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Original Article

Treating C1-2 subluxation with transarticular screw and posterior atlantoaxial fusion—A 5-year experience

Chih-Yun Fan Chiang, Chi-Chien Niu*, Meng-Ling Lu, Po-Liang Lai, Lih-Huei Chen, Wen-Jer Chen

Department of Orthopedic Surgery, Division of Spine, Chang Gung Memorial Hospital at Linkou, Chang Gung University of Medicine, Taoyuan, Taiwan, ROC

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ABSTRACT

Purpose: Since the introduction of C1–2 transarticular screw fixation by Magerl and Seemann in 1979, the technique has been used effectively in the treatment of atlantoaxial instability. In this study, a 5-year experience of using the technique of C1–2 transarticular screw fixation and posterior atlantoaxial fusion for atlantoaxial instability in 11 operations was reviewed.

Materials and methods: From 2003 to 2007, 11 patients with atlantoaxial instability, with a mean age of 57 years, were included in the study. All patients underwent C1–2 stabilization with transarticular screw fixation and posterior atlantoaxial fusion. Preoperatively, every patient received a computed tomographic (CT) scan of the C2 level to determine the trajectory of screw placement and anatomic variations. Postoperatively, all patients were maintained in a hard neck collar for 6 weeks, and no halo fixation was used in any patient. A visual analog scale (VAS) was used for treatment assessment.

Results: The mean isthmus heights for male and female patients were 8.08 ± 0.93 mm and 5.20 ± 1.45 mm, respectively, and the mean isthmus widths were 7.01 ± 0.98 mm and 4.54 ± 1.40 mm, showing significant difference ($p < 0.05$). Three female patients had an isthmus width less than 3 mm, and two had an isthmus height less than 4 mm due to high riding of vertebral artery. No significant difference between the sizes of right and left C2 isthmus was noted in this study. The average trajectory angle was 47.18 ± 5.27° caudo-cephalically and 4.85 ± 3.46° medially for males, and 38.30 ± 4.80° caudo-cephalically and 4.14 ± 1.67° medially for females. According to the results of the CT scan, three patients underwent unilateral screw fixation due to small isthmus size and risk of vertebral artery injury. Osseous fusion after surgical treatment, had been documented in 10 patients. The mean follow-up period was 2.6 years (range 22 months ~ 4.5 years). The mean VAS was 7.55 ± 0.82 preoperatively and 1.81 ± 1.17 at 1 year after the operation ($p < 0.05$). There were no instances of screws loosening, superficial wound infection, errant screw placement, dural laceration, or operation-related neurovascular injury in this study.

Conclusion: This study provides bone data of the C2 isthmus. C1–2 transarticular screw fixation with posterior atlantoaxial fusion provides stable fixation and a high fusion rate. Preoperatively, a CT scan is essential to recognize the location of a large vertebral foramen and narrow isthmus to avoid the risk of vertebral artery injury.

1. Introduction

The causes of atlantoaxial instability include trauma, inflammatory disease, infection, tumor, and congenital or acquired abnormalities. Dorsal wire fixation plus screw fixation is usually used as the treatment for atlantoaxial instability. Common wiring techniques include Gallie fusion[1] and Brooks-Jenkins fusion.[2] The technique of C1–2 transarticular screw fixation, introduced by Magerl and Seemann, provides immediate postoperative stability and improves the fusion rate, so it has become the gold standard for treating atlantoaxial instability.[3] The main concern of using this method is the possibility of vertebral artery injury, which is the major complication of transarticular screw fixation. A cadaveric study by Abou Madawi et al[4,5] demonstrated that bilateral screws could not be placed in up to 20% of specimens, because of the anatomic variations in the location of the foramen transversarium, which placed the vertebral artery at risk during screw placement. Preoperatively, CT scan of the height and width of the C2 isthmus

* Corresponding author. Department of Orthopedic Surgery, Chang Gung Memorial Hospital at Linkou, 5, Fushing Street, Gueishan Township, Taoyuan County 333, Taiwan, ROC. Tel.: +886 3 328 1200x2423; fax: +886 3 328 9582.
E-mail address: niuchien@adm.cgmh.org.tw (C.-C. Niu).

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were assessed to determine the anatomic variations, which preclude safe screw placement in some cases.[6,7] The isthmus of C2 is defined as the portion of the bone bridge that the screw must travel through at the level of the transverse foramen (Fig. 1).

A 5-year experience of using the technique of C1–2 transarticular screw fixation and posterior atlantoaxial fusion for atlantoaxial instability in 11 operations was reviewed. The anatomic variations of the isthmus height and width for the screw placement were determined by the CT scan.

