Posterior Atlantoaxial Fixation

Biomechanical In Vitro Comparison of Six Different Techniques

Marcus Richter, MD,* René Schmidt, MD,* Lutz Claes, PhD,† Wolfhart Puhl, MD,* and Hans-Joachim Wilke, PhD,‡

Study Design. Six different techniques for atlantoaxial fixation were biomechanically compared in vitro by nondestructive testing.

Objective. To evaluate the immediate three-dimensional stability of a new atlas claw combined with transarticular screws and alternative techniques for transarticular screw fixation in comparison with established techniques.

Summary of Background Data. Posterior transarticular screw fixation in combination with wire–bone graft constructs is frequently used for C1–C2 fixation. Sublaminar wire passage carries the potential risk of neurologic complication. Transarticular screw fixation is technically demanding and, for anatomic reasons, not always feasible.

Methods. Six human cervical specimens were loaded nondestructively with pure moments, and unconstrained motion at C1–C2 was measured. The six specimens were instrumented with each of the following fixation techniques: Gallie fixation, transarticular screws and Gallie fixation, transarticular screws, transarticular screws and a new atlas claw, isthmic screws in the axis and the atlas claw, and lateral mass screws in the atlas and isthmic screws in the axis connected with rods.

Results. The transarticular screws restricted lateral bending and axial rotation best. The three-point fixations (transarticular + Gallie and transarticular + claw) additionally restricted flexion–extension, with lowest values for transarticular screws and the atlas claw. The alternative techniques were not as stable as the three-point fixations, but more stable than the Gallie fixation.

Conclusions. Biomechanically, the three-point fixation with transarticular screws and the atlas claw provides a rigid internal fixation that is not dependent on bone graft and sublaminar wire construction. In cases wherein transarticular screws are not feasible, the isthmic screws and claw or the lateral mass screws and isthmic screws are biomechanical alternatives with less immediate stability. [Key words: atlantoaxial fixation, biomechanics. claw fixation, immediate stability, sublaminar wiring, transarticular screw fixation] Spine 2002;27:1724–1732.

A variety of techniques for atlantoaxial fixation by anterior, 4,15,33,52 bilateral,4,14,56 and posterior approaches have been described. In recent years, several new posterior wiring techniques and modifications have been described.4,7,13,17,18,46,42,51–53 These techniques differ in number of sublaminar wires, wire position, graft position, and bone graft shape. All of these techniques are associated with potential risks associated with the use of sublaminar wires,1,5,12,19,20,33,38 which were intensively studied and described in segmental spinal instrumentation.5,21,30,32,44,47,54,63,66,71

Other techniques tried to avoid these risks by using clamp or claw constructs.29,31,43 In 1979, Magel and Seemann27 introduced a new technique using transarticular screws through the C1–C2 articulation. In several studies, this technique showed biomechanical stability superior to that of different wire fixations for lateral bending and/or rotation.22,28,44,46,57,67 Although clinical success rates were high1,16,24,37,38,61,70 and the biomechanical stability for lateral bending and axial rotation was excellent, there still was a biomechanical deficit in flexion and extension2,46. The Magel technique also is technically demanding, and some recent studies show a higher rate of complications, such as malpositioned screws, neurologic deficit, and vascular compromise, than earlier studies.36,70

Anatomic or radiologic studies of the atlantoaxial region have suggested that in up to 20% of the cases, a safe placement of transarticular screws is not possible, mostly because of a high-riding transverse foramen.1,15,16,50 Alternative techniques, such as a combination of screws in the lateral masses of C1 and screws in the isthmic part of C2 or pedicle screws at C2 connected by rods, were described.41

The purpose of this biomechanical in vitro study was first to evaluate the stability of a new atlas claw construct in combination with transarticular screws, which avoids the need for posterior wiring. Second, this study aimed to compare alternative screw fixation techniques, which do not pass the C1–C2 articulation, in cases wherein a safe transarticular screw placement is not possible.

