Delayed presentation of aortic injury by pedicle screws: Report of two cases and review of the literature

Stavros K. Kakkos, MD, MSc, PhD, and **Alexander D. Shepard, MD,** *Detroit, Mich*

Objectives: **Perforation of the aorta by pedicle screws is a rare but serious complication of spine fixation surgery. This article reviews the clinical presentation and management of this complication.**

Methods: **Presented are two cases of thoracic aorta perforation by a pedicle screw and a review of the appropriate literature performed using a MEDLINE search.**

Results: **Literature review identified eight additional patients. In most cases, aortic perforation was recognized and managed within 18 months of the spine surgery. Clinical presentation included acute bleeding, necessitating urgent exploration in two patients, and pseudoaneurysm formation in five cases, two of which were infected. Depending on the extent of aortic damage and the presence or absence of infection, management ranged from endovascular grafting, to screw burring with closure of the perforation site, to aortic reconstruction with a tube graft and complete orthopedic hardware removal. Outcome was favorable in all patients who were operated on.**

Conclusions: **The small number of reported cases indicates either the rarity of this complication or unawareness of its existence. The true incidence of this complication is probably under-reported. Orthopedic and vascular surgeons should be aware of this potentially fatal problem. Prevention remains the best treatment. Once encountered, a variety of techniques are available to manage this complication with reasonable outcome. (J Vasc Surg 2008;47:1074-82.)**

Iatrogenic injury to the aorta is a rare but well-recognized complication of a variety of procedures, including spine surgery.[1] Aortic perforation frequently results in bleeding, which is usually manifested by rapid hematoma formation or hemodynamic instability, or both.[2] Aortic trauma can also result in pseudoaneurysm formation, which presents in a more delayed fashion. Scattered reports have been published during the last 20 years of aortic pseudoaneurysms resulting from pedicle screw penetration. We describe two new cases of pedicle screw perforation of the thoracic aorta and review the relevant literature in regards to diagnosis and treatment modalities as well as prevention.

PATIENTS AND METHODS

Patient 1. A 55-year-old man presented to the emergency department with a 2-week history of recurrent upper back pain and chills. He had a history of thoracic spine osteomyelitis that had been treated with débridement and internal fixation at another hospital 11 months before presentation. His medical history also included hypertension, bipolar disorder, and appendectomy. Social history included ongoing tobacco, alcohol, heroin, and cocaine abuse.

From the Division of Vascular Surgery, Department of Surgery, Henry Ford Hospital.

Competition of interest: none.

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Reprint requests: Alexander D. Shepard, MD, Division of Vascular Surgery, Department of Surgery, Henry Ford Hospital, 2799 W Grand Blvd, Detroit, MI 48202 (e-mail: ashepar2@hfhs.org).

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On examination the patient appeared in good general condition, with a normal temperature, a blood pressure of 150/90 mm Hg, a pulse of 94/min, and a respiratory rate of 20/min. He had a well-healed right thoracotomy scar and a scar in the middle of his upper back without evidence of infection. Laboratory tests included a normal white cell count of 6800/μL but an elevated sedimentation rate of 68 mm/h (normal, <10 mm/h) and C-reactive protein of 6 mg/dL (normal, <0.5 mg/dL). Platelets were 720,000/μL and the creatinine level was 1.4 mg/dL (normal, ≤1.2 mg/dL). Blood cultures grew methicillin-resistant *Staphylococcus aureus* (MRSA).

Thoracic spine radiographs revealed lateral migration of one of the inferior screws of the right lateral paraspinal plate and focal paraspinal soft tissue bulges in this region (Fig 1).

A computed tomography (CT) scan of the chest (Fig 2) demonstrated a focal contrast collection along the medial aspect of the distal descending thoracic aorta contiguous with the aortic lumen that was consistent with a pseudoaneurysm. The CT showed posterior fusion of T6 through T10 with posterior rods; T6, T7, and T10 bilateral transpedicular screws; a right paraspinal side-plate also extending from T6 to T10, with vertebral body screws at those levels; and a vertebral cage extending from T7 to T10. The anterior-inferior side-plate screw protruded laterally from the side-plate 13 mm. There was a 15-mm left lateral protrusion of the superior-most side-plate screw at T6 projecting to the medial margin of the descending thoracic aorta. The CT showed significant lucency about the vertebral cage prosthesis and substantial soft tissue density about the vertebral bodies from the levels of T6 to T10. Soft tissue density also tracked along the left posterior pleural space.

