Radiological and anatomical evaluation of the atlantoaxial transarticular screw fixation technique

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Sixty-one patients treated with C1–2 transarticular screw fixation for spinal instability participated in a detailed clinical and radiological study to determine outcome and clarify potential hazards. The most common condition was rheumatoid arthritis (37 patients) followed by traumatic instability (15 patients). Twenty-one of these patients (one-third) underwent either surgical revision for a previously failed posterior fusion technique or a combined anteroposterior procedure. Eleven patients underwent transoral odontoidectomy and excision of the arch of C-1 prior to posterior surgery. No patient died, but there were five vertebral artery (VA) injuries and one temporary cranial nerve palsy. Screw malposition (14% of placements) was comparable to another large series reported by Grob, et al. There were five broken screws, and all were associated with incorrect placement.

Anatomical measurements were made on 25 axis bones. In 20% the VA groove on one side was large enough to reduce the width of the C-2 pedicle, thus preventing the safe passage of a 3.5-mm diameter screw.

In addition to the obvious dangers in patients with damaged or deficient atlantoaxial lateral mass, the following risk factors were identified in this series: 1) incomplete reduction prior to screw placement, accounting for two-thirds of screw complications and all five VA injuries; 2) previous transoral surgery with removal of the anterior tubercle or the arch of the atlas, thus obliterating an important fluoroscopic landmark; and 3) failure to appreciate the size of the VA in the axis pedicle and lateral mass. A low trajectory with screw placement below the atlas tubercle was found in patients with VA laceration.

The technique that was associated with an 87% fusion rate requires detailed computerized tomography scanning prior to surgery, very careful attention to local anatomy, and nearly complete atlantoaxial reduction during surgery.

Clinical Material and Methods

Clinical Review

The medical records of all patients treated with the atlantoaxial transarticular screw fixation technique were reviewed and patients were assessed at the outpatient clinic. During the follow-up review, all patients underwent detailed clinical and radiological evaluation. In this paper we concentrate mainly on the radiological as well as the anatomical analysis of the technique.

Radiological Studies

Patients underwent postoperative radiological evaluation that included the following techniques.

Plain X-Ray Films. Lateral views (neutral, flexion, and extension) and anteroposterior transoral view.

Plain Computerized Tomography Scanning. Thin axial slices and coronal and sagittal reconstruction through the atlantoaxial lateral masses. Sagittal reconstruction at
the midpoint of both right and left C1–2 lateral masses (through the screw trajectory) was a routine part of computerized tomography (CT) scanning.

Further Study. Patients with residual neurological deficits were examined by means of magnetic resonance imaging and/or magnetic resonance angiography. The six patients with vertebrobasilar symptoms or with CT scans showing one screw encroaching on the vertebral artery (VA) were examined using conventional angiography.

Definitions of Terms

Screw Position. Using the radiological studies, screw positions were checked and assigned to one of two categories: 1) well positioned, if the screw passed through both lateral masses of C-1 and C-2 vertebrae, crossed the joint in between, and protruded through the anterior cortex of C-1 by less than 5 mm; or 2) malpositioned, if the screw was too short, too long (protruding > 5 mm out of the C-1 cortex), too high (pointing to the basiocciput), or if it missed the lateral mass of C-1 by being pointed too low, too lateral, or too medial.

Stability. The C1–2 segment was considered to be stable if there were no observed movements between the posterior arch of C-1 and the spinous process of C-2 in flexion–extension positions on lateral radiographs.

Fusion. Bone fusion was considered osseous if there was continuity of bone between the posterior arches of both atlas and axis and there was no observed movement between C-1 and C-2 in the dynamic study.

Anatomical Studies

We studied 25 dry adult C-2 vertebrae obtained from the Department of Anatomy of the Royal College of Surgeons of England. Our study focused on the pedicle and lateral mass of C-2 bilaterally. Pedicle parameters included the following: 1) height, measured from the superior surface of the pedicle to its inferior surface within the transverse foramen; 2) width, measured from the internal surface of the pedicle to its external surface at the level of the transverse foramen; and 3) the medial angle of the facet–pedicle complex, that is, the angle between the facet–pedicle complex axis and a line passing through the midline of the vertebral body and the spinous process (Fig. 1A).