Materials and Methods

Six human cadaver specimens, all male (mean age, 76.7 years; range, 54–96 years), consisting of C0 to at least C3 or to a maximum of C7, as obtained, were used. The specimens were examined, and plain radiographs were taken to exclude soft tissue or bone damage. The specimens then were stored frozen at −20°C in triple-sealed plastic bags.

After thawing, the muscle tissue was removed carefully, and all the ligaments and bony structures were preserved.

From the *Department of Orthopedics and SCL, University of Ulm, and the †Department of Orthopedic Research and Biomechanics, University of Ulm, Ulm, Germany.

Supported by Ullich medizintechnik, Ulm, Germany.

Acknowledgment date: August 6, 2001.

First revision date: December 3, 2001.

Second revision date: February 6, 2002.

Acceptance date: February 12, 2002.

Device Status/Drug Statement: The devices and drugs that are the subject of this manuscript are not FDA-approved for this indication and are not commercially available in the United States.

Conflict of Interest: Corporate and industry funds were received to support this work. One or more of the authors have received or will receive benefits for personal or professional use from a commercial party related directly or indirectly to the subject of this manuscript (e.g., honoraria, gifts, consulting fees).

DOI: 10.1097/01.BRS.0000020301.07340.8F
The segments up to C3-C4 were fixed by placing screws through the vertebral bodies and facets so that only the segments from C0 to C3 had free movement. The cranial and caudal vertebrae then were embedded in polymethylmethacrylate (Technovit 3040; Heraeus Kulzer GmbH, Wehrheim, Germany). To obtain a better anchorage of the vertebrae in the polymethylmethacrylate, short screws were partially driven into the embedded parts of the vertebra. Two screws were inserted in the atlas and axis to fix the motion analysis system to the specimen.

Atlantoaxial instability was produced by dissection of all the ligaments (cruciate, alar, and apical ligaments) surrounding the dens, as well as part of the tectorial membrane, with a surgical blade through the spinal canal. Then a dens osteotomy simulating a dens fracture Type 2, according to the Anderson and D'Alonzo classification, was created.

For the Gallie fixation, the technique described by McGraw and Rusch using a titanium alloy wire 0.8 mm in diameter (Ti-6Al-4V; Ulrich medizintechnik, Ulm, Germany) was used. The wires were tightened with simple pliers. To prevent changing bone stability of the grafts, the graft was simulated by wooden blocks, as previously described.

The isthmic screws (length, 18–24 mm) were inserted in the axis according to the trajectory for transarticular screws, without passing the C1-C2 articulation, and combined with the atlas claw (C2 + claw, picture equivalent to Figure 2).

For the lateral mass screws in the atlas, a 2.6-mm wire was inserted, after which 4-mm screws were inserted over the K-wire and connected to the isthmic screws in C2 by rods and closed connectors (C1 + C2, Figure 3).

The specimens always were tested in the following order: Gallie, TA + Gallie, TA, TA + claw, C2 + claw, and C1 + C2. This order was chosen because it poses the smallest risk of biasing effects by structural damage through the preparation or drilling required for the different instrumentations.

All instrumentations were from the titanium alloy (Ti Al-4V6) modular system neon (neon occipito cervical system; Ulrich GmbH, Ulm, Germany), consisting of two screw types: 4-mm cannulated self-tapping and self-drilling screws for transarticular C1-C2 instrumentation and 4-mm cannulated self-tapping screws for pedicle and isthmic instrumentation at C2 and lateral mass instrumentation at C1, as well as for 4.5-mm rods, closed connectors, and the atlas claw.

The screw trajectory for the transarticular screw fixation, as described Magerl and Seemann, was used. However, two K-wires were inserted first through the C1-C2 articulation. Then plain radiographs were taken, and the position was reviewed. This technique was described previously by Dickman et al. Using K-wires and cannulated screws, a dislocation of C1-C2 during screw insertion was avoided, and there was a chance that the wire position could be corrected in the event of a nonoptimal screw trajectory. If a correct position was obtained, cannulated, self-drilling 4-mm screws (length, 40–48 mm) for transarticular instrumentation were inserted over the K-wires. The bilateral transarticular screws were tested alone (TA), in combination with the previously described Gallie fixation (TA + Gallie, Figure 1) and with a new atlas claw (TA + claw, Figure 2). The claw grabs the arch of the atlas and is fixed to the transarticular screws, analogous to a screw and rod system, with the connector tightened to the screw by a nut, providing constrained movement.
Table 1. Range of Motion and Neutral Zone for the Destabilized and Instrumented Specimen Under a Load of ±1.5 Nm*

