J Neurosurg 84:552–558, 1996

Posterior instrumentation of the unstable cervicothoracic spine

Jens R. Chapman, M.D., Paul A. Anderson, M.D., Christopher Pepin, M.D., Sean Toomey, M.D., David W. Newell, M.D., and M. Sean Grady, M.D.

Departments of Neurological Surgery and Orthopaedics, University of Washington, Seattle, Washington

Fractures, tumors, and other causes of instability at the cervicothoracic junction pose diagnostic and treatment challenges. The authors report on 23 patients with instability of the cervicothoracic region, which was treated with posterior plate fixation and fusion between the lower cervical and upper thoracic spine. During operation AO reconstruction plates with 8- or 12-mm hole spacing were affixed to the spine using screws in the cervical lateral masses and the thoracic pedicles. Postoperative immobilization consisted of the patient's wearing a simple external brace for 2 months. The following parameters were analyzed during the pre- and postoperative treatment period: neurological status, spine anatomy and reconstruction, and complications. Follow up consisted of clinical and radiographic examinations (mean duration of follow up, 15.4 months; range, 6–41 months).

No neurovascular or pulmonary complications arose from surgery. All patients achieved a solid arthrodesis based on flexion-extension radiographs. There was no significant change in angulation during the postoperative period, but one patient had an increase in translation that was not clinically significant. There were no hardware complications that required reoperation. One patient requested hardware removal in hopes of reducing postoperative pain in the cervicothoracic region. One postoperative wound infection required debridement but not hardware removal. The authors conclude that posterior plate fixation is a satisfactory method of treatment of cervicothoracic instability.

Key Words • **spine** • **cervicothoracic junction** • **trauma** • **instrumentation**

Spinal instability at the cervicothoracic junction poses significant clinical challenges.[2,15,26] The region is difficult to image with plain radiography and difficult to immobilize with external orthoses because of the biomechanical forces exerted in this transitional portion of the spinal column. All immobilization techniques should ideally avoid further neurological deficits, prevent loss of reduction, and promote bone healing for long-term stability. A number of internal fixation techniques have been developed for stabilization of cervical fractures and dislocations. These techniques involve the use of wires or plates and screws applied anteriorly or posteriorly and have achieved excellent results with low morbidity.[1,3,4,6,8,12,16,21,29,31] The purpose of this study is to report the use of AO reconstruction plates at the cervicothoracic junction in 23 patients. Specifically, we examined the areas of neurological deficit, spine stability, maintenance of alignment, and complications after using this internal fixation technique.

Clinical Material and Methods

Patient Population

This study was based on the charts and radiological records of 23 consecutive patients who were treated at the University of Washington's Harborview Medical Center for cervicothoracic instability, defined as pathology involving the vertebral segments C7 through T4. All of the patients were treated by posterior arthrodesis using AO reconstruction plates and autogenous iliac bone graft according to the technique described by Anderson, *et al.*[3]

Initial diagnosis of acute cervicothoracic fracture was made using plain radiography or computerized tomography (CT) scanning. Computerized tomography was obtained in all patients within 24 hours of admission to delineate their bone injury more fully. Patients with acute injury were placed in tong traction, and all patients with acute spinal cord injury were immediately treated with high-dose methylprednisolone.[7] Closed reduction was achieved in all trauma cases within the first 12 hours of hospitalization. No trauma patient underwent prereduction imaging to identify disc herniation; in some circumstances noncontrast CT scanning was required to identify bone pathology because of an inability to image the cervicothoracic junction satisfactorily with plain radiographs. Reduction of burst fractures typically required increased traction weight of up to 60% of body weight. There were no adverse neurological or musculoskeletal consequences of this higher weight. In no case was there significant preoperative compromise of the spinal canal due to disc, bone, or tumor located anteriorly, as confirmed by myelography with CT scanning or magnetic resonance (MR) imaging. No patient underwent concomitant or delayed anterior spine procedures. Postoperative imaging of the spine was confined to radiographs or noncontrast CT scans.

