Transpedicular Screw Fixation for Traumatic Lesions of the Middle and Lower Cervical Spine: Description of the Techniques and Preliminary Report

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Summary: Thirteen patients with fractures and/or dislocations of the middle and lower cervical spine were treated by transpedicular screw fixation using the Steffee variable screw placement system. Postoperative immobilization was either not used or simplified to short-term use of a soft neck collar. Recovery of nerve function and correction of kyphotic and/or translational deformities were satisfactory. All patients had solid fusion without loss of correction at the latest follow-up. There were no neurovascular complications. It was concluded that transpedicular screw fixation is as strong a fixation procedure for the cervical spine as it is for the thoracic and lumbar spine. This surgical procedure is associated with some risks of major neurovascular injuries; however, safety is adequate if the procedure is performed by experienced surgeons using meticulous surgical techniques. Key Words: Transpedicular screw fixation—Cervical spine—Spinal injury.

The indications for surgical stabilization of cervical spinal fractures and dislocations have been controversial. However, at the present time, in cases of neurological involvement most investigators recommend surgical reduction, decompression, and stabilization (3,15,19,21). For the traumatic unstable cervical spine, spinal instrumentation, e.g., anterior cervical plate, spinous process wiring, Luque SSI, posterior plate-screw fixation, and others are available for immediate stabilization of the unstable segment. In posterior screw fixation methods for the middle and lower cervical spine (i.e., the plate-screw fixation initially performed by Roy-Camille and the hook-plate stabilization by Magerl et al. and others), screws are inserted into the lateral portion of the articular masses, not extending beyond the posterior column (5,9,13,19-21). Thus, there is not much difference in stability between the posterior cervical plate and nonscrew fixation methods based on the results of comparative biomechanical studies, with the exception of the flexural stability provided by the posterior hook-plate described by Ulrich et al. (4,8,23,24). On the other hand, in the thoracic and lumbar spine, transpedicular screw fixation methods offer three-column stability and have proven to be the most rigid posterior fixation methods (12).

In the upper cervical spine, the procedure for posterior C1-2 transarticular screw fixation described by Magerl et al. does not call for the screws to be inserted into the C2 pedicles; they cross the isthmus close to its posterior surface and exit C2 at the posterior rim of the upper articular surface (14). Roy-Camille et al. have reported direct screw fixation of C2 pedicles in a hangman fracture (20,21). However, there have been no reports referring to transpedicular screw fixation in the middle or lower cervical spine.
Our concept was that screws for posterior plate fixation inserted into the vertebral body through the pedicle would provide better stability and strength than the other fixation anchors, including the lateral mass screw in the cervical spine. In August 1990, the senior author (K.Ao) started performing transpedicular screw fixation with the Steffee variable screw placement (VSP) system (22) to treat middle and lower cervical spinal injuries. The purpose of this study is to report the early results in 13 cases of middle or lower cervical spinal injuries treated by transpedicular screw fixation, to describe our indications and techniques, and to recommend this procedure for more extended cervical disorders in addition to traumatic lesions.

MATERIALS AND METHODS

Thirteen patients with middle or lower cervical spinal injury were treated by transpedicular screw fixation using the Steffee VSP system at Kushiro Rosai Hospital and Hokkaido University Hospital between August 1990 and April 1992 (Table 1). There were 12 men and one woman, with an average age of 43.2 years (range 15–80). The cause of the injury was a fall in six patients, a motor vehicle accident in five, and a sports injury in two. The types of fractures and dislocations were described according to the mechanistic classification of Allen et al. (2). Distractive flexion injury including stages 1, 2, and 3 occurred in seven cases. Stage 1 compressive extension injury occurred in five cases, including four cases of unilateral superior articular process fracture and one case of a separation fracture of the articular mass described by Judet et al. (11). Stage 3 vertical compression injury occurred in one case. Impaired motion segments were C4–5 in three patients, C5–6 in two, C6–7 in five, C7–T1 in one, C4–6 in one with stage 3 vertical compression injury, and C5–7 in one with a separation fracture of the C6 articular mass. Preoperatively, according to the Frankel criteria (7), there were three patients with complete loss of spinal cord function (grade A) and five patients with an incomplete spinal cord lesion (grade B in two, grade C in one, and grade D in two). Another five patients with stage 1 compressive extension injury had a single nerve root lesion. The time interval from injury to surgery ranged from 7 h to 81 days.

