Pedicle Screws Enhance Primary Stability in Multilevel Cervical Corpectomies: Biomechanical In Vitro Comparison of Different Implants Including Constrained and Nonconstrained Posterior Instrumentations

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Study Design. Six human cervical spines were tested in vitro in a biomechanical nondestructive set-up to compare different anterior, posterior and combined instrumentations after a corpectomy C4–C6.

Objectives. To evaluate the primary three-dimensional stability of the different instrumentations.

Summary of Background Data. The clinical results after stabilization of multilevel corpectomies are often disappointing. Higher biomechanical stability could enhance the rate of successful outcomes. The best instrumentation for these high-grade instabilities has yet to be found.

Methods. Six human cervical specimens were loaded nondestructively with pure moments and unconstrained motion at C3/7 was measured. The six specimens were instrumented with each of the following fixation techniques: 1. Cage 2. Nonconstrained posterior screw and rod system with lateral mass (NC-LM) 3. and pedicle screws (NC-P) 4. Constrained posterior screw and rod system with lateral mass (C-LM) and 5. pedicle screws (C-P) 6. Circumferential (C-P and anterior plate) 7. Anterior plate (OAP)

Results. For flexion/extension and axial rotation the circumferential instrumentation showed lowest ROM values, followed by C-P. The use of pedicle screws showed only a lower ROM when using the constrained system. No difference was found between the two screw types in the nonconstrained system. The anterior plating had the lowest stabilizing effect of all instrumentations, except for the cage alone.

Conclusions. Usage of pedicle screws enhances primary stability only when using an constrained screw and rod system. In axial rotation the nonconstrained system showed no distinct difference compared to the intact state, independent of the screw type. [Key words: multilevel corpectomy, high-grade instability, biomechanics, primary stability, constrained and nonconstrained screw and rod systems, pedicle screws] Spine 2003;28:1821–1828

Anterior cervical corpectomy is an increasingly used technique for a wide diversity of disorders, including degenerative changes, trauma, infections, kyphotic deformities after laminectomy, and neoplasms. According to some authors, corpectomy is even recommended instead of multilevel interbody fusions due to better results. The clinical results for one- or two-level corpectomies are good, with high fusion rates. In contrast, the results and complications in multilevel corpectomies (more than two levels) with early failure rates from 30% to 100%, dependent on the fusion length, are often disappointing. As many of the causing conditions underline a progressive devolution, the success rates of these technical challenging procedures should be enhanced to better serve the patients. Saunders et al found that there is no unique morbidity in four-level corpectomies compared to a shorter decompression range, which would exclude this procedure. In vitro experiments with posterior fixations, including posterior plating, have shown superior primary stability when compared with anterior procedures in multilevel corpectomies. Recent screw and rod systems showed better biomechanical stability than posterior plate fixations, particular for flexion–extension. Also, new constrained screw and rod systems were developed. Here, the linkage between screw, connector, and rod is rigid, thereby minimizing the motion between screw and rod under load. Pedicle screw fixations showed increased stability compared to conventional anterior or posterior constructs in multilevel cervical instability. When compared with lateral mass screws, they also showed in vitro higher pullout forces that could be beneficial in these cases. Especially in the multilevel instability after corpectomy, a higher biomechanical stability could enhance success rates and is therefore desirable. Therefore, the purpose of this study was to evaluate the primary stability of screw and rod systems in a multilevel corpectomy model under inclusion of lateral mass and pedicle screws and compare them to anterior plating and circumferential fixation. This information could be a further step to improve methods for reconstruction in these challenging clinical cases.

Material and Methods

Six human cadaveric specimens, 2 male and 4 female, mean age 80 years (range 66–92 years), consisting of C2 to at least Th1 or Th2, as obtained, were used. The specimens were examined, and plain radiographs were taken to exclude soft tissue or bone
damage and then stored frozen at \(-20^\circ\text{C}\) in triple-sealed plastic bags. After thawing, the muscle tissue was carefully removed, and all the ligaments and bony structures were preserved. To prevent dehydration, specimens were kept moist with saline solution. Handling specimens in the above-described manner does not affect their biomechanical properties. Bone mineral density was measured in the vertebral bodies of C4 and C6 by quantitative computed tomography (QCT) after calibration of the CT (XCT 960, Stratec Medizintechnik GmbH, Pforzheim, Germany) with a standardized phantom. The cranial and caudal vertebrae were embedded in polymethylmethacrylate (PMMA; Technovit 3040, Heraeus Kulzer GmbH, Wehrheim, Germany). To obtain a better anchorage of the vertebrae in the PMMA, short screws were partially driven into the embedded parts of the vertebrae. Screws were inserted laterally in the vertebral bodies of C3 and C7 to fix the motion analysis system to the specimen.

