Indirect Foraminal Decompresion may be Superior to Direct Foraminotomy in Extension: A Cadaveric Study

Scott Seibert, Ashin Modak, Jenni Buckley, Dimitriy Kondrashov

The Taylor Collaboration, San Francisco CA
SF Orthopaedic Residency Program, San Francisco CA
St Mary's Spine Center, San Francisco CA

Purpose: The purpose of this study is to use 3D X-ray reconstructions to compare the effects of both a direct posterior foraminal decompression and indirect decompression via ALIF interbody distraction on intervertebral foraminal area with respect to flexion and extension of the spine.

Methods: Eight cadaveric specimens (L5-S1) were used for this study. The edge of the superior vertebrae and approximately half of the sacrum were cast in quick-set resin (Smooth Cast 300). After intact testing, the left side of each specimen was subject to a direct, unilateral foraminal decompression by a trained orthopaedic surgeon. After testing of the effects of the direct foraminotomy, both sides of the specimen were subject to an indirect decompression via an ALIF interbody distraction. Specimen were placed into a custom made, pure moment jig. 3D X-ray scans were then taken of the specimen mounted in the jig, under no load, 3.5Nm of flexion, and 3.5 Nm of extension. The 3D X-ray scans were first converted into DICOM format, and these were imported using segmentation software. Once the models of the lumbar segment had been made, 3D models of the left and right foraminal spaces were created. The model of the foraminal space was cut into lateral cross sections 1mm thick, and the lowest cross sectional area of the foramen was recorded.

Results: There was a general trend of decreasing foraminal area in the neutral positions between test rounds. However, there were no significant differences in foraminal area in any loading condition in any round of testing. In all cases, the extension loading case had the smallest foraminal area, and the flexion loading case had the largest area. Both groups showed a significant difference ($p<0.05$, ANOVA, Tukey-Kramer HSD Comparisons) between these loading cases during intact testing. During the next round of testing, the group subject to the foraminotomy continued to show significant differences between the three groups, while the group which was not subject to foraminotomy did not show any significant difference between the no-load and extension cases. In the last round of testing, all foraminal areas were closely grouped. The group that were subject to the ALIF interbody distraction as well as the direct foraminotomy showed a significant difference between flexion and extension loading conditions only, while the group subject to only the ALIF showed no significant difference between loading conditions.

Conclusion: This data suggests that an ALIF may be more effective in treating foraminal stenosis as it can increase foraminal area and keep this area constant in all three loading conditions.

Among the aging population, as the spine undergoes degenerative changes, spine pathology is relatively common. As the lumbar spine degenerates, a patient may have lower back pain, leg pain, or a combination of the two. Radiculopathy often manifests as leg pain and can be indicative of nerve root compression, such as by a stenotic