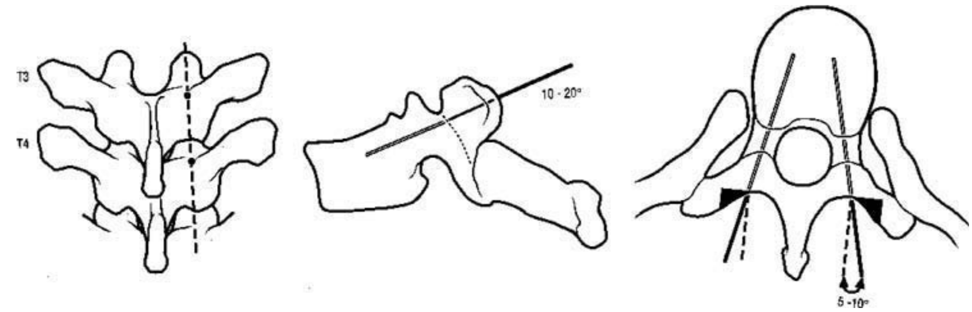

FIG. 1. Schematic drawings. *Left:* Sketch displaying the starting point for hole placement to drill into the pedicle in the upper thoracic spine. The hole should be in the midline and approximately 1 to 2 mm below the superior lip of the facet. *Center:* A lateral projection of an upper thoracic vertebra, showing the drill angle from a sagittal plane. *Right:* An axial projection of an upper thoracic vertebra, showing the drill angle from a horizontal plane.

Operative Procedure

Operative stabilization was performed between 3 and 7 days after admission for patients with acute injury. Surgical techniques included awake intubation and prone positioning using the Styker frame. A wide surgical exposure is necessary to identify the structures on which the plates and screws are placed. The full extent of the cervical lateral masses should be exposed, taking care not to damage facet joint capsules above the intended fusion site. In the thoracic spine, surgical exposure should include the transverse processes.

Accurate placement of drill holes is critical to avoid neurovascular injury and to ensure screw purchase. There is considerably less tolerance in the thoracic spine to drilling new holes; therefore, holes must be placed first according to anatomical landmarks. In the thoracic spine, screws are preferably placed in the pedicles because the transverse processes (which evolve from the lateral masses in the cervical spine) are considerably less strong for fixation purposes. The starting point for screw placement is in the mid facet line just at the edge of the superior facet (Fig. 1). The screw is angled inward 5° to 10° with a 10° to 20° caudal angulation. An air-powered drill with a 2.0-mm Kirschner wire and an adjustable drill guide are used to drill the holes. The drill depth is set at 12 mm and a smaller blunt-tipped Kirschner wire is used to probe the hole to check for cortical perforation cranially, caudally, laterally, and, most critically, medially. Drilling is continued with sequential lengthening of the drill guide in 3-mm increments until a 20-mm depth is reached. All holes are tapped with a 3.5-mm cancellous bone tap.

The starting point for screw placement in the cervical spine is 1 mm medial to the center of the lateral mass. The screws are oriented 30° to 40° cephalad and 10° to 20° outward. The air-powered drill with a 2.0-mm Kirschner wire and an adjustable drill guide is again used to drill the holes. The adjustable drill guide is initially set at 14 mm. A smaller blunt-tipped Kirschner wire is used to probe the hole to check for perforation of the far cortex. If penetration of the cortex does not occur, the drill guide is adjusted to allow 2 mm of further advancement. Penetration of the far cortex usually occurs at 15 to 18 mm.

Holes are placed initially in the thoracic pedicles, then in the most superior cervical lateral mass to be incorporated in the construct. The AO reconstruction plates with an 8- or 12-mm hole spacing are contoured to fit the curvature of the cervicothoracic region (Fig. 2 *left*). Prior to plate attachment, the dorsal third of all facet joints to undergo arthrodesis is decorticated, and cancellous autologous bone graft is inserted. The plate is affixed to the spine with screws at the thoracic and cervical sites (Fig. 2 *center* and *right*). The same drilling procedure is followed to place screws in the remaining caudal cervical lateral masses, with the exception that the existing plate holes define the entry point and must be carefully selected to obtain the best possible trajectory. Interspinous wiring was used in those patients with intact spinous processes primarily to secure an autologous bone graft. The duration of postoperative immobilization was 2 months and was achieved using a Minerva brace in 21 patients and a Philadelphia collar in two patients.

