Prediction of Lumbar Spine Instability Relation to the Removal Range of Lumbar Decompression Surgery by Using Finite Element Analysis

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Disclosures:

Introduction: Human aging often leads to chronic modifications in intervertebral discs, leading to conditions like lumbar foraminal stenosis, characterized by herniated nucleus pulposus, osteoarthritis, and ligament hypertrophy. These can result in neural ischemia and faulty nerve conduction, causing symptoms from radiating pain to intermittent neurogenic claudication. Initial treatments usually recommend conservative measures to minimize surgical damage and slow spinal degeneration. However, when ineffective, they can worsen the patient's condition, making comprehensive decompression through laminectomy or facetectomy necessary. These techniques may alleviate symptoms but can cause long-term complications like accelerated disc degeneration due to altered spinal alignment. Recent focus is on minimally invasive techniques and targeted therapies to treat the lesion without aggravating spinal degeneration. Given that low-grade static spondylolisthesis may not require instrumentation or fusion, endoscopic surgery presents a promising alternative. We conducted a biomechanical analysis of endoscopic treatment to determine the optimal facetectomy to target the lesion without compromising spinal stability.

Methods: Our model is Previously validated 3-dimension intact lumbar finite element model(L1-S1) of volunteer with no known spinal disease. The surgical model was implemented based on the normal model (Intact model). Different procedures of lumbar decompression surgery were simulated performed by the following varying types of model. Surgical level is L4-L5, and the superior facet on the left side of L5 was divided into 9 areas and resect. Five surgical models were implemented according to decompression surgery; Type 1 (Endoscopic foraminotomy- resection range: 30%), Type 2 (Extended endoscopic foraminotomy- resection range: 55%), Type 3 (Microscopy conventional facetectomy- resection range: 100%), Type 4 (Microscopic laminotomy- resection range: 45%), Type 5 (Microscopic subtotal laminectomy-excision range: 45%). As for the load conditions, a follower load of 400N to maintain the vertebral structure and a pure moment of 10Nm were applied for six spinal movements (flexion and extension, left and right lateral bending, left and right axial rotation). In addition, the movement of the inferior endplate of S1 was fixed in all directions. Then, the mobility of the spine following decompression was analyzed through ROM, and the possibility of degeneration of the lumbar spine was predicted through Annulus PVMS and intradiscal pressure (ABAQUS, v2022, Dassault Systemes).

Results: ROM analyzed each level of the lumbar spine and the entire lumbar spine. Compared to the normal model, the ROM of the surgical level showed the greatest increases in right axial rotation (13%) and left lateral bending (48%) in Type 4 and extension (51%) and right axial rotation (29%) in Type 6. Also, in the case of Type 6, extension movements of adjacent level (L3-L4) and the entire lumbar spine increased. Intradiscal pressure of the surgical level compared to the normal model showed the increase in type 4 right axial rotation (23%), type 6 extension (32%) and right axial rotation (12%) in the surgical level. In particular, the adjacent level of Type 6 extension showed increase (30%) unlike other types. Annulus PVMS also showed a similar increase trend, with increase in left lateral bending (24%) in the Type 4 surgical level. The surgical level and adjacent level (L3-L4) of Type 6 increased respectively (each 45%, 46%).

Discussion: Therefore, conventional facetectomy and subtotal laminectomy, which remove the entire facet and lamina during lumbar decompression, are expected to increase the mobility of the lumbar spine and cause instability. In addition, in the case of subtotal laminectomy, there is a possibility of surgical side effects such as disc herniation because the effect on the adjacent level is bad. As a result, it is considered that endoscopic surgery, which is minimally invasive than microscopic surgery, can maintain the stability of the lumbar spine. However, the function of muscles and ligaments is not expressed in detail in our model. If these functions and model shapes are implemented, it is expected to be closer to more clinical results.

Significance: As a result, endoscopic foraminotomy and extended foraminotomy were found to maintain better equilibrium distribution of load and spinal stability compared to total foraminotomy, potentially improving patient outcomes. Through this study, it can be predicted that the minimally invasive surgical method can secure structural stability of the lumbar spine and support the advantages of endoscopic surgery.

References: [1] Alison. H et al, Spine, 2007 [2] Ahn. Y et al, Annals of Translational Medicine, 2019 [3] Chen. WM.st et al, Lippincott Williams & Wilkins. 2009;34(20); E716-E723 [4] Frank M. Philips et al, The Spine Journal, 2009 [5] Li. J et al, BMC Musculoskeletal Disorders, 2019 [6] He. T et al, Frontiers in Bioengineering and Biotechnology, 2021

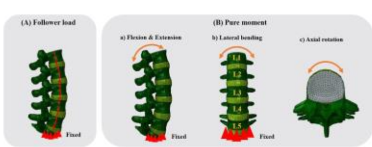

Figure 1. Loading & Boundary conditions. (A) Follower load (B) Pure moment - Movements of the lumbar spine: a) Flexion & Extension; b) Left and right lateral bending; c) Left and right axial rotation

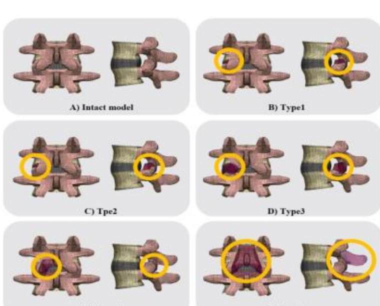

Figure 2. (A) Intact model-normal lumbar (B) Type 1 (Endoscopic foraminotomy); Type 2 (Extended endoscopic foraminotomy); Type 3 (Microscopy conventional facetectomy); Type 4 (Microscopic laminotomy); Type 5 (Microscopic subtotal laminectomy)

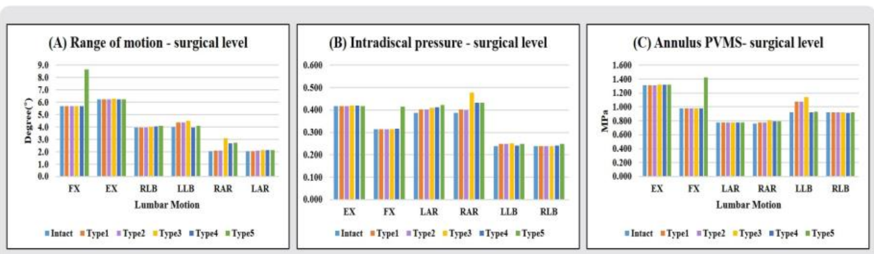

Figure 3. Graph of results. (A) Range of motion - surgical level; (B) Intradiscal pressure - surgical level; (C) Annulus PVMS- surgical level