Preoperative Management

Patients were immobilized with a Philadelphia collar. Cervical traction with tongs was not used because

<table>
<thead>
<tr>
<th>Case</th>
<th>Cause of Injury</th>
<th>Age (yr)</th>
<th>Gender</th>
<th>Mechanism of Injury</th>
<th>Fusion level</th>
<th>Neurological function by Frankel criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fall</td>
<td>63/M</td>
<td>M</td>
<td>Compressive extension</td>
<td>C5-6 + AF</td>
<td>E</td>
</tr>
<tr>
<td>2</td>
<td>Fall</td>
<td>29/M</td>
<td>M</td>
<td>Compressive extension</td>
<td>C5-6 + C7</td>
<td>E</td>
</tr>
<tr>
<td>3</td>
<td>Fall</td>
<td>21/M</td>
<td>M</td>
<td>Compressive extension</td>
<td>C5-6 + C7</td>
<td>E</td>
</tr>
<tr>
<td>4</td>
<td>Fall</td>
<td>21/M</td>
<td>M</td>
<td>Distractive flexion</td>
<td>C5-6 + C7</td>
<td>A</td>
</tr>
<tr>
<td>5</td>
<td>Fall</td>
<td>37/M</td>
<td>M</td>
<td>Distractive flexion</td>
<td>C5-6 + C7</td>
<td>A</td>
</tr>
<tr>
<td>6</td>
<td>Fall</td>
<td>80/M</td>
<td>M</td>
<td>Distractive flexion</td>
<td>C5-6 + C7</td>
<td>A</td>
</tr>
<tr>
<td>7</td>
<td>Fall</td>
<td>15/M</td>
<td>M</td>
<td>Distractive flexion</td>
<td>C5-6 + C7</td>
<td>A</td>
</tr>
<tr>
<td>8</td>
<td>Fall</td>
<td>19/F</td>
<td>F</td>
<td>Distractive flexion</td>
<td>C5-6 + C7</td>
<td>C</td>
</tr>
<tr>
<td>9</td>
<td>Fall</td>
<td>75/M</td>
<td>M</td>
<td>Distractive flexion</td>
<td>C5-6 + C7</td>
<td>D</td>
</tr>
<tr>
<td>10</td>
<td>Fall</td>
<td>64/M</td>
<td>M</td>
<td>Distractive flexion</td>
<td>C5-6 + C7</td>
<td>D</td>
</tr>
<tr>
<td>11</td>
<td>Fall</td>
<td>12/M</td>
<td>M</td>
<td>Distractive flexion</td>
<td>C5-6 + C7</td>
<td>D</td>
</tr>
<tr>
<td>12</td>
<td>Fall</td>
<td>12/M</td>
<td>M</td>
<td>Distractive flexion</td>
<td>C5-6 + C7</td>
<td>D</td>
</tr>
<tr>
<td>13</td>
<td>Fall</td>
<td>10/M</td>
<td>M</td>
<td>Distractive flexion</td>
<td>C5-6 + C7</td>
<td>D</td>
</tr>
</tbody>
</table>

- MVA, motor vehicle accident; AF, anterior fusion.
- Unilateral plating, unilateral wiring, or unilateral wiring of the lateral mass.
- Separated fracture of the lateral mass.
TRANSPEDICULAR SCREW FIXATION

of magnetic resonance imaging (MRI) examination, except in one case of extremely unstable stage 3 distractive flexion injury. Plain roentgenography, anteroposterior (AP) and lateral laminography, computed tomography (CT), and MRI were performed in all cases. Myelography was also performed in six cases.

