ORIGINAL ARTICLE

Posterior Cervical Lateral Mass Screw Fixation

Analysis of 1026 Consecutive Screws in 143 Patients

Lali H. S. Sekhon, MB, BS, PhD, FRACS

Objective: This study evaluates the results and complications of 1026 consecutive lateral mass screws inserted in 143 patients by a single surgeon.

Methods: Over a 50-month period, a total of 1026 lateral mass screws were placed in 143 patients ages 12–96 years (56 females and 87 males), with these records retrospectively reviewed. Screw position was evaluated by computed tomography (CT) scanning postoperatively, with screw positions assessed for facet, foraminal, or foramen transversarium violation.

Results: All screws were placed by a modification of the Anderson technique, but 20 screws were converted to Roy-Camille trajectories because of screw pullout. No patients experienced neural injury or vertebral artery injury as a result of screw placement. Three patients had screw pullouts using the Axis system, which did not require reoperation. Most patients had 14-mm screws placed. Postoperative CT scanning showed no compromise of the foramen transversarium or neural foramen. A total of 94 C7 lateral mass screws were placed without the need for pedicle screws at this level. Forty-four cases were performed with a screw/plate construct with the remainder performed using a polyaxial screw/rod construct. One patient had a symptomatic adjacent-level disc herniation that required surgical intervention. One patient required extension of laminectomy for residual compression.

Conclusions: Lateral mass screw fixation is a safe and effective stabilization technique. This study demonstrates the safety and efficacy of lateral mass cannulation for a range of cervical pathologies with the largest reported series of consecutive lateral mass screws in the literature. In most cases of subaxial disease, nonconstrained plate/screw systems provide a reasonable alternative to polyaxial screw/rod constructs. Most patients can be fixated with 14-mm length × 3.5-mm diameter screws. The C7 lateral mass can be drilled with an adjusted trajectory.

Key Words: cervical, lateral mass, surgery, vertebral artery, screw

(*J Spinal Disord Tech* 2005;00:000–000)

Received for publication December 30, 2004; accepted April 6, 2005.
From the Department of Neurosurgery and Spinal Injuries Unit, Royal North Shore Hospital and University of Sydney, Sydney, N.S.W., Australia.
Dr. Sekhon is a consultant for Stryker Spine and Medtronic Sofamor-Danek.
Reprints: Dr. L. H. S. Sekhon, 799 Pacific Highway, Level 10, Tower B, Chatswood, N.S.W., 2067 Australia (e-mail: surgeon@spinalneurosurgery.com).

Posterior cervical fixation with lateral mass screws has been increasingly used since the concept was first described by Roy-Camille in 1979.[1] Traditionally, posterior fixation of the cervical spine has involved some form of wire fixation. Wire fixation is cheap, has a proven long-term track record, and requires no special expertise or x-ray guidance.[2–6] Where wire fixation falls short is in the osteoporotic patient, where solid immediate stabilization is required, where the posterior elements have been removed or are compromised, or where forces other than pure flexion need to be counteracted.[7–10] Stainless-steel wire can also interfere with postoperative magnetic resonance (MR) imaging, unlike newer titanium plate or screw/rod constructs. Lateral mass screw fixation does not have the above shortcomings and has advantages over standard posterior wiring techniques, including the ability to instrument when a laminectomy has been performed, the ability to perform multiple levels quickly and easily, the ability to extend constructs with ease cranially or caudally, and biomechanical superiority.[11–14] To surgeons unfamiliar with the technique, reservations typically occur based on the fear of two potentially devastating complications: nerve root injury and vertebral artery injury. As a result, this technique has been slow to gain universal acceptance by older cervical spine surgeons. AU1

This report describes a retrospective operative review of 143 consecutive cases where lateral mass fixation was performed with a total of 1026 subaxial cervical screws placed. The cases presented cover multiple pathologies including degenerative disease, trauma, malignancy, etc., and also cases where concomitant occipital or thoracic fixation was performed. Operative and clinical outcomes, as well as computed tomography (CT) analysis, are provided with particular emphasis on neurologic and vascular complications.

METHODS AND MATERIALS

Over a 50-month period, a total of 1026 lateral mass screws were placed in a subaxial position (C3–C7) in 143 consecutive patients by a single surgeon. The demographics of these patients were analyzed through retrospective chart review.

