In vitro flexibility of the cervical spine after ventral uncoforaminotomy

Laboratory Investigation

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Object. Degenerative spine disorders are, in the majority of cases, treated with ventral discectomy followed by fusion (also known as anterior cervical discectomy and fusion). Currently, nonfusion strategies are gaining broader acceptance. The introduction of cervical disc prosthetic devices was a natural consequence of this development. Jho proposed anterior uncoforaminotomy as an alternative motion-preserving procedure at the cervical spine. The clinical results in the literature are controversial, with one focus of disagreement being the impact of the procedure on stability. The aim of this study was to address the changes in spinal stability after uncoforaminotomy.

Methods. Six spinal motion segments derived from three fresh-frozen human cervical spine specimens (C2–7) were tested. The donors were two men whose ages at death were 59 and 80 years and a woman whose age was 80 years. Bone mineral density in C-3 ranged from 155 to 175 mg/cm². The lower part of the segment was rigidly fixed in the spine tester, whereas the upper part was fixed in gimbals with integrated stepper motors. Pure moment loads of ± 2.5 Nm were applied in flexion/extension, axial rotation, and lateral bending. For each specimen a load-deformation curve, the range of motion (ROM), and the neutral zone (NZ) for negative and positive directions of motion were calculated. Median, maximum, and minimum values were calculated for the six segments and normalized to the intact segment.

Results. In lateral bending a strong increase in ROM and NZ was detectable after unilateral uncoforaminotomy on the right side. Overall, the ROM during flexion/extension was less influenced after uncoforaminotomy. The ROM and NZ during axial rotation to the left increased strongly after right unilateral uncoforaminotomy. Changes after bilateral uncoforaminotomy were marked during axial rotation to both sides.

Conclusions. Following unilateral uncoforaminotomy, a significant alteration in mobility of the segment is found, especially during lateral bending and axial rotation. The resulting increase in mobility is less pronounced during flexion and least evident on extension. Further investigations of the natural course of disc degeneration and the impact on mobility after uncoforaminotomy are needed. (DOI: 10.3171/SPI-07/11/537)

KEY WORDS • cervical spine • degenerative disc disease • in vitro spinal flexibility • uncoforaminotomy

Degenerative spinal disorders are, in the majority of cases, treated with ventral discectomy followed by fusion (also known as anterior cervical discectomy and fusion). Currently, however, nonfusion strategies are gaining broader acceptance. The introduction of cervical disc prosthetic devices was a natural consequence of this development. As early as 1996, ventral uncoforaminotomy was proposed as an alternative nonfusion technique in the treatment of cervical radiculopathy by Jho. He and his colleagues later reported excellent results in terms of outcome and successful preservation of the intact motion segment. Hacker and Miller, however, reported a failure rate of nearly 50% in their series of patients treated with uncoforaminotomy due to recurrent disc herniation or spinal instability. In his editorial comment, Jho focused on the technical shortcomings of the surgical strategy applied by Hacker and Miller. To clarify some aspects of this controversy, we performed a biomechanical study to evaluate the effects of uni- and bilateral uncoforaminotomy on spinal stability.

Materials and Methods

Six spinal motion segments derived from three human cadaveric cervical spine specimens (C2–7) were tested. The donors were two men whose ages at death were 59 and 80 years and a woman whose age was 80 years. Degenerative changes visible on plain radiographs were similar in severity in all specimens. Six cervical levels with advanced degenerative changes were considered sufficient to allow analysis of the impacts of the procedure on mobility. Bone mineral density in C-3 ranged from 155 to 175 mg/cm², as measured using quantitative computed tomography (XCT 960, Stratec Biomedical Systems). All specimens were frozen at −20°C after removal. Prior

Abbreviations used in this paper: NZ = neutral zone; ROM = range of motion; VB = vertebral body.
to testing, the overlying soft tissue was removed, leaving all spinal ligaments, facet joints and their capsules, and the disc space intact. Thereafter, each specimen was divided into two motion segments (C4–5 and C6–7), and both segments were tested. The upper part of the more cranial VB and the lower part of the lower VB were horizontally fixed in polymethylmethacrylate (Technovit 3040, Heraeus Kulzer) to allow a stable fixation within the spine tester. For additional stability, screws were drilled into the VB sticking into the polymethylmethacrylate.

