Interlaminar Fixation Using the Atlantoaxial Posterior Fixation System (3XS System) for Atlantoaxial Instability: Surgical Results and Biomechanical Evaluation

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Abstract

This study evaluated the surgical results for patients with atlantoaxial instability due to various lesions treated using the atlantoaxial posterior fixation system (3XS system; Kisco DIR, Paris, France), together with a biomechanical study of this system. The strength of the 3XS system during torsion was examined using a biomechanical simulation model. The 3XS system consists of a transverse unit, hooks, and rods. The lower part of the biomechanical simulation machine was rigidly fixed and the upper part was movable, allowing torsion to be applied until the point of failure. The test was started at 1.5 newton-meters, thought to be the maximum load on the upper cervical spine. The 3XS system tolerated torsion of up to 20 newton-meters, but became deformed. The instrument was fractured at 30 newton-meters. Fifteen patients, four with atlantoaxial instability, seven with os odontoideum, and four with odontoid fractures, underwent surgery using the 3XS system and an iliac bone fragment inserted between the C-1 and C-2 laminae. Postoperative rigid fixation of the lesion and optimal cervical alignment was obtained in all patients, and the patients were discharged within 2 weeks after surgery. Follow-up radiography showed bony fusion between C-1 and C-2 in all patients. Posterior fixations between C-1 and C-2 using the 3XS system were easy to perform and no surgical complications were encountered. The biomechanical study showed the 3XS system can tolerate torsions unlikely to occur during rotation movements in the atlantoaxial region in humans. The surgical use of the 3XS system for the treatment of atlantoaxial instability has several advantages.

Key words: atlantoaxial instability, biomechanics, cervical spine, instrumentation

Introduction

Atlantoaxial instability can result from various disorders, including fractures, rheumatoid arthritis, metastasis, and ligamentous injuries.14 Atlantoaxial instability can cause not only minor problems, like local pain or C-2 neuropathy, but also serious myelopathy or even sudden death. Several options are available for the treatment of atlantoaxial instability.2,4,6–8,13,15,16,18,19,21,22,24 Favorable results are obtained with most surgical procedures. The outcome of surgery depends on the surgeon's experience and the type of surgical procedure that is used.14 The purpose of surgical intervention is to decompress the neurological structures and to realign the cervical spine and stabilize the unstable segment.14 Furthermore, surgical procedures that are easy to perform have significant benefits over more difficult procedures.

Various advances have been made since a posterior wiring technique for atlantoaxial dislocations was first introduced in 1939.11 Posterior interlaminar fixation clamps were developed for atlantoaxial dislocation as the next step.1,3,18–20 However, dislodgment of the posterior interlaminar clamp and surgical failure were encountered.14 A transarticular screw fixation technique, in combination with C1–2 posterior wiring, was introduced in 1979,17 and has been widely adopted for the correction of atlantoaxial dislocations.2,4,6–9,13,15,16,18,19,21,22,24 The pseudoarthrosis rate is negligible for this technique,7,13 but a high degree of technical experience is required to perform the procedure. Furthermore, surgical planning using a neuronavigator system is necessary for safe and secure transarticular screw insertion. Several surgical complications have been reported, such as penetration of the vertebral
arteries by the screws,\textsuperscript{4,5,10,12} sometimes with fatal consequences.\textsuperscript{23}

Spinal instrumentation implants for atlantoaxial instability should be selected based on experimental biomechanical evidence.\textsuperscript{6,10,13,14,18} The long-term follow-up results must always be considered since good fixation after surgery may not continue. In this sense, the mechanical strength of the instruments used for the treatment of atlantoaxial instability should be experimentally confirmed.\textsuperscript{6,10,13,14,18}

Recently we have performed cervical posterior fusion for atlantoaxial instability due to various lesions using the atlantoaxial posterior fixation system (3XS system; Kisco DIR, Paris, France). We examined how much rotational force this instrumentation can tolerate without undergoing deformation or destruction by a biomechanical technique. Here, we describe 15 surgical cases and postoperative results together with biomechanical data for this instrumentation.