2. Materials and methods

From 2003 to 2007, four men and seven women, with a mean age of 59.5 years (range, 23–81 years) were included in our study (Table 1). Each patient had atlantoaxial instability. Atlantoaxial instability was documented as a result of trauma in six patients, a result of rheumatoid arthritis (RA) in four patients, and a result of os odontoideum in one patient. All patients received a preoperative fine-cut oblique axial and sagittal CT scan of C-spine (1 mm/cut). A line drawn from the rostral aspect of the inferior C2 facet to the midpoint of the posterior aspect of the C1 anterior tubercle, served as the planned trajectory of the screw placement (Fig. 2).[6,7]

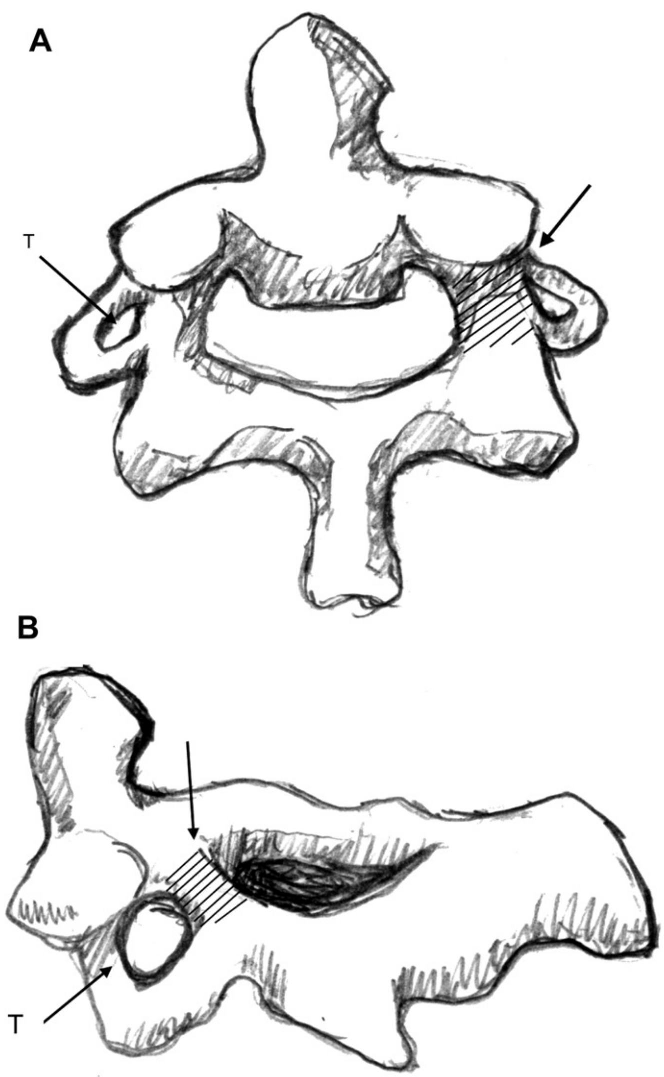

Fig. 1. (A), (B) C2 vertebra. Hatched areas represent the isthmus of pars interarticularis, the narrowest bridge of bone that the C1–C2 transarticular screw must traverse; T = foramen transversarium.

3. Surgical technique

After the satisfactory induction of general endotracheal anesthesia, patients were placed in Mayfield pins in a prone position. Lateral fluoroscopy was used to position the cervical spine in anatomic alignment. A midline incision was made from C1 to C2 to the tips of the spinous processes. C1 and C2 were widely exposed in the subperiosteal plane. The entry point for screw placement was 2–3 mm laterally and 3–4 mm medially above the C2–C3 facet. A 2.5-mm drill bit was sagittally aimed toward the anterior arch of C1 under a lateral fluoroscope. A 3.5-mm tap was used for the entire length of the trajectory to prevent possible anterior dislocation of the atlas during screw insertion. A 4-mm fully threaded screw of the appropriate length was then inserted, stopping just short of perforating the anterior cortex of the atlas. One $2 \times 3 \times 1$ cm unicortical bone block harvested from the iliac crest was laid on the decorticated cortical lamina of C1 and C2 and fixed in place by modified Gallie's technique with cable wire. The remaining decorticated lamina of both the atlas and the axis were covered by autologous, cancellous iliac crest bone grafts. Postoperatively, the patients were maintained with a rigid cervical collar for the first 6 weeks. No halo fixation was necessary after the operation. VAS was used for treatment assessment. A Japanese Orthopedic Association (JOA) cervical myelopathy evaluation questionnaire was used to evaluate the function and sensory disturbance of upper and lower extremities, and the bladder function, if the patient had myelopathy preoperatively. Fusion was considered to be complete if there was continuity of bone between the posterior arches of the atlas and axis without any movement on the flexion–extension radiographs.