<table>
<thead>
<tr>
<th></th>
<th>Lateral Bending</th>
<th>Flexion/Extension</th>
<th>Axial Rotation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ROM (°)</td>
<td>NZ (°)</td>
<td>ROM (°)</td>
</tr>
<tr>
<td>Destabilized</td>
<td>11.3 (8.3-19.8)</td>
<td>9.7 (0.0-16.2)</td>
<td>26.3 (21.4-32.5)</td>
</tr>
<tr>
<td>Gallie</td>
<td>9.4 (7.2-15.2)</td>
<td>8.1 (0.0-11.2)</td>
<td>6.1 (1.3-14.3)</td>
</tr>
<tr>
<td>TA + Gallie</td>
<td>0.1 (0.0-0.1)</td>
<td>0.1 (0.0-0.1)</td>
<td>0.3 (0.0-0.3)</td>
</tr>
<tr>
<td>TA</td>
<td>0.1 (0.0-0.1)</td>
<td>0.1 (0.0-0.1)</td>
<td>1.0 (0.1-2.7)</td>
</tr>
<tr>
<td>TA + claw</td>
<td>0.1 (0.0-0.1)</td>
<td>0.0 (0.0-0.1)</td>
<td>0.4 (0.2-0.5)</td>
</tr>
<tr>
<td>C2 + claw</td>
<td>0.6 (0.1-0.6)</td>
<td>0.5 (0.1-1.0)</td>
<td>1.0 (0.4-2.4)</td>
</tr>
<tr>
<td>Cl + C2</td>
<td>0.2 (0.1-0.3)</td>
<td>0.1 (0.0-0.3)</td>
<td>1.0 (0.4-2.6)</td>
</tr>
</tbody>
</table>

* ±0.5 Nm for axial rotation.

The specimens were mounted in a spine tester, previously described. The caudal vertebrae were rigidly fixed in the testing apparatus, and the cranial vertebra (Cl) was fixed in a Cardan joint containing integrated stepper motors that could introduce a noncontacting ultrasound motion analysis system (Zebris, Isny, Germany) with a resolution of 0.06°. The destabilized specimens showed a higher median ROM and NZ for all directions (Table 1) than the instrumented specimens. The P value for ROM and NZ compared with the destabilized was 0.05, except for the total NZ of destabilized versus Gallie for lateral bending (data not shown).

The Gallie fixation, as compared with the other instrumentations, showed a wider angular motion and total NZ for all directions and both loads (Table 1; Figures 4–6). The smallest distinction was for flexion-extension, which is the direction with the greatest motion restriction of the Gallie technique. The P values were smaller than 0.05 for ROM and NZ under both loads and in all directions (Tables 2–4 for ±2.5 Nm; data not shown), except for the comparison between Gallie and the Cl + C2 screw combination for flexion-extension (ROM) with a loading of ±1.5 Nm. This could be due to the fact that the combined C1 + C2 screw combination, only five specimens were tested. In one specimen, the screws for C2 could not be fixed to the specimen, so to prevent wrong values due to minor screw fixation, the specimen could not be put through the testing sequence. All the other fixations showed no visible loosening or breakage during the three cycles of testing when the fixations were compared before and after testing.

Results

The destabilized specimens showed a higher median ROM and NZ for all directions (Table 1) than the instrumented specimens. The P value for ROM and NZ compared with the destabilized was 0.05, except for the total NZ of destabilized versus Gallie for lateral bending (data not shown).

