Modified technique for C1–2 screw-rod fixation and fusion using autogenous bicortical iliac crest graft

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Abstract

Introduction Various techniques have been described for posterior atlantoaxial fusion. Sublaminar passage of the wire/cable is cumbersome with a risk of spinal cord injury. Packing morselized bone grafts into the C1–2 facet joints may be difficult and it may cause massive bleeding and neuropathic pain or posterior scalp numbness postoperatively. We introduce a modified method by using C1–2 screw-rod fixation (SRF) to compress a structural iliac bone graft between the posterior elements of C1 and C2 without supplemental wiring construct. **Materials and methods** From December 2006 to May 2009, 35 consecutive patients with atlantoaxial instability treated by this method were reviewed retrospectively. Clinical and radiographic history was recorded. Patients with neck pain had relieved significantly after surgery and the neurologic status was also improved greatly. Thirty-three (94.3%) patients gained bony fusion at 3 months postoperatively. No vertebral artery and spinal cord injuries were noted. There was no instrumentation failure during the observation period. **Conclusion** We conclude that the C1–2 SRF with construct-compression structural bone grafting can be used for C1–2 fusion with relatively simple performance and less time-consuming in selected cases.

Keywords Atlantoaxial instability · C1–2 fusion · Bone transplantation · C2 pedicle screw

Introduction

Atlantoaxial instability (AAI) can be caused by trauma, malignancy, congenital malformation, or inflammatory diseases. Most of these patients need a surgical intervention for reduction and stabilization of the C1–2 joint. Posterior fusion and instrumentation are a common way for C1–2 arthrodesis. The C1–2 transarticular screw fixation (TASF) combined with a posterior bone and wire construct is generally considered to be the “gold standard”, which can provide superior biomechanical properties. However, the TASF has several drawbacks, such as the procedure requires preliminary reduction of the C1–2 joint before screw placement and up to 23% of patients have anatomy unsuitable for this screw trajectory [1]. Currently, the C1 screw technique, first described by Goel and Laheri [2] and popularized by Harms and Melcher [3], can overcome the limitations of the TASF and has been widely used for atlantoaxial fusion. However, no screw fixation alone can provide long-term stability unless a sound bony fusion is achieved.

Many authors [4–6] supplemented a posterior wiring construct to secure the bone graft between C1 and C2 for bone fusion. Nevertheless, sublaminar passage of the wire/cable is cumbersome with a risk of spinal cord injury. Another choice for fusion is to pack morselized bone grafts into the C1–2 facet joints. However, this method has some limitations such as troublesome bleeding from the venous plexus and sacrificing the C2 nerve root for exposure of the C1–2 facet joints [3, 7]. The morselized bone grafts can also be onlaid the decorticated posterior elements of C1 and C2 [3, 8, 9], and could gain a high-fusion rate (93–100%). But it cannot support an immediate stability, and may cause pseudoarthroses [5] and excessive fusion because of

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migration of the onlay grafts [8], though it happened uncommon.

In response to these technical limitations, we modified the operative technique by securing the posterior structural bone graft with the C1–2 screw-rod construct instead of cable fixation for atlantoaxial fusion in 35 consecutive patients since 2006. This study was done to evaluate the clinical outcome of this technique.

Patients and methods

Patient population and study variables

From December 2006 to May 2009, 35 consecutive patients with AAI underwent this modified C1–2 screw-rod fixation and bicortical iliac crest graft fusion. Each surgical procedure was performed by the same senior orthopedic surgeon (B.N.).

We retrospectively reviewed the radiographs, clinic records, and hospital charts for the patients identified. Data collected included: patient age, gender, diagnosis, complications, and postoperative complications. Operative time, estimated blood loss (EBL) and the time of bone fusion were also recorded. Operative time and EBL were determined from the anesthesia and surgical nursing records. Surgical time was calculated from the time of skin incision until closure.