**Materials and Methods**

I. Patients

Fifteen patients with atlantoaxial instability due to various lesions underwent surgery with posterior interlaminar fixation using the 3XS system. Atlantoaxial instability was caused by ligamentous loosening without bony change (probably due to the aging process) in four patients, os odontoideum in seven patients, and odontoid fractures in four patients. All patients were males, aged from 32 to 73 years old (mean ± SD 51.5 ± 13.7 years) (Table 1).

<table>
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<td>M</td>
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<tr>
<td>2</td>
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<td>M</td>
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<tr>
<td>3</td>
<td>73</td>
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</tr>
<tr>
<td>5</td>
<td>48</td>
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II. Instrumentation

The 3XS instrumentation system consists of a transverse unit, hooks, and rods. The transverse unit is connected to two rods via a curved-linear bridge. Two types of transverse units are available with a hook angle of 39 degrees and a bridge length of 25 mm, or a hook angle of 30 degrees and a bridge length of 20 mm (Fig. 1 left column). The curve of the

![Fig. 1 Photographs showing the installation of the 3XS system. left column: The transverse unit is applied to the lamina of C-1. Two types of transverse units are available with a hook angle (A) of 39 degrees and a bridge length (B) of 25 mm (upper), or A of 30 degrees and B of 20 mm (lower). right: Two separate hooks (arrows) are fixed beneath the lamina of C-2. These hooks are then connected by two rods (arrowheads). A piece of iliac bone is placed between the laminae of C-1 and C-2.](image-url)
Fig. 2 Schematic drawings of the biomechanical test apparatus (left, center) and photograph of the instrument used to test the 3XS apparatus (right).

The transverse hook can be manually adjusted according to the patient's anatomy. These transverse hooks are hooked on the lamina of the atlas (C-1). The three types of hooks are small, large, or narrow, with the length/width of 8 mm/4 mm for the small hook, 10 mm/6 mm for the large hook, and 10 mm/4 mm for the narrow hook. Seven types of joint rods are available, with lengths of 20, 25, 30, 35, 40, 45, and 50 mm (Fig. 1 right).

III. Surgical procedure

The patient is placed in a prone position, and the head is fixed in place to reduce the atlantoaxial dislocation and maintain neutral lordosis of the cervical spine, as viewed using fluoroscopy. The laminae from C-1 to C-3 are exposed through a 4-cm midline skin incision. After dissection below the C-1 lamina, the optimal transverse hook is placed beneath the C-1 lamina. The joint rods of the optimal length are inserted into the holes of the transverse hook. The upper portion of the C-3 lamina is drilled to obtain sufficient space to insert the lower hooks beneath the C-2 lamina. The bilateral lower hooks at C-2 are connected to the transverse hook via the joint rods. A bone fragment taken from the iliac bone (single bone fragment) is inserted between the bilateral laminae of C-1 and C-2 to obtain permanent bony fusion. The cortex of the upper and lower surfaces of the iliac bone fragment is partly drilled to expose the bone marrow to facilitate tight bony fusion. The bilateral hooks are then compressed simultaneously and fixed with screws. After these procedures, lateral cervical radiography is used to ascertain that sufficient reduction of the atlantoaxial dislocation has been obtained.

IV. Biomechanical test

To confirm that the 3XS instrumentation system could tolerate the rotational force produced by neck movements in situ and to determine the ultimate strength of C1–2 instrumentation during axial rotation, we designed a biomechanical test for the 3XS implant. A fixture was designed with the same geometry as the instrumentation. The machine was composed of two parts, the lower of which was rigidly fixed and the upper part was movable, allowing a torsion force to be applied until the point of failure. The mechanical strength test was performed using this model (Fig. 2).

Using a transverse unit with C-1 and double C-2 hooks, the C-1 and C-2 hooks were connected by full-threaded rods (45 mm) on each side (Fig. 2). During axial rotation of the cervical spine, 1.5 newton-meters preloaded with 50 newtons is the most common maximum load. Therefore, the present test was started at 1.5 newton-meters of torque by slowly rotating the upper part and continuing until the 3XS was fractured (Fig. 3). The torque (newton-meters) at which distortion and fracture of the instrument occurred was measured (n = 3).