Fluoroscopy was performed in five different projections (lateral, anteroposterior, axial, left oblique 45°, right oblique 45°). Next, the lower part of the segment was fixed rigidly in the tester, while the upper part was fixed in gimbals with integrated stepper motors. Pure moment loads of ± 2.5 Nm were applied in flexion/extension, axial rotation, and lateral bending. Starting from a neutral position, three continuous cycles were completed in each loading plane. The first two cycles were used for preconditioning of the segment, and the curve was calculated during the third and last cycle (Fig. 1). The specimen was allowed to move without restriction in all five unguided directions of motion. Lateral bending, axial rotation, and flexion/extension were registered using a system based on ultrasound (Zebris, WinBiomechanics). This detector continuously registered relative movements of the two VBs, with a resolution of 0.1 mm.

After the first run, an upper uncoforaminotomy was performed on the right side according to descriptions of the technique published by Jho et al.10 and by Johnson and colleagues11 (Fig. 2). Then the second test was completed, followed by uncoforaminotomy on the left side. The third test was conducted thereafter. During the whole testing period the specimens were kept moist with saline solution. For each specimen the third cycle was plotted in a load-deformation curve, and the ROM and the NZ for negative and positive directions of motion were calculated. Median, maximum, and minimum values were calculated for the six segments. Furthermore, the percentage change from the presurgical status was calculated. Wilcoxon signed-rank tests were used to compare the ROM and the NZ after unilateral and bilateral uncoforaminotomy with the data for the intact motion segments. No correction for multiple tests was made because this study was experimental.

Results

In lateral bending, a strong increase in ROM and NZ was detectable after unilateral uncoforaminotomy on the right side (Fig. 3). Following bilateral uncoforaminotomy, the NZ was comparable to that in the intact segment, whereas ROM showed an increase that was marked on the right. Overall, the ROM during flexion/extension was less influenced after uncoforaminotomy. After right uncoforaminotomy, flexion but not extension showed a strong increase in ROM and NZ. After bilateral uncoforaminotomy, the ROM showed a slight increase, whereas the NZ decreased slightly (Fig. 4). The ROM and NZ during axial rotation to the left increased strongly after right uncoforaminotomy, whereas the ROM on axial rotation to the right increased after unilateral uncoforaminotomy, but not significantly. Changes were marked during axial rotation to the left and to the right after bilateral uncoforaminotomy (Fig. 5). The increases in ROM and NZ were strong in all directions of motion except for the increase in NZ during axial rotation to the left.

Discussion

In this biomechanical study the effects of upper uncoforaminotomy on spinal mobility were tested in vitro. To understand fully the influence of the uncoforaminotomy on mobility, the anatomy of the region has to be considered.

Uncovertebral Joint

It is widely agreed that the so-called uncovertebral joint consists of two elements: the uncinate process and the Luschka joint.6,7,13 The uncinate process is a bony protuberance extending from the lateral margins of the endplates of the lower vertebra extending cranially.14 The Luschka joint consists of fissures already present in the lateral part of the nondegenerative disc close to the anular lamellae. The adjacent collagenous fibers within the disc run parallel to the fissure. These fissures increase in size during aging, destabilizing the disc. Claussen et al.3 described the Luschka joint and the uncinate process as two separate entities that work together as complementary elements during spi-
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Fig. 3. Bar graphs showing results of lateral bending of cadaveric spine segments to the right and left (percentage changes compared with intact specimen). Whiskers show the range of values. The dark gray bar denotes the NZ, and the entire bar denotes the ROM. Unco = uncoforaminotomy.

Fig. 4. Bar graphs showing results of flexion and extension testing of cadaveric spine segments (percentage changes compared with intact specimen). See Fig. 3 for explanation of bars.