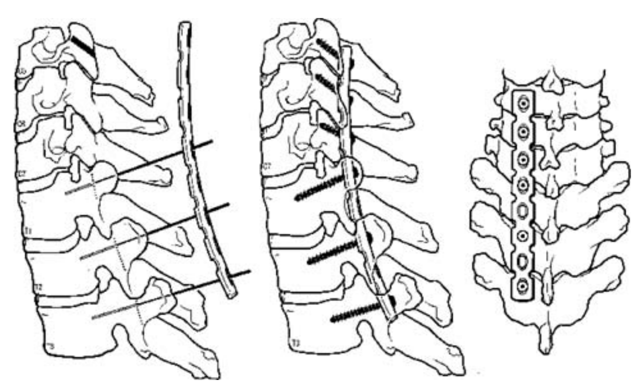

FIG. 2. Schematic drawings showing attachment of the plate. *Left:* The plate is contoured accurately by placing Kirschner wires into the holes drilled in the thoracic pedicles, then sliding the plate over the wires. This ensures that the holes in the plate will accurately line up with the holes in the spine. *Center:* Screw placement across the cervicothoracic junction. Note that the cervical lateral mass screws are angled cephalad and the thoracic pedicle screws are angled caudad. *Right:* A dorsal view after plate application. Note that screws are usually placed in every hole in the cervical spine and in every other hole in the thoracic spine. The surgeon must make accommodations for each individual's anatomy.

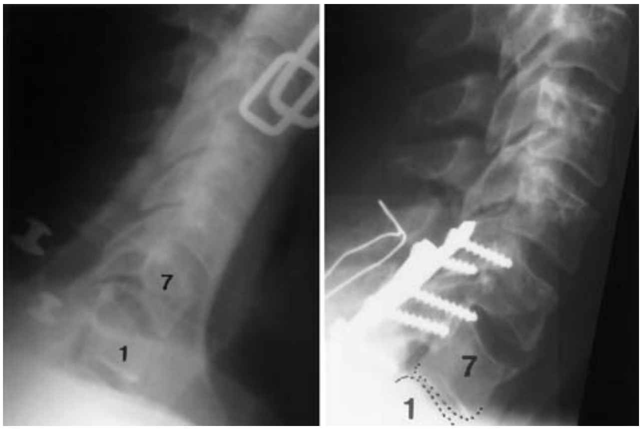

FIG. 3. Case 1. Lateral radiographs obtained prior to surgery *(left)* and 9 months postoperation *(right).*

Follow-Up Study

Patient follow up was conducted by physical examination and radiological studies. Lateral radiographs obtained prior to surgery, immediately postoperation, and at follow up were measured for sagittal plane deformity (by Cobb angle) and for vertebral body translation. Fusion was assessed clinically and by flexion-extension radiographs. Neurological condition was graded according to Frankel, *et al.*[18] (Grades A–E). The presence or absence of neck and extremity pain or any other complications was noted.

Illustrative Cases

Case 1. This 40-year-old man was involved in a fall from which he suffered a T-1 burst fracture. On examination he was determined to have a Grade D incomplete spinal cord injury. Figure 3 *left* shows this patient's initial radiograph. His displacement measured 2.5 mm and his angle of kyphosis was 23˚. Instrumentation and fusion from C6–T2 were performed. Nine-month follow-up radiographs (Fig. 3 *right*) showed a stable construct with no translation at C7–T1 and an 8˚ kyphosis; on physical examination the patient was intact (Grade E). Radiographs obtained at a 24-month follow-up examination showed no change in alignment.

Case 2. This 46-year-old man was injured while logging. His initial neurological exam showed a Grade C spinal cord injury, with normal cervical spine radiographs. Computerized tomography scans (Fig. 4 *left*) showed fracture dislocations at C7–T1 and at T3–4. The patient received reduction while prone using a 20-lb tong traction (Fig. 4 *center*). He then underwent posterior instrumentation and fusion from C5–T6. Radiographs obtained at 1 year (Fig. 4 *right*) showed good alignment, although the patient complained of interscapular pain at the time. The instrumentation was removed and a solid arthrodesis was identified at surgery. Removal of hardware failed to improve the patient's pain.