Results

I. Surgical results

The postoperative courses of all 15 patients were uneventful. On the day after the operation, all patients were ambulatory with a neck collar after confirming that the atlantoaxial dislocation had been sufficiently reduced and that good cervical alignment was being maintained. All patients were discharged from hospital within 2 weeks of surgery, and followed up in the outpatient clinic.

The postoperative follow-up period was between 1.5–3 years, and the mean follow-up period was
2.3 ± 0.7 years. No neurological deficits were detected in any patient, and all patients were able to return to their previous activities. Cervical radiography showed no obvious abnormalities or dislodgment of the implanted instrument. During the follow-up period, recurrence of atlantoaxial instability was not observed by dynamic cervical radiography, and tight bony fusion between C-1 and C-2 caused by the inserted iliac bone fragment was ascertained by cervical tomography and/or computed tomography in all patients.

II. Representative case

Case 1: A 72-year-old man complained of gait disturbance and difficulties in fine finger movements. The patient had no history of head and neck injuries. Neurological examination disclosed spastic gait and clumsy finger movements. Cervical radiography in the neutral position showed separation between the posterior surface of the anterior arch of C-1 and the anterior surface of an odontoid process (Fig. 4 center), which remarkably increased in the flexion posture of the neck (Fig. 4 left). T2-weighted magnetic resonance imaging showed a high intensity signal between the C-1 and C-2 levels. The diagnosis was atlantoaxial instability.

The patient underwent surgery using the 3XS system for posterior fixation between C-1 and C-2 (Fig. 5). The postoperative course was uneventful, and the patient was discharged 2 weeks after surgery. Gait disturbance and clumsy finger movements were remarkably improved postoperatively. Cervical radiography showed a rigid fixation between C-1 and C-2 (Fig. 6 left). Computed tomography showed that the transverse hooks were securely placed on the laminae of C-1 and C-2 (Fig. 6 right column).

III. Results of biomechanical test

The instrument became deformed at 20 newton-meters (Fig. 3 right), and was fractured at 30 newton-meters. Deformation and fracture of the instrument occurred between one side of the upper
Fig. 6 Case 1. left: Postoperative cervical radiograph showing rigid posterior fixation for atlantoaxial instability and good cervical alignment. right column: Postoperative computed tomography scans showing secure hooking on C-1 (upper) and C-2 laminae (lower).

Discussion

From the historical viewpoint, posterior interlaminar wiring technique was first reported for the treatment of atlantoaxial dislocation.11) Thereafter, interlaminar clamps were developed,1,18,20) but because of the high rate of dislodgment of these clamps and surgical failure,14) new techniques such as the transarticular screw fixation were introduced.17) Screw fixation is considered to be the most rigid fixation technique and is widely used for the management of atlantoaxial dislocation.2,4,6–9,13,15,16,18,19,21,22,24) However, a high degree of surgical experience and a neuronavigator system are necessary to avoid the serious complications associated with this technique. However, a neuronavigator system is not always available in any hospital. Therefore, we recently began using a newly developed posterior interlaminar fixation system, the 3XS system, for the treatment of atlantoaxial instability. A neuronavigator system and a high degree of surgical experience are not required when using the 3XS system. No postoperative problems and no recurrence of atlantoaxial instability occurred during the follow-up period in our series. Rigid bony fusion between C-1 and C-2 was ascertained in all patients.

To confirm the mechanical strength and resistance to cervical rotational forces, we examined the 3XS instrumentation using a biomechanical test. Various biomechanical tests have been performed to compare the stiffness of C1–2 posterior fixation systems.6,13,14,18) The maximum torque applied was 1.5 newton-meters (50 newtons preloaded), which was judged to be sufficient to recreate physiological motions.2,3,14,17) Our test also started at 1.5 newton-meters, and a progressively stronger torque was applied until 20 newton-meters, at which point permanent deformation occurred. Following this test, the torque was further increased until the system was completely fractured. The failure of the 3XS/C1–2 assembly occurred at a high torsion torque (> 30 newton-meters), and such values are not believed to occur in vivo. Based on our biomechanical test, the 3XS apparatus appears well capable of tolerating the rotational forces between C-1 and C-2, and can be safely applied to lesions at these cervical levels.