The measurements of the isthmus by CT scan were documented and compared between male and female patients, and between the right and left side. Statistical analysis was performed using SPSS version 12 (SPSS Inc., Chicago, IL, USA). A p value was calculated using the Wilcoxon signed rank test or Mann Whitney U test as appropriate. A p value <0.05 was considered significant.

4. Results

The mean isthmus heights for male and female patients were 8.08 ± 0.93 mm and 5.20 ± 1.45 mm, respectively, and the mean isthmus widths were 7.01 ± 0.98 mm and 4.54 ± 1.40 mm, respectively. There was a significant difference between the sizes of the isthmus of males and females ($p < 0.05$). Three female patients had an isthmus width of less than 3 mm (2.6 mm, 2 mm, and 2.5 mm) and two had an isthmus height less than 4 mm (3 mm and 3 mm) due to a high-riding vertebral artery. There was no significant difference between the size of the right and left C2 isthmus in this study. The average trajectory angles were $47.18 \pm 5.27°$ caudo-cephalically and $4.85 \pm 3.36°$ medially for males, and $38.30 \pm 4.80°$ caudo-cephalically and $4.14 \pm 1.67°$ medially for females. There were significant differences between the caudo-cephalic angles of males and females ($p < 0.05$).

Because the size of screw used in transarticular fixation was 4.0 mm in diameter, the screw could not be used if the size of the isthmus, either width or height, was less than 4 mm. Three female patients only underwent unilateral screw placement because the smaller the diameter of the isthmus for the screw trajectory, the higher the risk of vertebral artery injury (Fig. 3). The mean follow-up period was 2.6 years (range, 20 months ~ 4.5 years). Osseous fusion has been documented in 10 patients after the surgical treatment (Fig. 4). Also, solid posterior fusion was observed in all unilateral screw placement patients. Nine patients had a significant improvement of neck pain, and two patients had persisting neck soreness. The mean visual analog scale (VAS) preoperatively was 7.55 ± 0.82 and 1.81 ± 1.17 at 1 year after the operation ($p < 0.05$)

Table 1
Summary of characteristics in 11 patients undergoing transarticular screw fixation.

Patient	Sex	Age (y)	Causes	Isthmus width (mm)	Isthmus height (mm)	C-C (°)	M (°)	TAS
				R/L	R/L	R/L	R/L	
1	M	63	Trauma	8.5/8.3	9/8.7	48.1/51	1/6.5	Bil
2	M	76	Trauma	6/6.5	8.8/8.8	54.2/52.6	2/9	Bil
3	M	58	RA	6.1/6.7	8.3/6.9	44.6/39.6	3/6	Bil
4	M	67	Trauma	7/7	7/7	43.2/44	1/0	Bil
5	F	54	RA	2.6/4	3/4.5	38/39.6	4.1/3.6	L't
6	F	65	Trauma	4/2	5/3	35/36.7	5.3/4.7	R't
7	F	81	Trauma	2.5/4	5/5	39/40	4.7/4.1	L't
8	F	76	Os odontoideum	7/6	8.3/7.8	33/33.5	1/0.7	Bil
9	F	23	RA	4/7.1	5.7/5.1	32/33	2.4/6.6	Bil
10	F	51	RA	6.2/5.2	6.6/4.6	43.5/41	5.3/7.5	Bil
11	F	41	Trauma	4/5	5/4	46.5/45	3.3/4.5	Bil
Mean		59.55		5.44 ± 1.73	6.25 ± 1.90	41.53 ± 6.50	4.40 ± 2.32	

Bil = bilateral screw fixation; C-C = caudo-cephalic; L't = left-side screw fixation only; M = medial; R't = right-side screw fixation only; TAS = transarticular screw.