Lateral mass parameters included the following: 1) external height, measured from the midpoint of the superior facet to the lowest point on the inferior surface of the lateral mass; 2) internal height, measured from the midpoint of the superior facet to the nearest point on the inferior surface of the lateral mass or roof of the VA groove; and 3) depth of the VA groove, that is, the difference between the first two measurements (Fig. 1B).

Surgical Technique

The patients were anesthetized using fiberoptic nasotracheal intubation and placed prone on the operating table. Somatosensory evoked potentials were monitored throughout the procedure. A Mayfield head fixation set was used to secure the head, and the atlantoaxial subluxation was reduced with the aid of control fluoroscopy. Surgery was performed with the lower cervical spine in extension and the C1–2 joint in the neutral position with no rotation. As we have gained more experience with the technique, the importance of preoperative fluoroscopic positioning of the head has become apparent. In our view this step is the key to a successful procedure.

In the early cases, an extensive skin incision from the occiput to C-7 was required to allow proper alignment of the drill bit. In later cases, the drill guard was introduced via a separate, smaller paravertebral stab incision that required less neck muscle dissection. After a careful subperiosteal dissection of the C-1 and C-2 laminae, a titanium cable (Sof’ wire; Codman and Shurtleff, Inc., Randolph, MA) was inserted under the posterior arch of C-1. We applied traction on this cable, which aided in the intraoperative reduction of subluxation and in maintenance of the position of the spine during the procedure. Visualization of the C1–2 joint and the inner aspect of the C-2 pedicle on both sides is an essential step at this stage of the procedure.

Using fluoroscopy, K-wire was inserted into the dorsal aspect of the axis at the junction of the lamina with the articular mass strictly in the sagittal plane. After a careful subperiosteal dissection of the C-1 and C-2 laminae, a titanium cable (Sof’ wire; Codman and Shurtleff, Inc., Randolph, MA) was inserted under the posterior arch of C-1. We applied traction on this cable, which aided in the intraoperative reduction of subluxation and in maintenance of the position of the spine during the procedure. Visualization of the C1–2 joint and the inner aspect of the C-2 pedicle on both sides is an essential step at this stage of the procedure.

Using fluoroscopy, K-wire was inserted into the dorsal aspect of the axis at the junction of the lamina with the articular mass strictly in the sagittal plane. Nevertheless, based on our anatomical study we found that a trajectory of up to 15° in the medial direction was acceptable. After satisfactory positioning was achieved a cannulated drill 2.5 mm in diameter was passed over the K-wire and aimed at the top of the tubercle of the anterior arch of the atlas; this prevents the K-wire from slipping downward when...
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transfixing the joint. The drill crosses the isthmic part of C-2 and exits the axis in the posterior third of the atlantoaxial joint. After crossing the joint, the drill enters the atlas approximately in the middle portion of the articular process. The drill is left in place until the second drill hole has been made and the corresponding screw has been inserted. A 3.5-mm AO cortical screw (Synthes; Stratec Medical, Ltd., Oberdorf, Switzerland) was used originally, whereas lag screws are now available. A bone graft was harvested from the iliac crest, placed between the posterior arches of C-1 and C-2, and secured by titanium wire.

Stainless steel screws were used in the first 15 patients treated in this study, but we currently use titanium lag screws in conjunction with titanium cables to facilitate postoperative imaging. When the posterior arch of C-1 was deficient, the subchondral part of the C1–2 joint was removed, and the joint was packed with a bone graft once the screws had been inserted. Also, additional onlay grafts can be placed on the lateral parts of the posterior arches of C-1 and C-2. In eight patients the spinous process of C-7 was used as a bone graft. Also, monofilament nylon was used for securing the posterior arches of C1–2 in 15 patients. Immobilization was provided by a soft neck collar without the need for a halo brace, and early ambulation was encouraged, with patients usually out of bed the day after surgery.