Preoperative imaging including plain cervical radiographs with flexion and extension views (except for patients with acute fractures), magnetic resonance imaging (MRI), and thin-cut computerized tomography (CT) scans (including sagittal and coronal reconstructions) were available to each patient. MRI and CT were used to evaluate any anatomic/physical constraints that may limit the C1–2 screw placement, as well as the diseases diagnosis and classification. Patients with thin posterior arch of C1 or abnormality of VA at C1 that might compromise the C1 screw placement were excluded from this study. Twenty-two cases could reduce at extension view, 1 case could reduce at flexion view and 12 cases could achieve an appropriate position after skeletal traction for 3–7 days.

All patients were assessed clinically for neurologic recovery by the Japanese Orthopedic Association (JOA) scoring system. Patients presented with neck pain preoperatively were evaluated by Visual Analogue Scale (VAS).

Fusion was defined as the presence of bone bridging between the graft and both C1 and C2 and a lack of motion between the posterior elements and graft on flexion and extension cervical spine radiographs. CT reconstruction was routinely taken at each follow-up to assess the bone fusion until a bony fusion was achieved.

Surgical technique

Somatosensory and motor-evoked potentials (SSEPs and MEPs) were used to monitor the neurologic function during the entire course of the intubation, positioning phases, and surgery. Patients were placed in the prone position, and fluoroscopy showed a good alignment of C1–2 complex. A midline posterior opening was done to expose the posterior bony elements of C1 to C2. The iliac crest bone graft harvest could be done at the same time with another group of surgeons.

The inferior surface of the posterior arch of C1 was exposed as a landmark for screw placement. The dorsal cortex of the posterior arch at the entry point was decorated with high-speed burr. Screw (3.5 mm diameter, Summit, DePuy Spine) placement was conducted according to the Resnick method [6] and the Tan method [10]. The C2 nerve root dorsal ganglion was mildly retracted caudally to facilitate drilling, tapping and C1 unicortical all-threaded screw insertion. The superior aspect of C1 was left intact without separating the vertebral artery from the groove when preparing and inserting the C1 screw.

Careful exposure of the posteromedial border of the C2 pedicle facilitates the drilling and screw placement by the direct visualization of the pedicle. The C2 pedicle (or pars) screw was inserted according to C2 anatomic constraints. A longitudinal rod was used to connect the ipsilateral C1 and C2 screw at each side. A locking screw was tightened to secure the rod to C1 screw head, and another locking screw was placed, holding the rod loosely to the polyaxial head of the C2 screw.

The caudal rim of the posterior arch of C1, the cranial edge of the C2 laminae and spinous process were decoricated with a high-speed drill (Fig. 1). The interval between C1 and C2 lamina was measured in neutral position that was confirmed by lateral fluoroscopy. A tricortical bone graft, ~3.5 cm wide and 1.5 cm high, was taken from the patient's posterior iliac crest by osteotome. The donor site was 6.0 cm apart from the posterior superior iliac spine. The rounded cortical side of the graft was removed to create a bicortical bone graft (Fig. 2). The height of the graft was modified to a little larger size than the measured value of the interval between C1 and C2 lamina, and then it was notched to fit on the decoricated posterior elements of C1 and C2 according to the technique of the Sonntag's Modified Gallie fusion without wiring [11, 12].

Subsequently, by longitudinal compression between the screws (on both sides), which dragged posterior arch of C1 downward to C2, a stable position of the structural bone graft was achieved, and the C2 screws were tightened (Fig. 3). The sagittal alignment of C1–2 complex was reconstructed simultaneously (Fig. 4). Finally, all of the

Fig. 1 Drawing (a) and intraoperative photograph (b) showing the caudal rim of the posterior arch of C1 (black arrow) and the cranial edge of the C2 laminae and spinous process (white arrow) decorticated with a drill

