C1–2 transarticular screws combined with C1 laminar hooks fixation: a modified posterior atlantoaxial fixation technique and outcome in 72 patients

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Abstract

Purpose To retrospectively evaluate the outcome of C1–2 transarticular screws combined with C1 laminar hooks fixation.

Methods All patients underwent atlantoaxial fixation during a 5-year period. The surgical technique and treatment procedures were intensively reviewed and clinical symptoms, neurological function and imaging appearance were retrospectively evaluated.

Results The clinical and radiology follow-up indicated a stable arthrodesis and clinical relief from symptoms for all patients. All patients with neurological defects improved an average of 1.33 grade at their most recent clinical assessment, $P < 0.05$; their average admission ASIA motor score, pin prick score and light touch score improved to an average follow-up ASIA score of 99.80 (99.83 ± 0.38), 111.83 (111.83 ± 0.45), and 111.89 (111.89 ± 0.32), respectively. No neurovascular impairment and case of implant failure were observed.

Conclusions The C1–2 transarticular screws combined with C1 laminar hooks fixation is a reliable technique for atlantoaxial instability.

Keywords Cervical spine · Atlantoaxial articulation · Instability · Spinal fusion

Introduction

The atlantoaxial instability caused by fractures, rheumatoid arthritis, congenital deformity or traumatic lesions of the transverse ligament [1] often results in acute or chronic spinal cord compression, a possible threat to patient's life. Although conservative management could be appropriate for some patients, surgical intervention is usually necessary for other patients who suffer from serious atlantoaxial dislocations. The goal of most surgical interventions is to reconstruct the stability of atlantoaxial articulation.

From a biomechanical point of view, fusion techniques of the atlantoaxial articulation can be divided into three different types. One-point fixation stabilizes the motion segment merely from posterior structure (e.g., Gallie wiring, Halifax, clamps etc.). Two-point fixation stabilizes the articulation with C1–2 transarticular screws laterally placed into C1–2 lateral mass. Three-point fixation consists of the combination of the two previous types, thus stabilizing the C1–C2 motion segment both laterally and posteriorly. In biomechanical studies it has been shown that the three-point fixation is superior to both two- and one-point fixation [2, 3]. In 1986, Magerl and Seeman first developed the transarticular screw fixation technique. For a long time, this technique had remained the first choice for advanced practitioners because of its excellent biomechanical and clinical results. However, from the biomechanical point of view the technique merely is a two-point fixation and can not provide the restriction to 3-D motion of the atlantoaxial articulation.

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Based on the C1–2 transarticular screw method, the authors introduced the C1 laminar hook and C1–2 transarticular screws fixation (TA + Hook) that are connected with a rod, and bone grafts between C1–2 spinous process producing a modified three-point fixation system (Fig. 1). From March, 2006 to May, 2009 this fixation technique was applied to 72 patients who suffered from reduced atlantoaxial dislocations. The purpose of this study is to review the entire series of patients with regard to outcomes, complications, and to comment on TA + Hook fixation.

Fig. 1 Photograph of C1–C2 transarticular hooks and C1 laminar hooks

Methods

Patients and preoperative managements

Seventy-two patients, including 45 male and 27 female, suffered from reduced atlantoaxial dislocations. Their ages ranged from 6 to 76 years (average age 43.7 years). Etiological reasons included traumatic lesions of the transverse ligament ($n = 20$), Os odontoideum ($n = 20$), C1–2 rheumatoid arthritis ($n = 18$), and odontoid fractures ($n = 14$) (Fig. 2a, b). All patients had complained of neck pain on admission, and nine patients presented with neurologic deficits, seven patients had quadriplegia, and another two patients had both quadriplegia and paresthesia. There were six cases accompanied by other parts of injuries including four limb fractures and two chest traumas.