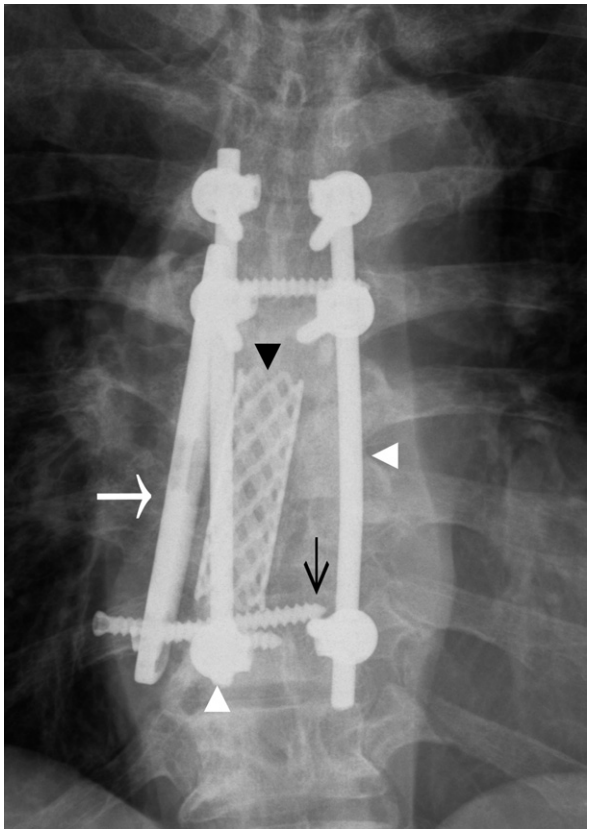

Fig 1. Patient 1. Chest radiograph demonstrates the lateral migration of one of the inferior transpedicular screws *(black arrow)* of the right lateral spinal fixation plate *(white arrow)* as well as focal paraspinal soft tissue bulge in this region. Two spinal rods *(white arrowheads)* and an intervertebral spinal cage *(black arrowhead)* are also shown.

An infectious process was suspected, although there was no classic radiographic evidence of abscess.

Thoracic aortography (Fig 3) showed a 2.0- × 1.8-cm pseudoaneurysm with a narrow neck arising from the medial aspect of the descending thoracic aorta at the lower margin of the cage prosthesis. A screw was also abutting the medial wall of the proximal descending thoracic aorta above the cage at the T6 level with apparent full-thickness wall penetration but no evidence of a pseudoaneurysm.

The patient underwent repair of his descending thoracic aorta lacerations and screw-tip burring in the operating room. After intubation with a double-lumen endotracheal tube, an 18-gauge lumbar drain was inserted to monitor cerebrospinal fluid (CSF) pressure and maintain a CSF pressure of ≤10 mm Hg. The left chest was opened through a sixth intercostal space incision, the inferior pulmonary vein and the left femoral artery were cannulated, and the patient was placed on atriofemoral bypass. Screw-tip perforation of the thoracic aorta at the T6 level was found. After proximal and distal aortic clamping, just above and below the injury site, a transverse aortotomy was performed at the level of screw-tip penetration (Fig 4, *A*).

Fogarty balloon occlusion catheters were used to control four back-bleeding intercostal arteries in the occluded segment of the aorta. The medial wall of the aorta was dissected off the screw and retracted to allow unfettered access. Approximately 1 cm of the screw tip was burred-off with a Midas Rex drill (Medtronic, Minneapolis, Minn), and the aortic defect and aortotomy were closed with interrupted 3-0 polypropylene sutures (Fig 5). After removal of the clamps and a check for hemostasis, attention was directed distally to the pseudoaneurysm at the T10 level.

After segmental aortic clamping, the aorta was again partially transected at the level of the pseudoaneurysm to expose its medial wall defect. A moderate-sized cavity adjacent to the aorta was entered and the hematoma was evacuated. An inflammatory rind was removed from the aortic wall, and surrounding necrotic debris was excised and sent for cultures. A screw pointing toward the aortic defect was identified and burred down, again using a Midas Rex drill (Fig 4, *B*).

A small piece of bovine pericardial patch (Vascu-Guard Vascular Patch, Synovis Surgical Innovations, St Paul, Minn) was used to close the 8- to 9-mm circular aortic defect with a running stitch of 4-0 polypropylene suture, which was continued anteriorly to close the aortotomy. A 36F chest tube was placed in the left hemithorax and the chest was closed.

Pseudoaneurysm cultures grew MRSA, and the patient was maintained on intravenous vancomycin and rifampin postoperatively for 8 weeks. His postoperative course was uneventful, and he was discharged home in good condition on day 20. Fifteen months later he remains well. On follow-up CT scanning the aorta appears without evidence of recurrence.