The Gallie fixation, as compared with the other instrumentations, showed a wider angular motion and total NZ for all directions and both loads (Table 1; Figures 4–6). The smallest distinction was for flexion-extension, which is the direction with the greatest motion restriction of the Gallie technique. The P values were smaller than 0.05 for ROM and NZ under both loads and in all directions (Tables 2–4 for ±2.5 Nm; data not shown), except for the comparison between Gallie and the Cl + C2 screw combination for flexion-extension (ROM) with a loading of ±1.5 Nm. This could be due to the fact that for the Cl + C2 screw combination, only five specimens were tested. In one specimen, the screws for C2 could not be fixed to the specimen, so to prevent wrong values due to minor screw fixation, the specimen could not be put through the testing sequence. All the other fixations showed no visible loosening or breakage during the three cycles of testing when the fixations were compared before and after testing.

Figure 4. Bilateral lateral bending under a load of ±2.5 Nm. Median, minimal, and maximal values are shown in degrees for ROM and the neutral zone (NZ).
The transarticular screw fixation alone (TA) and in combination with Gallie (TA + Gallie) or the new atlas claw (TA + claw) showed a major reduction in angular motion and NZ for all directions and loads when compared to destabilized specimens and Gallie. For lateral bending, identical median ROM values of 0.1° under both loads (±1.5 and ±2.5 Nm) occurred (Table 1; Figure 4). Also under axial rotation, the related median ROM values ranging from 0.1° to 0.2° for ±0.5 Nm (Table 1) and 0.8° to 0.9° for ±2.5 Nm (Figure 6) for both loads were measured. There were no P values less than 0.05 in either direction for ROM and NZ (Tables 2–4 for ±0.5 Nm).

The greatest differences were observed for flexion–extension. The highest median ROM of all the fixations containing transarticular screws, 1.6° (Table 1) and 3.4° (Figure 5), occurred for the TA fixation alone. The value for TA + Gallie fixation (0.9° and 1.9°) was lower, and the lowest values (0.4° and 0.6°) occurred for the TA + claw fixation. Referring to these values, P was less than 0.05 for TA + Gallie and TA + claw versus TA, and for TA + claw versus TA + Gallie for both loads and parameters.

When the different transarticular screw instrumentations were compared with the C2 + claw and C1 + C2 instrumentations, the greatest distinction of median ROM values occurred for axial rotation. The values for TA, TA + Gallie, and TA + claw, respectively, were 0.2°, 0.1°, and 0.1° for ±0.5 Nm (Table 1) and 0.8°, 0.9°, and 0.9° for ±2.5 Nm (Figure 6), as compared with fixation values of 0.5°, 0.3° and 5.3° and 2.3°, respectively, for C2 + claw and C1 + C2. The P value was less than 0.05 for the compared values, except for TA + claw versus C1 + C2 for ±0.5 Nm. The total NZ showed a P value less than 0.05 under ±0.5 Nm only for TA and TA + claw versus C2 + claw, whereas under a load of ±2.5 Nm, the P value was less than 0.05 for all the compared combinations (Table 5).

For lateral bending, the median values for total ROM were 0.1° for all fixations with transarticular screws under both loads, as compared with 0.6° and 0.2° (±1.5 Nm) and 1.4° and 0.3° (±2.5 Nm) for C2 + claw and C1 + C2 screw fixation (Table 1; Figure 4). The P value was less than 0.05, except for TA + claw versus C1 + C2 (±1.5 Nm) and TA versus C1 + C2 (±2.5 Nm, Table 2). For the total NZ compared with C1 + C2, no P value less than 0.05 under either load was obtained. For C2 + claw, a P value less than 0.05 was obtained for all comparisons under a load of ±1.5 Nm, but under ±2.5 Nm, TA versus C2 + claw showed no P value less than 0.05.
CornpanSQf1 01 the groups among 88ch other. 'ROM. 1 NZ. (Table 2). The total ROM values were 1.6° and 1.0° for C2 + claw and C1 + C2 in flexion–extension, and 3.3° and 2.6° for the higher load (Table 1 ; Figure 5). Only TA + claw versus C2 + claw showed a P value less than 0.05 for the load of ±1.5 Nm. Under the load of ±2.5 Nm, TA + Gallie versus C2 + claw and TA + claw versus C2 + claw and C1 + C2 had P values smaller than 0.05 (Table 3). The P values for NZ where distinguished from the P values for ROM only by TA + claw versus C1 + C2, for which a P value smaller than 0.05 occurred (Table 3).

