Management of Atlantoaxial Instability - Surgical Strategy Based on Biomechanical Viewpoints

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Abstract

The atlantoaxial complex is more easily destabilized in certain pathological conditions. Significant atlantoaxial instability is a potentially serious progressive condition that, if untreated, may result in local pain, myelopathy, or ultimately death. Surgical intervention is often indicated to realign and stabilize the segment, and to decompress the neural structures if necessary. Various types of procedure to fix the atlantoaxial complex can be found in the literature; posterior wiring procedures, interlaminar clamps, intra-articular screw fixation, transarticular screw fixation, and screw and rod fixation. Each surgical method has advantages and disadvantages. Not only anatomical but biomechanical conditions of the atlantoaxial complex are extremely variable in individual cases. Therefore, for successful treatment, it is important to select the most applicable surgical procedure to fix the atlantoaxial complex as strong as possible under detailed morphological assessment to secure safety of each patient.

INTRODUCTION

The atlantoaxial complex is more easily destabilized in certain pathological conditions. Common causes of atlantoaxial instability include inflammatory diseases (rheumatoid arthritis, infection), congenital disorders (os odontoideum), genetic disorders (Down syndrome), trauma (dens fracture, ligament injury), and tumor (primary or metastatic). Significant atlantoaxial instability is a potentially serious progressive condition that, if untreated, may result in local pain, myelopathy, or ultimately death. Surgical intervention is often indicated to realign and stabilize the segment, and to decompress the neural structures if necessary. In this article, I would like to concisely state our recent concept about the management of atlantoaxial instability.

Anatomical and biomechanical features of the atlantoaxial complex

The atlantoaxial complex is a unique structure which composed of two specific vertebrae; atlas and axis. It allows extensive motion while allowing vertebrae to be interlocked forming an amazingly stable three-dimensional structure. Stability of the normal segments is mainly provided by the ligamentous complex due to the lack of intervertebral discs. Ligaments connected between the atlas and the axis consists of the transverse ligament, the ala ligament, the anterior, and the posterior longitudinal ligaments. The atlantoaxial complex has relatively wide range of motion in the whole spine, especially in axial rotation by its unique structure. Consequently, once one of these ligaments is severely damaged, crucial atlantoaxial instability easily happen.

Stabilization technique of the atlantoaxial complex

Various types of procedure to fix the atlantoaxial complex can be found in the literature; posterior wiring procedures [1,2,3], interlaminar clamps [4,5], intra-articular screw fixation [6], transarticular screw fixation (TSF) [7], and screw and rod fixation (SRF) [8-11]. When atlantoaxial fixation is attempted, we have to pay great attention to vascular and neural structures. Particularly, injuries of the vertebral artery (VA) and the spinal cord (SC) are severe complications. VA injury has a possibility of cerebellar infarction. SC injury may occur respiratory quadriplegia. Bleeding from venous plexus is troublesome to control. C2 nerve root impairment causes uncomfortable irritation of the occipital lesion. Stabilization of the cervical spine using posterior wiring procedures and interlaminar clamps is obviously easier to accomplish. However, these do not provide sufficient immobilization across the atlantoaxial complex. Especially, posterior wiring procedures place the patient at risk of SC injury due to sublaminar passage of wires into the spinal canal. Intra-articular screw fixation with the Halifax interlaminar clamp is effective in strengthening the rotational stability and
clinically safe for neural structures despite massive bleeding from the periaricular venous plexus. TSF and SRF, on the other hand, afford a stiffer atlantoaxial arthrodesis than posterior wiring procedures and interlaminar clamps. However, approximately 10 to 23% of patients indicating atlantoaxial arthrodesis have anatomic variations in the path of the VA on at least one side and may not be suitable candidates for screw placement [12-15] (Table 1).

