Biomechanical Study of 3 Atlantoaxial Proactive Vertebral Artery Injury Prevention Fixation Combinations

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■ OBJECTIVE: **To evaluate the biomechanical stability of 3 atlantoaxial proactive vertebral artery injury prevention fixation combinations.**

■ METHODS: **We used 6 fresh human cadaveric C0-C4 specimens for the biomechanical test with moment control in 6 loading directions. First, range of motion (ROM) was measured in the intact specimens before they were destabilized; next, ROM of the 4 conditions fixed with 4 different fixation combinations were tested in alternating sequence: bilateral transarticular screw (TAS) and 3 test combinations: C1 laminar hook (C1LH) and C2 intralaminar screw (C2ILS) on 1 side combined with TAS (C1LH-C2ILS/TAS) or C1LH and TAS (C1LH-C2ILS/C1LH-TAS) or C1LH and C2ILS on the other side (C1LH-C2ILS/C1LH-C2ILS).**

■ RESULTS: **ROM of all 4 instrumented sets significantly decreased compared with intact specimens in all the loading cases (flexion, left and right lateral bending, left and right axial rotation) except extension. Compared with the TAS group, all 3 test groups showed higher stiffness in flexion and equivalent stability in the other 5 directions. Side-by-side comparison among the 3 test fixation techniques showed no significant difference.**

■ CONCLUSIONS: **The combination of C1LH and C2ILS supplemented with contralateral TAS or C1LH and TAS or C1LH and C2ILS was superior to bilateral TAS fixation with regard to biomechanics and vertebral artery safety.**

INTRODUCTION

Multiple posterior fixation techniques to stabilize the atlantoaxial complex have been described, among which transarticular screw (TAS) fixation has been accepted widely because of its superior biomechanics and graft fusion rate compared with early wiring techniques and interlaminar clamp techniques. However, TAS fixation is associated with the risk of vertebral artery (VA) injury, the consequences of which can range from lack of symptoms to brainstem stroke to death. The C1 lateral mass screw (C1LMS) and C2 pedicle screw (C2PS) (C1LMS-C2PS) technique, with equivalent biomechanics and a slightly higher rate of fusion relative to the TAS technique, has reduced the risk of VA injury.[1-3] More recently, the C2 intralaminar screw (C2ILS) has been considered as the best alternative anchorage of the axis because it recedes from the path of the VA,[4-6] and its fixation to a C1 lateral mass screw (C1LMS-C2ILS) can provide the same stability as the C1LMS-C2PS technique.[7,8] Nonetheless, VA injury resulting from C1LMS misplacement cannot be avoided completely even with the help of a computer-assisted navigation system.[9]

The C1 laminar hook (C1LH) seems to be a good alternative. Sugimoto et al.[10] found an advantage of proactive VA injury prevention with a fixation system of C1LH-C2ILS on the dominant VA side combined with contralateral C1LH-TAS for a patient with unilateral VA occlusion. Bone fusion was done 8 months after the operation, with no correction loss. Similarly, in our clinic practice, for patients with VA hypoplasia, we provided C1LH-C2ILS ipsilateral to the dominant VA side and TAS only on the other side for purpose of proactive VA injury prevention. Likewise, a satisfying solid bone fusion rate was achieved. It seems that bilateral C1LH-C2ILS could be an optimal fixation for the safety of

Key words
- Atlantoaxial fixation
- Biomechanics
- Vertebral artery injury prevention

Abbreviations and Acronyms
C1LH: C1 laminar hook
C1LMS: C1 lateral mass screw
C2ILS: C2 intralaminar screw
C2PS: C2 pedicle screw
CT: Computed tomography
ROM: Range of motion
TAS: Transarticular screw
VA: Vertebral artery

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bilateral VA. However, to date, there is no biomechanical study to our knowledge of the 3 combinations. Therefore, our current investigation focused on analyzing the changes in the range of motion (ROM) of C1-2 using the 3 fixation combinations (C1LH-C2ILS/TAS, C1LH-C2ILS/C1LH-TAS, C1LH-C2ILS/C1LH-C2ILS) in 6 directions and comparing the changes with those using TAS technique alone, to provide a basis for optimizing clinical practice.

MATERIALS AND METHODS

The study was approved by the ethics committee of our department.

Specimen Preparation

In this study, 6 human cadaveric C0-C4 specimens were used, which were obtained from fresh cadavers of 4 men and 2 women (mean age 39.7 years) who died from acute disease or accident (Table 1). All specimens were examined with plain radiographs and computed tomography (CT) to rule out any significant spinal osseous abnormalities and significant osteoporosis. After being harvested, they were immediately sealed with double plastic bags and stored at −20°C as Panjabi et al.[11] described previously. After thawing at room temperature for 10–12 hours, all extraneous musculature of each specimen was cleaned, with caution taken to maintain the disc and ligaments intact. First, 3 screws were drilled to fix C3 and C4 through the vertebral bodies. Next, the occiput and C3-4 were positioned in a custom cylinder cast and potted with polymethyl methacrylate with the C3-4 disc plane kept in horizontal. For better anchorage of C0 and C3-4, crossing Kirschner wires were driven into the embedded bone structure from the hole in the custom cast. Specialized markers, which consist of 4 noncolinear infrared light-emitting diodes, were implanted to C0, C1, C2, and C3 vertebra.