Results

Patient Demographics

The patients in this study ranged in age from 27 to 73 years with an average age of 47 years. Fifteen patients were men and eight were women. Radiological studies for all patients revealed unstable spines, as determined by the criteria of White and colleagues.[34] Nineteen patients had fractures or ligamentous instabilities caused by trauma. Twelve patients were involved in motor vehicle accidents with acute onset of instability; four were injured by falls (two of these individuals had ankylosing spondylitis); two were struck by falling trees while logging; and one patient was involved in a car–bicycle accident. Two patients developed instability after laminectomy for spondylosis and demonstrated progressive kyphosis and translation that corrected in extension. Two patients had metastatic tumors at the cervicothoracic junction involving both posterior and anterior elements of the vertebral bodies of C-7 and T-1. The duration of follow up averaged 15 months for the surviving patients (range 6–41 months). Two patients died at 2 and 4 months after surgery secondary to respiratory compromise. Another patient died accidentally from carbon monoxide poisoning 18 months after surgery.

Neurological Outcome

Neurological examination revealed the diversity within this population. Four patients were neurologically intact and five patients suffered from localized radiculopathies. Fourteen patients had a spinal cord injury, of which seven

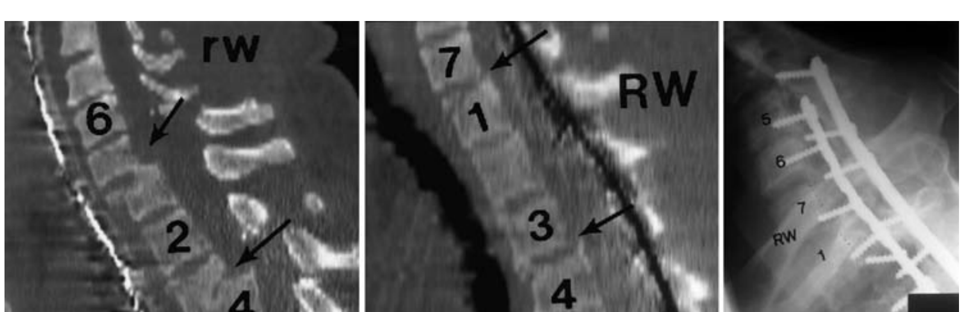

FIG. 4. Case 2. *Left* and *Center:* Computerized tomography scans obtained prior to surgery *(left)* and after closed reduction *(center).* *Right:* Lateral radiograph obtained 1 year postfusion showing good alignment and no evidence of hardware failure.

injuries were complete and seven incomplete. Patients were graded according to Frankel, *et al.*[18] On follow-up examination, no patient's neurological status deteriorated subsequent to surgery. The four patients who were intact before surgery remained intact at follow up. The five patients with radiculopathy all improved to asymptomatic at follow up. All incomplete quadriplegics improved at least one Frankel grade. All three Grade D patients improved to Grade E. Of the four patients with Grade C incomplete spinal cord injury, two improved to Grade D, and two improved to Grade E. Of the seven patients with complete spinal cord injury (Grade A), five remained unchanged, one improved to Grade B, and one to Grade C.

Spinal Anatomy and Reconstruction

Fracture types were equally variable. Six patients had vertebral body burst fractures, five at C-7 and one at T-2. Five patients had unilateral or bilateral facet fracture/dislocations and three patients had pure dislocations. Five patients had multiple element fractures at two to five levels. Two patients' instability was the result of previous accidents and spine procedures. Two patients had metastatic lesions of the vertebral bodies of C-7 and/or T-1.

The number of motion segments fused ranged from two to nine with an average of four. The length of instrumentation and fusion was determined by the particular underlying pathology as identified by a combination of plain radiographs, CT myelography, and/or MR imaging. Significant ligamentous injury was identified by widened interspinous process distance associated with kyphosis or facet joints showing separation on axial MR images or CT scans. Treatment of the burst fractures usually necessitated two or three levels of fusion; however, two cases with additional ligamentous injuries required more: one case included five motion segments and one included nine motion segments. Typically, patients with fracture dislocations required arthrodesis at two or three segments to achieve adequate stability; those with pure dislocations required three to four levels of fusion. Patients with multilevel injuries were successfully treated with arthrodesis of three to six motion segments. Patients with instability due to previous spinal procedures and those with metastatic lesions required five to seven motion segments of fusion.