Implants

The Steffee VSP system was originally designed for the lumbar spine and then used in the thoracic spine, so even the smallest plate is too large for the cervical spine. To fix a single motion segment in the middle or lower cervical spine, an original plate with two nested slots was divided, and both ends of the plate were shaved off with a grinder to avoid irritating the adjacent facet joints. The tips of 4.5-mm diameter VSP screws were cut off to proper length before or during surgery.

Surgical Procedure

After intubation, patients were put into the prone position on a Relton-Hall frame. The head was taped to the headrest with the cervical spine maintained in a neutral position, and the shoulders were pulled caudally by a heavy bandage for intraoperative lateral radiographic imaging of the lower cervical spine. A posterior midline skin incision was made, and the paravertebral muscles were dissected laterally to expose the lateral margins of the compromised facet joints. Because the insertion angle of the screw was intended to be 30–40° medially to the midline in the transverse plane, a longer skin incision was required than for a standard spinous process wiring procedure. In the six patients with facet-interlocking, stage 2 and 3 distractive flexion injuries, partial resection of the facet joint was performed bilaterally or unilaterally for reduction. In the five cases of nerve root compression by articular bone fragment, the fragment in the neural foramen was removed after partial resection of the inferior articular process.

The point of screw penetration at the posterior cortex of the articular mass was determined slightly laterally to the center of the articular mass and close to the posterior margin of the superior articular surface, taking into consideration the location of the vertebral artery, the spinal cord, and the pedicle (Fig. 1A). Before inserting the screws, the cortex at the point of insertion was penetrated with a high-speed burr and the entrance hole was enlarged to proper size to bury the screw anchor into the articular mass. After creating the screw insertion hole, the entrance of the pedicle was visible directly (Fig. 2A). A small nerve retractor was used for a pedicle probe, and the inner wall of the pedicle cavity was palpable with the retractor. The direction and the insertion depth of the retractor and the screw were confirmed by the intraoperative lateral image intensifier. In the patients with facet interlocking and those with articular process fractures, the inferomedial portion of the upper pedicle and the superomedial portion of the lower pedicle were palpable with the nerve retractor through the defect created by excision of the articular processes. Laminotomy was not performed to identify the medial aspect of the pedicle.

The intended angle of the screws based on measurements of preoperative CT images was 30–40° medial to the midline in the transverse plane (Fig. 1B), and parallel to the upper end-plate in the sagittal plane. Drilling of the pedicle was not performed to avoid neurovascular injuries. Insertion of the screw was greater than two thirds of the AP vertebral body depth, and the anterior cortex was penetrated by four screws in two cases.

MRI demonstrated retropulsed disk materials at the injured level in two patients. In those patients, to avoid neurological deterioration, slight distraction force was applied between the upper and lower screws before tightening the nuts. Decortication of the lamina and spinous processes was performed after completion of the instrumentation. Finally, chipped bones were routinely placed between the spinous processes and on the remaining exposed facet joint and laminae. An H-shaped bone was grafted between the spinous processes in six patients (Fig. 2B). The grafted bone was obtained from the ilium in nine cases and from the adjacent spinous processes in four. One-level
fixation was performed in 10 patients, whereas two-
level fixation was required in three patients, i.e., in a stage 3 vertical compression injury, in a C6-7 com-
pressive extension injury associated with disruption of the C7 vertebral body, and in a separation fracture of the C6 articular mass with instability at two motion segments. In the case of the vertical compression injury with severe spinal cord compression by a comminuted vertebral body, additional anterior decompression and an iliac strut bone graft was performed after the posterior surgery. In one of the cases of compressive extension injury, one of the pedicles was distracted by screwing, and plating was performed unilaterally with subsequent anterior interbody fusion. All surgery was performed by the senior author (K.A.), except in one case in which it was performed by the second author (H.I.), and the operative techniques were same in all cases.