Surgical Technique

The surgery was performed in a consistent fashion. Intubation was performed for cases with severe stenosis or gross instability in an awake fiberoptic fashion. The patient was positioned prone using three-pin skull fixation on a radiolucent spinal operating table. Almost all cases were performed

JOBNAME: jsd 00#0 2005 PAGE: 2 OUTPUT: Tuesday April 26 17:14:08 2005
lww/jsd/98316/BSD200002

with digital fluoroscopic guidance. Exposure of the lateral masses was effected in a subperiosteal fashion to the lateral margins of the facet joints. The motion segments to be fused had their facet joints decorticated. Great care was taken to protect the facet joints above and below the instrumented levels. The lateral masses were drilled and tapped prior to any decompression, if required. Screw length was decided predominantly through assessment of preoperative imaging; however, if bicortical fixation was specifically desired, the floor of the hole was palpated with the drill advanced at 2-mm intervals until anterior cortical breach occurred. Placement of instrumentation was performed after any decompression. A modified trajectory was taken for screw placement from standard trajectories.[10,15,16] The entry point was 1 mm medial to the midpoint of the facet joint. The screws were angulated 20–25° laterally and superiorly to try to attain the best purchase of the lateral mass with minimal risk of neural or vascular injury (Fig. 1), which is a modification of the Anderson technique.[11] At C7, lateral mass cannulation was effected through the use of a steeper trajectory to allow for the shallowness of the lateral mass, as shown in Fig. 1B (arrow). In most cases, morcellized local autograft bone from the posterior elements was placed over the decorticated lateral masses and into the appropriate facet joints prior to screw placement. The patients were monitored overnight in a high dependency unit and postoperatively were placed into an Aspen collar (Aspen Medical Products, Long Beach, CA).

Screw Position Assessment

For assessment of screw position, a thin-slice reconstructed CT scan was performed 24 hours postoperatively to confirm adequate screw placement. All lateral mass screws were evaluated for encroachment into the foramen transversarium (graded as either 0, 0–1, or >1 mm) or into the neural foramen. Any intraoperative or postoperative clinical evidence of nerve root or vertebral artery injury was also evaluated by further imaging to elucidate precise etiology. Evaluation was performed by the author, but any radiologic reports that suggested foramen transversarium or neural foramen violation were not ignored and were consistent with the author's scoring.

Postoperatively patients were evaluated clinically and radiologically at 6 weeks, 3 months, 6 months, 12 months, and yearly thereafter. All myelopathic patients underwent postoperative MR scanning. No living patients were lost to follow-up. Follow-ups ranged from 3 months to 4 years. Emphasis for our study remained on the initial postoperative imaging as the objective of this study rather than fusion status over time.

Results are expressed as means ± SD.

RESULTS

The demographics of the 1026 screws per 143 patients are shown in Table 1. The majority of patients were male, with an average age of 50–60 years, although patients up to 95 years were operated upon. Co-morbidities were relatively infrequently present. Only 6% of patients were workers compensation patients and only 15% smokers. Preoperative bone density studies were not found to be overly useful in planning surgical intervention and not routinely employed.

The 143 cases studied covered a wide range of pathologies. The indications included trauma (35 cases), degenerative disease (92 cases), iatrogenic instability (4 cases), rheumatoid arthritis (3 cases), malignant spinal tumor (6 cases), and benign spinal tumor (2 cases) (Fig. 2). Instrumentation was performed in cases where instability was present or where wide decompression would lead to instability. A variety of different implants were used including Axis (Medtronic Sofamor-Danek, Memphis, TN) and Cervifix plates and screws (Synthes Spine, Paoli, PA) and Vertex (Medtronic Sofamor-Danek), Summit (Depuy Spine, Raynham, MA),

