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Effect of Uncovertebral Joint Excision on the Motion Response of the Cervical Spine After Total Disc Replacement

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Study Design. *In vitro* biomechanical study.

Objective. To quantify the effects of uncinatectomy on cervical motion after total disc replacement (TDR).

Summary of Background Data. The effect of uncinatectomy on TDR motion is unknown. Partial uncinatectomy may be required to decompress the foramen; however, the residual uncinates can potentially limit TDR motion and serve as a source of progressive spondylosis. Complete resection of the uncinates may decrease this risk yet endanger destabilizing the segment.

Methods. Seven human cervical spines (C3–C7) (age, 63.4 ± 6.9 years) were tested first intact and then after implantation of a metal-on-polyethylene ball-and-socket semiconstrained prosthesis at C5–C6. Following this, gradually increased uncinatectomy was performed in the following order: 1) right partial-posteromedial (two thirds), 2) right complete, and 3) bilateral complete resection. Specimens were tested in flexion-extension, lateral bending, and axial rotation (±1.5 Nm). Flexion-extension was tested under 150 N follower preload.

Results. TDR without uncinatectomy increased C5–C6 flexion-extension range of motion from 8.4° ± 3.5° to 11.6° ± 3.4°, but statistical significance was not reached ($P > 0.05$). Lateral bending decreased from 6.2° ± 2.2° to 3.1° ± 1.4°, with a trend for statistical significance ($P = 0.07$). Axial rotation decreased from 5.5° ± 2.4° to 4.3° ± 1.4° after the implantation ($P > 0.05$). Both right partial and right complete uncinatectomy resulted in nearly symmetrical restoration of lateral bending to intact values and significantly increased flexion-extension compared with intact ($P \leq 0.05$); however, axial rotation still did not differ from intact ($P > 0.05$). Complete bilateral resection also restored lateral bending to intact values (7.3° ± 2.7°, $P > 0.05$); however, it resulted in significant increase in range of motion in flexion-extension (14.1° ± 3.0°, $P \leq 0.05$) and axial rotation (8.7° ± 2.4°, $P \leq 0.05$).

Conclusion. Unilateral complete or even partial uncinatectomy can normalize lateral bending after TDR. Bilateral complete uncinatectomy is not necessary to restore lateral bending and may result in significantly increased range of motion in flexion-extension and axial rotation compared with intact values.

Key words: cervical spine, artificial disc, total disc replacement, uncinate, kinematics. **Spine 2007;32:2965–2969**

Total disc replacement (TDR) has recently been examined as an alternative to anterior cervical discectomy and fusion (ACDF) for symptomatic cervical disc disease. Despite excellent results from ACDF, there is still a well-documented risk of postoperative stiffness, adjacent level degeneration, and pseudarthrosis resulting in surgical level instability.[1–5] By achieving physiologic levels of motion at the pathologic disc space, TDR can potentially avoid many of these complications.

Cervical arthroplasty remains a relatively new approach; therefore, many technical considerations have not been fully addressed. As in the case for ACDF, the initial preparation for cervical TDR involves anterior discectomy; however, what should be done with uncovertebral joints remains unclear. Hypertrophic changes at the uncovertebral joints can lead to foraminal stenosis and radiculopathy that may require their partial removal. There is some concern, however, that the residual uncovertebral joints may limit motion at the implanted level. Furthermore, in the case of ACDF, residual uncinate osteophytes can be expected to resolve as the motion of the segment is eliminated. With TDR, preserved motion may accelerate the degeneration of the remaining articulations and allow for regrowth of osteophytes. This may lead to complications requiring secondary intervention to address the degenerative changes resulting from the index surgery, adding to patient morbidity. Therefore, even if the initial results after TDR with partial uncovertebral joint removal are satisfactory, there is a chance of poorer outcomes in the long run. Complete resection of the uncovertebral joints may decrease the risk of progressive spondylosis and allow for insertion of disc prostheses with a larger footprint, thus decreasing the risk of implant subsidence and migration. Complete resection, on the other hand, may increase the risk of vertebral artery injury or cause hypermobility exceeding

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physiologic levels of motion. The effect of the uncovertebral joints on cervical motion after TDR remains unclear. Therefore, the purpose of this study was to quantify the effects of partial and complete resection of the uncovertebral joints on cervical motion after TDR.