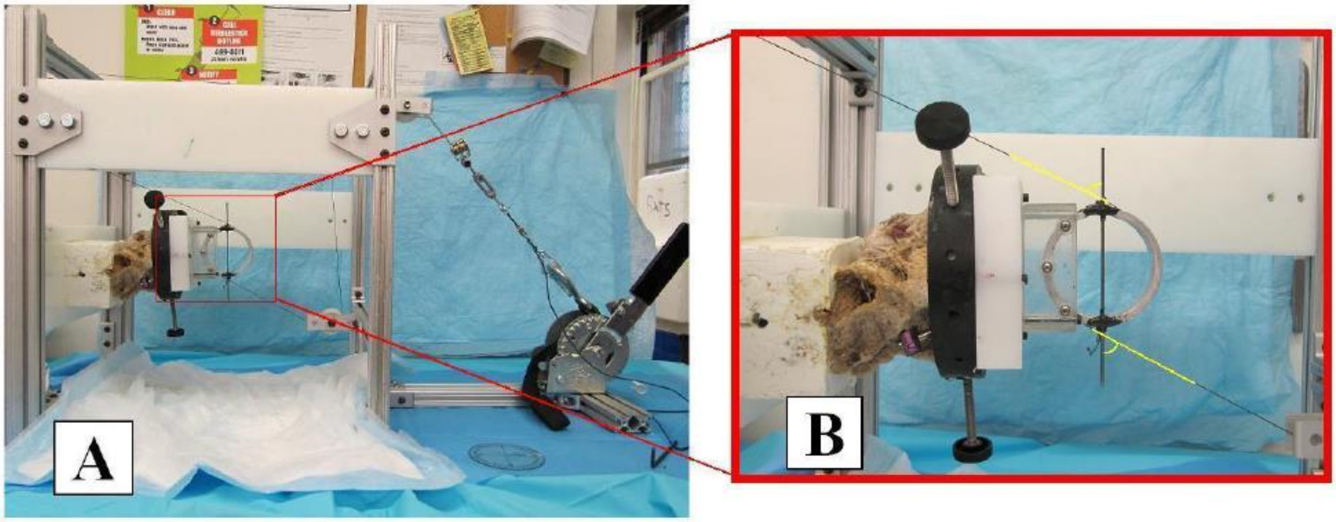

Figure 1. (A) Sample specimen in pure moment apparatus. The specimen is fixed horizontally and subject to pure moment via a fixed ring-pulley system. A winch and turnbuckle are used to generate tension on cables, which is measured by a load cell. (B) A goniometer is used to ensure that cables are parallel so that a pure moment is applied.

foraminal canal. Radiographic changes indicative of a degenerative lumbar spine include (but are not limited to) decreased intervertebral height. When intervertebral disc height is significantly reduced by disc degeneration, the intervertebral foraminal height is also reduced, and may contribute to foraminal stenosis.

Foraminal stenosis often occurs in the setting of degenerative spine changes. According to Watanabe, foraminal stenosis occurs in approximately 8%-10% of surgical cases of lumbar degenerative disease. [9] Surgical treatment has classically included a posterior foraminotomy and/or partial facetectomy to directly decompress the exiting nerve root as it passes through the spinal foramina. One characteristic of degenerative spine changes is loss of intervertebral disc space, which contributes to foraminal stenosis in the lumbar spine.

Although direct foraminotomy is often performed to treat foraminal stenosis, an alternative may be indirect decompression of the foramina by restoring lost intervertebral height. Schlegel et al distracted cadaveric spines and found statistically significant decompression in the foramina. Richards et al. investigated the use of an interspinous process device and found that it limited foraminal narrowing that would occur in extension. Hsieh P.C. et al, in a retrospective study comparing anterior lumbar interbody fusion (ALIF) to transforaminal lumbar interbody fusion (TLIF), found that foraminal height after ALIF increased by 18.5%. Another study by Lee et al, showed that after ALIF, the height and width were significantly increased from 5.2 and 4.5mm to 7.8 and 8.1mm, respectively. In a bovine ALIF model, Wang et al showed that the foraminal area and volume not only increased by 20 and 30% respectively, but also that the neuroforamen resisted deformation. Oliviera et al studied the effects of indirect decompression by extreme lateral interbody fusion (XLIF). In their nonrandomized clinical trial using magnetic resonance imaging (MRI), they found an increase in foraminal height by 13.5% and foraminal area by 24.7%. Lastly, posterior lumbar interbody fusion (PLIF) with a combination of segmental pedicle screws, interbody cages, and autogenous bone graft was also shown to benefit patients with concomitant lumbar foraminal stenosis in a retrospective study by Watanabe. These studies provide support for interbody devices to indirectly address foraminal stenosis by restoring intervertebral disc height. [1-5,9]

While these studies support the efficacy of indirect decompression using interbody devices, to the authors' knowledge, no study to date has evaluated the effect of various loads and positions of the spine on foraminal area. Our study aims to compare indirect decompression with direct posterior decompression to determine if their results are reproducible under various loads and physiologic positions ie flexion, extension, and neutral.

Methods

Specimen Preparation

Eight cadaveric specimens segments (L5-S1) were used for this study. The sacrum of each specimen was set in quick-set resin (Smooth Cast 300) up to 3 cm of the L5-S1 disk space. For L5, the superior end of the segment was fixed down to 0.5 cm of the top edge of the vertebral body. Care was taken to ensure that the foraminal space was left free of plaster and that vertebral motion was preserved. Specimen were then