Statistical Analysis

The data were evaluated by the chi-square test using commercially available software (Minitab, Inc., State College, PA). Significance was accepted at probability values of less than 0.05.

Results

Clinical Findings

Between February 1991 and March 1995, 58 adults and three children underwent operation via the atlantoaxial transarticular screw fixation technique12 for a variety of indications. The patients ranged in age from 7 to 77 years (mean 48.3 ± 17.1 years). Eighteen patients were male, and 43 were female; follow-up periods ranged from 6 to 72 months (mean 26 ± 12.2 months). Seventeen patients with rheumatoid and one with psoriatic arthritis were receiving regular steroid therapy. Twenty-three patients were regular smokers. The average hospital stay was 7.7 ± 2.8 days.

The indications for screw fixation were classified into three groups.

Group I. This group consisted of 37 patients with rheumatoid arthritis, seven of whom had a history of significant neck trauma, and five in whom posterior C1–2 fusion had failed. The mean duration of rheumatoid disease was 14.2 ± 7.2 years, with a range of 1.5 to 32 years.

Group II. This group consisted of 15 patients with traumatic atlantoxial instability, including two children with atlantoaxial rotatory subluxation.

Group III. This group was composed of nine patients with miscellaneous indications, including three with Chiari malformations associated with anteroposterior de-
to involve the occiput and the lower cervical spine by means of a Ransford loop. Two patients underwent revision because of screw breakage accompanied by instability and persistent neck pain. We performed a revision in the third patient because of progressive subaxial disease and cord compression.

There were no operative deaths. However, the reported surgical morbidity included one iliac wound infection, one velopharyngeal incompetence after transoral odontoidectomy, two chest infections, one pulmonary edema, and one acute gastric dilation.

**Radiological Findings**

One hundred twenty-one screws (50 lag and 71 fully threaded AO cortical screws) were inserted in 61 patients; in one patient it was not possible to insert a second screw because of a damaged right pedicle. The screw length used in adults ranged between 40 and 45 mm, with a diameter of 3.5 mm. In children, we used screws 34 mm in length. The Gallie fusion technique was used in 52 patients, with onlay fusion of C1–2 lateral masses in nine cases. The bone grafts were harvested from the iliac crest in 53 patients, and from the spinous process of C-7 in eight. Titanium cables were used in 37 patients, monofilament nylon in 15 patients, and no wiring was used for the other nine.

At the time of surgery all patients had unstable vertebrae, but complete reduction of the C1–2 displacement was possible in only 47 patients. Fourteen patients (23%) had incomplete reduction with persistent atlantoaxial displacement; 10 of these had rheumatoid arthritis.

In a total of 121 screw placements, 17 screws (12 left, five right; 14% overall) in 15 patients were categorized as malpositioned (Table 2) according to our previous definition. Malpositioned screws were located as follows: eight were too low, and two of them were too low and too long; four were too lateral; two were too medial; two were too long but with a good trajectory; and one screw was too high and too long. Nine of the 15 patients with malpositioned screws displayed incomplete reduction in conjunction with screw malposition (p < 0.001; Fig. 2 and Table 3).

Screw breakage was reported in five patients, four with rheumatoid arthritis and one with degenerative instability (Table 2). Screw breakage (4%) occurred between 2 and