Fig. 5. Bar graphs showing results of axial rotation of cadaveric spine sections to the right and left (percentage changes compared with intact specimen). See Fig. 3 for explanation of bars.

with ongoing degeneration, further reducing the foraminal size.\textsuperscript{12}

Furthermore, in their anatomical study Ebraheim et al.\textsuperscript{4} stated that the fibroligamentous tissue and intertransverse ligament, although thin and frail, appear to limit rotation and lateral bending.\textsuperscript{11}

Surgical Strategies and Consequences

Jho and colleagues\textsuperscript{9,10} saw no major alterations of spinal stability in their patients. In contrast, Hacker and Miller\textsuperscript{5} showed the anteroposterior view of a patient after ventral uncoforaminotomy with a subtle lateral tilt after surgery, accompanied by kyphosis in the treated segment on the lateral view. Consequently, in this study we set out to follow the Jho surgical technique\textsuperscript{10} as closely as possible (Fig. 2). Nonetheless, we found a detectable impact on mobility. One possible explanation is that when using the Jho technique the intertransverse ligament as well as the fibroligamentous tissue around the uncinate process, the nerve root, and the artery are dissected and partly resected to gain access to the neuroforamen.\textsuperscript{4,11} Even though the uncinate process is mainly preserved, an increase in mobility is present, especially during lateral bending, and is less pronounced during axial rotation, as shown in our results. The stabilizing influence of the paraspinal muscles was not considered in this in vitro study. Consequently, the destabilizing effect of the treatment might be smaller in vivo.

Another plausible explanation is the ongoing degeneration of the uncovertebral joint. In an anatomical study Benazzo et al.\textsuperscript{1} showed that early degeneration of the lateral portion of the cervical disc takes place independently from the central portion of the disc. This observation was also made by Claussen et al.,\textsuperscript{3} who reported increasing fissuring at the Luschka joint with advancing age. With ongoing de-
generation of the disc, the function of the Luschka joint is reduced, resulting in a decrease in mobility. In addition, the uncinate process becomes more prominent, further limiting mobility of the spinal segment. Therefore, the uncinate process becomes more important in limiting extensive motion. This means that our results were more pronounced because of the advanced age of the donors. Even though the dissection was done as far laterally as possible (soft tissue including the vertebral artery was visible), marked lateral degenerative changes of the uncovertebral joint present in the specimens were removed with the drill (Fig. 6). The increasing importance of the uncinate process in the presence of a decrease in disc height is also stated in the literature.12 Consequently, we compared our results with those studies after complete resection of the uncinate process. In good correlation to our results, Claussen et al.3 were able to show that axial rotation gained the most mobility relative to the intact motion segment. The influence on flexion/extension was only limited, similar to our findings. Kotani et al.,12 however, found that the changes after uni- and bilateral resection of the uncovertebral joint were most pronounced not during axial rotation but in extension, followed by lateral bending. One possible explanation for this discrepancy compared with our results is the preparation done to approach the uncovertebral joint. In our study the disc space and the posterior ligament were left unaltered, whereas Kotani et al. opened the anulus and partially resected the posterior longitudinal ligament to approach the uncovertebral joint (Fig. 6). The disc itself especially has a very important stabilizing influence in flexion/extension.2 Therefore, we believe that the resulting instability overruled the effect on lateral bending and on axial rotation. This assumption is supported by the findings of Chen et al.,2 who observed that after discectomy the role of the uncovertebral joint is to stabilize flexion/extension, followed by lateral bending. They also reported only a minor influence on axial rotation. In our study the effect on axial rotation was maximal after bilateral uncoforaminotomy.

Fig. 6. Radiographs showing the spine after removal of the far lateral portion of the uncinate process, simulating an uncoforaminotomy (indicated on one side by an arrow in all radiographs). Presurgical (A) and postsurgical (B) radiographs of level C4–5. Minor to moderate degenerative changes were present prior to lateral uncoforaminotomy. Presurgical (C) and postsurgical (D) radiographs of level C6–7. Osteochondrosis is present, with reduction in disc height and enlarged uncinate process.
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Conclusions

After anterior unilateral uncoforaminotomy, a significant change in mobility of the segment is found, especially during lateral bending and axial rotation. The resulting increase in mobility is less pronounced during flexion and least evident on extension. The degree of increase is based on the intrinsic capacity of the cervical disc space in connection with the uncovertebral process to control motion. Further investigations of the natural course of disc degeneration and mobility after uncoforaminotomy are needed.

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References


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