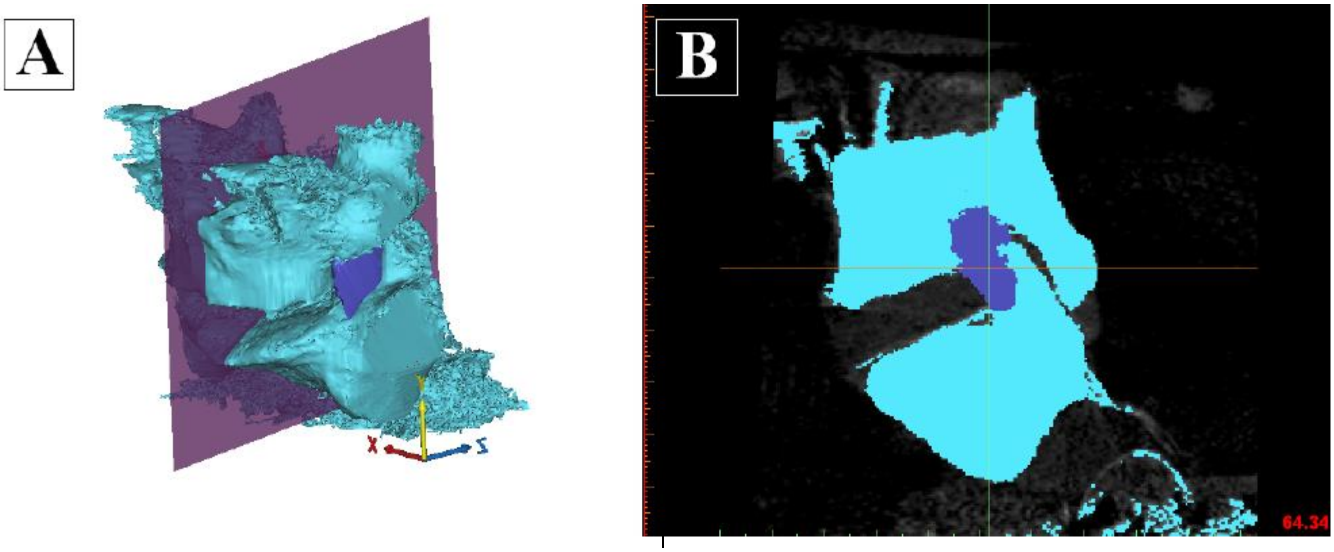

Figure 2. (A) A sample 3D reconstruction of the vertebrae (teal) and foraminal space (blue). Cross sections were made parallel to the sagittal plane (purple). (B) A sample cross section of the foraminal space (blue) The foraminal space is enclosed by the edges of the body, pedicles, and facets of the L5-S1 vertebrae

subject to intact testing, before any surgery had been performed.

Surgical Procedures

After intact testing, the left side of each specimen was subject to a direct, unilateral foraminal decompression by a trained orthopaedic surgeon. The foraminal space of the specimen was opened up using a kerrison rongeur until deemed fit by the surgeon (a Penfield #3 distractor was able to freely revolve in the space). After the surgery, the specimen were once again tested and scanned under no load, 3.5Nm of flexion, and 3.5 Nm of extension. The lowest foraminal areas of the specimen under the 3 conditions were recorded. After testing of the effects of the direct foraminotomy, both sides of the specimen were subject to an indirect decompression via an ALIF interbody distraction. A custom-cut (18mm anterior height, 10° or 18° lordotic angle) femoral ring allograft was inserted into the disc space. X-rays were used to ensure proper allograft fit, and a buttress screw was inserted through the anterior of the vertebral segment to minimize allograft movement. Posterior hardware was not used as it would interfere too much with the 3D X-ray scans. After the surgery, the specimen were once again tested and scanned under no load, 3.5Nm of flexion, and 3.5 Nm of extension. The lowest foraminal areas of the specimen under the 3 conditions were recorded .

Biomechanical Test Procedure

Specimen were placed into a custom made, pure moment jig. The jig was modeled after the same principles as the non-constrained pure moment apparatus first introduced by Craword [Crawford 1995]. A plastic cap consisting of a metal ring was attached to the superior lumbar vertebrae of the segment. Using a system of pulleys and nylon wire, the superior side of the specimen was subject to two offset forces resulting in a net moment. A goniometer was used to ensure that the two cables creating the forces were parallel to one another so there was no net force on the specimen. To ensure the minimal image distortion, the specimen was oriented horizontally, and parts of the jig directly in the line of sight of the C-arm (Phillips BV Pulsera) were made out of plastic. Tension on the wire was created using a winch and turnbuckle combination, and the resulting force was measured using a load cell. (see Figure 2) 3D X-ray scans were then taken of the specimen mounted in the jig, under no load, 3.5Nm of flexion, and 3.5 Nm of extension.