Materials and Methods

Specimens and Experimental Setup. Seven fresh-frozen, human cadaveric cervical spines from C3–C7 (age, 63.4 ± 6.9 years) were used. All specimens had minimal preexisting degenerative changes at C5–C6 without evidence of listhesis on anteroposterior and lateral digital fluoroscopy images. The specimens were thawed at room temperature (20°C) 24 hours before testing. The paravertebral muscles were dissected, while keeping the discs, ligaments, and posterior bony structures intact. The C3 and C7 vertebrae were anchored in cups using polymethylmethacrylate and pins.

The specimen was mounted on a six-component load cell (Model MC3A-6-250, AMTI Multicomponent transducers, AMTI Inc., Watertown, MA) at the caudal end and was free to move in any plane at the proximal end. A moment was applied by controlling the flow of water into bags attached to loading arms fixed to the C3 vertebra. The apparatus allowed for continuous cycling of the specimen between ±1.5 Nm moment endpoints in flexion-extension, lateral bending, and axial rotation.

The motion of C3, C4, C5, and C6 vertebrae relative to C7 was measured using an optoelectronic motion measurement system (Optotrak, Northern Digital Inc., Waterloo, Ontario, Canada). In addition, biaxial angle sensors were mounted on each vertebra to allow real-time feedback for the optimization of the preload path. Fluoroscopic imaging (GE OEC 9800 Plus digital fluoroscopy machine) was used during flexion and extension in order to monitor prosthesis motion. Sequential digital videofluoroscopic images were obtained over the full range of flexion-extension motion.

The concept of follower load was used to apply a compressive preload to the specimens during flexion-extension.[6] The compressive preload was applied along a path that followed the lordotic curve of the cervical spine. By applying a compressive load along the follower load path, the segmental bending moments and shear forces due to the preload application are minimized.[7] This allows the spine to support physiologic compressive preloads without damage or instability. The preload was applied using bilateral loading cables attached to the cup holding the C3 vertebra (Figure 1). The cables passed freely through guides anchored to each vertebra and were connected to loading hanger under the specimen. The cable guide mounts allowed anterior-posterior adjustments of the follower load path. The alignment (optimization) of the preload path was performed by adjusting the cable guides to minimize changes in cervical lordosis when compressive loads up to 150 N were applied to the specimen.

Experimental Protocol. Each specimen was subjected to flexion-extension, lateral bending, and torsional moments in random order. The moments used ranged within ±1.5 Nm for all loading directions and are within the range of moments used in previous biomechanical studies of human cervical spine segments. Flexion-extension was tested under 150 N preload. The load-displacement data were acquired until two reproducible load-displacement loops were obtained.

