range of motion (ROM), while the PI stress and the laminotomy procedures are usually neglected. The goal of this study was to identify differences in the PI stress and the facet joint forces for clinical procedures associated with low bone removal (Unilateral laminotomy, Bilateral laminotomy) versus procedures with high bone removal (Hemi laminectomy, Full laminectomy).

METHODS: A finite element model of a 49-year-old female lumbar spine published by Finley et al. [3] was used and analysed using FEBio [4]. The entire lumbar spine was analysed by applying a follower load and a moment. Additionally, an expansive pressure load on all four nuclei was applied and sliding contact algorithms were set at the facet joint surfaces. The L5 vertebra was fully constrained and 4 different combinations of moment and follower load were applied, 7.5 Nm and 1000 N for flexion, 7.5 Nm and 500 N for extension, 7800 Nm and 700 N for lateral bending and 5500 Nm and 720 N for axial rotation [3]. In this model, the L1 through L3 and L5 vertebral bodies were approximated as rigid to apply the follower load. The L4 vertebral body was considered non-rigid, while keeping the vertebral endplates rigid to maintain the consistency of the follower load. This approach was validated against existing models [2,3]. Four variations of the surgical procedures were simulated: Unilateral Laminotomy (ULO), Bilateral Laminotomy (BLO), Hemilaminectomy (HL) and Full Laminectomy (FL) (figure 1) and compared with the intact model. Each surgical procedure removed approx. 50% of the L45 facet joint and preserved at least 1 cm of the pars interarticularis. The intact IVD stress, PI stress, facet joint force, and ROM for each of these 4 procedures were compared. The PI stress was calculated as the average max effective stress of 3 elements within the PI.

RESULTS: Increased removal of the bone within the lamina resulted in increase in the stress within both the pars interarticularis and decrease in the facet joint forces, while the ROM of the spine remained unaffected**.** Right axial rotation caused the highest changes in the max stresses in the PI. These increases were 58.2%, 57.2%, 76.4% and 76.41% for ULO, BLO, HL and FL respectively compared to 6.3 MPa in the intact model (Figure 2a). The PI stresses during ULO and BLO are considerably lower than HL and FL for all motions applied (flexion, extension, rotation, lateral bending, (Figure 2a). The percent change in ROM for all four procedures did not exceed 15% (not shown). The facet joint force reduced with increased resection and the percent change in force both increased and decreased depending on which procedure and spinal motion was examined. (Figure 2b)

DISCUSSION: This study showed that by preserving the midline spinous process and reducing removal of the lamina, PI stress can be significantly reduced. The small increase in ROM is likely due to the partial preservation of the facet capsular ligament. This increase in ROM can also be attributed to the removal of the intra and supraspinous ligaments in the case of FL. PI stress increases may be attributed to reduced cross section of the PI and loss of ligaments [2]. Facet forces were reduced most likely because of the loss of cross section and contact area. This loss of force is probably transmitted through the disc instead of through the facet joints, which could provide evidence towards disc degeneration post-surgery. Although the PI stress does not reach failure stress of bone (~140 MPa) [6], patient specific variables and disc degeneration could potentially cause much higher stresses.

SIGNIFICANCE/ CLINICAL RELEVANCE: Performing the ULO or BLO procedures both reduce the risk of PI fracture when compared to HL and FL. Thus, surgeons should consider performing either of these two procedures over HL and FL to treat spinal stenosis with a reduced risk of increased PI stress or increased range of motion.

REFERENCES: [1] Thomé et al, *J. Neurosurg. Spine 2005 ;* [2] Spina, NT et al. *The Spine J. 2020* ; [3] Finley, SM et al. *CMBBE. 2018* ; [4] Mass, SA et al. *J Biomech Engg. 2012* ; [5] Dreischarf, M et al. *J. Biomech. 2014 ;* [6] Burstein AH et al. *J Bone Joint Surg AM, 1996*

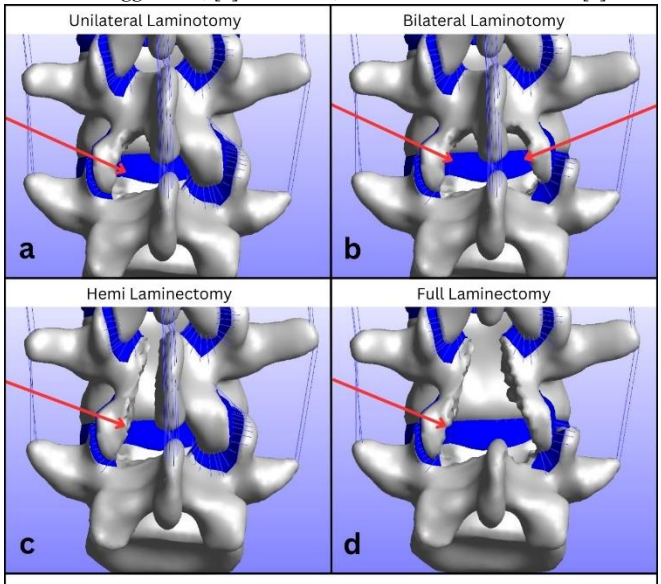

Figure 1: Representative images of the four procedures studied a) Unilateral laminotomy - ULO b) Bilateral laminotomy - BLO c) Hemi laminectomy - HL d) Full laminectomy – FL. Red arrows indicate regions of lamina that were removed.

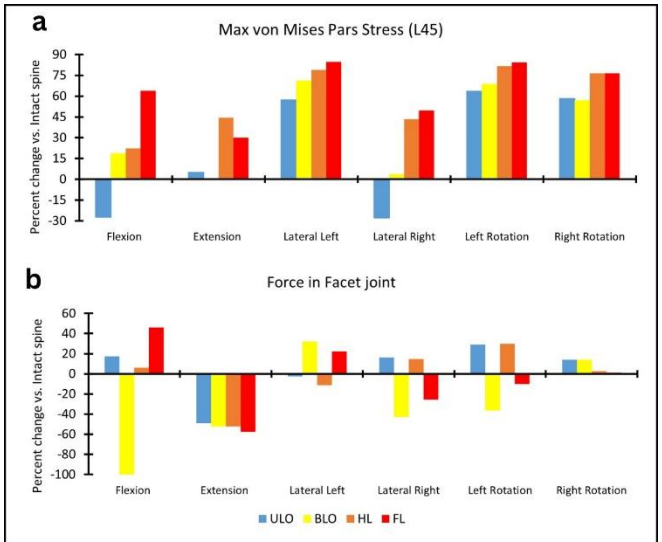

Figure 2: Percent change in the a) Max von Mises Pars Stress, and b) the L45 facet joint force, compared to values of the intact spine at the end of different spinal motions. PI stress increased more with more lamina removal procedures such as HL and FL.