<table>
<thead>
<tr>
<th>Complication</th>
<th>Rheumatoid Arthritis* (37 patients)</th>
<th>Traumatic Instability (15 patients)</th>
<th>Miscellaneous (9 patients)</th>
</tr>
</thead>
<tbody>
<tr>
<td>malpositioned screw</td>
<td>11 (29.7%)</td>
<td>2 (13.3%)</td>
<td>4 (44.4%)</td>
</tr>
<tr>
<td>screw breakage</td>
<td>4 (10.8%)</td>
<td>0</td>
<td>1 (11.1%)</td>
</tr>
<tr>
<td>VA injury</td>
<td>2 (5.4%)</td>
<td>1 (6.7%)</td>
<td>2 (22.2%)</td>
</tr>
<tr>
<td>nonunion</td>
<td>7 (18.9%)</td>
<td>0</td>
<td>1 (11.1%)</td>
</tr>
<tr>
<td>instability</td>
<td>4 (10.8%)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>complete graft resorption</td>
<td>2 (5.4%)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>partial graft resorption</td>
<td>9 (24.3%)</td>
<td>2 (13.3%)</td>
<td>1 (11.1%)</td>
</tr>
<tr>
<td>neural injury (CN XII)</td>
<td>1 (2.7%)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>incomplete reduction</td>
<td>10 (27%)</td>
<td>2 (13.3%)</td>
<td>2 (22.2%)</td>
</tr>
<tr>
<td>reoperation</td>
<td>3 (8.1%)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>no. of affected patients</td>
<td>11 (29.7%)</td>
<td>3 (20%)</td>
<td>4 (44.4%)</td>
</tr>
</tbody>
</table>

* One reoperation was performed for progressive subaxial disease. Abbreviation: CN = cranial nerve.
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TABLE 3
Comparison of problems encountered in patients with incomplete or complete reduction

<table>
<thead>
<tr>
<th>Complication</th>
<th>Incomplete (14 patients)</th>
<th>Complete (47 patients)</th>
</tr>
</thead>
<tbody>
<tr>
<td>malpositioned screw*</td>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td>screw breakage†</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>nonunion</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>instability</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>VA injury*</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>cranial nerve injury</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>no. of affected patients</td>
<td>9</td>
<td>8</td>
</tr>
</tbody>
</table>

* Statistically significant at p < 0.001.
† Statistically significant at p = 0.04.

12 weeks postoperatively. All broken screws but one were right sided, and were made of titanium; none of the steel screws broke. All five broken screws were associated with one of 17 malpositioned contralateral screws that missed the lateral mass of C-1 (p < 0.001) (Fig. 3). This means that if there is a malposition of one screw there is a one in three chance that the well-placed contralateral screw will break. Three broken screws were associated with incomplete reduction (14 patients).

Segmental instability was abolished between C-1 and C-2 in 57 (93%) of 61 patients, with an overall rate of sound osseous union of 87% (53 of 61). The rheumatoid group had an 81% fusion rate (30 of 37), the traumatic group demonstrated a 100% fusion rate (15 of 15), and the miscellaneous group had an 89% fusion rate (eight of nine). When we looked at the graft size, we noticed that the graft had been completely resorbed in two patients with rheumatoid arthritis and that it had been partially resorbed in nine patients with rheumatoid arthritis, two in the trauma group, and one in the miscellaneous group (Table 2). Nevertheless, six (50%) of these 12 patients with partial graft resorption achieved bone fusion.

Anatomical Findings

Based on 25 adult cadaveric C-2 vertebrae measured, the mean, range, and standard deviation (SD) of clinically relevant parameters were calculated (Tables 4 and 5). Significant variations exist in the morphological features of the C-2 vertebra; the anatomical course of the VA through the lateral mass of the C-2 vertebra was found to be asymmetrical in 52% of the specimens. In 20% of the specimens, the VA created a significant groove (VA groove) in the inferior surface of the C-2 lateral mass (Figs. 1B and 4A and B). In those specimens the pedicle was eroded and the internal height of the lateral mass was thinned down to less than or equal to 2 mm (Fig. 4A). The mean medial angle of the facet–pedicle complex viewed from the top surface was 14.1° (Fig. 1A). This represents the screw trajectory through the C-2 vertebra and means that a safe screw trajectory ranges between 0° parasagittal and 14° medial in the horizontal plane.