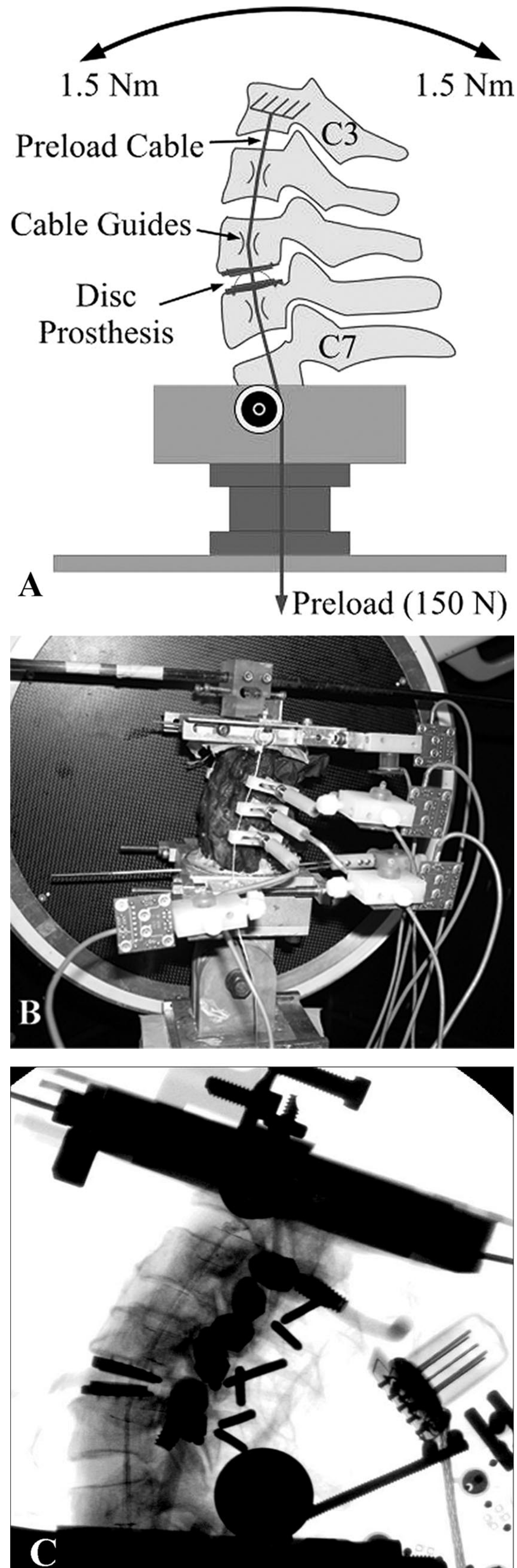

Figure 1. Experimental setup shown with TDR at C5–C6: **A**, schematic; **B**, specimen photo, and **C**, lateral radiograph.

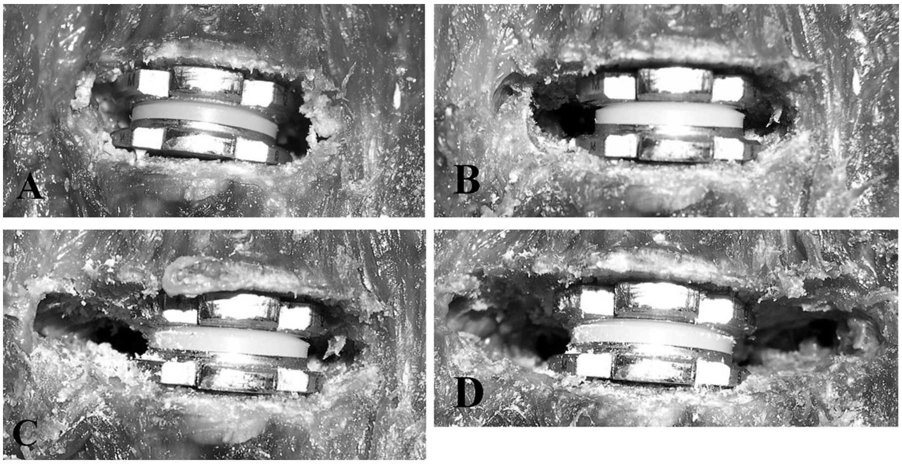

Figure 2. Sequential excision of the uncinate processes after TDR implantation at C5–C6 with the entire anterior anulus removed to allow access to the uncinates: **A**, without uncinatectomy; **B**, two-thirds right partial uncinatectomy; **C**, complete right uncinatectomy; and **D**, complete bilateral uncinatectomy.

After testing the intact spine, a C5–C6 discectomy was performed using standard instruments. An anterior window was made in the anulus wide enough to accommodate the prosthesis width. As a consequence, the anterior-lateral corners of the anulus fibrosus were left intact to provide stability during extension after implantation of the prosthesis (Figure 2A). The endplates were preserved but scraped clean. Trial sizes were used to estimate the size of the prosthesis footprint. Implant size was determined fluoroscopically and by direct visualization to provide the widest possible footprint without removing the uncinate processes. Next, a ball-and-socket type prosthesis (DePuy Spine, Raynham, MA) was implanted at C5–C6 using specified instruments. Proper placement was confirmed by fluoroscopy. Care was taken to restore the native disc height by comparing the restored disc height with adjacent levels without overdistracting the intervertebral space and facet joints.

After testing the specimen with a TDR at C5–C6, sequential excision of the uncinate processes was performed using a high-speed burr without removing the disc prosthesis. Access to the uncinate processes was gained by resecting the remaining parts of the anulus (Figure 2B–D). First, the posterior-foraminal part of the uncinate along with the inner half of the rest of the process was resected (partial right two thirds uncinatectomy, Figure 3) and the flexibility tests were repeated. The final two testing sequences were carried out in the same manner, after unilateral complete uncinatectomy and finally after bilateral complete uncinatectomy.