Patient 2. A 51-year-old man with a history of tuberculous spondylodiscitis (Pott's disease) with a prevertebral abscess underwent a thoracolumbar fusion at T11 to L2 level at another hospital 13 months before presentation. During an evaluation at our facility for chronic cholecystitis, a CT scan of the abdomen revealed penetration of the distal thoracic aorta by a pedicle screw as an incidental finding. His medical history was significant for hypertension, hepatitis C with cirrhosis, Pott's disease that was treated surgically and with four-drug antituberculosis therapy for 6 months, bilateral deep vein thrombosis, and chronic back pain. His surgical history included a L4 to L5 laminectomy in 1988, T11 to L2 thoracolumbar plating 13 months previously, and cholecystectomy. Social history included current use of tobacco (<1 pack/d), occasional alcohol consumption, and past use of heroin.

The result of the physical examination of his vasculature and neurologic system was unremarkable. The spinal surgery wounds were well healed. Radiographs demonstrated a compression deformity of L1 and nearly complete disc destruction at T12 to L1 compatible with the sequelae of infectious discitis. The left T11 pedicle screw was located in a left paravertebral position. Computed tomography scanning demonstrated penetration of the posterior wall of the

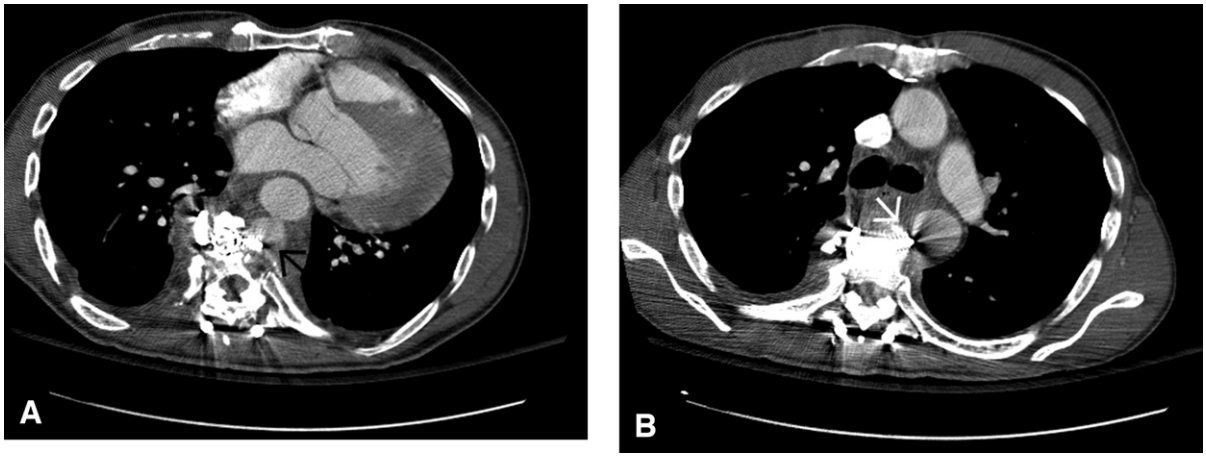

Fig 2. Patient 1. **A,** A computed tomography chest scan shows the side-plate screw *(black arrow)* protruding laterally from the side-plate associated with a focal contrast collection along the medial aspect of the distal descending thoracic aorta compatible with a pseudoaneurysm. **B,** Left lateral protrusion of the superior-most side-plate screw *(white arrow)* projecting to the medial margin of the thoracic aorta.