The corpectomy C4, C5, and C6 was created using rongeurs and a high-speed air drill. The posterior longitudinal ligament (PLL) was preserved. The corpectomy was at least 16 mm wide. After decompression, a small hole was drilled in the cranial and caudal endplate to accommodate the cage with a force sensor. The force sensor consisted of a miniature load cell (Miniatur-Druckkraftsensor Typ 8413, Burster Prüftechnik, Gernsbach, Germany) capable of measuring axial compressive forces only in a range between 0 and 500 N. The load cell was mounted in a specially modified cage on the basis of a routinely used cage (ADD, Ulrich Medizintechnik, Ulm, Germany). Spikes at the superior and inferior end prevented the cage from slipping. The cage was continuously adjustable to the desired graft height by either a screw thread at the lower end of the cage or the use of two stainless steel tubes of different lengths. The force sensor was adjusted to 40 Nm preload while the specimen was mounted in the spine tester with free movement of the specimen in all directions. Thereby, every specimen could adopt its own neutral position, and an identical axial preload could be adjusted.

The spinal instrumentations included the Cervifix system\(^\text{26}\) (Synthes, Umkirch, Germany) with 3.5 mm lateral mass screws (NC-LM) and pedicle screws (NC-P) (Fig. 1B). The other posterior spinal implant was the neon occipitocervical system\(^\text{27,28}\) (Ulrich Medizintechnik, Ulm, Germany) with 4.0 mm cannulated lateral mass (C-LM) and pedicle screws (C-P) (Fig. 1C). The anterior plate (OAP) was from the Osmium system (Ulrich Medizintechnik, Ulm, Germany; Fig. 1A). The lateral mass screws were inserted according to the technique described by Jeanneret et al.\(^\text{29}\) The pedicle screws were inserted after visualization of the pedicle by dissecting the intervertebral foramen. The screws for the anterior plate were inserted with monocortical bone purchase. The circumferential instrumentation was a...
combination of the OAP and the constrained screw and rod system with pedicle screws (C-P).

The specimen were mounted in a previously described spine tester, where the caudal vertebrae were rigidly fixed in the testing apparatus, and the cranial vertebra (C2) was fixed in a Cardan joint containing integrated stepper motors that could introduce pure moments separately around the three axes. The other five out of six degrees of freedom were free, enabling the specimen to move unconstrained. The segmental motion between C3 and C7 was measured by a high-resolution, noncontacting ultrasound motion analysis system (Zebris, Isny, Germany; resolution 0.06°). Nondestructive loads were applied as pure moments in alternating sequences for right/left lateral bending (± Mx), flexion–extension (± My) and right/left axial rotation (± Mz). The different instrumentations were tested between C3 and C7 with pedicle screws, left extension and right flexion. No movement with connector and screw head visible.

Figure 3. Simulated screw back-out with the constrained system with pedicle screws, left extension and right flexion. No movement between connector and screw head visible.

Results

The BMD was 179.9 mg/cm³ (median) in the vertebral bodies of C4 (range 99.3–303.6 mg/cm³) and 194.4 mg/cm³ in C6 (range 159.4–274.1 mg/cm³). The median of the ROM for the intact specimen was 17.8° for lateral bending (Table 1). All the other instrumentations had a lower median ROM value with P < 0.05, except for the cage and the anterior plate (Table 1; Figure 4). The two pedicle screw fixations had ROM values of 0.4° (C-P) and 0.7° (NC-P) with P < 0.05 when comparing them to the nonconstrained system with lateral mass screws (NC-LM). For the comparison with the constrained system (C-LM), only the C-P had a P < 0.05 (NC-P vs. C-LM, P > 0.05). Comparing the two lateral mass screws containing instrumentations showed no statistical difference; this was the case also in comparing the two pedicle screw instrumentations. For the circumferential instrumentation only for the comparison with the nonconstrained screw and rod system with lateral mass screws (NC-LM) a statistical difference occurred (Table 1).