Fig. 2 Drawing a showing a curved tricortical bone graft being harvested from the posterior iliac crest and being fashioned into a bicortical structural graft. Intraoperative photograph b showing a curved bicortical structural graft

Fig. 3 Intraoperative photograph a showing the technique for posterior atlantoaxial fusion using C1–2 screw-rod fixation and construct-compression structural bone graft. Drawing b showing the structural graft was fitted between the posterior elements of the C1–2 complex

screws were fastened securely. The rod distal to the C2 screw was cut in situ with the rod cutter. The wound was closed in a standard fashion over a suction drain. Postoperatively, the patients were immobilized in a cervical collar (Philadelphia type) postoperatively for 6–8 weeks. Standard postoperative protocol was followed and patient was discharged on 5th–7th day postoperatively.

All patients were followed up regularly at intervals of 3, 6, and 12 months, and annually thereafter. Lateral radiographs in neutral position, flexion, and extension were

taken before surgery and at every visit after surgery. The JOA score was also recorded at each visit. CT reconstruction was taken immediately after operation to verify the screw position.

To evaluate the clinical outcome, neck pain was compared between preoperatively and the 3-month follow-up postoperatively. Neurologic status was compared between preoperative and the final follow-up. The paired *t* test was used in the statistical analysis. All *P* values <0.05 were considered statistically significant.

Fig. 4 Drawing showing the sagittal alignment of C1–2 complex was reconstructed as the compression of structural bone graft

Results

Thirty-five patients (14 women and 21 men) were included in the study. The mean age of patients in the allograft group was 37 years (range 11–72 years). The pathology included ruptured transverse ligament in nine patients, nonunion after failed odontoid screw fixation of type II odontoid fractures in five patients, type II odontoid fractures with oblique fractures in the sagittal plane in four patients, type II odontoid fractures with significant irreducible displacement in three patients, os odontoideum in ten patients and rheumatoid arthritis in four patients. The mean duration of follow-up was 23.7 ± 11.1 months (12–48 months).

The average operation time of the 35 cases of this series was 115.7 ± 12.5 min (range 80–130 min); mean blood loss was 140 ± 50 mL (range 50–260 mL). Surgical complications, such as lamina fracture, dural injury, or spinal cord injury, were not detected in these series. The postoperative CT scans showed that three screws (3 patients) in C1 and five screws (4 patients) in C2 breached the medial cortex without screws breaching the transverse foramen of C1 and C2. There were no cases of neurologic deterioration after surgery or at follow-up related to the procedure. No VA injuries were detected intraoperatively and postoperatively.

There were no wound infections, posterior scalp numbness, or occipital neuralgia occurred during the observation period. Twenty-one patients with neck pain had relieved significantly from 5.2 in VAS mean value preoperatively to 0.7 at the 3-month follow-up ($P = 0.036$). The average JOA score of all the 35 patients was 11.0 points before surgery and 15.4 points at the final follow-up visit ($P = 0.000$). A statistically significant difference between pre- and post-operation showed the improvement of neurologic status (Table 1).

There were 33 (94.3%) patients gained bony fusion at 3 months after operation (Figs. 5, 6, 7). In one patient, a

Table 1 JOA scores and VAS in pre- and post-operation (mean $\pm$ standard deviation)

	Cases	Preoperative	Postoperative
VAS	21	5.2 ± 1.2	$0.7 \pm 0.6^*$
JOA	35	11.0 ± 3.3	$15.4 \pm 1.5^*$

VAS visual analogue scale, JOA Japanese Orthopaedic Association

* $P < 0.05$, compared with the preoperative data using paired t test

1-mm gap between the bone graft and the C2 laminae was observed at 3 months postoperatively. He was suggested with a collar and got fusion 6 months later. Another patient with rheumatoid arthritis got fusion at 8 months after surgery. There was no screw pullout or instrumentation failure.