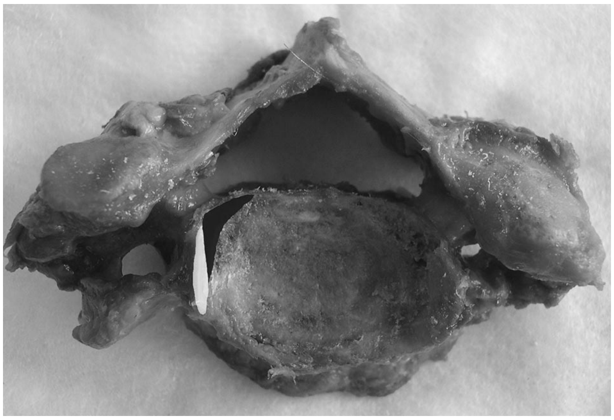

Figure 3. Progressive uncinate removal at each stage of the procedure. The dark area represents the extent of partial uncinatectomy that included the posterior-foraminal part and inner part of the rest of the process. Complete uncinatectomy was achieved by removing the remaining part of the process, depicted by the white area in the figure.

Data Analysis. The load-displacement data were analyzed to obtain the range of angular motion at the C5–C6 segment in flexion-extension, lateral bending, and axial rotation. The statistical analysis was performed using repeated-measures analysis of variance (analysis of variance, Systat Software Inc., Richmond, CA). *Post hoc* tests were done where indicated by analysis of variance results using Bonferroni correction for multiple comparisons. The following pairwise comparisons were made: 1) intact spine *versus* TDR with no uncinate resection, 2) intact spine *versus* TDR with partial right uncinate resection, 3) intact spine *versus* TDR with complete unilateral (right) uncinate resection, and 4) intact spine *versus* TDR with complete bilateral uncinate resection. The level of significance was set as Bonferroni-adjusted one-tailed $P \leq 0.05$. P values between 0.1 and 0.05 were considered to show a trend for statistical significance.

Results

TDR with fully intact uncovertebral joints increased the total flexion-extension range of motion (ROM) at C5–C6 from 8.4° ± 3.5° to 11.6° ± 3.4°; however, this change was not statistically significant ($P > 0.05$) (Table 1). Lateral bending decreased from 6.2° ± 2.2° to 3.1° ±

Table 1. Total Range of Motion of C5–C6 in Flexion-Extension, Lateral Bending, and Axial Rotation: Intact, TDR Without Uncinatectomy, and TDR With Gradually Increased Resection of Uncovertebral Joints

	C5–C6 Range of Motion (°)		
Specimen Condition	Flexion-Extension	Lateral Bending	Axial Rotation
Intact spine	8.4 ± 3.5	6.2 ± 2.2	5.5 ± 2.4
TDR	11.6 ± 3.4	3.1 ± 1.4†	4.3 ± 1.4
Right partial two thirds	12.8 ± 2.6	5.0 ± 2.3	6.3 ± 2.1
Right complete	13.3 ± 2.6*	5.0 ± 2.1	6.7 ± 1.7
Bilateral complete	14.1 ± 3.0*	7.3 ± 2.7	8.7 ± 2.4*

*Significant difference in ROM *vs.* intact ($P \leq 0.05$).
†Statistical trend for significant difference in ROM *vs.* intact ($P = 0.07$).

1.4°, with a strong trend for statistical significance ($P = 0.07$) (Table 1). Axial rotation decreased from 5.5° ± 2.4° to 4.3° ± 1.4° after the implantation; however, this decrease was not significant compared with intact ($P > 0.05$) (Table 1).