Cross Sectional Area Measurement

The 3D X-ray scans were first converted into DICOM format, and these were imported using segmentation software. Once imported, each scan was run through a threshold so that the outline of the bone was isolated. The outline of bone was then filled in to create a solid model of the bone. Next, 2 solid blocks were made that passed through each foramen space. A Boolean subtraction was used to remove the bone model from the solid blocks, resulting in the molding of the foramen space. The resulting foramen space model was then cleaned of stray marks and cut to take into account disk space. (any part of the model which fell in between the two vertebral bodies was removed). The model of the foraminal space was cut into lateral cross sections 1mm thick (Figure 3) , and the lowest cross sectional area of the foramen was recorded.

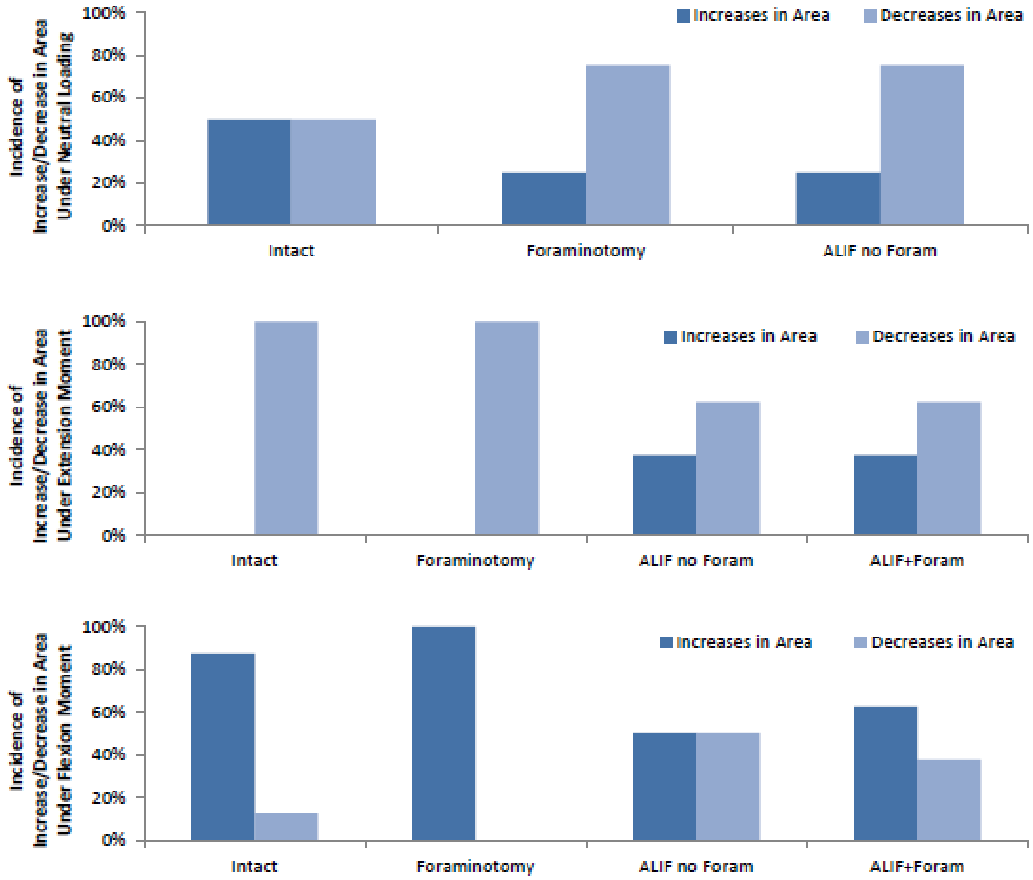

Figure 3. Effect of foraminotomy (Foram) and/or placement of allograft (ALIF). Results of neutral loading are shown at the top. The dark blue represents the percentage of specimens that had an increase in foraminal area, while light blue are those that showed a decrease (Dark blue + light blue = 100%). The effect of an extension moment are shown in the middle. The effects of a flexion moment are shown at the bottom. The occurrence of either an increase or a decrease in foraminal area was calculated from a comparison to the intact measurement under neutral loading.