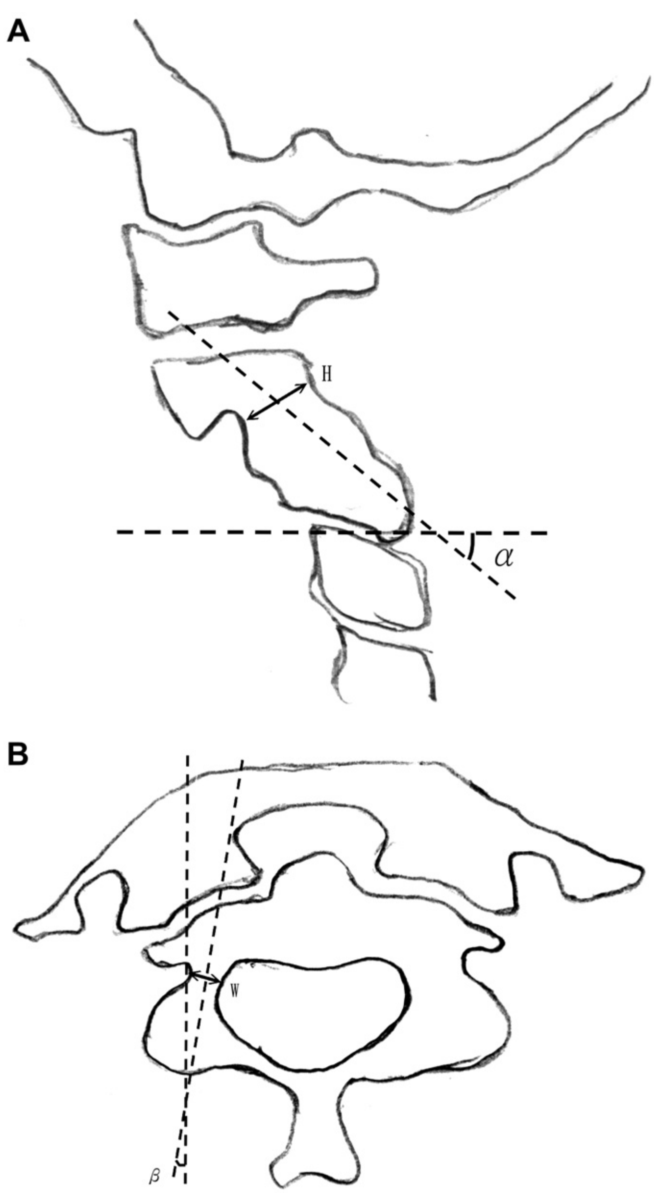

Fig. 2. (A) Sagittal cut of C1–2 CT. H = height of the isthmus; α = caudo-cephalic angle of screw trajectory; (B) oblique axial cut. B = medial angle of screw trajectory; W = width of the isthmus.

(Table 2). The patient with non-union had some residual neck soreness, but was much improved. Despite there being no fusion mass observed on the follow-up plain film, no C1–2 instability was noted in dynamic view. There were no complications such as screws loosening, superficial wound infection, errant screw

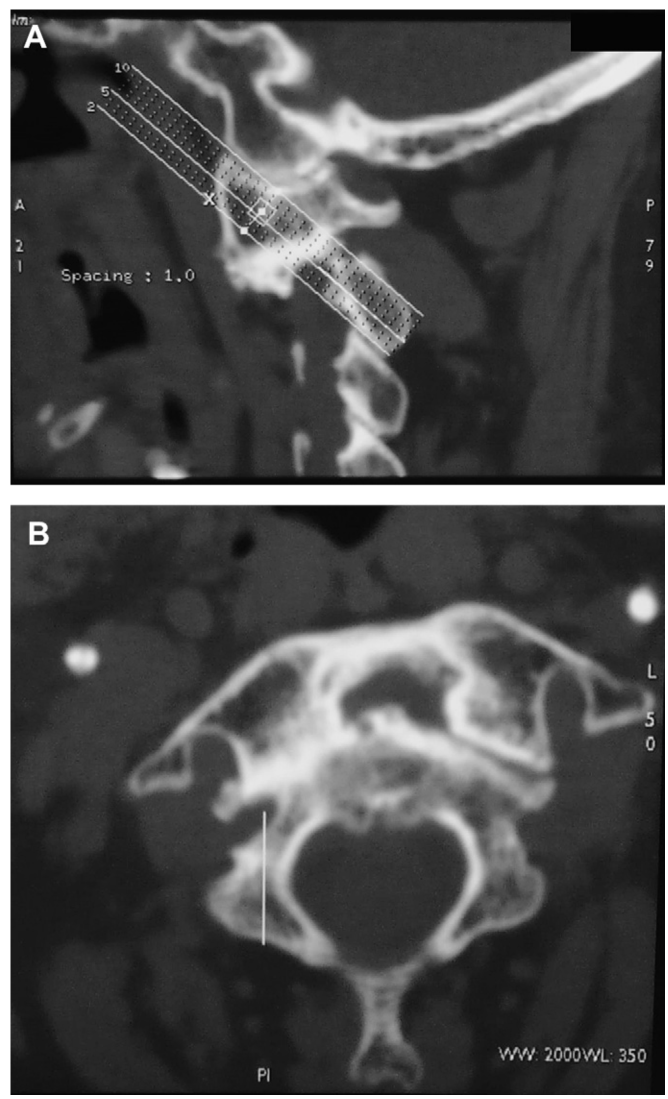

Fig. 3. (A) Sagittal; (B) axial cut of C2 isthmus by CT scan revealed narrow isthmus and threatening of vertebral artery in the route of screw placement.