All patients achieved a solid arthrodesis based on flexion–extension radiographs. The averages and ranges of translational and sagittal plane deformity before surgery, immediately after surgery, and at follow up are listed in Table 1. One patient with a previous fusion mass exhibited an increase in displacement from 0 mm to 3 mm on follow up; his kyphosis was reduced from 15° to 0°. This patient's x-ray films showed solid arthrodesis and he has experienced no postoperative complications.

TABLE 1

*Sagittal plane deformity and vertebral translation in 23 patients with cervicothoracic instability**

Factor	Immediate Preop	Postop	At Follow Up
kyphosis (°)			
mean	1.8	0.1	−4
range	30–(−30)	15–(−24)	10–(−23)
translation (mm)			
mean	2.6	1.5	0.7
range	0–11	0–10	0–5

* Negative numbers in parentheses refer to lordosis.

Postoperative Complications

One patient reported mild pain at follow up, whereas two patients reported significant pain. A 72-year-old woman reported occasional pain in her left shoulder girdle. A 40-year-old man, whose initial instability resulted from a fall, reported no pain until 39 months after surgery. That patient's flexion–extension radiographs revealed satisfactory alignment and solid fusion with no change from previous studies. A 46-year-old man had mechanical upper thoracic and interscapular pain despite excellent alignment and no apparent evidence of impingement of neural structures on radiography (Case 2). Twenty-one months after the initial fusion, the patient's hardware was removed in the hope of alleviating his pain, but no relief was obtained. At surgery, no evidence of pseudarthrosis could be identified.

No vascular or pulmonary complications were caused by this procedure. In one patient, two screws loosened but there was no plate failure and flexion–extension radiographs revealed solid arthrodesis. Wound dehiscence with no evidence of infection occurred in one patient 3 weeks after surgery; the wound healed after extensive debridement. There was a 3-mm retropulsion of a burst fragment in one patient, which caused slight canal compromise with no associated neurological problems; CT scans obtained 1 year after injury demonstrated complete resorption of the bone chip. One patient had a fusion that extended one level higher than the plate, but there were no associated complications.

Discussion

Diagnosis and treatment of the unstable cervicothoracic junction is particularly problematic for a number of reasons.[15,26] Lateral radiographs of the cervical spine often fail to reveal the anatomy at the cervicothoracic junction. The "swimmer's view" is often used to visualize this region. With this technique, the x-ray tube is positioned above the shoulder remote from the film and pointed toward the contralateral axilla adjacent to the film with the tube angled 10° to 15° toward the head. This view can be difficult to interpret, particularly in the obese or muscular patient, because of poor technique or viewer inexperience. In cases in which standard radiographs fail to image the region adequately or the patient is suspected of having a cervicothoracic fracture, CT should be used.

Treatment of cervicothoracic injuries is challenging because of significant biomechanical forces present at this portion of the spinal column. The lordotic and highly mobile cervical spine connects with the kyphotic and relatively immobile thoracic spine, resulting in a region that is structurally precarious.[2,13] Past treatment of cervicothoracic fractures has included external orthoses and immobilization with limited success. The halo fixation device is the most commonly used device to immobilize the unsta-

TABLE 2
*Pedicular anatomy of the cervicothoracic junction**

Anatomical Factor	Level	Authors & Year: An, *et al.*, 1994	Chapman & Anderson, 1994	Misenhimer, *et al.*, 1989	Zindrick, *et al.*, 1987
no. of specimens		22	4	6	24
coronal angulation (°)	C-7	34 (27–40)	41 (39–44)	—	—
	T-1	31.8 (27–37)	32 (30–33)	—	27 (16–33.5)
	T-2	26.5 (20–35)	31 (28–36)	—	19 (6–32)
sagittal angulation (°)	C-7	—	—	—	—
	T-1	—	—	—	—
	T-2	—	—	—	—
pedicle depth (mm)	C-7	33 (29–37)	—	—	—
	T-1	34.3 (28–39)	—	—	36.9 (26–45)
	T-2	38.2 (33–45)	—	—	38.2 (33–45)
inner pedicle diameter (mm)	C-7	5.2 (4–6.2)	7 (outer)	—	—
	T-1	6.3 (5–9)	9.4 (outer)	7.0 (6.5–8.5)	7.9 (5–10)
	T-2	5.5 (5–7)	11.8 (outer)	6.25 (4.8–8)	7 (3.5–10)
interpedicular distance (mm)	C7–T1	15.3 (13–18)	14	—	—
	T1–T2	—	18.3	—	—