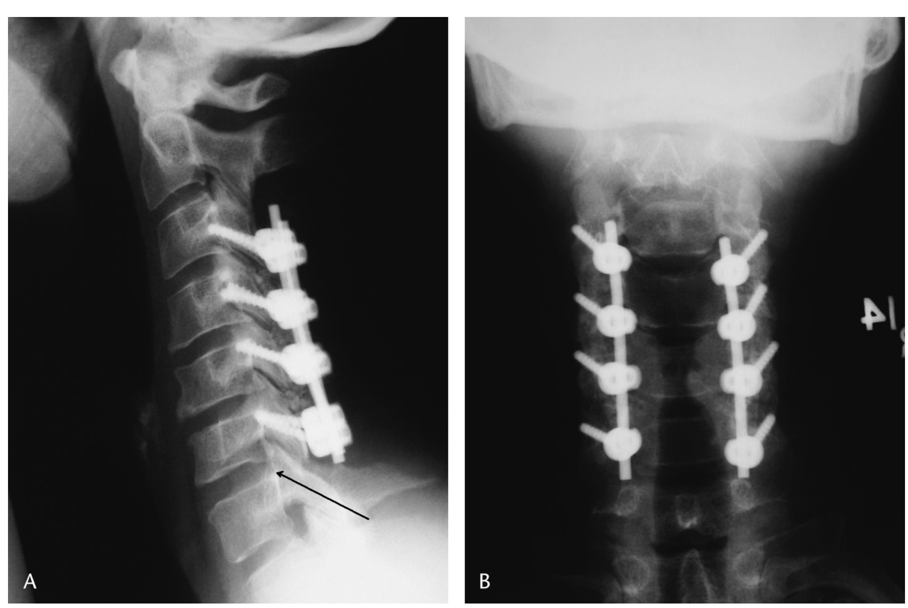

FIGURE 1. Anteroposterior (A) and lateral (B) postoperative C-spine radiographs of a typical patient who underwent C3–C6 lateral mass fixation, the most common construct used for spondylotic myelopathy. The position of the screws is well demonstrated; in the lateral radiograph, the steeper trajectory required to cannulate the relatively shallow C7 lateral mass is arrowed.

TABLE 1. Results Summary

AU6

Patient Demographics (n = 143)	No.	%
Males	87	60.8
Females	56	39.2
Age ± SD (y)	56.8 ± 19.71	
Age range	12–96	
Uninsured	79	55.2
Insured	40	28.0
Veterans affairs	2	1.4
Third party	6	4.2
Workers compensation	2	1.4
Smoking	15	10.5
Alcohol abuse	2	1.4
Respiratory disease	2	1.4
Diabetes	15	10.5
Rheumatoid arthritis	4	2.8
Technique (n = 1026)		
Standard Sekhon trajectory	1006	98.1
Rescue Roy-Camille trajectory	20	1.9
C7 lateral mass screws	94	9.2
C7 pedicle screws	4	0.4
3.5-mm screws	1018	99.2
4-mm rescue screws	8	0.8
Complications (n = 143 cases, 1026 screws)		
Root injury secondary screws	0	0.0
Vertebral artery injury	0	0.0
Dural tears	3	2.1
Blood transfusion	8	5.6
Superficial infection	4	2.8
Deep infection	1	0.7
Screw pullout (of 1026 screws)	6	0.6
Screw breakage (of 1026 screws)	4	0.4
Plate/rod breakage (patients)	1	0.7
Deaths	4	2.8
C5 root injury	1	0.7
Adjacent segment requiring surgery	1	0.7
Hematoma requiring evacuation	1	0.7
Outcomes		
Mean follow-up (mo)	22.04	13.2
Range of follow-up (mo)	1–50	
Instrumentation failure	2	1.4
Kyphosis (patients)	3	2.1
Preop. Nurick grade (of 94 cases)	2.3 ± 1.2	
Postop. Nurick grade (of 94 cases)	1.01 ± 0.5	

Oasys (Stryker Spine, Cestas, France), and Starlock (Synthes Spine) polyaxial screw/rod constructs. This spread of implants is shown in Figure 3. The majority of initial experience was with plate/screw constructs prior to the introduction of polyaxial screw/rod constructs (30.8% of all cases). The polyaxial screw/rod consructs all performed equally well in the subaxial region. The majority of constructs were stand-alone subaxial constructs, although lateral mass fixation was also incorporated as part of an occipitocervical or cervicothoracic construct or as additional supplemental fixation for an anterior construct (Fig. 4). F3 F4

All lateral masses between C3 and C7 were fixated. As is reflected by the proportion of cases associated with degenerative disease, 502 screws were placed into either C5 or C6 (see Fig. 6). A mean of 205.2 ± 64.9 screws were placed at each level with, on average, 7 screws placed per level. Intraoperatively, of the 1026 lateral mass screws placed, there was no observation of vertebral artery injury. C7 was able to be adequately drilled with a steeper trajectory (see Fig. 1) in 94 instances with only four C7 pedicle screws placed. If poor screw purchase was achieved with breakout from the lateral mass initially, conversion to a modified Roy-Camille[1,16] technique was effected. This was performed in 1.9% of all screws. Only eight 4-mm rescue screws were required. As a result, stripping of the screw thread was not as big an issue as lateral breakout of the lateral mass cortex. F6 AU2

