Changes in Foraminal Area with Anterior Decompression versus Keyhole Foraminotomy in the Cervical Spine: A Cadaveric Investigation

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Introduction: Anterior cervical discectomy and fusion (ACDF) with or without uncovertebral joint resection (UVR) and posterior keyhole foraminotomy (F) are established operative procedures to treat cervical disc degeneration and radiculopathy. Studies have demonstrated reliable results with each procedure [1,3], but none have compared the change in neuroforaminal area between indirect and direct decompression techniques. The purpose of this study is to determine which cervical decompression method most consistently increases the neuroforaminal area and how that area is affected by neck position. We hypothesized that ACDF with uncovertebral resection would be most effective to increase the neuroforaminal area.

Methods: Eight cadaveric cervical functional spinal units (C5-6 and C6-7) underwent sequential decompression. Each level was randomly assigned to a surgical sequence consisting of (1) bilateral F, (2a) ACDF, and (2b) ACDF+UVR. ACDF was performed with a 6 mm fibular strut allograft and anterior plating. After the initial procedure -- either (1) or (2a)+2b -- decompression by the other procedure was performed. In the intact state and after each procedure, the specimen was imaged in three different loading conditions: 1.5 Nm in flexion, 1.5 Nm in extension, and 0 Nm in neutral position (Figure 1). Images were imported into medical image processing software to isolate bony tissue and create solid models of the neuroforamina of interest using previously validated segmentation techniques (Figure 2) [4]. The cross-sectional area orthogonal to each foraminal trajectory was recorded at 1 mm slice thickness intervals. Minimum cross-sectional area of each foramen was then extracted for analysis. Six treatment groups were analyzed: Intact, F, ACDF, ACDF+UVR, ACDF+F, and ACDF+F+UVR (N = 16, 8, 8, 8, 8, respectively). The primary outcome measure was minimum cross-sectional area of each foramen at C5-6 and C6-7, in all three positions, for all treatment groups, with each foramen as its own control. One-way ANOVA was performed to determine any significant differences between treatment groups for each of three tested postures.

Results: Neuroforaminal area increased significantly (p < 0.05) with F (69 ± 13, 71 ± 13, 52 ± 19 mm²) versus intact (46 ± 11, 53 ± 12, 33 ± 9 mm²) in all positions (neutral, flexion, and extension, respectively). All treatments that included F -- F alone, ACDF+F, ACDF+UVR -- resulted in significantly greater area (p < 0.05) than intact in all anatomic positions (Figure 3). Significant differences in area were not observed for ACDF (51 ± 10, 49 ± 8, 41 ± 12 mm²) versus intact in any position (neutral, flexion, and extension, respectively). The area observed in neutral with F (69 ± 13 mm²) was maintained in extension (52 ± 19 mm²); however, significant decrease (p < 0.05) in area was observed for both ACDF+UVR and ACDF+F+UVR in extension (37 ± 7, 57 ± 14 mm²) versus neutral (48 ± 7, 71 ± 13 mm²).

Discussion: All procedures increased the neuroforaminal area in neutral and extension positions. Treatments that included foraminotomy all resulted in significantly increased area compared to intact in all three neck positions while anterior-only procedures did not. This increase in area was also maintained in extension, the position that produces the greatest nerve compression and symptoms and thus the most important neck position for which the neuroforaminal area must be maintained. The addition of UVR to ACDF did not significantly alter the area compared to ACDF alone. Moreover, only treatments with UVR resulted in significant decrease in area during extension compared to neutral. This supports previous findings which demonstrated that the uncovertebral joints -- specifically the posterior segment -- have a critical role in stabilizing the cervical spine, particularly in extension and lateral bending [2]. Therefore, resection of the uncovertebral joint may be unnecessary and possibly detrimental when performing ACDF. Limitations of this study include the scope of data analysis and biomechanical testing constraints. Since minimum cross-sectional area of the foramen was analyzed, our findings pertain mostly to localized bony stenosis and may not apply to soft disc herniation or degeneration. These indications would be addressed by incorporating soft tissue in a volumetric analysis. Additionally, surgical and testing protocols could be performed in a consistent amount of time for all specimens to ensure similar behavior of soft tissue during biomechanical loading. Even with these limitations, however, statistically significant results of this study suggest that direct decompression may have an advantage over indirect methods when assessing neuroforaminal area.

Significance: With a stable cervical spine, F may be preferable over ACDF to directly decompress the neuroforamen; however, ACDF continues to have an important role for indirect decompression and decompression of more centrally located herniated discs. Uncovertebral joint resection may be unnecessary and potentially detrimental when performing ACDF. Results of this study inform best practices for surgeons performing cervical decompression.
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Figure 1: Biomechanical test jig to reproduce anatomical postures (neutral, flexion, extension). A) Load cell, B) Specimen, C) Pure moment fixture
Figure 2: 3D model of right (red) and left (green) foramina for one level.

Foraminal Area vs. Treatment

![Graph showing foraminal area vs. treatment](image)

Figure 3: Comparison of six treatment groups in three loading conditions. Triangles represent statistically significant differences.

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