* Mean values are provided with ranges indicated within parentheses. — = not done.

ble cervical spine. Compared with other orthoses, the halo vest provides a more rigid immobilization of the cervical spine. However, failure of immobilization in the lower cervical spine is well documented in the literature, presumably owing to residual mobility at individual segments of the unstable spine.[32,35] Complications of halo immobilization include pin-site infections, pressure sores, nerve injury, dural penetration, dysphagia, severe pin discomfort, and disfiguring scarring.[19,20] These sequelae can be minimized by careful application of the apparatus.

Surgical treatment aimed at immediate stability is appealing because it provides spinal stability and permits early mobilization and rehabilitation. In the cervical spine the biomechanical features of the injury help direct the surgical technique. Lesions involving the vertebral body or disc are indications for anterior stabilization; lesions of the posterior elements are indications for posterior stabilization. Multiple techniques are well described for either approach.

Gaining access to the anterior aspect of the cervicothoracic junction is more difficult due to the presence of the sternum, clavicle, and great vessels, and the transition from cervical lordosis to thoracic kyphosis, which causes a significant variation in wound depth. Three basic techniques have been described to expose the anterior cervicothoracic junction: high transthoracic, lower anterior neck, and sternal splitting; selection of the appropriate technique depends on the extent of exposure required and the type of deformity.[27]

A kyphotic deformity may be approached with the high transthoracic approach in which a periscapular incision is made followed by resection of a portion of the third rib and displacement of the scapula forward and upward.[21] This technique provides limited exposure and involves the inherent risks of entering the chest cavity. A combined anterior thoracic and cervical approach that provides access from C3–T9 has been described by Micheli and Hood,[24] who reported successful fusions in six patients with severe cervicothoracic kyphoscoliosis using this approach.

Numerous low anterior neck approaches that provide limited exposure to the upper thoracic spine have been described. The supraclavicular approach provides limited exposure of the region; the transclavicular approach allows good access to the upper three thoracic vertebrae but seems unnecessarily destructive.[11,17] Birch, *et al.*,[5] reported a method that involves the elevation of the medial corner of the manubrium, the sternoclavicular joint, and the medial half of the clavicle on a pedicle of the sternocleidomastoid muscle. This exposure was used in 17 cases with good results and minimal complications.

Sternal splitting, as first described by Cauchoix and Binet,[9] has yielded unfavorable results. Using this technique, Hodgson and colleagues[22] reported a limited surgical field and a 40% mortality rate. Later, Sundaresan and coworkers[32,33] described a modified transsternal approach to T-1 and T-2 that involves resection of a portion of the clavicle and manubrium with much better results; Charles and Govender[11] also reported favorable results with this technique. Kurz, *et al.*,[23] recently reported three slight modifications to Sundaresan's approach that allow excellent visualization and working room from C3–T4 and hemostatic control of the great vessels. Generally, procedures involving an anterior approach to the cervicothoracic junction tend to be complex with potential for significant morbidity.

In 1979, Roy-Camille, *et al.*,[28] described a technique of cervical posterior instrumentation in which plates were fixed with screws to the lateral processes. A 95% fusion rate was reported by Cooper and coworkers[12] using this technique; Ebraheim and colleagues[14] reported a 100% fusion rate using this technique combined with autogenous iliac bone grafting. The use of other instrumentation for stabilization has been proposed and advocated, including interlaminar clamps, Daab plates, Harrington rods for long facet fusions, and hook plates.

A variation in screw placement from the technique of Roy-Camille, *et al.*,[28] was described by Anderson, *et al.*,[3] in 1991. Roy-Camille, *et al.*, advocated starting the screw in the exact center of the facet and aiming straight forward, whereas Anderson, *et al.*, advocated screw placement similar to the technique of Grob and Magerl,[21] in which screws are started 1 mm medial to the center of the facet and angled 30° upward and 10° outward. Biomechanical testing of these two techniques revealed more stiffness and a higher load to failure using the Anderson technique.