There was no clinical evidence of vertebral artery injury. One patient experienced a persistent C5 nerve root lesion with a satisfactory postoperative CT scan showing no violation by screws of the C4–C5 neural foramen. The cause of this deficit was thought to be secondary to an overaggressive foraminotomy. The operative incidence of neurologic injury of any cause was 0.7%, but it must be emphasized that there were no screw-related neurologic injuries. There was one deep infection in an 84-year-old man undergoing an occipitocervical fusion that required debridement and regrafting, but no removal of hardware was required. Three patients experienced screw pullouts. All cases were elderly with advanced facet joint disease where cannulation of the lateral masses was technically difficult partially because of the size of the lateral masses. All were with screw/plate constructs with pullout of cranial C3 or C4 screws noted at 6 weeks. Kyphosis occurred in two patients, but no further surgery was required. A typical patient with construct failure is shown in Fig. 7. No screw pullouts occurred with polyaxial screw/rod constructs. There was one plate breakage in a 26-year-old man undergoing occiptocervical fusion for an os odontodeum that occurred 2 years after surgery. This occurred with the Cervifix (Synthes Spine) occipitocervical plate, with breakage at the point of change of rod curvature between the occiput and C1. The hardware was removed without incident, and the patient did well. Of the four deaths, two were associated with malignancy and occurred some time after surgery. One patient with bilateral subaxial facet subluxations experienced a posttraumatic vertebral artery dissection and subsequent posterior fossa stroke. Despite simultaneous posterior fossa decompression and subaxial reduction and stabilization, the patient died. Finally, one patient had a massive pulmonary embolus 3 days postoperatively and eventually died. There was one clinically significant postoperative wound hematoma in a 76-year-old woman with severe myelopathy who underwent a C2–C5 laminectomy and fusion. This was evacuated 5 days postoperatively, manifest by worsening myelopathy. After evacuation, her clinical condition continued to improve. The overall complication rate was <3%. F7

The results of the postoperative CT scan evaluation of screw position are shown in Table 2. Significantly, 92.4% of screws were bicorticate, although in 88% of cases, 14-mm screws were used, based on an estimate from the preoperative axial CT or MR scan (Fig. 8). Eight screws, typically at the C7 T2 F8

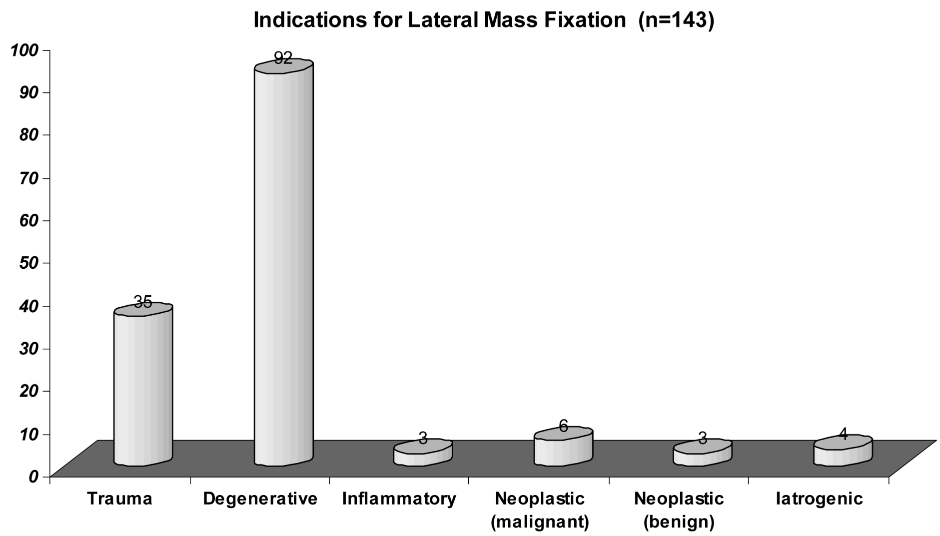

FIGURE 2. Graph showing the typical indications for lateral mass fixation. Most cases were performed for degenerative spondylotic myelopathy and then trauma.

level, had violated the inferior facet joint. Twenty screws (1.9%) breached the foramen transversarium by 0–1 mm. No screw violated the foramen transversarium by >1 mm. No case entered the neural foramen or canal.

Only one patient to date has developed symptomatic adjacent-segment degeneration. In that case, a 36-year-old man underwent a C3–C6 laminectomy and fusion and 13 months later presented with an acute C7 radiculopathy secondary to an acute foraminal disc protrusion that responded well to a posterior keyhole foraminotomy. Sixteen months later, he has not developed any C6–C7 instability and remains well. One patient with severe stenosis required a delayed extension of his laminectomy by one level because of posterior drift of the spinal cord, which led to compression at a caudal spinal level that was not compressing the spinal cord prior to the initial surgery. This was uneventfully performed.

DISCUSSION

This report shows that after placement of 1026 lateral mass screws in 143 patients of various ages and undergoing surgery for various pathologies, no screw-related injuries to the vertebral artery or nerve roots occurred. This is the largest reported series of consecutive lateral mass screws to date.