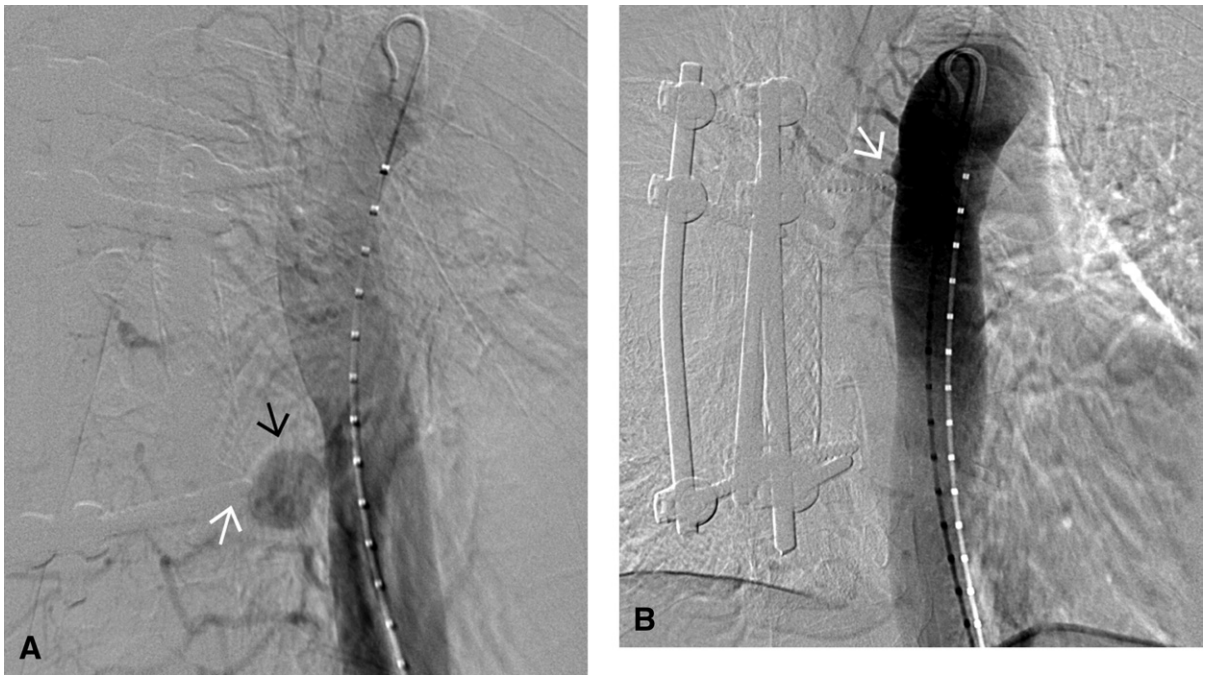

Fig 3. Patient 1. **A,** Thoracic aortography shows a 2.0- × 1.8-cm pseudoaneurysm lumen *(black arrow)* arising from the medial aspect of the descending thoracic aorta at the level of the inferior screw *(white arrow)*. **B,** Image shows a screw abutting the medial wall of the proximal descending thoracic aorta above the cage at the level of T6 with full-thickness wall penetration and associated small extravasation of contrast *(white arrow)*.

aorta by this screw, without evidence of associated pseudoaneurysm or dissection (Fig 6).

Patient underwent aortic repair and screw-tip burring in the operating room. Multiple attempts at placement of a spinal drain were unsuccessful because of dense scarring over the lumbar spine at the site of his previous laminectomy. The surgical exposure was through a left eighth intercostal space thoracoabdominal incision. After partial circumferential division of the diaphragm and medial visceral rotation, the distal descending thoracic aorta and paravisceral abdominal aorta were exposed.

Aortoaortic bypass was established, and the aorta was clamped just above and below the involved area and mobilized off the screw tip. Division of one pair of intercostal

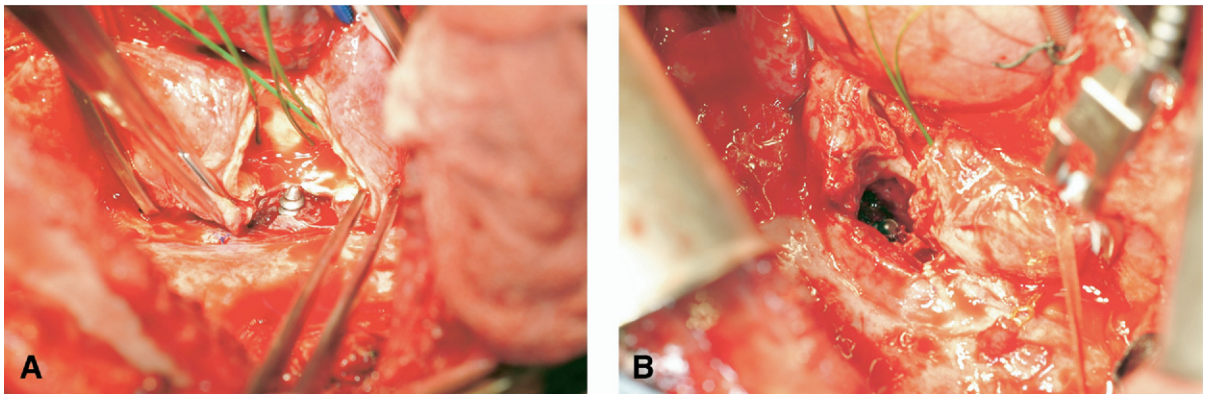

Fig 4. Patient 1. **A,** Operative photo shows screw-tip perforation of the right (medial) wall of the thoracic aorta at the T6 level through a transverse aortotomy. Four 3F Fogarty catheters are used to control backbleeding from two pairs of intercostal arteries in the occluded segment of aorta. **B,** Operative photo shows pseudoaneurysm cavity at the T-10 level, with the screw pointing towards the aortic defect. Again, 3F Fogarty catheters were used to occlude backbleeding intercostals.