In comparisons of the C2 + claw and C1 + C2 instrumentations, there was a tendency toward smaller median values for total ROM and total NZ for the C1 + C2 screw combination, with a wider spread difference between the minimal and maximal values for the C2 + claw instrumentation. There were no P values less than 0.05 for the comparisons between these two groups.

### Discussion

In this study, the values for the destabilized specimens in lateral bending and flexion–extension corresponded very well with the data for odontoid fracture or dissected ligaments of C1–C2 presented by Crawford et al.\(^\text{10}\) Under axial rotation, the current values were approximately 10° less on the average, probably because the authors loaded the specimen with ±0.5 Nm instead of ±1.5 Nm, as Crawford et al.\(^\text{10}\) did. The values in the study from Crawford et al.\(^\text{10}\) were reported separately for transected ligaments and odontoid fracture. In the current study, simultaneous ligamentous and bony injuries were produced, but the values probably can be compared because an odontoid fracture increases angular motion more, sometimes significantly more, than a ligamentous disruption. These findings also are reported in the study of Crawford et al.\(^\text{10}\)

The two three-point fixations tested in this study (TA + Gallie and TA + claw) showed the smallest overall ROM and NZ, with distinctly smaller values for the TA + claw instrumentation in flexion–extension. The resistance in flexion–extension to the higher load, ±2.5 Nm in the current study, a load commonly used for *in vitro* investigations of the middle and lower cervical spine, was greatest for TA + claw. Whereas the median ROM values slightly more than doubled, as compared with the values at ±1.5 Nm, the value for TA + claw rose only about 50%.

Recent studies also have showed that the highest stability is provided by three-point fixations of the atlantoaxial complex.\(^\text{29,46}\) Two main aims of internal stabilization are immediate postoperative stability and long-term stability. The immediate postoperative stability contributes to the duration and acceptability of the postoperative treatment. The long-term stability usually is achieved by bone fusion, for which a rigid internal fixation is considered a main factor for occurrence. The "real" *in vivo*–appearing forces are not known exactly, and the amount of instability after trauma or other conditions is not exactly predictable.

To the authors' knowledge, the only study presenting negative effects from rigid internal fixation is the McAfee et al.\(^\text{39}\) study of an animal model. In this study, a device–related osteoporosis occurred, which, however, was compensated by improved mechanical properties. For

### Table 2. P Values for Lateral Bending Under a Load of ±2.5 Nm

<table>
<thead>
<tr>
<th></th>
<th>Gallie</th>
<th>TA + Gallie</th>
<th>TA</th>
<th>TA + Claw</th>
<th>C2 + Claw</th>
<th>C1 + C2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gallie</td>
<td>0.0277</td>
<td>0.0277</td>
<td>0.0277*</td>
<td>0.0277*</td>
<td>0.0277*</td>
<td>0.0431*</td>
</tr>
<tr>
<td>TA + Gallie</td>
<td>0.0277</td>
<td>0.0277</td>
<td>0.0277*</td>
<td>0.0277*</td>
<td>0.0277*</td>
<td>0.0431*</td>
</tr>
<tr>
<td>TA</td>
<td>0.0277</td>
<td>0.0277</td>
<td>0.0277*</td>
<td>0.0277*</td>
<td>0.0277*</td>
<td>0.0431*</td>
</tr>
<tr>
<td>TA + claw</td>
<td>0.0277</td>
<td>0.0277</td>
<td>0.0277*</td>
<td>0.0277*</td>
<td>0.0277*</td>
<td>0.0431*</td>
</tr>
<tr>
<td>C2 + claw</td>
<td>0.0277</td>
<td>0.0277</td>
<td>0.0277*</td>
<td>0.0277*</td>
<td>0.0277*</td>
<td>0.0431*</td>
</tr>
<tr>
<td>C1 + C2</td>
<td>0.0431</td>
<td>0.0431</td>
<td>0.0431*</td>
<td>0.0431*</td>
<td>0.0431*</td>
<td>0.0431*</td>
</tr>
</tbody>
</table>

Comparison of the groups among each other.
* ROM.
+ NZ.