After unilateral partial uncinatectomy, flexion-extension ROM increased to 12.8° ± 2.6°, that was significantly higher compared with intact ($P \leq 0.05$). Total lateral bending increased to 5.0° ± 2.3° and total axial rotation increased to 6.3° ± 2.1°, neither of which was significantly different compared with intact ($P > 0.05$). An increase in lateral bending after right partial uncinatectomy was noted on both sides. Right lateral bending that was decreased from 3.8° ± 1.6° to 1.6° ± 0.9° after prosthesis implantation, increased to 2.6° ± 1.7° after right partial uncinatectomy. Similarly, left lateral bending that was decreased from 2.4° ± 0.9° to 1.4° ± 0.6° after prosthesis implantation, increased to 2.4° ± 1.0° after right partial uncinatectomy.

After unilateral complete uncinatectomy flexion-extension ROM was 13.3° ± 2.6° ($P \leq 0.05$ compared with intact). Total lateral bending ROM increased to 5.4° ± 2.1° and total axial rotation ROM increased to 6.7° ± 1.7°, neither of which was significantly different compared with intact ($P > 0.05$). Complete right uncinatectomy increased right lateral bending to 3.1° ± 1.2° and left lateral bending to 2.3° ± 1.1°.

After bilateral complete uncinate resection, the total flexion-extension ROM reached 14.1° ± 3.0°, which was significantly larger that that of the intact C5–C6 segment ($P \leq 0.05$). The total lateral bending ROM reached 7.3° ± 2.7° (Table 1). However, neither the total lateral bending ROM nor the motions in left or right lateral bending were significantly different than those of the intact C5–C6 segment ($P > 0.05$). The total angular ROM in axial rotation reached 8.7° ± 2.4°, which was significantly larger that that of the intact C5–C6 segment ($P \leq 0.05$).

Discussion

The cervical segment is comprised of five distinct articulations: the intervertebral disc, a pair of uncovertebral joints, and a pair of zygoapophyseal (facet) joints. A device designed to replace the intervertebral disc should functionally interact with the remaining joints to achieve three-dimensional motions that are within normal physiologic ranges. The purpose of this study was to investigate the role of uncovertebral joints in modulating cervical kinematics after TDR.

The present study showed that artificial disc replacement with fully intact uncovertebral joints may result in a remarkable decrease in lateral bending, a finding that is consistent with the results for other cervical TDRs with similar mechanics.[8] The current study also showed that a progressive resection of the uncovertebral joint had a significant effect on motions in all planes for the cervical segment with TDR. This is consistent with Kotani *et al*[9] who noted that progressive resection of the uncovertebral joint after limited anterior anulotomy with nucleotomy decreased stiffness in extension, lateral bending, and torsion. They concluded that the foraminal part of the uncinates, followed by the posterior part, has the most important role in segmental stability.[9] These findings concur with ours, as the current study also found that resection of the posteromedial two thirds, equivalent to resection of the foraminal and posterior part of the uncinate process reported by Kotani *et al*,[9] can significantly increase ROM and restore lateral bending after TDR. As shown in the current study, both unilateral partial and unilateral complete uncinatectomy restored the mobility of the implanted level to intact values. A remarkable finding is that unilateral uncinate resection resulted in symmetric increase in lateral bending and axial rotation. This may imply that the possible restraint mechanism includes a simultaneous abutment against the ipsilateral uncinate process and tensile resistance of the contralateral, a mechanism also previously implied by others.[9]

The increased ROM associated with complete bilateral uncinatectomy raises a concern about hypermobility. Holmes *et al*[10] reported that the average angular motion in flexion-extension at C5–C6 was 15.6° ± 4.9° based on a study of 50 subjects. Ishii *et al*[11] reported an average one-sided lateral bending motion at C5–C6 of 4.3° ± 1.4° in 12 subjects, and Mimura *et al*[12] reported an average 1-sided axial rotation motion at C5–C6 of 5.4° ± 4.3° in 20 subjects. Based on these comparisons, it may appear that the angular motion after TDR with complete bilateral uncinate resection does not exceed physiologic levels. However, the *in vivo* measurements of ROM were made on radiographs obtained from living individuals, and may not be comparable to the precise ROM measurements of cadaveric specimens in the present study using optoelectronic sensors. Furthermore, the possibility that the *in vitro* measurements of ROM in the cadaveric spines may not accurately reflect the *in vivo* measurements in living individuals due to differences in load magnitudes should not be overlooked. Therefore, we compared ROM after gradual uncinatectomy to the intact values of our specimens, assuming that this is the normal ROM as all specimens in the study had minimal preexisting degenerative changes.