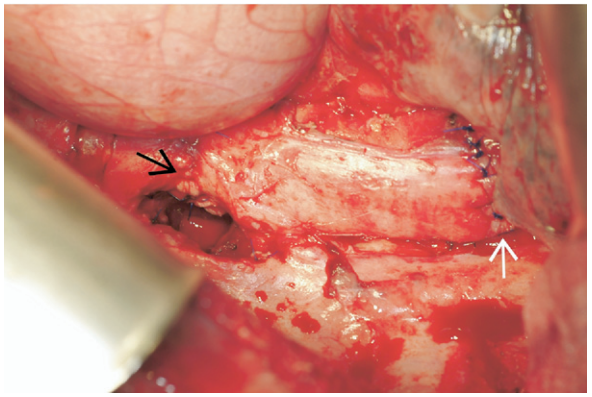

Fig 5. Patient 1. Intraoperative photo shows the proximal (T-6 level) aortotomy closure with interrupted 3-0 polypropylene suture *(white arrow)* and the distal (T-10 level) aortotomy patch closure with a running 4-0 polypropylene suture *(black arrow)*.

arteries allowed retraction of the aorta medially to expose the perforation site in its posterior wall (Fig 7). The hole was repaired primarily with a figure-of-eight 3-0 polypropylene suture. A 1-cm length of the offending screw tip was then burred off using a Midas Rex drill. The aortic clamps were removed, and the patient was taken off the bypass. A 36F chest tube was placed in the left hemithorax and chest was closed.

The patient's postoperative course was uneventful, and he was discharged home in good condition on day 6. Six months later, he remains asymptomatic.

Literature search. A MEDLINE/PUBMED search was performed in April 2007. The key words *aortic pseudoaneurysm* and *delayed or internal fixation* or *aortic screw* were used to identify similar cases in the literature. This was followed by a manual search of the references of the relevant articles.

RESULTS

The literature review identified eight additional cases of aortic penetration by a pedicle screw or erosion by associated orthopedic hardware,[3-11] with one case being published twice.[3,4] Cases of acute aortic injury that occurred intraoperatively or were recognized ≤30 days postoperatively were not included.[12] A case of fatal delayed aortic rupture after surgical evacuation of a postoperative hemothorax and secondary infection that occurred during reoperation intended to remove spinal hardware was excluded because the authors attributed the aortic rupture to infection and not direct injury.[13] A second fatal case was also excluded because the aorta was eroded by the synthetic mesh that was used to cover the orthopedic hardware.[14]

Table I summarizes the presentations and clinical characteristics of these eight patients plus our two. Most patients were young or middle-aged (mean age, 47; range, 16-77 years). The thoracic aorta was the site of injury in all but two patients. An anterior approach for spinal fixation had been used in six of 10 patients. The indications for spinal fixation were kyphoscoliosis/scoliosis (n = 5), vertebral fracture (n = 3), and osteomyelitis of the thoracic spine (n = 2, our cases). Most aortic injuries (8 of 10) were recognized ≤18 months (median, 11 months; range, 1 month-20 years) after spine surgery. Clinical presentation ranged from asymptomatic perforation of the aorta to acute bleeding in two patients that necessitated urgent exploration. Five patients had an associated pseudoaneurysm, and in two of these, the aneurysm was infected.

Management of the aortic injuries is detailed in Table II. One patient refused intervention, and the authors had no information on his outcome. Endovascular management was performed in two cases with a 36-mm Talent (Medtronic, Minneapolis, Minn) and a 28-mm AneuRx (Medtronic) stent graft, respectively. The remaining seven patients had open surgical repair. A left thoracotomy was used in five patients; the approach used was not stated in