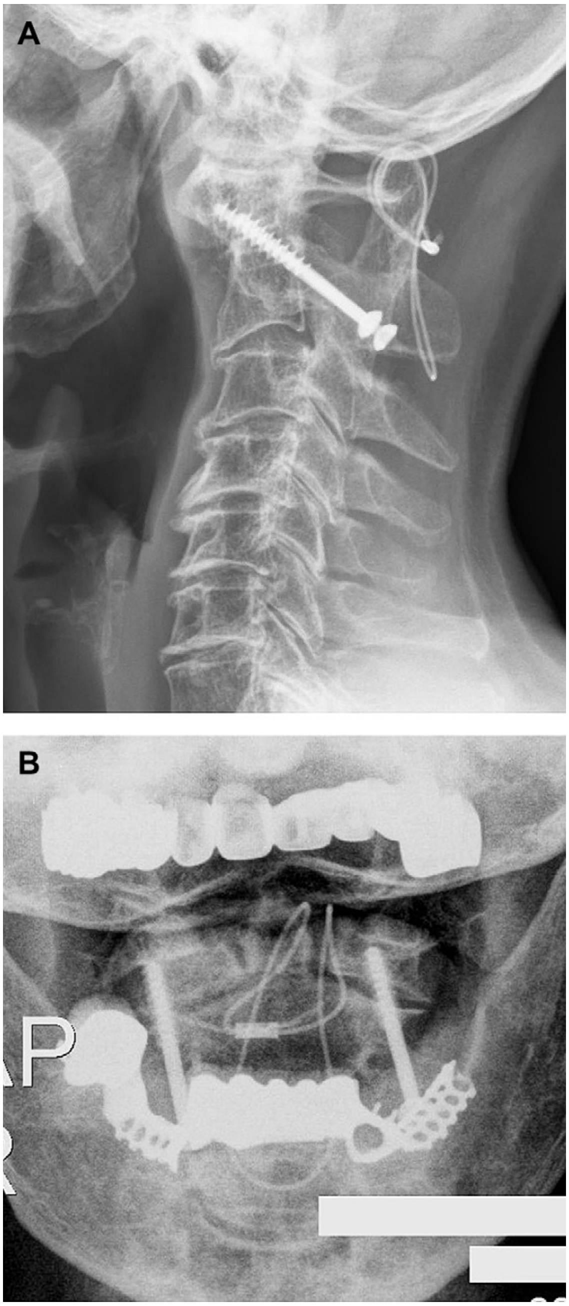

Fig. 4. (A) Lateral view of C-spine with solid posterior fusion mass; (B) open-mouth view showed C12 transarticular screw fixation and posterior Gallie's wiring.

placement, dural laceration, and injury to the vertebral artery, spinal cord, or hypoglossal nerve. Preoperatively, there were three patients who had myelopathy. As a result, two had numbness and weakness of upper limbs, which were improved 12 months after the operation. The other patient, who received C3–7 laminoplasty concomitantly for C3–7 stenosis, had paraplegia postoperatively, not due to the C1–2 fixation but to the reclosure of C3–7 laminoplasty. The JOA scores were improved postoperatively but without statistical significance.

Table 2
Evaluation of neck pain using visual analog scale (VAS).

	Pre-op	Post-op 3 mo	Post-op 12 mo	Post-op 24 mo
VAS of neck pain	7.55 ± 0.82	2.91 ± 0.94	1.81 ± 1.17	1.00 ± 1.73
p	—	$<0.05^*$	$<0.05^*$	$<0.05^*$

$^*p < 0.05$ = significant.

5. Discussion

The Magerl transarticular screw method is more technically demanding than dorsal wiring techniques, but it has two advantages. Firstly, it does not rely on the posterior elements to be intact, and it can be used in patients in whom dorsal wiring techniques are contraindicated.[8] Secondly, biomechanical cadaveric studies have shown that the transarticular screw construct is stable not only in flexion–extension, but also in rotation, which increases the stability and fusion rates of the construct (range, 87–98%),[5,9–14] compared with modified Gallie fusion plus bone grafting and halo vest immobilization (58%).[15] The need for halo immobilization is obviated postoperatively.[16]

The fusion rates of atlantoaxial screw fixation ranging from 87% to 100% has been documented in clinical series.[1,2,17–23] High fusion rate and stability make it the ideal treatment option for C1–2 subluxation. The reported complication rates for this technique are low, ranging between 2% and 14%, depending on the series.[5,9,12,14] The risk of vertebral artery injury with this technique has been well documented in the literature. Madawi et al[4,5] reported intraoperative vertebral artery injuries in 8.2% of their patients. The risk of vertebral artery injuries was 4.1% per patient, or 2.2% per screw inserted.[8] The main limitation of the transarticular technique relates to anatomic variations that preclude safe screw placement and increase the risk of complications.