From the biomechanical viewpoint, the transarticular screw fixation method is most resistant to all directions of movement at C1–2, and the Gallie type fixation is the least stable,13,14) using a loading force of 0–1.5 newton-meters. Our results are not simply comparable, as our test started to load from 1.5 newton-meters and increased up to 30 newton-meters. At 1.5 newton-meters, nothing happened in the 3XS system, indicating that the 3XS system is not less stable compared with the transarticular screw method.

Surgical intervention for the treatment of atlantoaxial instability requires a stable prosthetic device. Biomechanical data confirming that the device can tolerate in situ rotational torques is necessary. Furthermore, the surgical procedure should be as safe as possible and easy-to-perform. We believe that surgical intervention using the 3XS system for the treatment of atlantoaxial instability offers several significant benefits.

Acknowledgments

We would like to express our sincere appreciation to Mr. Gilles Vericel, Mr. Laurent Gautrot, Mr. Cedric Barrier, and Ms. Nadia E.L. Hakour in Kisco DIR for their technical assistance.

References


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Commentary on this paper appears on the next page.
**Commentary**

The difficulties involved in any surgical procedure to achieve atlantoaxial fusion are considerable. Long-term results from posterior atlantoaxial fusion are often not satisfactory and transpedicular screw fixation is associated with a noticeable risk and requires additional posterior fixation. The often used soft wire fixation of bone grafts loosens when resorption of the bone graft occurs. The investigation of a new posterior fixation system is therefore of interest to any neurosurgeon dealing with this challenge. The report presented by Nishizawa and coworkers is an important contribution. The new posterior fixation system not only proved to withstand the expected biomechanical forces by an extreme safety margin but also showed good clinical results. As the authors address all the pertinent literature and alternatives to their fixation system it appears obvious that this device merits attention and because of its practicability should be tried in clinical routine.

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The authors present an inter-laminar fixation method for atlantoaxial dislocation using an alternative 3XS fixation system. They discuss their successful experience with 15 surgically treated cases and their biomechanical studies suggest that the fixation system is strong enough to sustain the stresses of a variety of movements that occur in the highly mobile segment of the spine.

The system appears to be stronger and more stable than the previously described clamps. The possible problem that one can anticipate with such a device is that the clamps may not adequately grip the arch of the atlas or the C-2 lamina. There remains the possibility of loosening of the grip during the early postoperative phase and strong external stabilization appears to be necessary to restrict any neck movements. It would be better if some device is made that grips the arch of atlas and lamina of axis in a circumferential manner simulating sublaminar wiring.

Any implant will be successful if it can firmly grip the region and permits absolutely no movements for at least a period of 8–10 weeks. Absence of movement provides an opportunity for bone fusion and ultimate stabilization. The midline procedures like sublaminar wiring and clamps provide firm and segmental stabilization but may not be able to provide a ‘zero’ movement situation as there is a limit to tightening of the wires or the clamps. The other disadvantage is that one is working at a distance away from the fulcrum of the movements, which is at the atlantoaxial joint. It appears that these may be the reason that lateral methods of fixation incorporating screw implantation in the atlantoaxial joint are more successful, have a higher reported fusion rate and are currently popular. We have described a lateral mass plate and screw fixation technique for atlantoaxial dislocation in 1994. Our method incorporates resection of the C-2 ganglion, wide drilling of the articular cartilage of the atlantoaxial joint, introduction of bone graft within the joint capsule and subsequently interarticular fixation of the region with lateral mass plate and screws.

As the authors mention, midline interlaminar fixation has a distinct advantage of being technically easy when compared to lateral transarticular and interarticular fixation methods. There is also a possibility of vertebral arterial injury in the lateral fixation methods for those not very familiar with the anatomy of the region. The authors have demonstrated excellent results with their method providing proof of a firm fixation. If they can continue to demonstrate such a success in a larger number of patients and with a longer duration of follow-up, the device that they have discussed can certainly become more popular.

**References**


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