For flexion–extension, again the highest median ROM value occurred for the intact specimen with 26.6°, followed by the cage with 19.3° (P > 0.05; Table 2). The anterior fixation (OAP) had the highest median ROM when compared to the posterior and circumferential instrumentations (Figure 5; Table 2). For the two fixations with lateral mass screws and the nonconstrained system with pedicle screws, no statistical difference occurred (P > 0.05; Table 2). The constrained system with pedicle screws (C-P) had the lowest value of the posterior instrumentations with 1.4° (P < 0.05) when compared to all the other posterior fixations. The lowest median ROM value overall was measured for the circumferential with 0.4° and a P < 0.05 when compared to all the other tested fixations (Table 2; Figure 5).

For axial rotation, the highest median ROM was found for the cage with 25.8°, followed by the anterior plate (20.1°) and the intact state with 18.5° (Table 3; Figure 6). The anterior plate, the nonconstrained system with lateral mass screws and pedicle screws, had a P >

Table 1. Median ROM Values for Lateral Bending in Degrees and P Values

<table>
<thead>
<tr>
<th>ROM</th>
<th>Intact</th>
<th>Cage</th>
<th>NC-LM</th>
<th>C-LM</th>
<th>NC-P</th>
<th>C-P</th>
<th>360°</th>
<th>OAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>P Value</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</table>

ROM = range of motion; NC-LM = nonconstrained screw and rod system with lateral mass screws; C-LM = constrained system with lateral mass screws; NC-P = nonconstrained screw and rod system with pedicle screws; C-P = constrained system with pedicle screws; 360° = circumferential fixation; OAP = anterior plate.
Intact
Anterior plate
C-P
C-LM
NC-P
NC-LM
Cage
Circumferential

Figure 4. Bilateral lateral bending under a load of ±1.5 Nm. Median, minimal, and maximal values in degrees for ROM and NZ.
NC = nonconstrained system; C = constrained system; LM = lateral mass screws; P = pedicle screws.

Discussion
This biomechanical in vitro study was performed to determine the primary stabilizing effect of different cervical fixation devices in a three-level corpectomy model.

The anterior plating achieved a higher stability than the intact state for lateral bending, not for flexion-extension or axial rotation. Furthermore, for all motion directions, a lower primary stability occurred when compared to the posterior and circumferential instrumentations. The neutral zone as a measure of laxity for the different instrumentations showed similar trends as the ROM with smaller median values (Figures 4–6).

Table 2. Median ROM Values for Flexion–Extension in Degrees and P Values

<table>
<thead>
<tr>
<th>ROM</th>
<th>Intact</th>
<th>Cage</th>
<th>NC-LM</th>
<th>C-LM</th>
<th>NC-P</th>
<th>C-P</th>
<th>360°</th>
<th>OAP</th>
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<td>C-P</td>
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<td>0.0277</td>
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<td>360°</td>
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</table>

ROM = range of motion; NC-LM = nonconstrained screw and rod system with lateral mass screws; C-LM = constrained system with lateral mass screws; NC-P = nonconstrained screw and rod system with pedicle screws; C-P = constrained system with pedicle screws; 360° = circumferential fixation; OAP = anterior plate.

0.05 when compared to the intact state. The constrained system had median values of 6.2° for lateral mass and 3.0° for pedicle screws with a consecutive P < 0.05 when compared to the anterior and nonconstrained posterior fixations, as well as the intact state. The circumferential fixation had again the lowest overall ROM value of 1.6° and P < 0.05 in comparison with all other tested instrumentations. The neutral zone as a measure of laxity for the different instrumentations showed similar trends as the ROM with smaller median values (Figures 4–6).