Outcome Measures and Statistical Analysis

Foraminal area measurements were analyzed for incidence of increase and decrease in area as well as percent change in area. Incidence of increase and decrease was performed by comparing the foraminal area of each surgical treatment and loading direction to the area of the foramen in an intact state under neutral load. If the area under loading/surgical treatment was larger, the measurement was recorded as an increase in area. If the area under loading/surgical treatment was smaller, the measurement was recorded as a decrease in area. Increases and decreases were assigned for all surgical treatments and loading directions. Incidence was calculated as the number of increases or decreases divided by total number of foramen in the specific surgical treatment of loading group. This incidence is represented as a percentage. Percent increases or decreases in foraminal area were measured as the difference between the foraminal area for each surgical treatment and loading direction as a fraction of the area of the foramen in an intact state under neutral load. One-way ANOVA was performed on all percent change measurements for statistical significance between the means.

Results

Direct foraminotomy resulted in an increase in the area of the foramen in 50% of our specimens under neutral loading as shown in Figure 3. Indirect decompression of the foramen via ALIF reduced the rate of increase in area to 25%. In the instances where the foramen exhibited an increase in area, ALIF produced on average a 18.7% +/- 12.2% increase in foraminal area compared to foraminotomy's average increase of 5.3% +/- 3.9% as shown in Figure 4. This trend was not found to be statistically significant ($p=0.35$). The addition of foraminotomy to the ALIF treatment did not produce a larger incidence of area increase. With the application of an extension bending moment, all foramen were observed to decrease in area in our intact specimens an average of 10.9% +/- 7.4%. All of the directly decompressed foraminotomy specimens also decreased in area during extension. Only after

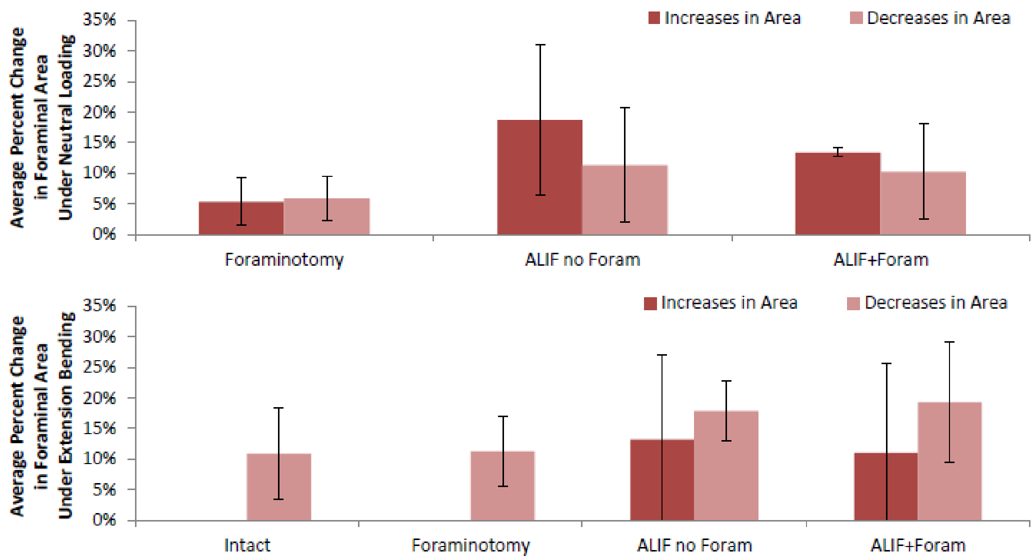

Figure 4. Average percent change in foraminal area for each surgical treatment. Results of neutral loading are shown at the top and extension loading are shown at the bottom. Percent change was calculated from the area of the foramen in its intact state under neutral loading.

ALIF did we observe any decreases in area of the foramen. ALIF w/o foraminotomy decreased in area 37.5% of our specimens with an average increase in foraminal space of 13.2% +/- 13.8%. The addition of a foraminotomy to the ALIF specimens did not effect the incidence of decreased area in foramen during extension. Flexion bending moment decreased the area of the foramen in 87.5% of our specimens. Direct foraminotomy improved the incidence of decreased area to 100% of our specimens during flexion. ALIF w/o foraminotomy decreased area in 50% of our specimens. The addition of foraminotomy to our ALIF specimens increased the incidence of distraction to 62.5%.

A bimodal distribution of the ALIF procedure was observed. Of the eight measurements in the group subject to an ALIF only, three showed an increase in foraminal area due to extension, while the rest showed a decrease. Moreover, it was noticed on X-ray that those ALIF procedures that showed increase in foraminal area had allografts placed more posteriorly than those that showed a decrease. Specifically, all specimen that displayed an increase in foraminal area had allografts that were placed more posteriorly than the posterior edge of the inferior vertebrae (S1).