Biomechanical Testing

The embedded specimens were mounted on the servohydraulic materials testing system (MTS 858 Bionix II; MTS Systems, Eden Prairie, Minnesota, USA) (Figure 1). During the testing, this validated pure moment testing system[12,13] applied quasistatic loads to the skull leading to a maximum pure moments of 2.0 N-m, and the moment loading rate was 0.1 N-m/second. Moments were applied to generate the following 6 loading modes: extension, flexion, left lateral bending, right lateral bending, left axial rotation, and right axial rotation. All tests were repeated for 3 loading and unloading cycles. The first 2 cycles were used to minimize the viscoelastic effect, and the data for the third cycle were recorded for statistical evaluation. Throughout the whole experiment, all specimens were kept moist by spraying them with saline solution.

Table 1. Specimen Demographics

Specimen	Age (years)	Sex	Cause of Death
1	23	Male	Acute blood loss
2	34	Male	Acute blood loss
3	48	Male	Myocardial infarction
4	46	Male	Myocardial infarction
5	43	Female	Acute blood loss
6	44	Female	Cardiac arrest
Mean ± SD	39.7 ± 9.5		

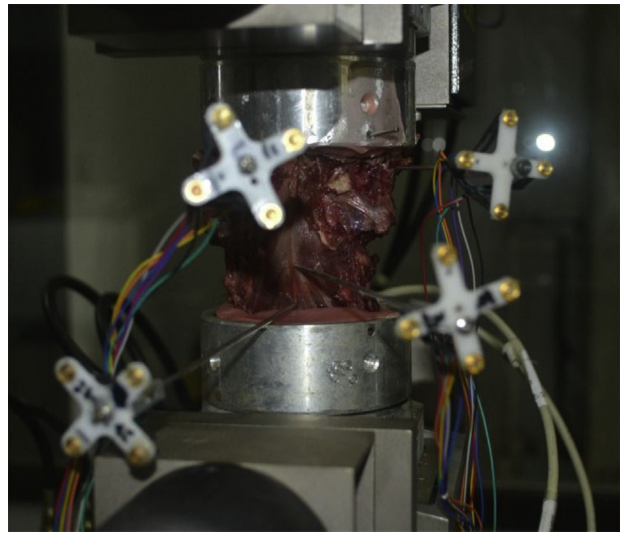

Figure 1. Anterior view of specimens mounted on the servohydraulic materials testing system (MTS 858 Bionix II).

Testing Sequence

The specimens were first tested intact before they were destabilized (using type II odontoid fracture model) and stabilized with 4 different fixation combinations in alternating sequence to reduce the bias caused by the testing order. The 4 different fixation combinations were bilateral TAS as a control and 3 test fixation combinations. The 3 test combinations included C1LH-C2ILS on the assumed dominant VA side (left) combined with 1) TAS (Figure 2), 2) C1LH-TAS, or 3) C1LH-C2ILS on the other side (right). The 5 conditions were termed 1) the intact group, 2) the TAS group (TAS/TAS), 3) the TAS' group (C1LH-C2ILS/TAS), 4) the C1LH-TAS group (C1LH-C2ILS/C1LH-TAS), and 5) the C1LH-C2ILS group (C1LH-C2ILS/C1LH-C2ILS). Testing conditions for each specimen consequently followed a specific sequence: specimen 1 (1, 2, 3, 4, 5); specimen 2 (1, 3, 4, 5, 2); specimen 3 (1, 4, 5, 2, 3); specimen 4 (1, 5, 2, 3, 4); specimen 5 (1, 2, 3, 4, 5); specimen 6 (1, 3, 4, 5, 2).

Polyaxial titanium 3.5-mm TAS and C2ILS were used. The entry point for TAS was in the medial half of the inferior facet of C2 (2 mm up and 2 mm in). Under lateral fluoroscopic guidance, TAS is inserted in a sagittal direction entering C2, crossing the isthmus, and exiting C2 at the posterior rim of the upper articular surface, through the C1-2 facet joint to the level of the back of the anterior tubercle of C1, within the lateral mass of C1. The entry point for C2ILS was on either side of the junction of the spinous process and the lamina. One screw had a superior entry point, whereas the other screw had an inferior entry point on the opposite side of the same spinous process. Once the cortical windows were made by