This stands in contrast to the good results for one- or two-level instabilities. With a longer decompression, a higher instability is produced. The resulting longer lever arm, as well as the loss of distraction by graft or cage settling, seem to overcome the stability potential of anterior plates. The higher failure rate leads to reoperation or, in case of pseudarthrosis, to a poor clinical outcome. The benefit of corpectomy and anterior stabilization is the prevention of an additional posterior approach to the spine.

For flexion-extension, the two systems with lateral mass screws and the nonconstrained system with pedicle screws showed similar ROM values. In contrast to lateral bending, the higher screw pullout forces of pedicle screws compared with lateral mass screws did not automatically enhance the stability of the instrumentation for flexion-extension. As for the constrained system with pedicle screws, a lower ROM was found when compared to the other posterior instrumentations; the effect of the screw type for stability is dependent upon the screw and rod system used. The fixation between the screw and the connector to the rod is like a shim in the nonconstrained system. If the screw com-
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Figure 5. Flexion-extension under a load of ±1.5 Nm. Median, minimal, and maximal values in degrees for ROM and NZ. NC = nonconstrained system; C = constrained system; LM = lateral mass screws; P = pedicle screws.

presses the connector to the bone an approximative angle, a stable (constrained) situation is achieved. But as the surface of the bone is uneven, in contrast to the plain surface of the connector, the material properties of the smooth metal surface and the moist surrounding tissue are forwarding gliding processes, and the tightening of the screw to the bone is dependent on the predetermined bone stock, this approximative stable angle situation is sometimes difficult to achieve. Especially in osteoporotic bone stock, the tightening of the screw always bears the risk of overwinding the screw and thereby damaging the bone stock. Another point of more clinical interest is the backing up of screws, sometimes seen in radiograph routine checkups. This implicates a loosening of screw stability by shortening of the screw-bone contact surface area, but for the nonconstrained system, it implicates a further loss of stability by loosening the conjunction between screw and connector and thereby consecutive obligatory between screw and rod. In the simulated screw back-out in Figure 2, the connector is gliding to the bone surface in extension and to the screw head in flexion. In the constrained system, the fixation of the screw to the connector and thus to the rod is independent of the tightening between screw and bone stock. For the constrained system, the linkage between screw and connector is dependent upon tightening a screw nut to a screw thread, which also clamps the rod to the connector. This is only a mechanical linkage, which is unaffected by the surrounding anatomic conditions and consequently highly reproducible (Figure 3). As long as the appealing forces are not larger than the stability of the screw thread–screw nut conjunction, the stability of the system is mainly determined by the tightening of the screw to the bone. In a clinical situation, the loosening of the screw thread–screw nut linkage by appealing forces is unlikely, as such forces would probably first damage anatomic structures and lead, for example, to fracture of the lateral mass.

For axial rotation, the differences were even more distinct than for flexion-extension (Tables 2 and 3; Figures 5 and 6). Neither the anterior plate nor the nonconstrained system with both screw types had a distinctly lower ROM than the intact state. And again, within the nonconstrained system, no difference in stability for the different screws appeared, in contrast to the constrained system. Subsequently, the stability of the constrained system is mainly determined by the screw length and the tightening to the bone stock, resulting in differences of

## Table 3. Median ROM Values for Axial Rotation in Degrees and P Values

<table>
<thead>
<tr>
<th>ROM</th>
<th>Intact</th>
<th>Cage</th>
<th>NC-LM</th>
<th>C-LM</th>
<th>NC-P</th>
<th>C-P</th>
<th>360°</th>
<th>OAP</th>
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<tbody>
<tr>
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ROM = range of motion; NC-LM = nonconstrained screw and rod system with lateral mass screws; C-LM = constrained system with lateral mass screws; NC-P = nonconstrained screw and rod system with pedicle screws; C-P = constrained system with pedicle screws; 360° = circumferential fixation; OAP = anterior plate.
stability for lateral mass and pedicle screws, which stands in contrast to the nonconstrained system. The influence of the screw-connector and connector-rod linkage, under the used force moments in this in vitro setting, seem to be negligible for the constrained system.