Discussion

Many patients suffer from foraminal stenosis of the spine. As people age, the intervertebral disc desiccates and loses height. Stress is transmitted through the facet joints posteriorly, which concomitantly become arthritic. The facet joints are synovial joints and when arthritic, may hypertrophy and form osteophytes that can contribute to foraminal stenosis.

Along with facet arthritis, loss of disc height as a result of degenerative disc disease may contribute to narrowing of the spinal foramina. Traditionally, spine surgery to address symptomatic foraminal stenosis has been to decompress the exiting nerve roots by performing a direct foraminotomy via a posterior approach. This has limited their technique of obtaining fusion (when indicated) to posterior instrumentation.

Considering that loss of disc height contributes to foraminal stenosis, restoring this height indirectly decompresses the spinal foramina. This approach is supported by the studies mentioned in the background of this article. Flexion improves the space available for the exiting nerve root. Under extension, the foraminal decompression may be lost with direct foraminotomy alone. We found that the direct foraminotomy lost area in extension and this was statistically significant. We did not find the same loss of area in extension when using an interbody allograft. On the other hand, we found that some of the ALIF specimens actually had an increase in foraminal area (while all of the foraminotomy specimens lost area). We concluded that indirect decompression of the foraminal area after placement of an interbody allograft may be maintained in a position of extension.

Furthermore, we found that when the ALIF group showed an increase in foraminal area, it did so to a greater degree than posterior foraminotomy. According to Hasegawa et al., a decrease in posterior disc height to 4 mm or less, or a decrease in foraminal height to 15 mm or less, were critical features of nerve root compression in the foramen [22]. We believe that

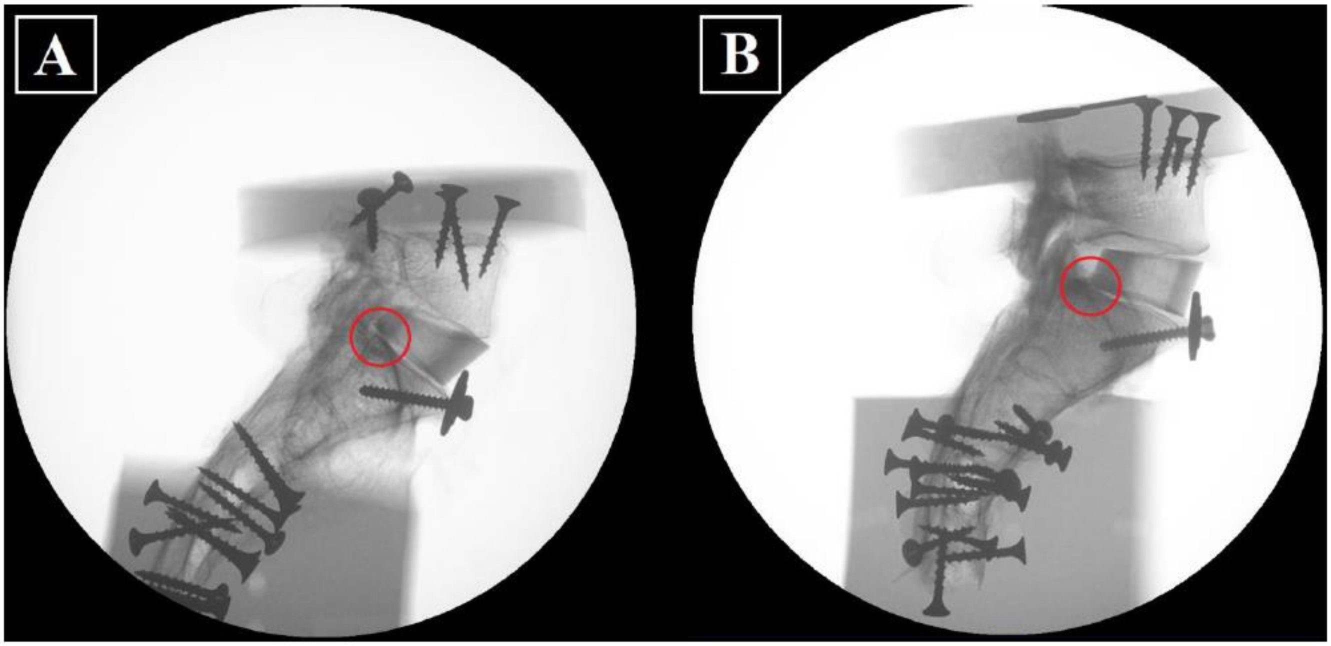

Figure 5. Typical allograft position in specimen that showed an increase (A) or decrease (B) in foraminal area in extension. In specimen that showed an increase in area, the posterior edge of the allograft was past the posterior edge of the S1 vertebrae, but this was not the case in the specimen that showed a decrease in foraminal area due to extension.