On admission, each patient underwent a complete cervical radiographic examination including anteroposterior and lateral cervical radiographs as well as a thin computed tomography (CT) scan and three-dimensional (3-D) reconstruction image. The patients' atlanto-dental intervals (ADI) ranged from 4 to 10 mm (average ADI 5.4 mm) in the lateral flexion–extension cervical radiographs (Fig. 2a); 59 patients whose ADI were more than 5 mm were diagnosed with atlantoaxial instability. Preoperatively the patients who had injuries of other parts achieved satisfactory clinical improvement after the regular specific treatments; and they had no complications to influence the practice of spinal surgery. Cranial tong traction was given after admission; after 1 week the lateral flexion–extension cervical radiograph was given to evaluate the status of reduction of the atlantoaxial articulation.

Apart from general preoperative preparations including blood chemistry, electrolytes, chest X-ray, abdominal B

Fig. 2 Representative preoperative radiographic images of patient 17. **a** A preoperative lateral flexion–extension view radiograph showing the atlantodental interval with 7.0 mm indicated instability of atlantoaxial articulation. **b** A coronal CT scan image through den

of C2 showing an asymmetry of the odontoid and its relationship to the lateral mass of the C1 demonstrating a rotatory dislocation of atlantoaxial articulation and Os odontoideum

Fig. 3 **a** A diagram of CT imaging showing preoperative measure of the dimensions of C2. **b** A sagittal view of CT reconstructive imaging for measuring the internal height of C2 isthmus. **c** A sagittal view of

CT for measuring the isthmic height of C2. **d** A cross-sectional view of CT for measuring the width of the C2 isthmus

ultrasonic examination etc., thorough preoperative imaging and analysis of the atlantoaxial articulation are required to evaluate whether there is a high-riding VA under the lateral mass of C2. In a sagittal and cross section 2D reconstruction image (Fig. 3a), an internal height of C2 lateral mass (Fig. 3b), an isthmic height (Fig. 3c) and width of C2 (Fig. 3d) can be measured by operative doctors. Some authors [4–7] defined the high-riding VA on the basis of sagittal two-dimensional CT reconstruction image: an internal height less than 2 mm, an isthmus height and width less than 5 mm, or both. However, the isthmus height and width is more important because the screw goes through the isthmus itself regardless of the internal height. For the patients whose C2 isthmic height and width is less than 5 mm in preoperative imaging, it is very dangerous to place the C1–2 transarticular screw of diameter 4.0 mm.

Surgical procedure and postoperative care

All patients underwent atlantoaxial fusion using bilateral C1–2 transarticular screws and C1 laminar hooks fixation.

In this procedure, the patient is placed in the prone position while maintaining C1–C2 reduction as much as possible; the reduction is confirmed with C-arm fluoroscopy or radiography. Posterior midline cut was made from the C1 to the C2 spinal process. The Vertex laminar elevator was used to strip away the soft tissue above and below the posterior arch of C1. The adept situation between Vertex laminar elevator and the posterior arch of C1 was inspected. Because the vertex laminar hook was mainly designed for the physiological structure of the cervical vertebra lamina below C2, occasionally the high-speed drill was used to fix the posterior arch of C1 to fit the contour of the Vertex laminar hook. The Vertex laminar hook was placed to hang on the posterior arch of the atlas. The opening height of the commonly used C1 laminar hook is 5.5 mm. The placement of the transarticular screw was monitored using C-arm fluoroscopy or radiography. A hole was bored at approximately 2 mm superior-outside the inner edge of the C2 inferior articular process. The 3.5 mm drill bit was used to drill cautiously into the C2 isthmus. The appropriate drill direction was determined according to the

C-arm fluoroscopy or radiography imaging. The drill bit followed along the sagittal surface, near the inner surface of the isthmus of the C2 and passed through the posterior part of the atlantoaxial articulations and went into the lateral mass of C1. The screw must enter along the pre-designed angle, to avoid penetrating the cortical portion and damaging the vertebral artery and the spinal cord. A small ball probe was used to palpate the length and wall of the hole to guarantee that no cortical breakthroughs into the spinal canal had occurred. The depth of the screw hole should be measured carefully in order to choose appropriate screw length. A 4.0 mm polyaxial cortical screw was cautiously inserted along the same trajectory. The same procedure was used to implant the opposite side screw. Next, the rod was cut into the appropriate size and pre-curved, then fitted into the top open of the C1 laminar hook and the top open of the polyaxial transarticular screw. At last, nuts were twisted in order to achieve temporary fixation.