Discussion

Recently, many screw fixation systems were reported for the treatment of atlantoaxial instability. The TASF and the C1–2 SRF were the two most popular ways for posterior C1–2 fusion and had similar biomechanical status [13–15]. The clinical results were satisfactory because of their excellent stability. Wang et al. [8] gained a 100% fusion rate at the 3-month follow-up by using TASF and morselized autogenous iliac crest grafts for a series of 57 patients with atlantoaxial instability or dislocation. Finn and Apfelbaum [16] retrospectively reviewed 269 patients fixed by TASF and bicortical iliac crest allograft placed in an interpositional manner using a modified Sonntag–Dickman wiring technique. The clinical outcomes were excellent, with nearly 100% of patients achieving stable bony union. The average time of fusion was 9.2 months (range 3–24 months). Hillard et al. [17] also reported 89 consecutive patients treated by TASF or C1–2 screw-rod fixation with bicortical iliac crest allograft or autograft, the bone fusion rate was high ($>91\%$) at the final follow-up. The above data showed that a good biomechanical stability could reach a high-fusion rate, no matter autograft or allograft and morselized grafts or structural graft. While the autograft tended to show fusion much earlier than allograft, it was also confirmed in our series that most patients got solid fusion at 3 months after surgery. The bicortical iliac graft placed in a load-bearing environment could remedy the weakness of SRF in resisting extension [14] and might be another factor that could encourage bone fusion. This modified fixation and fusion could also reconstruct the sagittal alignment of C1–2 complex with a good C1–2 fusion angle. It was suggested that the ideal C1–2 fusion angle will be between 25 and 30° [18, 19]. This modified bone graft without supplemental sublaminar wiring makes the surgery much simpler, less time-

Fig. 5 A 44-year-old woman with rheumatoid arthritis. Open-mouth anteroposterior roentgenogram (**a**), lateral flexion/extension radiographs (**b**, **c**) showing atlantoaxial instability preoperatively. Postoperative open-mouth anteroposterior radiograph (**d**) and lateral cervical radiograph (**e**) after SRF. Open-mouth photograph (**f**) obtained

3 months after surgery and lateral flexion/extension radiographs (**g**, **h**) demonstrating no motion between the anterior elements of the C1–2 complex. CT sagittal reconstruction image (**i**) showing a bony fusion between the posterior arch of C1 and C2

consuming and reduces the potential risk of neurologic complication.

On the other hand, there was not a fixation alone that could provide timeless stability unless a solid fusion is achieved. Most instrumentation failed before bone fusion or together with pseudarthrosis [17, 20, 21]. Therefore, it was important to accelerate the fusion, especially for those

with old age or with osteoporosis. We suggested each patient to be with a cervical collar postoperatively.

However, it is hard to evaluate the fusion just with plain X-ray films. The measure of the motion between the posterior elements and graft on flexion and extension cervical spine radiographs might be easy and effective for TASF or other wiring fixation. It might be difficult for SRF because

Fig. 6 A 61-year-old man with type II odontoid fracture with posterior displacement. Open-mouth anteroposterior radiograph (a), lateral cervical radiograph (b) and CT sagittal reconstruction (c) pre-operatively showing type II odontoid fracture with posterior displacement. Postoperative open-mouth anteroposterior radiograph (d) and lateral cervical radiograph (e) depicting a good placement

of SRF. Lateral flexion/extension radiographs in 3 months follow-up (g, h) demonstrating no motion between the anterior elements of the C1–2 complex. CT sagittal reconstruction (i) showing a bony fusion between the posterior arch of C1 and C2 and a bridging trabecular bone between the fracture segments

the fixation could shelter the posterior elements and graft in lateral cervical radiographs. CT reconstruction is one of the few useful ways that could assess the fusion which can show the detail of the bone form accurately. Lee et al. [21] used CT scans with sagittal and coronal reconstruction to evaluate fusion for those with SRF or TASF. Aryan et al. [20] also evaluated the fusion of the C1–2 joint with CT reconstruction. In our study, we took CT scan and reconstruction to assess the bone fusion at each follow-up until the bony fusion was confirmed together with radiographs. In our opinion, when patients with AAI fixed by SRF, CT

reconstruction is an irreplaceable way that can demonstrate the bridging trabecular bone directly in early stage. The open-mouth, anteroposterior, lateral, and flexion and extension radiographs can be used to evaluate the fixation and the alignment of C1–2 complex.