Posterior plating of the cervicothoracic junction requires a variation in the site of screw placement from previously described techniques. In the cervical spine screws are placed in the lateral masses, but in the thoracic spine the lateral masses evolve into the transverse processes, which may be insufficiently strong for screw placement. A thorough understanding of the morphology of the cervicothoracic spine is very useful (Table 2). Stanescu, *et al.*,[30] provide a detailed report of morphometry of the cervicothoracic junction. The thoracic pedicle width decreases as one proceeds from T1–5, from an average of 7.8 mm to 4.4 mm. The screws used in this reported series have a diameter of 3.5 mm, increasing the risk of pedicle screw insertion at the T4–5 level. Furthermore, the inward angle of the pedicle grows more perpendicular to the vertebral body from T1–5 because the lamina width decreases.

Conclusions

Posterior lateral mass plating with AO reconstruction plates and autogenous iliac bone graft has proved to be a successful method of treatment for fractures of the cervicothoracic junction based on the parameters of our investigation. No patient's neurological status deteriorated as a result of this procedure. All patients had a solid arthrodesis based on flexion–extension radiographs. Only one patient experienced an increase in deformity (3 mm of displacement), which was not clinically significant. Complications due to the surgery were minimal and no vascular or pulmonary accidents occurred. Significant pain was experienced by only 8% of the patients. Circumstances in which a posterior only approach would be insufficient or inadequate include anterior pathology that compromises the spinal canal or potential for loss of vertebral body height due to tumor. In these situations, an anterior decompression with vertebral body or disc space reconstruction can be combined with posterior instrumentation and fusion if satisfactory anterior instrumentation is not possible or likely to fail.

In summary, posterior cervicothoracic arthrodesis using AO reconstruction plates and autogenous iliac bone graft is a promising method of treatment for cervicothoracic instability.

References

1. Aebi M, Mohler J, Zach GA, et al: Indication, surgical technique, and results of 100 surgically-treated fractures and fracture-dislocations of the cervical spine. **Clin Orthop 203:**244–257, 1986
2. An HS, Vaccaro A, Cotler, JM, et al: Spinal disorders at the cervicothoracic junction. **Spine 19:**2557–2564, 1994
3. Anderson PA, Henley MB, Grady MS, et al: Posterior cervical arthrodesis with AO reconstruction plates and bone graft. **Spine 16 (Suppl 3):**72–79, 1991
4. Bailey RW, Badgley CE: Stabilization of the cervical spine by anterior fusion. **J Bone Joint Surg (Am) 42:**565–594, 1960
5. Birch R, Bonney G, Marshall RW: A surgical approach to the cervicothoracic spine. **J Bone Joint Surg (Br) 72:**904–907, 1990
6. Böhler J, Gaudernak T: Anterior plate stabilization for fracture-dislocations of the lower cervical spine. **J Trauma 20:**203–205, 1980
7. Bracken MB, Shepard MJ, Collins WF Jr, et al: Methylprednisolone or naloxone treatment after acute spinal cord injury: 1-year follow-up data. Results of the second National Acute Spinal Cord Injury Study. **J Neurosurg 76:**23–31, 1992
8. Caspar W, Barbier DD, Klara PM: Anterior cervical fusion and caspar plate stabilization for cervical trauma. **Neurosurgery 25:**491–502, 1989
9. Cauchoix J, Binet JP: Anterior surgical approaches to the spine. **Ann R Coll Surgeons 21:**237–243, 1957
10. Chapman J, Anderson PA: Posterior plate fixation of the cervico-thoracic junction. **Techn Orthop 9:**80–85, 1994
11. Charles R, Govender S: Anterior approach to the upper thoracic vertebrae. **J Bone Joint Surg (Br) 71:**81–84, 1989
12. Cooper PR, Cohen A, Rosiello A, et al: Posterior stabilization of cervical spine fractures and subluxations using plates and screws. **Neurosurgery 23:**300–306, 1988
13. Delamarter RB, Batzdorf U, Bohlman HH: The C7–T1 junction: problems with diagnosis, visualization, instability and decompression. **Orthop Trans 13:**218, 1989 (Abstract)
14. Ebraheim N, An HS, Jackson WT, et al: Internal fixation of the unstable cervical spine using posterior Roy-Camille plates: preliminary report. **J Orthop Trauma 3:**23–28, 1989
15. Evans DK: Dislocations at the cervicothoracic junction. **J Bone Joint Surg (Br) 65:**124–127, 1983
16. Fehlings MG, Cooper PR, Errico TJ: Posterior plates in the management of cervical instability: long-term results in 44 patients. **J Neurosurg 81:**341–349, 1994
17. Fielding JW, Stillwell WT: Anterior cervical approach to the upper thoracic spine. **Spine 1:**158–161, 1976
18. Frankel H, Hancock DO, Hyslop G, et al: The value of postural reduction in the initial management of closed head injuries of the spine with paraplegia and tetraplegia. **Paraplegia 7:**179–192, 1969
19. Garfin S, Botte MJ, Waters RL, et al: Complications in the use of the halo fixation device. **J Bone Joint Surg (Am) 68:**320–325, 1986
20. Glaser JA, Whitehill R, Stamp WG, et al: Complications associated with the halo-vest. A review of 245 cases. **J Neurosurg 65:**762–769, 1986
21. Grob D, Magerl F: Dorsale Spondylodese der Halswirbelsäule mit der Hakenplatte. **Orthopäde 16:**55–61, 1987
22. Hodgson A, Stock FE, Fang HSY, et al: Anterior spinal fusion: the operative approach and pathological findings in 412 patients with Pott's disease of the spine. **Br J Surg 48:**172–178, 1960
23. Kurz LT, Pursel SE, Herkowitz HN: Modified anterior approach to the cervicothoracic junction. **Spine 16 (Suppl 10):**542–547, 1991
24. Micheli LJ, Hood RW: Anterior exposure of the cervicothoracic spine using a combined cervical and thoracic approach. **J Bone Joint Surg (Am) 65:**992–997, 1983
25. Misenhimer GR, Peck RD, Wilse LL, et al: Anatomic analysis of pedicle cortical and cancellous diameter as related to screw size. **Spine 14:**367–372, 1989
26. Nichols CG, Young DH, Schiller WR: Evaluation of cervicothoracic junction injury. **Ann Emerg Med 16:**640–642, 1987
27. Perry J: Surgical approaches to the spine, in Pierce D, Nickel