A bone block, approximately $2 \times 1 \times 1$ cm (Fig. 4), was harvested from the right posterior iliac crest in the usual manner. The bone transplantation bed was prepared. The high-speed drill was used to remove the cortical bone at the lower part of the C1 posterior arch, as well as at the upper edge of the C2 laminar, and a superior notch was made in the spinous process of C2. The bone block was inserted between the C1 posterior arch and the C2 spinous process and wedged between the C1 and C2 connection rods. Pressuring pliers were used to compress the inner fixation systems at both sides at the same time in order to lock the bone block between the C1 posterior arch and the C2 spinous process. This technique maintains the stability of the bone graft and improves the fusion rate, because compression of a bone graft is considered to be a factor

Fig. 4 A representative intraoperative photograph demonstrating the technique of bone graft and adequate space for the bone block between bilateral implants

necessary for fusion to occur. Finally, the nuts were completely tightened. With this implant, the posterior arch, the autogenous bone block, and the same side C2 laminar were fixed together (Fig. 3).

Surgery time ranged from 60 to 90 min. Blood loss was 260–820 ml, average 350 ml. Attention was paid to inspect the postoperative complications. Limbs functional exercise started in bed from the second day after surgery. Drainage tube was extracted and cervical radiography was performed 2–3 days after surgery. Patients started to exercise their foot without any external support from the fifth day and were discharged from hospital 7–10 days after surgery. Philadelphia collar was used for support for 2 weeks after surgery.

Clinical outcomes assessment

The follow-up period was 18–24 months (average 20.32 months). A complete cervical spine imaging check was performed including lateral flexion–extension views with the patient and reconstructed CT images. Also the most recent Frankel grade and ASIA scores were recorded. All imaging and clinical evaluations were conducted by three independent spinal doctors (non-surgeons). The fracture healing was considered complete when the line of the fracture disappeared; the stability of C1–2 articulation existed when ADI is less than 3 or 5 mm (for children); and, in sagittal reconstructive image of the cervical, the bone graft was considered to be fully healed when a complete bone connection was formed between bone graft and the surface of graft bed. Simultaneously, the clinical outcomes were considered good when at least a 1-grade Frankel score improvement was achieved, and any possible complications related to surgery were investigated.

The SPSS 10.0 software was used to analyze the experimental data as mean $\pm$ standard deviation (mean $\pm$ SD). A one-way analysis of variance (ANOVA) was used to compare multiple data sets, and paired *t* test was used to perform pairwise comparison. Differences were considered significant if the *P* value was smaller than 0.05.

Results

During the preoperative evaluation, the author observed that five patients had an internal height more than 2 mm, but an isthmus height less than 5 mm bilaterally or unilaterally. Based on the previous evaluating rules, for these five patients (6.9 %), the C2 pedicle screw was substituted for the C1–2 transarticular screw to finish the fixation in order to prevent VA impairment.

Neck pain completely disappeared at 3 months postoperatively. The admission and follow-up Frankel grades and

Table 1 Neurological outcomes

Patient no.	ASIA grade of admission	ASIA grade of 3 months postoperatively
22	B	A
14	C	B
15	B	A
16	C	A
32	C	A
45	B	A
70	C	A
34	B	A
65	B	A

AISA scores were reviewed; all patients with neurological deficits improved an average of 1.33 grade at their most recent clinical assessment, $P < 0.05$ (Table 1); their average admission ASIA motor score, pin prick score and light touch score were, respectively, 98.27 (98.27 ± 1.60), 111.04 (111.04 ± 1.08), and 110.77 (110.77 ± 1.44), which, respectively, improved to an average follow-up ASIA score of 99.80 (99.83 ± 0.38), 111.83 (111.83 ± 0.45), and 111.89 (111.89 ± 0.32), $P < 0.01$. There were no wound infections, instance of dural laceration cases, verified or suspected VA impairments and implant failures.