Extensive work has been done both clinically and in the laboratory on lateral mass fixation. The various trajectories have been assessed in terms of their likelihood to cause neurovascular injury. Ebraheim et al[17,18] have looked specifically at this in the cadaver and shown the foramen transverarium lies in line with the midpoint of the lateral mass. As a result, a laterally directed screw will likely miss the vertebral artery. Further work by Xu et al[16] suggested that the potential risk of nerve root violation is higher with the Magerl[23] and Anderson[11] techniques than with the An[19] technique. Heller

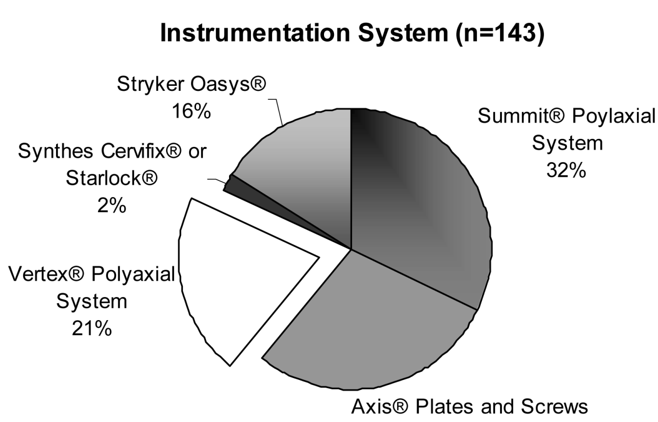

FIGURE 3. Graph showing the various instrumentation systems used. Semiconstrained screw/plate systems such as the Axis system were used for the initial cases, with polyaxial screws used for the majority of cases. For subaxial fixation, there was little difference between the various polyaxial systems in terms of intraoperative use.

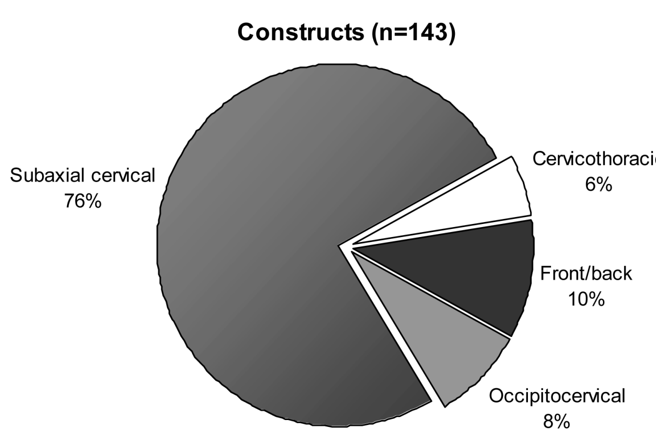

FIGURE 4. Graph showing the scenarios in which lateral mass screws were used. The majority were stand-alone subaxial fixations, but extension above and below C3–C7 or in complement to an anterior construct was occasionally performed.

AU7

TABLE 2. Screw Position on CT (n = 1026)

		%
Biocorticate purchase	948	92.4
Violation of facet joint	8	0.8
0- to 1-mm foramen transversarium breach	20	1.9
>1-mm foramen transversarium breach	0	0.0
Intervertebral foramen entry	0	0.0
Canal violation	0	0.0

et al[20,21] predicted a maximum 3.6% incidence of nerve root injury using the Roy-Camille and Magerl trajectories, well above that found in this series, presumably because of the screw length used and more lateral trajectories.

Pait et al divided the lateral masses into quadrants with the upper outer quadrant being the eventual target for screw placement with the lowest risk of vertebral artery or nerve root injury.[22] In terms of screw trajectory, Roy-Camille et al advocated that the starting point be located in the midpoint of the lateral mass and the drill be oriented perpendicular to the posterior aspect of the cervical spine and 10° lateral.[1] Magerl recommended starting the drill hole 2–3 mm medial and superior to the midpoint of the lateral mass and angling 30° upward and 25° outward.[23] Anderson proposed that the starting point for screw insertion be 1 mm medial to the midpoint of the lateral mass and that the screw be angled 30–40° cranial and 10° lateral.[11] Finally, An et al[19] suggested angling 15–18° superiorly and 30–33° laterally, with a starting point 1 mm medial to the center of the lateral mass.[19] In this series, we found that by using Anderson's starting point and then angling 25° laterally rather than 15°, this was an easily remembered, taught, and reproducible angle and reduced the risk of vertebral artery injury as well as captured the upper and outer quadrant as described by Pait et al.[22]