Postoperative Management and Clinical Evaluation

Postoperative immobilization varied according to the patient’s neurological status, general condition, and type of employment. Patients with severe spinal cord lesions (Frankel grade A or B) started their rehabilitation 5–10 days after surgery without any external support. Eight patients with mild nerve lesions (Frankel grades C and D, and radiculopathy) were allowed to ambulate with a soft neck collar the day after surgery. These eight patients and one of the Frankel B patients returned to their original jobs 3–6 weeks after surgery, before bony union was complete. The collar was worn for 8 weeks in five patients who returned to heavy work. However, the collar was worn only for 2–3 weeks in three patients who returned to light work.

Follow-up physical examinations and radiographic evaluations were performed on all patients. To assess stability and deformity, flexion-extension and oblique x-ray films were obtained in all patients 3, 6, 9, and 12 months after surgery, and if possible at 18 and 24 months. Lateral laminograms were obtained in all patients 6 and 12 months after surgery. Bony union was evaluated independently by three of the authors (K.A., H.I., H.T.). An assessment of solid union was made on the basis of the presence of a homogeneous fusion mass on lateral laminograms and a segmental motion of <2° on flexion-extension films. Postoperative CT scans were obtained in all patients to assess screw placement. The CT window and width were adjusted to reduce metal artifacts. The range of follow-up for these patients was 12–32 months, with an average of 22 months.

RESULTS

Duration of surgery and intraoperative blood loss for the posterior procedure were measured, excluding the anterior surgical portion, in two cases of combined anterior and posterior surgery. The average operation time was 145 min (range 95–210), and the average intraoperative blood loss was 283 ml (range 50–600). There were no increases in neurologic deficit in this series. Using the Frankel criteria, three Frankel A patients remained Frankel A; however, two of these three patient showed descent of the level of paralysis by one or two spinal cord segments. Two Frankel B
patients improved to Frankel C and D, and one Frankel C patient, two Frankel D patients, and five patients with radiculopathy returned to normal neurologic status.

At the latest follow-up, all cases had solid bony union. Three judges were unanimous about bony union in all cases. There were no cases of implant component, connection, or bone interface failure. Kyphotic and translational deformities were satisfactorily corrected, and the correction was maintained in all cases. No patients had loss of correction of kyphosis >1°; and correction of translation was maintained completely in all cases. The averages and ranges of translational and kyphotic deformity before surgery, immediately after surgery, and at follow-up are shown in Table 2. There were no complications involving the spinal cord, nerve roots, or vertebral artery.

Assessment of screw placement into the pedicle by postoperative CT images was difficult because of the metal artifacts, but the direction of the inserted screw...
could be assessed. The angle of the inserted screws ranged from 25° to 45° medial to the midline in the transverse plane. The medial cortex of the three pedicles in two patients, two of the C5 pedicles and one of the C6 pedicles (Fig. 3), appeared to be perforated by the screw threads. In one other case, according to the oblique film assessment, the site of insertion of one screw into the C5 pedicle was too far inferior, and some of the screw threads had obviously intruded into the neural foramen. There were no neurological complications in these three cases.

CASE PRESENTATIONS

The following are the case presentations (Table 1) with their corresponding figures: case 7 (Fig. 3), case 12 (Fig. 4), case 13 (Fig. 5), and case 11 (Fig. 6).

DISCUSSION

Surgical decompression and stabilization is required to treat most of the cases of cervical spinal injuries with neurological impairment. The decompression and stabilization procedure should differ depending on the pathology in each case. Surgical correction of the malalignment and stabilization by the isolated posterior or the combined anterior and posterior approach is common in cases of compressive flexion, compressive extension, distraction flexion, and stage 2 distractive extension injuries (15,19–21). Conversely, in vertical compression injuries with anterior spinal cord compression, anterior decompression and stabilization are indicated.

Usually, some of the anterior or posterior stabilizing structures are preserved to some extent, except in
stage 4 distractive flexion injuries or stage 5 compressive extension injuries. Therefore, from a biomechanical view point, it is preferable to avoid surgical destruction of the residual stabilizing structures. For this reason, an optimal procedure should be a single anterior or posterior method augmented by rigid instrumentation. Generally, posterior fixation devices have an advantage over anterior devices for the fixation of posterior injuries. Similarly, anterior fixation devices are more suitable than posterior devices for the fixation of anterior injuries (1).