At 3, 6, and 12 months after surgery, all patients who underwent the lateral flexion–extension were evaluated using radiography and 3-D reconstruction CT images to check the position of screws, fusion rate of bone grafts and atlantoaxial stability. Of 134 C1–2 transarticular screws related to 67 patients, 6 (4.4 %) screws cut out dorsally in the isthmus of C2, which were related to 5 (7.5 %) patients. For the rest 128 (95.6 %) screws, satisfactory positions were achieved (Fig. 5c). At 6 months after surgery, these patients with fracture were completely healed; although 69 patients (95.8 %) achieved complete fusion of the bone graft (Fig. 5a, c), the bone grafts of three patients (4.2 %) were not fully fused, these patients previously suffered from osteoporosis, after being reinforced in the treatment of osteoporosis and continually fixed with collar for 6 months, they achieved a full healing of bone graft. Also, there was no unstable appearance in the atlantoaxial joint on the lateral flexion–extension radiograph (Fig. 5a) at each follow-up point.

Discussion

Treatment of atlantoaxial instability can be challenging. There are a number of fusion techniques including posterior wiring, Apofix clamp, C1–2 transarticular screws,

Harms constructs, and C1–2 transarticular screw combined with Gallie technique, etc. Each type of technique has a unique set of risks and benefits. The choice of technique is related to the anatomy of the patient and their disease process and to the familiarity of the surgeon with any particular technique.

Gallie and Brooks technique, as two traditional posterior wiring techniques, are still used currently. However, they are considered less biomechanically stable compared to C1–2 transarticular screw and Harms technique [3, 8–12], which had been demonstrated in the author's previous biomechanical study [13]. Also, they carry a neurologic risk because sublaminar wires are passed under the C1 arch. Harms technique composed of C1 lateral mass screws coupled to C2 pedicle screws has been reported to be a relatively effective method to provide a solid fusion construct in patients with atlantoaxial instability [14]. From a theoretical biomechanical viewpoint, it still is a one-point fixation, but as the screws are rigidly fixed to the longitudinal members of the construct, its biomechanical properties are probably superior to Gallie fixation and alone C1–2 transarticular fixation [11, 14, 15], as proved in the current biomechanical study. C1–2 transarticular screws have been reported to have contributed to a solid stability in patients with atlantoaxial instability [11, 14–19]; Also, the results from the author's previous biomechanical study have proved that alone C1–2 transarticular screw can provide much better biomechanical stability compared to Gallie fixation, but its biomechanical stability is inferior to TA + Gallie or TA + hook fixation because it merely is a two-point fixation and cannot provide the restriction to 3-D motion of the atlantoaxial articulation. Additionally, there were still some reports that the C1–2 transarticular screw was broken and bone graft block showed nonunion after surgery [13, 20], consequently the long-term atlantoaxial stability cannot be guaranteed.

Based on C1–2 transarticular screw, the bilateral C1–2 transarticular screws and C1 laminar hooks fixation were introduced. This not only fully inherits the essence of a “three-point” fixation but also significantly enhances the ability to limit anterior–posterior motion because an additional atlas hook is used to further restrict the flexion motion of atlantoaxial articulation, as well as the bone graft between posterior arch of C1 and spinous process of C2 is able to restrict the extension motion, as previously described [21]. More importantly, the author's previous biomechanical study [13] had showed that this technique results in minimal angular values for ROM and theoretically can provide the most excellent biomechanical stability, compared to several established fixation techniques, such as Gallie, alone TA, TA + Gallie, etc.