### Table 3. P Values for Flexion–Extension Under a Load of ±2.5 Nm

<table>
<thead>
<tr>
<th></th>
<th>Gallie</th>
<th>TA + Gallie</th>
<th>TA</th>
<th>TA + Claw</th>
<th>C2 + Claw</th>
<th>C1 + C2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gallie</td>
<td>0.0277</td>
<td>0.0277</td>
<td>0.0277*</td>
<td>0.0277*</td>
<td>0.0277*</td>
<td>0.0464*</td>
</tr>
<tr>
<td>TA + Gallie</td>
<td>0.0277</td>
<td>0.0277</td>
<td>0.0277*</td>
<td>0.0277*</td>
<td>0.0277*</td>
<td>0.0464*</td>
</tr>
<tr>
<td>TA</td>
<td>0.0277</td>
<td>0.0277</td>
<td>0.0277*</td>
<td>0.0277*</td>
<td>0.0277*</td>
<td>0.0464*</td>
</tr>
<tr>
<td>TA + claw</td>
<td>0.0277</td>
<td>0.0277</td>
<td>0.0277*</td>
<td>0.0277*</td>
<td>0.0277*</td>
<td>0.0464*</td>
</tr>
<tr>
<td>C2 + claw</td>
<td>0.0464</td>
<td>0.0277</td>
<td>0.0277*</td>
<td>0.0277*</td>
<td>0.0277*</td>
<td>0.0464*</td>
</tr>
<tr>
<td>C1 + C2</td>
<td>0.0464</td>
<td>0.0277</td>
<td>0.0277*</td>
<td>0.0277*</td>
<td>0.0277*</td>
<td>0.0464*</td>
</tr>
</tbody>
</table>

Comparison of the groups among each other.
* ROM.
+ NZ.
Table 4. P Values for Axial Rotation Under a Load of ±2.5 Nm

<table>
<thead>
<tr>
<th></th>
<th>Gallie</th>
<th>TA + Gallie</th>
<th>TA</th>
<th>TA + Claw</th>
<th>C2 + Claw</th>
<th>C1 + C2</th>
</tr>
</thead>
<tbody>
<tr>
<td>TA + Gallie</td>
<td>0.0277</td>
<td>0.1380*</td>
<td>0.0277*</td>
<td>0.0277*</td>
<td>0.0277*</td>
<td>0.0431*</td>
</tr>
<tr>
<td>TA</td>
<td>0.0277</td>
<td>0.1380*</td>
<td>0.0277*</td>
<td>0.0277*</td>
<td>0.0277*</td>
<td>0.0431*</td>
</tr>
<tr>
<td>TA + claw</td>
<td>0.0277</td>
<td>0.1380*</td>
<td>0.0277*</td>
<td>0.0277*</td>
<td>0.0277*</td>
<td>0.0431*</td>
</tr>
<tr>
<td>C2 + claw</td>
<td>0.0277</td>
<td>0.1380*</td>
<td>0.0277*</td>
<td>0.0277*</td>
<td>0.0277*</td>
<td>0.0431*</td>
</tr>
<tr>
<td>C1 + C2</td>
<td>0.0431</td>
<td>0.1380*</td>
<td>0.0431</td>
<td>0.0431*</td>
<td>0.0431*</td>
<td>0.0431*</td>
</tr>
</tbody>
</table>

Comparison of the groups among each other.
* RCM.

The transarticular screw fixation in this study contributed most to stability in lateral bending and axial rotation, as previously described. The resistance to the higher load was greatest for lateral bending, in which median ROM values did not increase. The median NZ was the same or smaller than the median ROM. The use of transarticular screws is biomechanically desirable, but in some cases not easily feasible clinically. Especially a larger groove of the vertebral artery (VA) in the axis, often called “a high-riding transverse foramen,” makes a safe screw trajectory impossible, or at least increases the risk of a iatrogenic artery damage, in up to 20% of the cases. This was the same or smaller than the median ROM. The use of other more stable wiring techniques probably would improve stability, but usually, in addition to the time requirement and technical specification, more sublaminar wires, and sometimes a longer intraspinal wire pathway, are needed due to the sublaminar passage of C1 and C2, as in the Brooks technique.