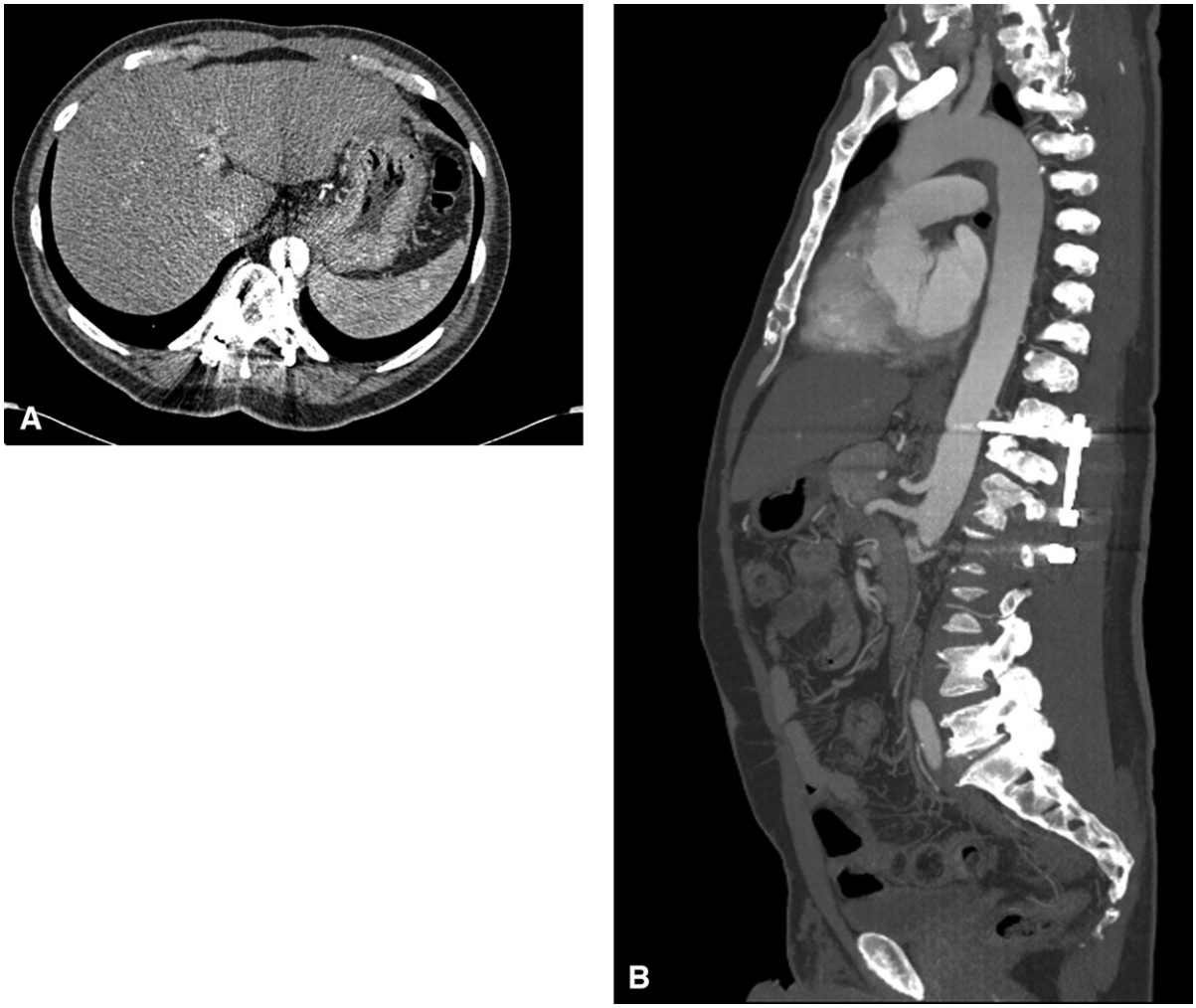

Fig 6. Patient 2. **A,** Computed tomography chest scan demonstrates a screw penetrating the posterior wall of the aorta without evidence of associated pseudoaneurysm or dissection. **B,** Computed tomography angiography.

two cases. Distal aortic perfusion was used in five of these seven cases. Cerebrospinal fluid drainage was used in only one case. None of these nine patients presented with complications of spinal cord ischemia.

The aorta was managed with primary repair in three patients; the remaining four patients required placement of a patch or tube graft. Complete removal of all orthopedic hardware was performed in four patients; screw-tip burring or total screw removal alone was performed in four additional patients. New hardware was placed in two of the four patients whose hardware was removed. The procedural outcome was favorable in all nine patients, with no deaths or major complications reported.

DISCUSSION

In the current report, we describe two cases of thoracic aortic perforation by vertebral pedicle screws and present a review the literature. Vascular trauma is a rare but well-recognized complication of spine surgery. Most previous reports have detailed cases of abdominal vascular injuries after operations on the lumbar spine.[15-17] Little has been written about vascular injuries after operations on the thoracic spine. Such injuries may be immediately apparent or become manifest in the early postoperative period[17]; however, others may not present for months to years after the spine operation, as documented in the current study.

Pseudoaneurysms are the most common late manifestation of penetrating aortic injuries.[18,19] A surprising finding was that there were only four cases of aortic pseudoaneurysms in this series, which may be because the offending screw was still in place and immobile. In our first patient, the screw responsible for the distal pseudoaneurysm was obviously loose as a result of vertebral body infection. Clinical presentation of aortic pseudoaneurysms varies, including absence of symptoms,[20] abdominal or chest pain,[20-23] symptoms from compression of surrounding structures,[18,20,24] and finally, acute bleeding.[25] Sometimes these pseudoaneurysms can be infected,[26] as in our first patient.