Discussion

There is an elegance in the technique described by Magerl and Seemann that attracts a spine surgeon and this is matched by the biomechanical superiority of this form of fixation in resisting all possible motion, including rotation at the atlantoaxial joint. Problems have
arisen and although these have not been documented in the literature we are aware of serious neural and vascular injuries associated with this procedure around the world. This, coupled with our own experiences with VA injuries despite meticulous attention to detail, prompted us to raise the possibility that there might be contraindications as yet undescribed that will help surgeons choose the safest and most efficient form of stabilization for individual patients. This study offers a detailed radiological audit of our patients and a novel study of the osteometry of the axis vertebra.

Our series is the second largest in the literature (Table 6), with only the multicenter Swiss study\(^8\) exceeding it in size. In that report, 99% of patients achieved stability, and fusion occurred in 95%. Yet there were problems with poor screw position in 15% and broken or pulled out screws noted in 5% of these patients. In our study, whereas fusion was slightly less successful (87%), rates of stability (93%), screw malposition (14%), and breakage (4%) were comparable to those seen in the Swiss study (Table 6). We report five VA injuries, three manifested by brisk bleeding, and two occlusions, one of which developed into a brainstem stroke when the contralateral screw broke some weeks later. We are not sure whether these injuries were the result of inexperience with the technique or of factors that were not appreciated at the time of surgery.

The case mix reported in the literature may be significant. Sixty-one percent of our patients had rheumatoid arthritis, twice the incidence in the series reported by Grob, et al.\(^8\) We were well aware of a high incidence of lateral mass destruction, particularly in those patients with translocation of the dens, and therefore avoided this type of fixation in such patients. The quality of the bone may be a factor in these patients and we now insist on careful CT reconstruction through the lateral masses before embarking on screw fixation.

Of interest too is the fact that the other smaller series that reported no vascular injuries and the lowest incidence of screw malposition were composed totally\(^10\) or predominantly\(^17\) of patients with traumatic instability. There were no vascular injuries in our trauma patients and the screw positions were as good as in the other series (Table 2).

Twenty-one of our patients underwent either surgical revision for a previously failed posterior fusion procedure or a combined anteroposterior procedure. In fact 11 patients underwent transoral surgery prior to the C1–2 screw placement and in these the incidence of screw malpositioning was 55% (p = 0.01); also there were three VA injuries and one cranial nerve palsy. Clearly, the loss of such an important landmark for lateral fluoroscopy as the anterior tubercle on the arch of the atlas reduces the accuracy of K-wire placement. Additionally, with the loss of the anterior arch and the dens it is very difficult to know how successful subluxation reduction has been.

The single most important risk factor in our series was incomplete reduction of the atlantoaxial joint prior to the passage of the screw (Table 3). In nine of the 14 patients with incomplete reduction the screw was malpositioned (p < 0.001). All five VA injuries were associated with incomplete reduction (p < 0.001) and three of the broken screws were found in this group of patients (p = 0.04). The importance of complete reduction prior to screw fixation has not been emphasized in the literature. Certainly in the situation of acute trauma the problem may not arise, but given our case mix it has obviously been important.

### Table 4

<table>
<thead>
<tr>
<th>Measure</th>
<th>Pedicle Width (mm)</th>
<th>Pedicle Height (mm)</th>
<th>Pedicle–Facet Angle (˚)</th>
</tr>
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<tbody>
<tr>
<td>mean</td>
<td>7.8</td>
<td>7.8</td>
<td>14.1</td>
</tr>
<tr>
<td>SD</td>
<td>1.6</td>
<td>1.6</td>
<td>2.7</td>
</tr>
<tr>
<td>minimum</td>
<td>3.4</td>
<td>4.8</td>
<td>9.0</td>
</tr>
<tr>
<td>maximum</td>
<td>12.2</td>
<td>10.0</td>
<td>20.0</td>
</tr>
</tbody>
</table>