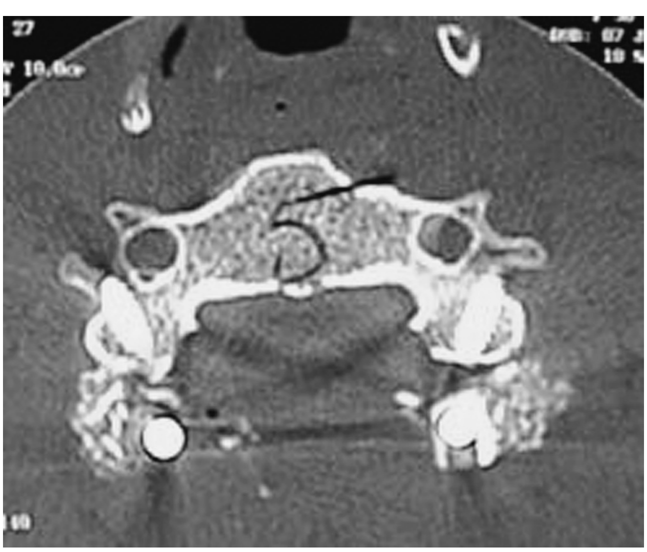

FIGURE 5. Postoperative axial CT scan showing typical bicorticate fixation. Note that the foramen transversarium is not breached as a result of the obliquity of the trajectory; typically, with a 14-mm screw, bicorticate fixation is attained.

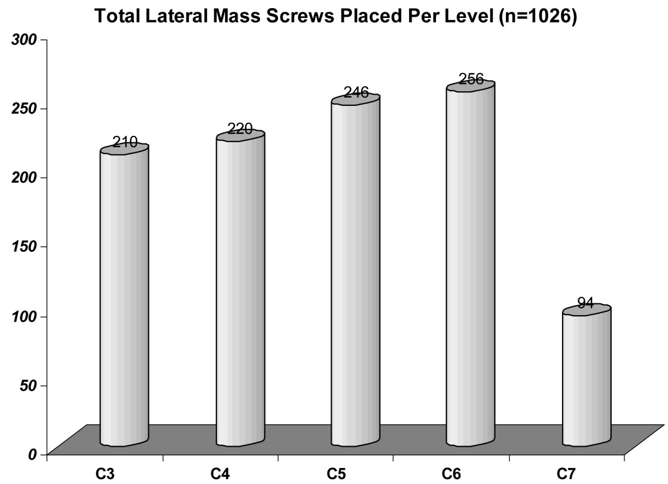

FIGURE 6. Graph showing the spread of the 1026 screws analyzed in terms of their location in the subaxial spine. Not surprisingly, C5 and C6 were most frequently instrumented, in concert with the high number of degenerative myelopathies treated using this technique.

Most of the screws placed in this series were 14-mm screws. An et al have suggested a screw length of 11 mm is safe.[19] Roy-Camille et al recommended 14–17 mm.[1] The average vertical distance between the posterior midpoint of the lateral mass and the vertebral foramen from C3 to C6 has been found to be approximately 9–12 mm.[24] Consequently, 14 mm obliquely should adequately span the lateral mass. Of note in our study was that >90% of screws were bicorticate in nature when 14-mm screws were placed. This knowledge considerably quickened the duration of procedures as incremental drilling was not routinely performed. It was evident on the postoperative CT scans that 14-mm-length screws did not pass the posterior lip of the foramen transversarium, lowering the risk of vascular injury. Heller et al[25] performed cadaveric studies looking at screw pullout and found that bicorticate fixation with large-diameter non-self-tapping screws had the greatest resistance to pullout. Coupled with this, Seybold et al[26] have suggested that 14-mm screws are equal to bicorticate screws in terms of pullout strength when tested in cadaveric spines, a finding that would be in agreement with our technique. It seems in most cases that 14-mm screws achieve bicorticate fixation and using non-self-tapping screws improves screw pullout.

The low failure rate of the lateral mass screws with low complication rate suggests more dangerous techniques such as cervical pedicle screws[27–29] are for the most part not required to attain adequate fixation. Of note in this series is that in most cases, the C7 lateral mass could be drilled with a steeper trajectory with no need for a C7 pedicle screw.

The screw pullouts occurred only in patients who underwent screw/plate constructs as opposed to the newer polyaxial screw/rod construct. The former constructs are