The observed hypermobility (compared with intact controls) after bilateral complete uncinatectomy raises a question about what to do in cases of bilateral foraminal stenosis. The present study showed that bilateral complete uncinatectomy can induce instability after TDR and therefore should be avoided. Bilateral partial uncinatectomy can also decompress a bilateral foraminal stenosis. Whether bilateral partial uncinatectomy can preserve rotational stability cannot be answered by the current study, as this procedure was not include in the testing protocol.

The risk of injury to the vertebral artery during uncinatectomy, which is greater at the more cephalad levels because the vertebral artery migrates posteriorly as it ascends, is also an important concern. In case of vertebral artery injury, the uncovertebral joint resection on the contralateral side has to be abandoned. However, as shown by our results, unilateral uncinatectomy was effective in increasing ROM and can restore lateral bending and axial rotation ROM to intact levels after cervical TDR. The total increase in the ROM is nearly symmetrically distributed among both sides despite unilateral resection, and concerns about unilateral instability within a normal appearing total ROM are not justified. Furthermore, our findings suggest that uncinate removal can be limited to the side of concurrent foraminal stenosis without compromising the stability after disc prosthesis implantation. However, a possible drawback of partial removal is that motion preservation may accelerate the degeneration of the remaining articulations and may allow for regrowth of osteophytes. Therefore, even if the initial results after TDR with partial uncovertebral joint removal are satisfactory, there is a chance of poorer outcomes in the long run.

A limitation of this study is that the anterolateral part of the anulus was retained during TDR implantation, as a window wide enough only to accommodate the prosthesis width was made in the anterior anulus. The anterolateral portion of the anulus was retained to enhance stability in extension after the implantation of the prosthesis. Care was taken not to overdistract the intervertebral space after implantation to avoid excessive tensioning of soft tissues that could have a restricting effect on the ROM. Avoidance of overdistraction may have preserved flexion-extension ROM; however, it is possible that the remaining lateral anulus fibers may have restricted the coupled lateral bending–axial rotation motion. Removal of the retained part of the anulus during uncinatectomy may have also influenced the ROM in lateral bending. The bilateral increase in the ROM after unilateral right sided uncinatectomy, seen in the current study, supports this hypothesis.

Another limitation of the study is that none of the specimens in the study had moderate or severe degenerative changes. Including specimens with various degrees of degeneration may have given a specimen population closer to the patient population seen in clinical practice. However, we chose to include a homogenous population of specimens without degeneration to avoid the introduction of another variable in our study. Furthermore, inclusion of healthy specimens provided the baseline normal kinematics for comparisons after the various surgical procedures tested. Our population might be the clinical equivalent of cases with disc herniations only without any spondylotic changes. The resection of uncinate processes might have a different effect in cases with more severe degeneration.

■ Conclusion

Dissection of the posteromedial part of uncinates can restore the lateral bending to intact values after TDR. Even partial unilateral uncinatectomy can nearly symmetrically normalize lateral bending without significantly increasing axial rotation beyond intact values. Therefore, the resection can be limited at the site of concurrent symptomatic foraminal stenosis or can be abandoned on the contralateral side in case of ipsilateral vertebral artery injury, provided that complete discectomy has been performed. Extrapolation of these results to different cervical levels and to different prostheses designs may not be appropriate, since differences in the anatomy of the uncinates and the prosthesis design characteristics are likely to influence the kinematics of the implanted segment. However, as a ball-and-socket type prosthesis has a fixed center of rotation, it is reasonable to expect similar kinematic behavior from other existing designs with a fixed center of rotation.

■ Key Points

- This biomechanical study quantified the effects of partial-posteromedial and complete resection of uncovertebral joints on cervical spine motion after total disc replacement.
- Unilateral complete or even partial uncinatectomy can normalize lateral bending without significantly increasing axial rotation.
- Complete bilateral resection of the uncovertebral joints may result in significantly increased range of motion in flexion-extension and axial rotation.
- Uncinatectomy can be limited to the site of concurrent foraminal stenosis only, or contralateral resection can be abandoned in cases of ipsilateral injury of vertebral artery, provided that complete discectomy has been performed.

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