this critical restoration of foraminal height would more likely be achieved by placing an interbody device, as our ALIF group demonstrated a greater increase in foraminal area than our foraminotomy group.

However our results also show that maintenance of foraminal area likely depends on the position of where the surgeon places the interbody device and may be lost if placed too anteriorly. We believe that if the allograft was placed anteriorly, this created a hinge-like effect allowing the adjacent vertebral bodies to rock over the intervertebral graft and close down posteriorly. This implies that the surgeon should place the intervertebral device as posteriorly as possible and our study may therefore help direct surgeon technique.

Limitations of our study include using cadaveric models, which underwent appreciable degeneration between rounds of testing that is unlikely to occur in vivo. Considering that we removed the anterior longitudinal ligament (ALL), our interbody graft to restore disc height more closely resembles ALIF than it does the other approaches to interbody fusion. The concept of indirect decompression relies on ligamentotaxis, which is likely very different in vivo. Also, postoperative subsidence of the interbody device is a potential issue we could not investigate with our cadaveric study. Furthermore, we noted a general trend of decreasing foraminal area in the neutral positions between test rounds. We attribute this to using cadaveric models, which likely degenerated after each round of testing.

Furthermore, we recognize that facet arthropathy and osteophytes also contribute to foraminal stenosis. In patients with more advanced degenerative disease, osteophyte formation may preclude the ability to indirectly decompress the exiting nerve root by restoration of disc height alone. In a retrospective study by Choi et al, foraminal stenosis was found to be the main cause of failed ALIF. They noted that osteoarthritis was more advanced in particular facet arthropathy. They theorized that advanced facet disease not only has concomitant osteophytes, but also has hindered ability to restore foraminal height and size. In their review of failed ALIF surgery, L5-S1 had a greater percent of 'unfavorable outcome' than L4-5. They attributed this to the anatomy of L5-S1, stating that the sacral slope made anterior exposure more difficult and that the pubic symphisis could be an obstacle to optimal trajectory during surgery. [7,8]

In another study, Oliviera comments that when consenting for the XLIF, the patient be made aware that a second surgery posteriorly may be necessary if radicular symptoms persist, to directly decompress the foramina. The surgeon should look for preoperative characteristics that may make restoration of disc height insufficient. These include uncontained disc herniation, significant facet arthrosis with osteophyte formation, calcified disc, osteophytes from the posterior endplate, and possibly synovial cysts. [5] While

Table 1. Percentage of specimens that exhibited an increase and decrease in foraminal area after extension.

Type of Change after Extension	Percent of Specimens	Median Percent Change (ALIF only group)
Increase	37.5%	9.2%
Decrease	62.5%	-11.3%

patients with advanced disease and facet pathology may hinder the ability to successfully decompress the foramina, with proper patient selection there may still be a role for indirect decompression through interbody fusion.

Conclusion

Lumbar interbody fusion maintains the foraminal area in extension while direct foraminotomy may not. Clinical implications are that interbody devices that restore height may be a better alternative to treating lumbar degenerative disc disease with concomitant foraminal stenosis than a posterior approach with direct foraminotomy because the increase in foraminal area is maintained in extension.

References

1. Schlegel JD, Champine J, Taylor MS, et al. The role of distraction in improving the space available in the lumbar stenotic canal and foramen. Spine. 1994 Sep 15;19(18):2041-7

2. Richards JC, Majumdar S, Lindsey DP, et al. The Treatment Mechanism of an interspinous process Implant for Lumbar Neurogenic Intermittent Claudication. Spine. 2005; 30 (7):744-749

3. Hsieh PC, Koski TR, O'Shaughnessy BA, et al. Anterior lumbar interbody fusion in comparison with transforaminal lumbar interbody fusion: implications for the restoration of foraminal height, local disc angle, lumbar lordosis, and sagittal balance. J Neurosurg Spine 2007; 7(4):379-86