Because this technique uses a special domestic instrument to compress the bone graft between C1 posterior arch

Fig. 5 Representative postoperative radiographic images of patient 17. **a** A lateral flexion/extension view radiograph taken 12 months postoperation demonstrating the proper anatomic alignment of C1–C2 without motion. **b** A sagittal reconstruction CT image demonstrating a solid fusion without a secondary displacement. **c** A coronal reconstruction CT image demonstrating the proper position of the C1–C2 transarticular screw in the lateral mass of the atlas

and C2 spinous process, while keeping the stability of the bone graft, it significantly improved the fusion rate for compression of a bone graft which is considered to be a factor necessary for fusion to occur. Also, the high bone fusion rate is not dependent on a solid external fixation for long time (3 months or more). In this group of patients, although all patients were fixed with Philadelphia collar merely for 2 weeks, approximately 96 % fusion rate was still achieved.

Although satisfactory biomechanical outcomes and clinical results were achieved for TA + Hook fixation from our previous and current studies, the placement of C1–C2 transarticular screw is still technically demanding. Some anatomic or radiologic studies of the atlantoaxial region have considered that in up to 20 % of the cases [22, 23], the proper placement of the C1–C2 transarticular screw is not possible mainly because of a high-riding vertebral artery (VA) [7, 18, 22, 24]. Therefore, aiming at the safe placement of a C1–C2 transarticular screw, spinal surgeons should pay attention to the following points. First, they

should completely know the contraindications of this modified technique that is incompetence of lateral mass of C1, unreduced atlantoaxial articulation dislocation, absence or incompetence of posterior arch of atlas, high-riding vertebral artery, malformation of atlantoaxial vertebral artery, and poor surgery skill. In this group of cases, the authors conducted a careful preoperative evaluation for all patients to rule out surgical contraindications in order to achieve the safety of implanting C1–C2 transarticular screws. Secondly, the careful and complete preoperative preparations are especially important for surgeons. Preoperatively, a satisfactory reduction of a dislocation of atlantoaxial articulation is required; additionally, thorough preoperative imaging and analysis of the atlantoaxial articulation are required to evaluate whether there is a high-riding VA under the lateral mass of C2. Some authors [4–7] defined the high-riding VA on the basis of sagittal two-dimensional CT reconstruction image, which is a simple and widely accepted method of evaluation. They adopted Bloch et al. [25] definition of the high-riding VA:

an internal height less than 2 mm, an isthmus height and width less than 5 mm, or both. However, the isthmus height and width are more important because the screw goes through the isthmus itself regardless of the internal height. For the patients whose C2 isthmus height and width are less than 5 mm in preoperative imaging, it is very dangerous to place the C1–2 transarticular screw of diameter 4.0 mm. In this group of cases, preoperatively the author observed that five patients had an internal height more than 2 mm, but an isthmus height less than 5 mm bilaterally or unilaterally. Based on the above evaluating rules, the C2 pedicle screw was substituted for the C1–2 transarticular screw to finish fixation to prevent VA impairment. Finally, the surgeon should consistently learn the technique to place a transarticular screw along the safest trajectory. Considering the anatomic course of the VA, the safest screw trajectory is via the most posterior and medial part of the isthmus [23]. Therefore, even if the trajectory cut out dorsally in the isthmus of C2, the situation is still safe. In this group of cases, although 6 (4.37 %) screws cut out dorsally in the isthmus of C2, there were no appearances of neurovascular injuries.

Once a suspected or verified VA injury occurs during preparation or insertion of the first transarticular screw, leaving the remaining side untouched and choosing alternatives will prevent bilateral impairment. The authors' previous biomechanical study has demonstrated that C1 + C2 fixation, at a load of ± 1.5 Nm, had almost the same mechanical stability as TA [11]. Compared to the control and Gallie groups, it clearly had a greater ability to limit motion. This also was found by Melcher et al. [11] for the C1 + C2 technique, with the same instability pattern under a load of ± 1.5 Nm. Therefore, in cases wherein transarticular screws are not feasible, C1 + C2 fixation is an alternative.

Conclusions

The preliminary results showed that the bilateral C1–2 transarticular screws and C1 laminar hooks fixation is a relatively safe and effective fusion technique for atlantoaxial instability. In the future, studies focusing on larger patient groups with longer-term follow-up will help to determine the overall durability and efficacy of bilateral C1–2 transarticular screws and C1 laminar hooks fixation.

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