Usually, we employ TSF or SRF because of its strong stability. In comparison between TSF and SRF, stiffness is almost same. VA injury is more likely in TSF. In TSF procedure, body habitus, for example, obesity or hyperthoracic kyphosis, may prohibit achieving the low angle needed for correct placement of the screw across C1 and C2. SRF is possible to reduce alignment intraoperatively. C2 nerve root injury is more likely in TSF. Bleeding from venous plexus is more likely in SRF. SRF is more costly than TSF because SRF needs a greater number of implants than TSF (Table 2).

**Biomechanical study compared TSF and SRF**

I previously performed a biomechanical study between TSF and SRF using human cadaveric cervical spines [16]. Ten fresh ligamentous human cervical spine specimens were stabilized using TSF in 5 spines or SRF in the other 5 spines. The specimens were sequentially tested in the intact state, following injury, unilateral, and bilateral stabilization. Three-dimensional spatial locations were recorded in response to the applied loads using an optical motion analysis system (OPTOTRAK). The data was converted to angular displacements and the stabilized cases were compared to intact states for evaluating the efficacies of the two techniques in stabilizing the C1-2 segments. Experimental loads were applied to the spine in the form of pure moments through a system of weights, nylon strings, and pulleys. The specimens were loaded in increments of 0.5 Nm from 0 Nm to 2.0 Nm in five equal steps. Every specimen was tested in six modes of angular motion.

In comparing between TSF and SRF, the unilateral SRF was more rigid than the unilateral TSF in flexion and left axial rotation. There were no statistical distinctions in all motion directions although the motion of TSF was a little lower with respect to that of SRF in extension, right lateral bending, left lateral bending, and right axial rotation (Figure 1).

The bilateral procedure in both of the groups was equally more effective across the C1-C2 segment than the unilateral procedure. However, the SRF group afforded higher stability than the corresponding TSF group in flexion and extension. Nevertheless, if TSF and SRF were independently compared in the destabilization phase, both were equally stiff due to severe instability after destabilization (Figure 2).

In summary of this biomechanical study, the unilateral SRF was much stiffer than the unilateral TSF in flexion, but not significant, and the bilateral procedures in both of group were equally more effective for atlantoaxial stability.

We concluded that in general a surgeon should undertake the bilateral fixation to achieve sufficient stability across the atlantoaxial complex. Either technique will provide satisfactory results, although the SRF technique may be better in flexion and extension modes. One should use the SRF procedure while trying to achieve stability with the unilateral system.

**Clinical experience of unilateral fixation with SRF**

I would like to introduce the clinical results of the unilateral procedure with SRF [17]. Four consecutive cases with atlantoaxial instability that were performed posterior fixation with the unilateral SRF were studied. All cases were female with a mean age of 53 years. There were 3 cases of rheumatoid arthritis and 1 case of os odontoideum. The side of surgery was left in all 4 cases. A piece of corticocancellous bone was additionally fixed between the C1 posterior arch and the C2 lamina covered with some bone chips according to McGraw method with a polyethylene tape. We clinically and radiographically investigated in these cases.

Bone union was achieved in all cases. Radiographically, atlantoaxial interval and C1/2 angle were both attained to normal range and retained at 6 months after surgery. Improvements of clinical findings evaluated by Ranawat’s scale [18] were obtained in all cases. We had no neurovascular and infection related complications.

In summary of this clinical study, bone union and improvement of clinical symptoms were obtained in all cases without any intraoperative complications, and both atlantoaxial interval and C1/2 angle were radiographically restored to normal range and maintained at 6 months after surgery.

We concluded that the unilateral SRF was biomechanically stiff enough to obtain bone union without the alteration of postoperative treatment for the bilateral procedure. The unilateral SRF could be used while trying to achieve stability of atlantoaxial joint due to problems in the path of the VA.

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**Table 1** Characteristics of various atlantoaxial fixations.