4. Lee DY, Lee SH, KS K, et al. A morphometric analysis of neuroforamen in grade 1 isthmic spondylolisthesis by anterior lumbar interbody fusion with pedicle screw fixation. J Korean Neurosurg Soc 2007; 41:377-381

5. Oliveira L, Marchi L, Coutinho E, et al. A Radiographic assessment of the ability of the extreme lateral interbody fusion procedure to indirectly decompress the neural elements. Spine. 2010; 35(265):331-337

6. Ghogawala Z, Benzel EC, Amin-Hanjani S, et al. Prospective outcomes evaluation alter decompression with or without instrumented fusion for lumbar stenosis and degenerative grade 1 sponylolysthesis. J Neurosurg Spine. 2004; 1:267-272

7. Choi KC, Ahn Y, Kang BU, et al. Failed anterior lumbar interbody fusion due to incomplete foraminal decompression. Acta Neurochir. 2011; 153:567-574

8. Kim SY, Maeng DH, Lee SH, et al. Anterior Lumbar interbody fusion for lumbosacral junction in steep sacral slope. J Spinal Disord Tech. 2008; 21:33-38

9. Watanabe K, Yamazaki A, Morita O, et al. Clinical outcomes of posterior lumbar interbody fusion for lumbar foraminal stenosis; preoperative diagnosis and surgical strategy. J Spinal Disord Tech 2011;24:137-141

10. Chen D, Fay LA, Lok J, Yuan P, Edwards WT, Yuan HA. Increasing neuroforaminal volume by anterior interbody distraction in degenerative lumbar spine. Spine 1995; 95:74-79

11. Wang M, Dalal S, Bagaria VB, McGrady LM, Rao RD. Changes in the lumbar foramen following anterior interbody fusion with tapered or cylindrical cages. Spine 2007; 7:563-569

12. Hallett A, Huntley JS, Gibson JN. Foraminal stenosis and single-level degenerative disc disease: a randomized controlled trial comparing decompression with decompression and instrumented fusion. Spine (Phila Pa 1976) 2007; 32(13):1375-80.

13. Kim JG, Jin YJ, Chung SK, Kim KJ, Kim HJ. Unilateral augmented pedicle screw fixation for foraminal stenosis. J Korean Neurosurg Soc 2009; 46(1):5-10.

14. Klopfenstein JD, Kim LJ, Feiz-Erfan I, et al. Retroperitoneal approach for lumbar interbody fusion with anterolateral instrumentation for treatment of spondylolisthesis and degenerative foraminal stenosis. Surg Neurol 2006; 65(2):111-6.

15. Hunt T, Shen FH, Shaffrey CI, Arlet V. Contralateral radiculopathy after transforaminal lumbar interbody fusion. Eur Spine J. 2007; 16(3):311-4.

16. Tokuhashi Y, Ajiro Y, Umezawa N. Subsidence of metal interbody cage after posterior lumbar interbody fusion with pedicle screw fixation. Orthopedics. 2009 Apr;32(4)

17. Hallett A, Huntley JS, Gibson JN. Foraminal stenosis and single-level degenerative disc disease: a randomized controlled trial comparing decompression with decompression and instrumented fusion. Spine. 2007 Jun 1;32(13):1375-80.

18. Anderson PA, Tribus CB, Kitchel SH. Treatment of neurogenic claudication by interspinous decompression: application of the X STOP device in patients with lumbar degenerative spondylolisthesis. J Neurosurg Spine. 2006 Jun;4(6):463-71.

19. Gercek E, Arlet V, Delisle J, Marchesi D Subsidence of stand-alone cervical cages in anterior interbody fusion: warning. Eur Spine J. 2003 Oct;12(5):513-6.

20. Osman SG, Nibu K, Panjabi MM, et al. Transforaminal and posterior decompressions of the lumbar spine. A comparative study of stability and intervertebral foramen area. Spine. 1997; 22(15):1690-5.

21. Min JH, Jang JS, Kim SK, Maeng DH, Lee SH (2009) The ligamentotactic effect on a herniated disc at the level adjacent to the anterior lumbar interbody fusion: report of two cases. Journal of Korean Neurosurgical Society 46:65–67

22. Hasegawa T, An HS, Haughton VM, Nowicki BH (1995) Lumbar foraminal stenosis: critical heights of the intervertebral discs and foramina. A cryomicrotome study in cadavera. J Bone Joint Surg Am 77:32–38