Spinal fixation devices are required to control all types of spinal motion, i.e., translation along and rotation about each of the three axes of spinal motion. In addition, this multidirectional stabilizing capability is preferably obtained by isolated anterior or posterior short segmental fixation, saving as many free mobile segments as possible. However, the cortex of the vertebral bodies in the cervical spine is not as strong as that of the posterior bony elements. Consequently, even if the screws penetrate the posterior cortex of the vertebral body, anterior plate fixations do not provide as sufficient stability as posterior fixation procedures in cases of posterior injury or combined anterior and...
posterior injuries (4,23,24). Additional use of posterior instrumentation on anterior cervical plates may be recommended. At the present time, spinous process wiring, posterior plating, Luque SSI, and other techniques are available to stabilize the unstable cervical spine posteriorly. However, based on biomechanical studies, none of these fixation devices provides adequate stability in the combined anterior and posterior discoligamentous cervical injury model, except for flexural stability results provided by posterior hook-plate (4,8,23,24). According to the results of the biomechanical studies of posterior plate fixation by Gill et al. (8) and Montesano et al. (16), bicortical screws provided a better stabilizing effect than did unicortical screws. However, the stiffness provided by bicortical screws did not exceed that produced by spinous process wiring. Furthermore, screw insertion into the lateral portion of the articular mass exposes the spinal nerves or vertebral artery to injury (10), and sublaminar wiring places the cervical spinal cord at risk, especially in cases of narrowed spinal canal. Based on biomechanical studies, among established stabilizing procedures, only the combination of anterior and posterior instrumentation can be expected to provide sufficient stability for an extremely unstable cervical spine without major external support (24). Transpedicular screw fixation systems have been developed for the thoracic and lumbar spine, and
their excellent stability and strength allows the patients to walk immediately after surgery without any external support. Despite the perceived risks of thoracic and lumbar transpedicular screw placement, exact knowledge of the anatomy of the pedicle and careful surgical techniques allow safe placement. Except for pedicular screwing of C2 by Roy-Camille (20,21), transpedicular screw fixation in the cervical spine has not been performed for fear of injuring the vertebral artery, spinal cord, and nerve roots. Roy-Camille stated that screwing into the C3 to C6 pedicle would be an unacceptable risk (21). However, the pedicle of the cervical spine is a strong structure of the vertebra, as in the thoracic and lumbar spine. Thus, the stability obtained by transpedicular screw fixation in the cervical spine should be equal to or greater than that achieved by combined anterior and posterior instrumentation. However, further comparative biomechanical study is needed to assess the stabilizing effect by this procedure precisely.

The most severe complication of transpedicular screw fixation of the cervical spine is injury of the vertebral artery or spinal cord. Such complications, which could be fatal, should be completely prevented by exact screw placement into the pedicles. In some patients, especially in females, the diameter of the pedicles is too small to insert a screw. Consequently, CT examination, adjusted to the bony elements, is recommended preoperatively to determine the diameter of the pedicles, and the patients with very small pedicle diameters should be excluded from this procedure. Direct exposure of the pedicle cavity by creation of a hole at the insertion points and the use of pedicle probe and image intensifier are essential to the safety and success of cervical pedicle screw placement. In addition, we recommend confirmation of the location of the medial, superior, and inferior surfaces of the pedicles with a small nerve retractor, if possible, in cases in which facetectomy and/or laminotomy has been performed.