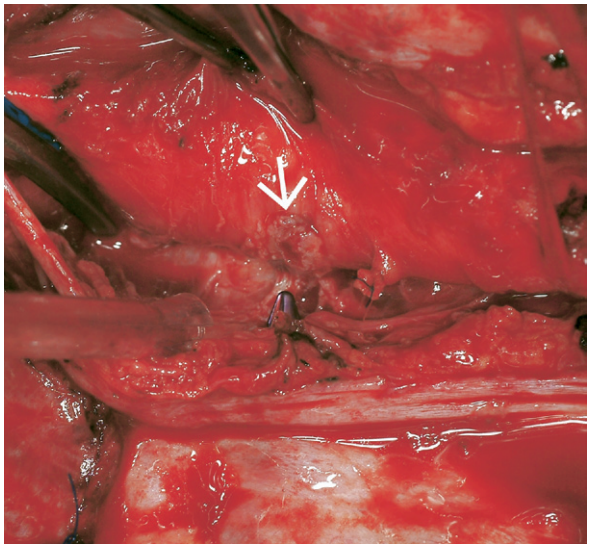

Fig 7. Patient 2. Operative photo shows the descending thoracic aorta retracted medially to expose the screw tip and perforation site *(white arrow)* in the posterior aortic wall.

Several CT scanning studies after spinal instrumentation have demonstrated a significant 4% to 25% incidence of screw malposition.[27-31] Actual screw penetration of the aorta is not necessary to cause injury. Mere impingement by a fixation screw can lead to aortic wall thinning and the potential for eventual erosion.[32] Proximity of the screw tip to aortic wall has been reported in 2% to 12% of cases.[33-35] Because the natural history of screws abutting the aorta remains unknown, the clinical significance and proper treatment of this entity are unclear.

The etiology of screw misplacement and aortic perforation has been attributed to an altered spatial relationship of the spine to the aorta in patients undergoing spinal fixation. In some patients with scoliosis, the spine deformity moves the descending thoracic aorta from a relatively anterolateral position to a more posterolateral position relative to the vertebral column. This change increases the possibility of the aorta being located in the direct line of screws passed from the right chest.[36-40] Even changes in body orientation result in relative position changes in the thoracic aorta, mostly at levels T4 to T8. The aorta is located posterolaterally to the spine in the supine position and more anterolaterally in the prone position.[13]

Once present, aortic pseudoaneurysms obviously should be repaired to prevent rupture,[14,41] but the treatment of asymptomatic aortic screw-tip penetration without pseudoaneurysm is empiric. Depending on the extent of the aortic wall defect, repair options include primary closure,[21,22] patch angioplasty,[18,23] placement of a stent graft,[42] and interposition grafting.[19,43] All these techniques were used in the cases reported in the current review. The presence of infection can complicate management,[26,44] necessitating use of a homograft or a biologic patch in some cases.[44] Distal aortic perfusion during aortic cross-clamping, a technique commonly used in thoracoabdominal aortic aneurysm repair[45] for the purpose of vital organ protection, was used in several cases.[46] This modality is probably not necessary for easily accessed, simple primary repairs.

Stent grafts have been previously used to treat aortic pseudoaneurysms and trauma with results comparable with open repair.[20,25] In cases of screw-tip penetration, however, removal of the screw tip is probably necessary to avoid the risk of tearing the stent graft fabric and recurrent bleeding. Simple burring of the screw tip is usually sufficient enough to prevent recurrence. Full hardware removal is reserved for infected cases, followed by secondary fixation if spine instability results. Infected hardware is usually associated with vertebral osteomyelitis and may require extensive débridement and use of myocutaneous flaps.[47] Our first patient refused to allow his hardware to be removed. Finally, observation for small pseudoaneurysms when repair might represent a technical challenge has also been suggested.[48]

The outcome in this series was universally successful, with no deaths or spinal cord ischemic complications; however, this result should not lead to an underestimation of the magnitude of the problem. The need for thoracic aortic clamping, with resultant vital organ ischemia, and the potential for associated infection increase the risk for major complications and death with this entity. We know of at least one unreported fatal case, and it seems likely that other cases with a poor outcome have not been reported.

