Injuries of the subaxial cervical spine including facet joints and posterior ligaments are common. In the Subaxial Injury Classification (SLIC) scale, translation or rotation injuries are assigned the highest number of points (4 points). Significant ligament disruptions are almost always associated with injuries of the subaxial spine. Various strategies can be employed in the management of these injuries. Several options for surgical treatment have already been described, with good outcomes having been reported using anterior-posterior, posterior, and anterior approaches.

Dvorak et al. developed an algorithm for unilateral or bilateral facet fracture-dislocations without vertebral body fracture. They described surgical possibilities when performing anterior, posterior, or anterior-posterior fixation. Each approach has its advantages. Dvorak et al. suggested an anterior approach if MRI shows the disc to be in the spinal canal. If no disc material is seen on MRI, either an anterior or posterior approach can be used. If fracture reduction is successful, anterior fusion is sufficient for treating these cases. In the discussion, Dvorak et al. stated that the extent of the facet injury might predict the success of stand-alone anterior discectomy and fusion for facet frac-
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The proposed algorithm does not distinguish between injuries with unilateral or bilateral facet joint fractures. Along with the fact that the proposed algorithm does not have a high level of proof, many surgeons prefer the posterior approach. Based on biomechanical studies, it seems that posterior stabilization provides greater stability than anterior fusion. Other surgeons prefer the anterior approach because the disc disruption can be addressed satisfactorily and a solid anterior fusion can be achieved. Johnson and colleagues have postulated that facet fractures might have an impact on the stability of anterior plate fixation. Regarding their findings, unilateral or bilateral facet fractures lead to increased shear forces, possibly resulting in failure, whereas intact facets might offer resistance to translation forces.

The aim of the present study was to evaluate the specific contribution of facet joint injuries within the proposed Dvorak algorithm to better understand the influence of different facet joint injuries on the primary stability provided by anterior plate fixation. Along with anatomical repositioning, involvement of the facet joints might be another factor for determining if anterior fusion is biomechanically sufficient. An ethics committee determined that approval for the study was not required because all vertebral bodies were taken from individuals who had donated their bodies to medical science.

Methods

Fifteen fresh-frozen intact cervical spines (C3–T1) were used for this cadaver study. Computed tomography scans were acquired before the procedure to exclude bone abnormalities. Dual-energy x-ray absorptiometry (DXA) scans were obtained prior to the study. Bone mineral density was measured using peripheral quantitative CT (XCT Research Bone Scanner, Stratec Medizintechnik GmbH) on all fresh-frozen cervical spines.

Specimens were stored at −20°C and were thawed at room temperature overnight before the study. Specimens were kept moist during all of the procedures using NaCl-soaked wound dressings. To assure comparability of the groups, the spines were matched according to size and subsequently randomized into one of three groups. All tissues except ligaments and discs were dissected from the cervical spines, which were embedded in cold-curing resin for surface testing and impressions (Technovit 3040, Kulzer, Germany). All dissections were performed by a medical student (S.B.) who was trained on 8 formalin-fixed spine segments that were used to establish the preparation protocol.

To simulate a translational rotation injury with complete intervertebral disc—ligament rupture and facet dislocation according to the SLIC scale, the entire posterior and anterior ligament complex between C-4 and C-5 was cut (complete vertebral dissection). After separating the vertebral bodies, the discs were completely removed. In the first group (Group 1), the bone of the facet joints was left intact. In the second group (Group 2), one facet joint between C-4 and C-5 was completely resected using an oscillating saw and a Luer rongeur; the contralateral side was left intact. In the third group, both facet joints between C-4 and C-5 were removed. A single-level anterior discectomy and interbody grafting procedure (using a tricortical autogenous bone) was performed next (Fig. 1). The height of the bone graft was determined relative to the sagittal diameter of the vertebral body. The length was determined based on the desire to leave a one-quarter safety distance to the dorsal part of the vertebral body. An anterior cervical locking plate (Vectra, Synthes) (Fig. 1) was placed with a minimal distance of 2–3 mm to the next intervertebral disc. Monocortical screws (4.0 mm in diameter) were used for fixation. Visual inspection and radiological control with fluoroscopy were performed after inserting the screw to avoid misplacement of the screw into the intervertebral disc space (Fig. 2). To simulate the weight of the human head and its effect as a cervical spine lever, a 1-kg axial load was used (one-fifth of the average mass of the human head). A K-wire was drilled through the upper vertebral body and 0.5-kg masses were applied to the left and right sides (Fig. 1).