A preoperative fine-cut CT scan helps surgeons to determine the anatomic variation that may preclude the trajectory of a transarticular screw. We observed that the average width and height of the C2 isthmus were smaller in female patients (4.54 mm and 5.20 mm, respectively). The diameter of the available transarticular screws is 4.0 mm in our facility. Even when the isthmus is abnormally small, transarticular screw fixation is safe in most patients. With careful preoperative planning and surgical technique, the risk of vertebral artery injury can be kept to a minimum. For each patient, a fine-cut CT scan for C1–2 complex is essential in preoperative planning, especially in females, whose C2 isthmus size is generally smaller.

Computer-generated image guidance has been introduced recently as a useful adjunct to provide an even more accurate three-dimensional representation of the craniocervical junction.[24–26] Frameless stereotaxy provides preoperative planning and intraoperative visualization of the trajectory through the C2 pars while allowing navigation around potential hazards such as an anomalous vertebral artery.[25] Some authors advocate that image guidance may allow for safer and more accurate screw placement.[24,26] Two large studies that used lateral fluoroscopy have reported 14% and 15% of screws to be malpositioned,[5,27] compared with another study that used intraoperative navigation and only had 8% of screws malpositioned.[28] The drawback of image-guided transarticular screw placement based on preoperative images is that the anatomic relationship is changeable after surgical positioning, and the use of navigational registration is limited to the C2 segment (registration of C1 is not possible).[28] However, registration of C2 alone can minimize the main risk of transarticular screw fixation, because the injury to the vertebral artery is usually at the C2 level.[29]

We did not experience vertebral artery injury in this study. Gluf et al[30] reported that vertebral artery injury usually presented with brisk bleeding from the drill hole in excess of that which would be expected from bone bleeding, but it was not usually pulsatile bleeding. The placement of the screw is suggested, because once the vessel is injured, it is unlikely to be salvageable. The screw placement can usually resolve the bleeding, which may be problematic if unchecked, because it is in a location that is not readily accessible. Also, in this manner, at least one-sided fixation can be achieved.[14] Apfelbaum[17] and Gluf[30] reported fatalities from bilateral vertebral artery injuries. Coric et al[18] described an arteriovenous fistula (AVF) resulting from damage to the artery during screw placement, which resulted in delayed-onset myelopathy due to distended arterialized epidural veins. Angiography, CT angiography, or magnetic resonance (MR) angiography is recommended after any suspected injury to detect the asymptomatic AVF.[30]

If vertebral artery injury is encountered during transarticular screw insertion, a sublaminar wire is traditionally the recommended clinical salvage method to avoid the risk of injuring the contralateral vertebral artery. Alternatively, several screw-based methods have been developed. Atlantoaxial fusion through the use of C1 lateral mass and C2 pedicle screws was first described by Goel[31] and subsequently popularized by Harms and Melcher.[32] It has reduced the risk of vertebral artery injury and has been shown to be equivalent to transarticular screws.[33,34] Although technically simpler than the transarticular screw technique, C2 pedicle screw placement still remains technically demanding and cannot be used in patients who have a medially located foramen transversarium or narrow C2 pars. Leonard[35] and Wright[36,37] proposed a new technique which involves the insertion of laminar screws into the laminae of C2 in a bilateral crossing fashion and then uses rods to connect to C1 lateral mass screws. This technique provides safe C2 fixation without any risk of vertebral artery injury. Recently, screw fixation with C1 lateral mass to C2 pedicle has been found to have the same stability as C1 lateral mass to C2 laminar screws.[38,39] An *in vitro* biomechanical study reported by Hossein concluded that fixation of the atlantoaxial complex using unilateral transarticular screw supplemented with contralateral C1 lateral mass and C2 intralaminar screws, is biomechanically equivalent to C1 lateral mass and C2 pedicle screws;[40] both are biomechanically superior to C1–C2 sublaminar wire in axial rotation. These methods provide us with more options, in addition to transarticular screws, during preoperative planning.

A morphometric study of lateral mass from C1 to C2, involving 42 patients with RA among the Chinese population[41] reported the mean C2 isthmus height to be 4.69 ± 1.66 mm, and the mean C2 isthmus width 5.14 ± 1.23 mm, which was generally smaller than that of the Western population.[42] Notably, nine patients (21.4%) were suitable for unilateral and 20 patients (47.6%) might have a high risk for bilateral screw penetration. This revealed that an inflammatory reaction not only exacerbated osteoporosis but also limited the use of screw placement, owing to the risk of vertebral artery injury in up to half of the lateral masses. Modification of screw diameter, unilateral transarticular screw fixation, or alternative techniques for C1–C2 arthrodesis should be considered in most Chinese patients with RA.

The limitations of this study are the small number of patients and the heterogeneity of the patient population. A larger series is required to be representative of the average C2 measurement. However, these data provide us with more knowledge about the morphology of the C2 isthmus in the Chinese population. The difference of isthmus width and height between females and males, as well as high-riding vertebral artery and anatomic variations, should be considered in preoperative planning. Despite the limitation of the patient numbers, we are looking forward to further development of the navigation system and alternative techniques in the future.