VH (eds): **The Total Care of Spinal Cord Injuries.** Boston: Little, Brown & Co, 1977, pp 53–79

28. Roy-Camille R, Saillant G, Berteaux D, et al: Early management of spinal injuries, in McKibbin B (ed): **Recent Advances in Orthopedics.** Edinburgh: Churchill-Livingstone, 1979, pp 57–87
29. Segal D, Whitelaw GP, Gumbs V, et al: Tension band fixation of acute cervical spine fractures. **Clin Orthop 159:**211–222, 1981
30. Stanescu S, Ebraheim NA, Yeasting R, et al: Morphometric evaluation of the cervico-thoracic junction. Practical considerations for posterior fixation of the spine. **Spine 19:**2082–2088, 1994
31. Stauffer ES, Rhoades ME: Surgical stabilization of the cervical spine after trauma. **Arch Surg 111:**652–657, 1976
32. Sundaresan N, Shah J, Feghali JG: A transsternal approach to the upper thoracic vertebrae. **Am J Surg 148:**473–477, 1984
33. Sundaresan N, Shah J, Foley KM, et al: An anterior surgical approach to the upper thoracic vertebrae. **J Neurosurg 61:** 686–690, 1984
34. White AA, Southwick WO, Panjabi MM: Clinical instability in the lower cervical spine. A review of past and current concepts. **Spine 1:**15–27, 1976
35. Whitehill R, Richman JA, Glaser JA: Failure of immobilization of the cervical spine by the halo vest. A report of five cases. **J Bone Joint Surg (Am) 68:**326–332, 1986
36. Zindrick MR, Wiltse LL, Doornik A, et al: Analysis of the morphometric characteristics of the thoracic and lumbar pedicles. **Spine 12:**160–166, 1987

Manuscript received August 2, 1995.
Accepted in final form October 9, 1995.

Address reprint requests to: Jens R. Chapman, M.D., Department of Orthopaedics, University of Washington, Harborview Medical Center, 325 Ninth Avenue, Box 359798, Seattle, Washington 98104.