The sample was placed in the loading jig. The force vector was positioned at the C3–4 facet joint to produce a flexion movement. Continuous loading was performed using a servohydraulic test bench (Electroforce LM2 TestBench, Bose) at 2 N/sec. During testing, a load displacement curve was generated, and the mean load failure was measured when the force changed from a positive to a negative value on the load displacement curve (Fig. 3).

The measured values were compared statistically using the Kruskal-Wallis test (GraphPad Prism 5.03, GraphPad Software Inc.). Statistical significance was assigned at a p < 0.05. Results are presented as the mean ± SD.

Results

Measurement of all specimens using DXA showed osteoporosis (T score of −4.5 ± 1.8). The peripheral quantitative CT measurements showed a mean bone density of 201.6 ± 76.7 mg/cm³. A translational rotation injury was successfully created in all of the cadaver cervical spines studied. There were no complications or technical problems.

In Group 1, in which both facet joints were still intact, the mean load failure was 174.6 ± 46.93 N. The mean load failure in Group 2, in which only one facet joint was removed, was 127.8 ± 22.83 N. In Group 3, in which both facet joints were removed, the mean load failure was 73.42 ± 32.51 N (Fig. 4). There was a significant difference between the first group (both facet joints intact) and the third group (both facet joints removed) (p < 0.05, Kruskal-Wallis test).

Discussion

Unilateral or bilateral facet fracture-dislocation and bilateral facet dislocation without fracture are highly unstable injuries. The translation and rotation injury mechanisms lead to significant ligament disruption. Vaccaro et al. proposed the Subaxial Injury Classification (SLIC) scoring system that takes into account injury morphology, integrity of the disc-ligament soft-tissue complex and neurological status. Translation and rotation injuries...
are assigned the greater number of points on the morpho-
logical scale (4 points). Because these injuries are typi-
cally associated with significant ligament disruption (2
points), the SLIC injury score is already 6 points before
the neurological status is taken into consideration. Surgi-
cal treatment is recommended if the patient has a score of
5 or more. Various surgical strategies have been described
in various studies using posterior, anterior, or posterior-
anterior fixation.1,2,5,10–14,19,21–23,27,28

Dvorak et al. developed an algorithm based on the
SLIC score.8 In cases of unilateral or bilateral facet frac-
ture-dislocation/subluxation without disc prolapse into
the canal, they recommended 2 options: anterior cervi-
cal discectomy and anterior open reduction as well as
posterior open reduction and lateral mass fixation and
fusion. If anterior open reduction is successful, anterior
fusion and plate fixation are recommended. If the ante-
rior procedure is not successful, 360° fixation is recom-

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rior procedure is not successful, 360° fixation is recom-
mended, which combines anterior and posterior open
reduction, fixation, and fusion. Nevertheless, surgical
strategies have not been precisely established. There is
still a lack of guidance for using the anterior, posterior,
or combined surgical procedures.34 Historically, surgical
treatment was performed using posterior interspinous or

![Fig. 1. Preparation of cadaveric spines: interbody grafting using a tricortical autogenous bone graft (A); anterior cervical locking plate fixation (B); and the K-wire drilled through the upper vertebral body and loaded with 0.5 kg on the left and right sides to simulate the head mass (C).]

![Fig. 2. Postprocedure radiographs: both facets intact (A); one facet intact (B); and both facets removed (C).]
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oblique wiring; more recently lateral mass screws have been used.\(^1\) Several studies have also reported good clinical outcomes and high fusion rates in association with anterior disectomy, fusion, and plate fixation.\(^1\) Kwon et al. reported on a prospective randomized controlled study in which they compared anterior with posterior stabilization for unilateral facet injuries of the cervical spine. They found a small trend toward less pain in the anteriorly treated patients and observed increased wound infections in the posteriorly treated patients.\(^1\) Nevertheless, they found both procedures to be viable options for surgical treatment. One advantage of the anterior approach is the possibility of performing decompression, reduction, interbody grafting, and instrument-augmented stabilization all in the same operative field. This is especially relevant because of the high incidence of disc herniation in patients with bilateral cervical disc dislocations.\(^3,9,20,26\) Anterior plate instrumentation via a primary anterior approach has become a popular treatment for bilateral cervical facet dislocations.\(^7\) Nevertheless, Johnson et al. described a 13% radiographic failure rate for anterior plate fixation in patients with flexion injuries of the subaxial cervical spine, including 75% with bilateral facet injuries. The authors postulated that facet fractures might have an impact on the stability of anterior plate fixation. Regarding their findings, unilateral or bilateral facet fractures led to increased shear forces, possibly resulting in failure, whereas intact facets might offer resistance to translation forces.\(^6\)

The purpose of our biomechanical cadaver study was to simulate 3 different C4–5 facet joint injuries and compare the stability of anterior plate fixation in combination with an interbody bone graft. In the first group, we only simulated a ligament–facet joint injury without fracture; the second group represented a unilateral fracture; and the third group was defined as a bilateral facet joint dislocation in combination with complete facet destruction. The main purpose was to evaluate if anterior stabilization alone provides sufficient mechanical fixation in all 3 injury types.