In recent surveys, the authors emphasized that a suspected or verified VA injury during preparation or insertion of the first transarticular screw should entail leaving the remaining side untouched to prevent bilateral impairment. Madawi et al described 61 patients treated with TA screw fixation and 5 VA injuries, all associated with incomplete reduction. Therefore, each individual case should be assessed for its suitability for TA screw fixation, including anatomic features and reducibility. If TA screw fixation is not feasible, other techniques should be selected to achieve a high immediate stability.

The C2 + claw or C1 + C2 techniques are possible alternatives. Their median overall ROM was larger than that of the three-point fixation, but showed a distinct reduction of ROM and NZ, as compared with the Gallie fixation. This was also found by Melcher et al for the C1 + C2 technique, with the same instability pattern under a load of ±1.5 Nm. However, the reduction of motion, as compared with that of the destabilized specimen or the Gallie fixation, was less than in the current study, probably because rods with a diameter of 4.5 mm rather than 3 mm were used. These authors also used a polyaxial screw-rod construct, which could be less stable than the screw-rod system with closed connectors used in the current study. They concluded that the stability for the C1 + C2 construct and the TA screws was the same, although they did not test the TA screws. The current authors found similar results, except under the higher load of ±2.5 Nm for axial rotation, in which a distinct difference occurred.

In the current study, the spreading of the motion values for C1 + C2 and C2 + claw instrumentations were larger than for the TA-containing fixations, especially for the C2 + claw construct. The current specimen had a great range of age, which could have contributed to different values for the bone mineral density (BMD). The TA screws could possibly resist the differing BMD values better because of the longer screw length, which was approximately twice that of the screws for C1 + C2 and C2 + claw. Because BMD was not measured in this study, a correlation of BMD, screw tightening, and consecutive, the ROM can only be assumed.

The Gallie fixation is probably one of the lesser stable fixations, as compared with other wiring techniques, especially the method of Brooks and Jenkins, but it is the simplest technique and the least time consuming. Therefore, it is often used in combination with transarticular screws. The use of other more stable wiring techniques probably would improve stability, but usually, in addition to the time requirement and technical specification, more sublaminar wires, and sometimes a longer intraspinal wire pathway, are needed due to the sublaminar passage of C1 and C2, as in the Brooks technique.

In a review of complications resulting from sublaminar wiring in the middle and lower cervical spine, Geremia et al found greater anterior bowing of the wire if more than one sublaminar wire passage was performed. Case reports of wire or cable complications from atlantoaxial articulation have been published, but basic studies such as those investigating the chronic effects of wiring and complications during the insertion or removal of wires, were conducted only for segmental spinal instrumentation. The results cannot simply be applied to the atlantoaxial complex because the free space in the atlantoaxial region is larger than in the thoracic spine, which is described appropriately by Steel’s “rule of thirds.” However, in some circumstances, with narrowing of the spinal canal from preexisting conditions such as congenital spinal stenosis, disc protrusion, or facet joint hypertrophy, or from acute narrowing caused by fixed atlantoaxial displacement or rheumatoid pannus, the
risk of neurologic complications during sublaminar wire passage is increased. Smith et al. described several factors with increased risk of complication during fusion of the upper cervical spine by the use of wiring techniques that are not always to be attributed to a narrowing of the free space of the spinal canal. These authors concluded that in these cases, alternatives to the usual surgical techniques are required. Most of the wiring techniques also require bone grafts, not only to permit bone fusion, but also to create immediate stability. If bone grafts collapse or dislodge, the immediate stability is affected. This also can be the case when underlying diseases such as rheumatoid arthritis or osteoporosis affect the bone strength.

The use of techniques not dependent on bone grafts for stability also could simplify the use of bone surrogates with minor mechanical stability in the future. On the other hand, the graft with the claw technique is an onlay graft, which lacks compression. This could influence the fusion rate because compression of a bone graft is considered to be a factor necessary for fusion to occur.