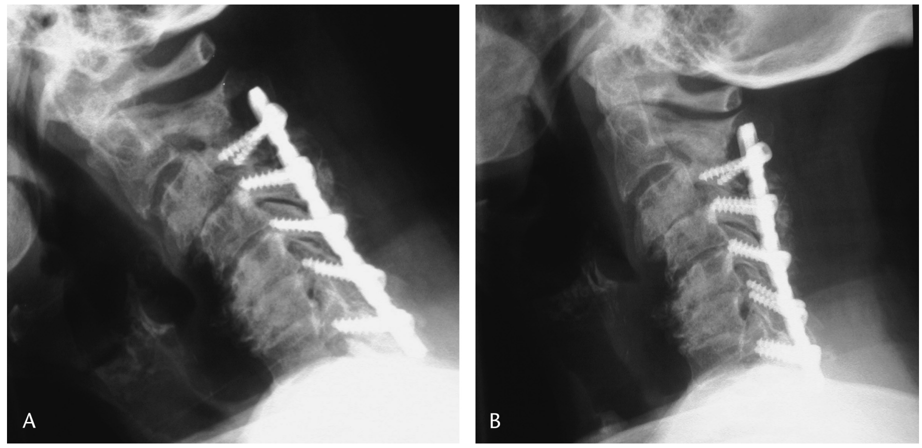

FIGURE 7. Flexion (A) and extension (B) lateral cervical spine radiographs from one of two patients who experienced screw pullout of cranial screws in a screw/plate construct that led to focal kyphosis but with no movement on dynamic imaging. No revision surgery was performed in this case. All pullouts occurred in osteoporotic upper cervical subaxial lateral masses, but no screw pullouts occurred with the polyaxial screw systems. An option to prevent this may have been to take the construct up to C2 at the time of initial surgery, but this would sacrifice another motion segment.

semiconstrained; that is, the backout of one screw may not lead to failure of the construct. A cross-link can also not be placed on these. The more constrained polyaxial screw/rod systems inherently prevent screw backout unless complete failure of the instrumentation scaffold occurs, a situation not clinically seen. In most cases, the variable polyaxiality of the screw systems was not as crucial as a fixation between C2–C3 or C7–T1. As a result, for most cases, a screw/plate construct would have sufficed, an issue of some importance, given the large cost difference between the older and new systems.

CONCLUSION

Lateral mass fixation is a safe and reliable method of posterior stabilization suitable for a wide range of pathologies. In most cases, 14 × 3.5–mm screws can be used. The risk of vertebral artery or nerve root injury should approach zero.

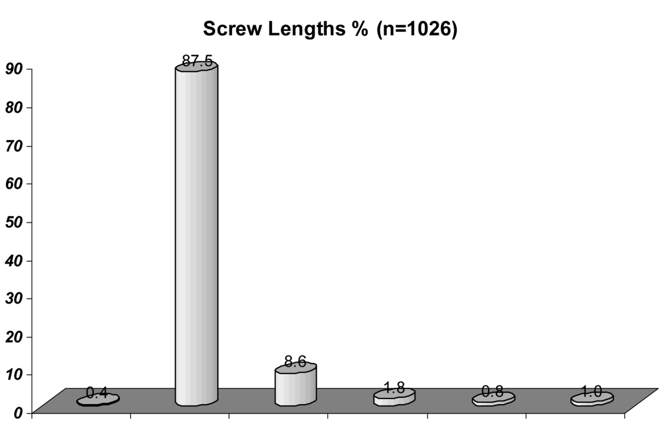

FIGURE 8. Graph showing typical screw lengths used for lateral mass fixation. In almost all patients, 14-mm screws were adequate; 16- and 18-mm screws were typically used in males with traumatic injuries, and longer screws were typically not fully seated with their heads flush with the bony surface of the lateral mass to allow for easier rod contouring on long constructs.