<table>
<thead>
<tr>
<th></th>
<th>Simplicity</th>
<th>Stiffness</th>
<th>VA Injury</th>
<th>SC Injury</th>
</tr>
</thead>
<tbody>
<tr>
<td>Posterior wiring</td>
<td>○</td>
<td>x</td>
<td>○</td>
<td>x</td>
</tr>
<tr>
<td>Interlaminar clamp</td>
<td>○</td>
<td>x</td>
<td>△</td>
<td>×</td>
</tr>
<tr>
<td>Intra-articular screw fixation</td>
<td>△</td>
<td>△</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Transarticular screw fixation</td>
<td>△</td>
<td>△</td>
<td>△</td>
<td>○</td>
</tr>
<tr>
<td>Screw and rod fixation</td>
<td>△</td>
<td>△</td>
<td>△</td>
<td>△</td>
</tr>
</tbody>
</table>

○: high / △: medium / ×: low  
SC: spinal cord, VA: vertebral artery

**Table 2** Comparison of features between TSF and SRF.

<table>
<thead>
<tr>
<th></th>
<th>TSF: transarticular screw fixation</th>
<th>SRF: screw and rod fixation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simplicity</td>
<td>enough</td>
<td>enough</td>
</tr>
<tr>
<td>VA Injury</td>
<td>likely</td>
<td>less likely</td>
</tr>
<tr>
<td>Effects of body habitus, obesity, hyperthoracic kyphosis</td>
<td>likely</td>
<td>less likely</td>
</tr>
<tr>
<td>Intraoperative reduction</td>
<td>impossible</td>
<td>possible</td>
</tr>
<tr>
<td>C2 nerve root injury</td>
<td>likely</td>
<td>less likely</td>
</tr>
<tr>
<td>Bleeding from venous plexus</td>
<td>less likely</td>
<td>likely</td>
</tr>
<tr>
<td>Required implants (cost)</td>
<td>2 screws</td>
<td>4 screws + 2 rods (1 crosslink)</td>
</tr>
</tbody>
</table>

TSF: transarticular screw fixation, SRF: screw and rod fixation
However, after this clinical series, we experienced a case of breakage of C1 lateral mass screw in patient with performing the unilateral fixation with SRF at 4 years postoperatively (Figure 3). This case was 60 year old female with atlantoaxial subluxation due to rheumatoid arthritis. Because we became aware of this case of instrumentation failure, in the case of the unilateral fixation with SRF, the C2 laminar screw has been positively provided if the C2 pedicle screw is not available due to anatomical problems. This technique was introduced by Wright in 2004 [19]. In the biomechanical testing reported by Gorek, there were no statistically significant differences between the C2 laminar screw and the C2 pedicle screw [20].

Our surgical strategy for atlantoaxial instability

On the bases of these biomechanical study and clinical experiences, we constructed the surgical strategy for atlantoaxial instability simply summarized in the figure 4. In general, we undertake the bilateral fixation by TSF or SRF to achieve sufficient stability across the atlantoaxial complex (Figures 5 and 6). In patients with high riding VA, TSF is restricted for possible VA injury. So, the bilateral SRF should be employed (Figure 6). Further, if the unilateral C2 pedicle screw is not available, we choose the unilateral SRF or the C1 lateral mass screws and the C2 pedicle combined with the C2 laminar screws. Then, if both of the C2 pedicle screws are not available, the C1 lateral mass and C2 hooks, the interlaminar clamp, or the posterior wiring procedure are obliged to be done. While, if the C1 lateral mass screws are not available, fusion level should be extended.
to occipitum and then, between C0 and C2 is connected with the occipital plate and the C2 pedicle or laminar screws (Figure 8). Further, needless to say, accompanying sufficient bone graft must be indispensable for achievement of solid bony fusion even if any type of stabilization techniques will be attempted.

**SUMMARY**

I briefly introduced our current concept about the surgical strategy of atlantoaxial instability based on biomechanical viewpoints. Not only anatomical but biomechanical conditions of the atlantoaxial complex are extremely variable in individual cases. Therefore, for successful treatment, it is important to select the most applicable surgical procedure to fix the atlantoaxial complex as strong as possible under detailed morphological assessment to secure safety of each patient.

**REFERENCES**