To simulate a spinal flexion movement, continuous loading was applied dorsally on the C3–4 facet joints. To simulate the weight of the human head and its effect as a cervical spine lever, a 1-kg load was applied to the fresh-frozen specimens (one-fifth of the average mass of the human head). This load is critical for the human cervical spine without the stabilizing effect of the neck muscles before buckling.\(^24\)

The load was applied continuously at 2 N/sec until the force changed from a positive to a negative value on the load-displacement curve (mean failure load). The caudal screws broke out in every specimen; there were no plate failures. There was a significant difference in the mean failure load between Group 1 and Group 3. Anterior plate stabilization provided significantly higher biomechanical stability when both facet joints were intact. If both facet joints are completely destroyed, anterior plate fixation alone does not seem to provide enough stability based on our biomechanical testing. The absolute values and their meaning for patients with osteoporosis remain unclear. In addition, the important effect of the stabilizing muscles could not be simulated in this model.

Various biomechanical studies have shown that posterior stabilization provides greater stability than anterior fixation after unilateral and bilateral facet disruption.\(^4,6,7,17,25,29,31\) Do Koh et al. compared anterior and posterior plate fixation in a biomechanical study.\(^6\) They found that anterior fixation with interbody grafting failed to provide stabilization and concluded that posterior plating leads to better stability than anterior plating with locked fixation screws. If anterior plate fixation is performed, additional external bracing is recommended, especially in cases of posterior ligament disruption. Conversely,
Traynelis et al. found a biomechanical advantage associated with anterior plate fixation in extension and bending compared to posterior wiring procedures when treating C-5 teardrop fractures with posterior ligament instability. Kim et al. performed a biomechanical comparison of 5 surgical approaches in cases of bilateral subaxial cervical facet dislocation. They showed that anterior plate fixation combined with interbody graft placement provided greater biomechanical stability relative to an intact spine in all loading models.

Our results suggest that anterior plate fixation in combination with interbody graft placement as a treatment for facet joint injuries is sufficient only if there is a ligament injury alone and the bone in both facets is still intact. If the bone in one or both facet joints has been destroyed, anterior plate fixation might not be sufficient based on our biomechanical findings. Our study has some limitations. All of the fresh-frozen spines showed osteoporosis on DXA scans and all had low bone quality, which made it challenging to achieve stable fixation. Furthermore, all muscles and soft tissues except the ligaments were removed; soft tissue could be important to simulate more physiological conditions. Also, the weight of the head was simulated with an axial load of 1 kg. Furthermore, the loading model achieved cervical spine flexion without rotation movements. Despite these limitations, the study showed comparable results with regard to biomechanical stability, with the differences between Group 1 and Group 3 being statistically significant. To our knowledge, this is the first biomechanical study that compares stability after treatment of 3 facet joint injuries.

Conclusions

Fractures of the facet joints in cervical fracture-dislocations have a significant influence on spinal stability. Based on our biomechanical findings, anterior plate fixation in combination with interbody bone grafting as a treatment for facet joint injuries may be sufficient only if the bone in both facet joints is intact. If the bone in one or both facet joints is destroyed, anterior plate fixation in combination with bone grafting seems to be insufficient and additional posterior stabilization may be needed. Further biomechanical and clinical trials are needed to verify these findings.

Disclosure

Dr. Krüger reports being a consultant for Vexim, Medtronic, Soteira, and DFINE, Inc. Author contributions to the study and manuscript preparation include the following. Conception and design: Oberkircher, Krüger. Acquisition of data: Oberkircher, Born, Bergmann. Analysis and interpretation of data: Oberkircher, Born, Struwer, Bliemel, Krüger. Drafting the article: Oberkircher, Struwer, Bliemel, Krüger. Critically revising the article: Oberkircher, Born, Struwer, Bliemel, Buecking, Wack, Ruchholtz, Krüger. Reviewed submitted version of manuscript: Oberkircher, Born, Struwer, Bliemel, Wack. Administrative/technical/material support: Born, Bliemel, Buecking, Wack, Bergmann. Study supervision: Krüger.

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Address correspondence to: Ludwig Oberkircher, M.D., Department of Trauma, Hand, and Reconstructive Surgery, Philippus University Marburg, Baldingerstraße, Marburg D-35033, Germany. email: oberkirc@med.uni-marburg.de.