6. Conclusions

C1–2 transarticular screw fixation with posterior atlantoaxial fusion provides stable fixation and a high fusion rate. Preoperatively, CT scanning is essential to identify a medially located large vertebral foramen and narrow isthmus to avoid the risk of vertebral artery injury. The transarticular screw method is feasible and relatively safe, if both the C2 isthmus width and height are more than 4.5 mm. If the size of either C2 isthmus is less than 4 mm, the a transarticular screw should be avoided in that side. Unilateral transarticular screw fixation can still perform its role well to achieve satisfactory fusion.

References

1. W. Gallie. Fractures and dislocations of the cervical spine. Am J Surg 46 (1939) 495–499.
2. A.L. Brooks, E.B. Jenkins. Atlanto-axial arthrodesis by the wedge compression method. J Bone Joint Surg Am 60 (1978) 279–284.
3. F. Magerl, P.S. Seemann. Stable posterior fusion of the atlas and axis by transarticular screw fixation. In: P. Kehr, A. Wiedner (Eds.). Cervical Spine Research Society. Cervical Spine I. Springer-Verlag, New York, 1986. pp. 322–327.
4. A.A. Madawi, G. Solanki, A.T. Casey, H.A. Crockard. Variation of the groove in the axis vertebra for the vertebral artery: implications for instrumentation. J Bone Joint Surg Br 79 (1997) 820–823.
5. A.A. Madawi, A.T. Casey, G.A. Solanki, G. Tuite, R. Veres, H.A. Crockard. Radiological and anatomic evaluation of the atlantoaxial transarticular screw fixation technique. J Neurosurg 86 (1997) 961–968.
6. G. Christopher, A. Curtis, K.H. Volker. The anatomical suitability of the C1-2 complex for transarticular screw fixation. J Neurosurg 85 (1996) 221–224.
7. T. Scott, M. Richard. Preoperative oblique axial computed tomographic imaging for C1-C2 transarticular screw fixation: technical note. Neurosurgery. 37 (1995) 150–152.
8. J.A. Menendez, N.M. Wright. Techniques of posterior C1-C2 stabilization. Neurosurgery 60 (2007) S-103–S-111.
9. D. Grob, J.J. Crisco 3rd, M.M. Panjabi, P. Wang, J. Dvorak. Biomechanical evaluation of four different posterior atlantoaxial fixation techniques. Spine 17 (1992) 480–490.
10. P.B. Hanson, P.X. Montesano, N.A. Sharkey. Anatomic and biomechanical assessment of transarticular screw fixation for atlantoaxial instability. Spine 16 (1991) 1141–1145.
11. T. Henriques, B.W. Cunningham, C. Olerud, N. Shimamoto, G.A. Lee, S. Larsson, P.A. McAfee. Biomechanical comparison of five different atlantoaxial posterior fixation techniques. Spine 25 (2000) 2877–2883.
12. B. Jeanneret, F. Magerl. Primary posterior fusion C1/2 in odontoid fractures: indications, technique, and results of transarticular screw fixation. J Spinal Disord 5 (1992) 464–475.
13. D. Qu, D. Jin, W. Zhao, S. Zhong. Biomechanical evaluation of atlantoaxial transarticular screw fixation technique. Chin J Traumatol 3 (2000) 89–92.
14. G.S. Song, N. Theodore, C.A. Dickman, V.K. Sonntag. Unilateral posterior atlantoaxial transarticular screw fixation. J Neurosurg 87 (1997) 851–855.
15. I.D. Farey, S. Nadkarni, N. Smith. Modified Gallie technique versus transarticular screw fixation in C1-C2 fusion. Clin Orthop 359 (1999) 126–135.
16. R.W. Haid Jr., B.R. Subach, M.R. McLaughlin, G.E. Rodts Jr., J.B. Wahlig Jr.. C1–C2 transarticular screw fixation for atlantoaxial instability: a 6-year experience. Neurosurgery 49 (2001) 65–70.
17. R. Apfelbaum. Screw fixation of the upper cervical spine: indications and techniques. Contemp Neurosurg 16 (1994) 1–8.
18. D. Coric, C.L. Branch Jr., J.A. Wilson, J.C. Robinson. Arteriovenous fistula as a complication of C1–2 transarticular screw fixation: case report and review of the literature. J Neurosurg 85 (1996) 340–343.
19. T.J. Coyne, M.G. Fehlings, M.C. Wallace, M. Bernstein, C.H. Tator. C1–C2 posterior cervical fusion: long-term evaluation of results and efficacy. Neurosurgery 37 (1995) 688–693.
20. C.A. Dickman, V.K. Sonntag. Posterior C1–C2 transarticular screw fixation for atlantoaxial arthrodesis. Neurosurgery 43 (1998) 275–281.
21. M.E. Dunn, E.L. Seljeskog. Experience in the management of odontoid process injuries: an analysis of 128 cases. Neurosurgery 18 (1986) 306–310.
22. J. Dvorak, M.M. Panjabi. Functional anatomy of the alar ligaments. Spine 12 (1987) 183–189.
23. T. Fuji, T. Oda, Y. Kato, S. Fujita, M. Tanaka. Accuracy of atlantoaxial transarticular screw insertion. Spine 25 (2000) 1760–1764.
24. O. Bloch, L.T. Holly, J. Park, C. Obasi, J. Kim, J.P. Johnson. Effect of frameless stereotaxy on the accuracy of C1–2 transarticular screw placement. J Neurosurg 95 (2001) 74–79.
25. K.T. Foley, M.M. Smith. Image-guided spine surgery. Neurosurg Clin North Am 7 (1996) 171–186.
26. C. Wigfield, C. Bolger. A technique for frameless stereotaxy and placement of transarticular screws for atlanto-axial instability in rheumatoid arthritis. Eur Spine J 10 (2001) 264–269.
27. D. Grob, B. Jeanneret, M. Aebi, T.M. Markwalder. Atlanto-axial fusion with transarticular screw fixation. J Bone Joint Surg Br 73 (1991) 972–976.
28. F.L. Acosta Jr., A. Quinones-Hinojosa, C.A. Gadkary, M.H. Schmidt, C.T. Chin, C.P. Ames, W.S. Rosenberg, et al. Frameless stereotactic image-guided C1-C2 transarticular screw fixation for atlantoaxial instability: review of 20 patients. J Spinal Disord Tech 18 (2005) 385–391.