The choice of titanium for spinal fixation devices has the benefit of superior diagnostic capability with magnetic resonance imaging (MRI), as compared with steel devices. Yet, titanium wires showed less strength in vitro than stainless steel wires, as did titanium cables when compared with stainless steel cables. This shortens the life of titanium wires and cables.

According to the results of this in vitro study and other previously described studies, biomechanically, the most rigid instrumentation for axial rotation and lateral bending probably is the transarticular screw fixation. However, to improve the stability for flexion–extension and to achieve a three-point fixation, a supplementary fixation should be used. Naderi et al. showed that an increasing number of fixation points decreases the magnitude of C1–C2 motion. The most rigid combination in the current study was the TA + claw construct, which avoided the need of a sublaminar wire passage and was not dependent on bone graft stability. Because of the titanium alloy, a good MRI capability also is achieved. In cases wherein a transarticular screw placement is not possible, perhaps the C2 + claw or C1 + C2 screw combination can be used. The efficacy of the atlas claw in combination with transarticular screws or isthmic screws in the axis, and that of the C1 + C2 screw combination need to be validated in clinical studies with long-term follow-up evaluation before the results of this in vitro biomechanical study can finally be assessed.

Study Limitations

All of the specimens in this study were male, which is the consequence of specimen availability. The same reason also applies to the age of the specimen. There is decreased cervical spine motion with age, and perhaps also with gender, which could have influenced the results. The comparison among the different instrumentations should not have been affected, whereas the overall ROM could have been less, as compared with younger specimens and mixed genders. The testing order was not randomized. Therefore, the results could have been influenced in favor of the spinal implant tested first. The Gallie fixation showed higher median values for ROM and NZ, as did all the other instrumentations, and the instrumentation tested last (C1 + C2) showed smaller median values for ROM and NZ than the one tested before (C2 + claw), which argues against such an impact. The Gallie fixation, as performed in the current study with simple pliers, is susceptible to differences resulting from tightening of the wire by twisting. Because the tension applied to the wires was not monitored, varying tensions cannot be ruled out.

Perhaps a more consistent tension, with subsequent higher stability, could have been achieved by using multistrand cable instead of monofilament wire. The results of the Gallie fixation in this study should be interpreted with these limitations kept in mind. Nevertheless, the authors used this fixation because they think that it is performed quite often in clinical settings in addition to a transarticular screw fixation. For the Gallie fixation, wooden grafts were used instead of bone. The mechanical properties of the two materials are not the same, but the benefit of using wood is a better standardization among the tested specimens as a result of not changing the properties of the grafts. This was a biomechanical study with a small number of tested specimens, and consequently limited statistical significance. This reinforces the need for validation of the results by clinical studies.

Conclusions

In this in vitro biomechanical study, the three-point fixation techniques showed the smallest median values for ROM and NZ, with smallest values for the TA + claw instrumentation. Transarticular screw fixation was the most stable for lateral bending and axial rotation. The C2 + claw and C1 + C2 instrumentations showed higher median ROM and NZ values than the three-point fixations, which probably are useful, however, in situations wherein a transarticular screw fixation is not feasible.

Key Points

- Transarticular screws resisted lateral bending and axial rotation best in this biomechanical in vitro study.
- Three-point fixation provided additional stability in flexion and extension, with distinctly smaller ROM for the TA + claw construct, which is not dependent on bone graft stability and sublaminar wire passage.
- Isthmic screws in combination with the atlas claw and lateral mass screws C1 and isthmic screws C2 are less stable, but may be alternatives in cases wherein TA screw fixation is not feasible.
Acknowledgment

The authors thank Ulrich medizintechnik Co. for providing the funds for realization of this study.

References

70. Wright NM, Laurynsen C. Vertebral artery injury in C1-C2 transarticular screw fixation: Results of a survey of the AANS/CNS section on disorders of

Address reprint requests to

Marcus Richter, MD
RKU Orthopädische Klinik mit Querschnittgelähmtenzentrum der Universität Ulm
Oberer Eselsberg 45
89081 Ulm
Germany
E-mail: marcus.richter@medizin.uni-ulm.de