REFERENCES

1. Roy-Camille R, Gaillant G, Bertreaux D. Early management of spinal injuries. In: McKibben B, ed. *Recent Advances in Orthopedics*. Edinburgh: Churchill-Livingstone; 1979:57–87.
2. An HS, Coppes MA. Posterior cervical fixation for fracture and degenerative disc disease. *Clin Orthop*. 1997;X;101–111. AU3
3. Branch CL Jr, Kelly DL Jr, Davis CH Jr, et al. Fixation of fractures of the lower cervical spine using methylmethacrylate and wire: Technique and results in 99 patients. *Neurosurgery.* 1989;25:503–512.
4. Crockard A. Evaluation of spinal laminar fixation by a new, flexible stainless steel cable (Sof'wire): Early results. *Neurosurgery.* 1994;35:892–898.
5. Geisler FH, Mirvis SE, Zrebeet H, et al. Titanium wire internal fixation for stabilization of injury of the cervical spine: Clinical results and postoperative magnetic resonance imaging of the spinal cord. *Neurosurgery.* 1989;25:356–362.
6. Mirvis SE, Geisler F, Joslyn JN, et al. Use of titanium wire in cervical spine fixation as a means to reduce MR artifacts. *AJNR Am J Neuroradiol*. 1988;9:1229–1231.
7. Deen HG, Birch BD, Wharen RE, et al. Lateral mass screw-rod fixation of the cervical spine: A prospective clinical series with 1-year follow-up. *Spine J.* 2003;3:489–495.
8. Graham AW, Swank ML, Kinard RE, et al. Posterior cervical arthrodesis and stabilization with a lateral mass plate. Clinical and computed tomographic evaluation of lateral mass screw placement and associated complications. *Spine*. 1996;21:323–329.
9. Horgan MA, Kellogg JX, Chesnut RM. Posterior cervical arthrodesis and stabilization: an early report using a novel lateral mass screw and rod technique. *Neurosurgery.* 1999;44:1267–1271.
10. Muffoletto AJ, Hadjipavlou AG, Jensen RE, et al. Techniques and pitfalls of cervical lateral mass plate fixation. *Am J Orthop*. 2000;29:897–903.
11. Anderson PA, Henley MB, Grady MS, et al. Posterior cervical arthrodesis with AO reconstruction plates and bone graft. *Spine*. 1991;16:S72–S79.
12. Errico T, Uhl R, Cooper P, et al. Pullout strength comparison of two methods of orienting screw insertion in the lateral masses of the bovine cervical spine. *J Spinal Disord*. 1992;5:459–463.
13. Shapiro S, Snyder W, Kaufman K, et al. Outcome of 51 cases of unilateral locked cervical facets: Interspinous braided cable for lateral mass plate fusion compared with interspinous wire and facet wiring with iliac crest. *J Neurosurg*. 1999;91:19–24.
14. Ulrich C, Arand M, Nothwang J. Internal fixation on the lower cervical spine—Biomechanics and clinical practice of procedures and implants. *Eur Spine J.* 2001;10:88–100.
15. Xu R, Ebraheim NA, Klausner T, et al. Modified Magerl technique of lateral mass screw placement in the lower cervical spine: An anatomic study. *J Spinal Disord*. 1998;11:237–240.
16. Xu R, Haman SP, Ebraheim NA, et al. The anatomic relation of lateral mass screws to the spinal nerves. A comparison of the Magerl, Anderson, and An techniques. *Spine*. 1999;24:2057–2061.

17. Ebraheim NA, Xu R, Stanescu S, et al. Anatomic relationship of the cervical nerves to the lateral masses. *Am J Orthop*. 1999;28: 39–42.
18. Ebraheim NA, Xu R, Yeasting RA. The location of the vertebral artery foramen and its relation to posterior lateral mass screw fixation. *Spine*. 1996;21:1291–1295.
19. An HS, Gordin R, Renner K. Anatomic considerations for plate-screw fixation of the cervical spine. *Spine*. 1991;16:S548–S551.
20. Heller JG, Carlson GD, Abitbol JJ, et al. Anatomic comparison of the Roy-Camille and Magerl techniques for screw placement in the lower cervical spine. *Spine*. 1991;16:S552–S557.
21. Heller JG, Silcox DH, Sutterlin CE. Complications of posterior cervical plating. *Spine*. 1995;20:2442–2448.
22. Pait TG, McAllister PV, Kaufman HH. Quadrant anatomy of the articular pillars (lateral cervical mass) of the cervical spine. *J Neurosurg*. 1995;82: 1011–1014.
23. Jeanneret B, Magerl F, Ward EH, et al. Posterior stabilization of the cervical spine with hook plates. *Spine*. 1991;16:S56–S63.
24. Wellman BJ, Follett KA, Traynelis VC. Complications of posterior articular mass plate fixation of the subaxial cervical spine in 43 consecutive patients. *Spine*. 1998;23:193–200.
25. Heller JG, Estes BT, Zaouali M, et al. Biomechanical study of screws in the lateral masses: Variables affecting pull-out resistance. *J Bone Joint Surg Am*. 1996;78:1315–1321.
26. Seybold EA, Baker JA, Criscitiello AA, et al. Characteristics of unicortical and bicortical lateral mass screws in the cervical spine. *Spine*. 1999;24:2397–2403.
27. Abumi K, Kaneda K. Pedicle screw fixation for nontraumatic lesions of the cervical spine. *Spine*. 1997;22:1853–1863. AU4
28. Abumi K, Shono Y, Ito M, et al. Complications of pedicle screw fixation in reconstructive surgery of the cervical spine. *Spine*. 2000;25:962–969.
29. Abumi K, Takada T, Shono Y, et al. Posterior occipitocervical reconstruction using cervical pedicle screws and plate-rod systems. *Spine*. 1999;24:1425–1434.
30. ~~Xu R, Haman SP, Ebraheim NA, et al. The anatomic relation of lateral mass screws to the spinal nerves. A comparison of the Magerl, Anderson, and An techniques. *Spine*. 1999;24:2057–2061.~~ AU5