Much like the entry point of pedicle screw for lumbar and thoracic vertebra, there are different methods for C1 screw placement [2, 3, 6, 10, 22]. Each has its advantage and shortcoming. In this study, we used the Resnick method [6] for C1 screw insertion. This method has the advantages as follows. First, the entry site is more superior

Fig. 7 A 53-year-old man with ruptured transverse ligament who suffered a fall injury. Anteroposterior radiograph (a) and lateral flexion/extension radiographs (b, c) preoperatively showing AAI. Postoperative anteroposterior radiograph (d) and lateral cervical radiograph (e) after SRF. Anteroposterior photograph (f) obtained at

3 months follow-up and lateral flexion/extension radiographs (g, h) demonstrating no significant motion between the anterior elements of the C1–2 complex. Sagittal reconstruction of CT scan (i) showing a bony fusion between the posterior arch of C1 and C2

and the sagittal angle of screw trajectory in the cephalad direction is smaller than that via the Harms technique. Therefore, the gap between C1 screw head and C2 screw head is enlarged and benefits for compression to secure the bone graft. Second, the screws via posterior arch and lateral mass minimize caudal retraction of the C2 nerve root dorsal ganglion and avoid irritation of the C2 root, which might cause neuropathic pain [23]. Third, most patients with forward dislocation of C1 on C2 have an exaggerated distance of the posterior elements of C1 and C2. The compression could realign the C1–2 complex in sagittal plane effectively. Furthermore, the unicortical screw placement provided the same pullout resistance and three-dimensional stability as bicortical C1 lateral mass fixation via the Harms technique [24]. It plays an important role in compression without screw pullout.

It seems that we have achieved the promising clinical outcome. There are still some attentions must be paid as follows. First, a careful preoperative planning for morphometric evaluation of C1–2 complex is required for both screw insertion and bone transplantation. Since this fusion style not only requires intact posterior elements of C1 and C2 for bone graft, but also anatomic feasibility for screw fixation. CT scan and reconstruction plays an irreplaceable role in the preoperative evaluation. In our study, preoperative CT scans and reconstructions were available to each patient. If the C1 posterior arch is not thick enough (<4.0 mm) for screw passing, we can insert screw partially through the posterior arch into the lateral mass via screw cutting out of the inferior portion of the posterior arch reported by Ma et al. [24]. By doing so, no cortex breaching at the C1 posterior arch under the vertebral artery groove was detected and no posterior arch of C1 fracture occurred in our series. There were no residual posterior scalp numbness and neuropathic pain postoperatively. However, once the C1 posterior arch is rather thin (<3.0 mm) and not suitable for screw insertion, other methods for both fixation and fusion should be under consideration. Second, bone quality is also need to evaluate, especially for those in years or with inflammatory diseases such as rheumatoid arthritis. A bicortical iliac crest bone graft is suggested for fusion, which can stop bone collapse from compression.

The fusion rate in our series was 94.3% at 3 months postoperatively and 100% in 12 months follow-up, which showed that the modified C1–2 SRF with construct–compression structural bone could be used for C1–2 fusion. C1-screw placement through posterior arch was shown to be a safe procedure in experienced hands. Regarding blood loss, stability and VA, anatomic evaluation before surgery is of paramount importance to rule out those C1 posterior arches not suitable for this technique. Postoperative CT scans should be assessed for C1-screw placement and C2-screw

placement and in the future benchmark studies should compare fusion rates using CT scans at 6- or 12-months follow-up.

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