The differences between the two systems, besides the aspect of angle stability, were the diameter of screws and rods and the material used. The screw trajectories were the same, so that this could not be a valid difference. The screw diameter was 4.0 mm for the constrained and 3.5 mm for the nonconstrained system. This was due to the fact that the constrained system was used with cannulated screws, which is technically not feasible for a diameter less than 4.0 mm. If this had been the reason for the different results for flexion-extension and axial rotation, one could expect that within the system, a difference of the stability achieved by the different screws would still occur. This was not the case, as for the nonconstrained system ($P > 0.05$) when comparing lateral mass and pedicle screws, in contrast to the constrained system. The diameter of the rods, as well as the material used, should also not affect the results within the different systems, as we did not see any deformation of the rods by the applied forces.

The circumferential instrumentation had for flexion-extension and axial rotation the lowest median ROM values, whereas for lateral bending, as among the posterior instrumentations, the results were not so distinct. As the circumferential consisted of the constrained system with pedicle screws, which was the most stable posterior fixation and an additional anterior fixation, it is not surprising that this instrumentation was the most stable. The questions are more how much stability is needed for a solid fusion, and does this imply the necessity of a combined anterior and posterior fixation. These questions can only be answered by long-term clinical studies comparing constrained posterior instruments with circumferential fixations.

This study has some limitations. We did not randomize the testing sequence of implants to minimize the effect of additional instrumentation. Therefore, the cage was always tested first, followed by the posterior fixations with lateral mass and pedicle screws. The nonconstrained system was always tested first due to the lower screw diameter, thereby allowing the use of the same screw trajectories. The last tested posterior fixation (C-P) was then extended to a circumferential fixation by adding the anterior plate, and after removal of the rod system, the anterior plate was tested alone. The pedicle screws remained so that possible damage of the vertebral body bone stock, which could weaken the fixation of the anterior plate, was prevented. As the last tested con-

<table>
<thead>
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<th>Lateral Bending</th>
<th>Flexion–Extension</th>
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</table>
strained posterior fixation showed a lower ROM, it seems unlikely that the testing sequence had a significant effect for the posterior instrumentations, but the anterior plate with higher median ROM in all directions compared to the posterior fixations could have been affected. Nevertheless, the superior stability of posterior instrumentations was also found by other authors.\textsuperscript{51} The used anterior plate did not provide a locked screw-plate conjunction, which in vitro showed a significantly increased rigidity that could enhance stability.\textsuperscript{39,40} Also, by using a bicortical fixation, we could have enhanced stability\textsuperscript{40} at the cost of a higher risk in clinical use. Another point that a biomechanical study can hardly accommodate for is the stabilizing potential of the spine surrounding tissues, especially the muscles, which can counterbalance occurring forces in the clinical case and therefore even out a lower biomechanical stability of implants. In addition, the small number of tested specimens, the high age of the specimens, and the interindividual differences in biomechanical properties reduce the significance of the results obtained and limit the conclusions that can be drawn from this study for clinical use.

Summarizing the results of this biomechanical in vitro study, the sole anterior plating did not provide a satisfying primary stability in this multilevel corpectomy model. The stability of the used posterior instrumentations for axial rotation and flexion–extension depends crucially on whether constrained or nonconstrained systems were used. The stability of the constrained system can be enhanced by the use of pedicle screws instead of lateral mass screws, whereas the higher risk of the screw trajectory for the nonconstrained system only offers a slight benefit for lateral bending, not for flexion–extension and axial rotation. Furthermore, this benefit is not evident when comparing to the constrained system with lateral mass screws. When a high biomechanical stability in cervical multilevel corpectomies is desired, a constrained posterior instrumentation should be preferred. Whether this has to be combined with additional anterior plating for clinical use has to be determined, as with all results of biomechanical in vitro studies, by long-term clinical studies.

\section*{Key Points}

- Pedicle screws enhance primary stability when using a constrained screw and rod system in a multilevel corpectomy.
- Constrained screw and rod systems provided distinctly higher stability for axial rotation in comparison with the nonconstrained system, independent of screw type used.
- Anterior plating had only a distinct difference in stability for flexion–extension, not for lateral bending or axial rotation, when compared to the intact state.
- Circumferential instrumentation showed the lowest median ROM values for flexion–extension and axial rotation.

\section*{Acknowledgment}

The authors thank Ulrich Medizintechnik Co. for its donation of the funds to realize this study.

\section*{References}

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