Panjabi et al. have reported a detailed anatomical study of the pedicles of the cervical spine (17). According to them, the average angle of the pedicle axes from lateral to midline in the transverse plane was 45° at C4, 39° at C5, 29° at C6, and 33° at C7. However, the screw insertion angle in this series, slightly less than these values in some cases, was acceptable and safe enough for both the spinal cord and the vertebral artery. Because of the small depth of the pedicle in the cervical spine, the direction of the screw insertion is not so severely restricted. The cervical nerve roots run anterolaterally at ~45° with respect to the coronal plane and downward ~10° with respect to the transverse plane (6,18). Within the foramina, they are located at and below the disk level, i.e., in the inferior half of the neural foramina (18). Thus, there is some room between the medial and inferior surface of the pedicle and the neural elements. Slight perforation of pedicle by screw threads in the medial or inferior direction is relatively safe for the spinal cord and nerve roots in the cervical spine. Anterior to the vertebral bodies covered by the anterior longitudinal ligament, the pharynx is located above C4 and the esophagus below C5 in the median portion. If screw insertion is too deep, the constrictor of the pharynx or esophagus may be injured. Too deep screw insertion, such as more than a few millimeter beyond the vertebral body, should be avoided.

In this series, perforation of the pedicle by screw threads was suspected in three pedicles and was obvious in one pedicle, despite proper screw direction. The cause of these perforations is suspected to be mainly the maladaptation between screw and pedicle diameter. According to the values reported by Panjabi et al., pedicle diameter is smallest at C3 or C4 and increases in size toward the cervicothoracic junction. Thus, in the mid-cervical spine, even the screw with the smallest diameter of 4.5 mm is sometimes too large. Screws of appropriate size for the mid-cervical spine need to be made.

Transpedicular screw fixation, with its stability and strength, appears to be a useful stabilizing procedure for the reconstruction of the injured cervical spine without destruction of the pedicle or vertebral body such as distractive flexion or compressive extension injuries. Moreover, this procedure is applicable as posterior reinforcement for vertebral body replacement in cases of vertical compression injury, spinal tumor, or tuberculous spondylitis of the cervical spine. In addition to these uses, transpedicular screw fixation would be useful for longer fixation, e.g., fixation from

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**TABLE 2. Angular and translational deformity in the sagittal plane**

<table>
<thead>
<tr>
<th></th>
<th>Preoperative</th>
<th>Postoperative</th>
<th>follow-up</th>
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<tbody>
<tr>
<td>Kyphosis (n = 13)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>10.9°</td>
<td>(-0.5°)</td>
<td>0°</td>
</tr>
<tr>
<td>Range</td>
<td>3-21°</td>
<td>(-4°)-3°</td>
<td>(-3°)-2°</td>
</tr>
<tr>
<td>Translation (mm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(n = 12)</td>
<td>6.4</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Range</td>
<td>1-14</td>
<td>0-2</td>
<td>0-1</td>
</tr>
</tbody>
</table>

*Note. Negative numbers in parentheses refer to lordosis. A case of vertical compression injury of C5 was excluded from measurements of translation.*

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the upper to lower cervical spine or from the middle cervical spine to the thoracic spine. It would also be useful for cases of destruction of the lamina because in such patients it is difficult to stabilize the spine by spinous process wiring or sublaminar wiring without sacrificing the adjacent intact motion segments.

From a review of this study, the stiff internal stabilizing effect of transpedicular screw fixation precludes the need for additional anterior surgery and postoperative external support even for extremely unstable cervical spines such as in the four cases of stage 3 distractive flexion injury treated in this series. The procedure allowed easy nursing care, early ambulation and rehabilitation, and early return to the patients previous job. There were no pseudarthroses or complications involving the vertebral artery, spinal cord, or nerve roots. Direct exposure of the pedicle cavity before screw placement and the help of an image intensifier adequately confirmed screw insertion. However, this surgical procedure is associated with some risks of major neurovascular injuries. Therefore, it requires precise knowledge of the anatomy of the cervical spine and meticulous surgical techniques, and should be performed only by the surgeons experienced both in transpedicular screw fixation in the thoracic and lumbar regions and in surgery of the cervical spine.

CONCLUSIONS

Transpedicular screw fixation with the Steffee VSP system provided high stability and strength in the treatment of traumatic middle and lower cervical spinal lesions without any neurovascular complications. However, this procedure is associated with some risks of major neurovascular injuries. It should be performed only by experienced surgeons using the meticulous surgical techniques described. In addition to traumatic lesions, we also recommend this procedure for more extended cervical reconstructions.

REFERENCES


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