### Table 5

<table>
<thead>
<tr>
<th>Measure</th>
<th>External Height (mm)</th>
<th>Internal Height (mm)</th>
<th>VA Groove (depth/mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>mean</td>
<td>7.9</td>
<td>3.9</td>
<td>4.0</td>
</tr>
<tr>
<td>SD</td>
<td>1.2</td>
<td>1.4</td>
<td>1.3</td>
</tr>
<tr>
<td>minimum</td>
<td>5.3</td>
<td>1.8</td>
<td>1.0</td>
</tr>
<tr>
<td>maximum</td>
<td>10.5</td>
<td>9.0</td>
<td>7.1</td>
</tr>
</tbody>
</table>

FIG. 4. Anatomical and radiological appearance of an enlarged VA groove. A: Photograph depicting anatomy; C-2 viewed from below showing large VA groove nearly eroding most of the C-2 lateral mass and pedicle (left curved arrow). The right pedicle is normal (right curved arrow). In these circumstances transarticular screw fixation would not be recommended. B: Spine CT reformat showing enlarged left VA groove (1).
Our radiological and anatomical studies may provide an explanation of this risk factor. In atlantoaxial subluxation there is a “falling forward and downward” of the tubercle of the anterior arch of the atlas. Even with fluoroscopically demonstrated perfect alignment on the anterior tubercle, the position of the atlas will put the VA at risk (Fig. 5). In general terms, it would seem to be advisable always to aim “high” at the top of the tubercle, although this presents the greatest technical difficulty for the surgeon.

The anatomical measurements revealed that 20% of the measured lateral masses (those with an internal height of ≤2 mm) were grooved by the VA to the extent that the artery might be damaged even with a most accurate alignment. In some patients the pedicle was smaller than the diameter of the screw. The shape and depth of this VA groove was quite variable and we found asymmetrical grooving of the C-2 lateral mass in 52% of our specimens (Fig. 4A). In our material the depth of the groove ranged from 1 to 7 mm (Table 5), depending on the size of the lateral mass and the dominance and/or the anatomical variation of the VA. According to George and Laurian the VAs are frequently asymmetrical (59%), with the dominant artery located more frequently on the left side (36%). This correlated with the VA injuries in our series in that all were left sided.

The importance of a proper preoperative CT scan to show the anatomy of the pedicle and the lateral mass and exclude erosion whether secondary to VA abnormal anatomy or rheumatoid arthritis cannot be overemphasized (Fig. 6). It is quite inappropriate to embark on the procedure using plain radiographs alone. The use of oblique axial CT scanning for the C1–2 joint as proposed by others may be a considerable asset in this procedure.

We have emphasized the anatomical and pathological factors associated with complications. Although all the screws that broke were made of titanium we believe that the metal characteristics of the screws are less important than their placement. In all five instances of breakage, the...
screw on the contralateral side was incorrectly placed. Titanium instrumentation should be used so that appropriate postoperative imaging of the neuraxis can be obtained.

Whereas we have detailed the factors associated with a potentially poor outcome, the choice of method for reducible atlantoaxial fixation is still in our hands. This operation is not recommended for the inexperienced surgeon. Detailed anatomical and radiological workup is essential, even for an experienced surgical team.

Conclusions

The transarticular screw fixation technique is comparatively safe, but it is demanding and requires a great deal of technical precision. In our view, it is not recommended in the following situations: incomplete reduction of C1–2 subluxation; pathological destruction or collapse of C-2; aberrant VA anatomy or large VA groove (20% of cases); following transoral odontoidectomy; and cranial assimilation of C-1. Immediate postoperative CT scanning with sagittal reconstruction of the C1–2 lateral masses is strongly recommended to check screw position. External stabilization in a halo brace is mandatory if one screw has been malpositioned. Ultimately it is the surgeon’s choice to weigh the biomechanical superiority of the technique against the possible risk of screw malposition and neural or vascular injury and to choose the technique believed to be appropriate to the patient. Based on a deeper understanding of our technical shortcomings and refined surgical indications we believe this technique will be a valuable tool in the armamentarium of the spine surgeon.

References


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