29. A. Weidner, M. Wahler, S.T. Chiu, C.G. Ullrich. Modification of C1–C2 transarticular screw fixation by image-guided surgery. Spine 25 (2000) 2668–2674.
30. W.M. Gluf, M.H. Schmidt, R.I. Apfelbaum. Atlantoaxial transarticular screw fixation: a review of surgical indications, fusion rate, complications, and lessons learned in 191 adult patients. J Neurosurg Spine 2 (2) (2005) 155–163.
31. A. Goel. C1–C2 pedicle screw fixation with rigid cantilever beam construct: case report and technical note. Neurosurgery 51 (2002) 853–854.
32. J. Harms, R.P. Melcher. Posterior C1–C2 fusion with polyaxial screw and rod fixation. Spine 26 (2001) 2467–2471.
33. H. Kuroki, S.S. Rengachary, V.K. Goel, S.A. Holekamp, V. Pitkänen, M.A. Ebraheim. Biomechanical comparison of two stabilization techniques of the atlantoaxial joints: transarticular screw fixation versus screw and rod fixation. Neurosurgery 56 (2005) 151–159.
34. R.P. Melcher, C.M. Puttlitz, F.S. Kleinstueck, J.C. Lotz, J. Harms, D.S. Bradford. Biomechanical testing of posterior atlantoaxial fixation techniques. Spine 27 (2002) 2435–2440.
35. J.R. Leonard, N.M. Wright. Pediatric atlantoaxial fixation with bilateral, crossing C-2 translaminar screws. Technical note. J Neurosurgy 104 (2006) 59–63.
36. N.M. Wright. Posterior C2 fixation using bilateral, crossing C2 laminar screws: case series and technical note. J Spinal Disord Tech 17 (2004) 158–162.
37. N.M. Wright. Translaminar rigid screw fixation of the axis: technical note. J Neurosurg Spine 3 (2005) 409–414.
38. R. Claybrooks, M. Kayanja, R. Milks, E. Benzel. Atlantoaxial fusion: a biomechanical analysis of two C1–C2 fusion techniques. Spine J 7 (2007) 682–688.
39. J. Gorek, E. Acaroglu, S. Berven, A. Yousef, C.M. Puttlitz. Constructs incorporating intralaminar C2 screws provide rigid stability for atlantoaxial fixation. Spine 30 (2005) 1513–1518.
40. E. Hossein, P. Tejaswy, K.G. Vijay, F. Scott, F. Ahmad, K. Nikhil. Biomechanical analysis comparing three C1–C2 transarticular screw salvaging fixation techniques. Spine 35 (2010) 378–385.
41. T.Y. Chen, K.L. Lin, H.H. Ho. Morphologic characteristics of atlantoaxial complex in rheumatoid arthritis and surgical consideration among Chinese. Spine 29 (2004) 1000–1004.
42. I.M. Mandel, B.J. Kambach, C.A. Petersilge, B. Johnstone, J.U. Yoo. Morphologic considerations of C2 isthmus dimensions for the placement of transarticular screws. Spine 25 (2000) 1542–1547.