To prevent aortic injury, spine surgeons should be aware of the anatomic changes that occur with scoliosis and avoid excessive pedicle screw penetration at any level.[40] Preoperative three-dimensional imaging is helpful in planning surgery.[38] Because of the positional changes of the aorta, Huitema et al[13] suggested that before anterior thoracolumbar spine surgery is performed, the position of the aorta in the prone and supine positions should be determined to decide the best operative approach. Modification of operative technique with appropriate change in the entry angle of pedicle screws has been suggested.[49] Controlled screw insertion with the use of a guiding device,[50] or under fluoroscopic,[51] CT,[52,53] or robotic guidance,[54-57] has also been used.

In 1986 Dunn[58] described six cases of "aortic erosion" associated with the use of anterior spine fusion devices placed from left-sided approaches. Dunn recommended insertion of these devices from the right side, but if this was impossible, device fixation as far posterior on the vertebral body as possible and coverage with a layer or two of cardiovascular felt to prevent direct impingement on the aorta. The United States Food and Drug Administration recently approved the use of a polytetrafluoroethylene cardiovascular patch (Preclude Vessel Guard, W. L. Gore & Associates, Inc., Flagstaff, Ariz) for aortoiliac coverage during re-do anterior verte-

Table I. Presentation of aortic injury by orthopedic hardware in 10 patients described in this review

First author	*Year*	*Age*	*Original surgery*		*Time to presentation*	*Clinical presentation*
			Indication	*Procedure*		
Jendrisak[4] Woolsey[3]	1986 1986	25	L2 fracture	ASF with Dunn prosthesis, rib grafting	6 weeks	Rupture of suprarenal aorta at L1 with retroperitoneal hematoma[a]
Sokolic[5]	1991	16	Scoliosis	Anterior spondylosyndesis of T5-L1	5 months	Rupture of descending thoracic aorta at T5 with hemothorax caused by a loosened device screw
Matsuzaki[6]	1993	52	Kyphosis	PSF with Cotrel-Dubousset prosthesis of T6-T9	8 months	Thoracic aorta erosion by a screw, incidental CT scan finding
Lim[11]	1999	50	L1-L2 fracture	PSF with Harrington distraction rods of T11-L5	10 months	Aortic pseudoaneurysm causing lower back pain and bowel habit change and a tender abdominal mass[b]
Ohnishi[7]	2001	53	T11 fracture	ASF with smooth-rod Kaneda prosthesis, T10-T12 bone grafting	20 months	Thoracic aorta pseudoaneurysm[a]
Choi[8]	2001	50	Kyphoscoliosis	PSF with Cotrel-Dubousset instrumentation of thoracolumbar spine	14 months	Aortic pseudoaneurysm at T6, infected with MRSA caused by a device screw
Minor[9]	2004	77	Scoliosis	Posterior thoracic spinal instrumentation	1 month	Aortic erosion by a T5 screw, incidental CT scan finding
Been[10]	2006	40	Scoliosis	Anterior Zielke procedure	20 years	5 cm thoracic aorta pseudoaneurysm caused by a device screw, CT scan finding performed for shortness of breath
Current report						
Patient 1	2008	55	Thoracic spine osteomyelitis	Débridement, ASF for thoracic spine osteomyelitis	11 months	Aortic pseudoaneurysm at T6 and T10, infected with MRSA
Patient 2	2008	51	Tuberculous spondylodiscitis	Posterior T11-L2 thoracolumbar plating	13 months	Aortic erosion by a T11 screw, incidental CT scan finding

ASF, Anterior spine fusion; *CT,* computed tomography; *PSF,* posterior spine fusion.
[a]Caused by the orthopedic hardware.
[b]Attributed to injury from a pedicle screw.

Table II. Management of aortic injury by orthopedic hardware in nine patients described in this review

First author	*Approach*	*Cardiopulmonary bypass*	*Management*			*Outcome*
			Aorta	*Prosthesis*	*Spine*	
Jendrisak,[4] Woolsey[3]	NS	No	Primary repair	Removal	Secondary PSF	Good
Sokolic[5]	Left thoracotomy	Partial	Primary repair	Removal	Deferred	Good
Matsuzaki[6]	Left thoracotomy	Yes	Resection and repair with a tube graft	Screw burring	NA	Good
Ohnishi[7]	NS	NK	Resection and repair with a tube graft	Removal	Secondary PSF	Good
Choi[8]	Left thoracotomy	Partial	Resection and repair with a tube graft	Removal[a]	Deferred	Good
Minor[9]	Hybrid	NA	Endovascular repair	Screw removal	NK	Good
Been[10]	Left common femoral artery	NA	Endovascular repair	Left in place	NA	Good
Current report						
Patient 1	Left thoracotomy	Partial, atriofemoral	Primary aortic repair (T6) and repair with a patch (T10)	Screw burring	NA	Good
Patient 2	Left thoracotomy	Partial, aortoaortic	Primary repair	Screw burring	NA	Good

ASF, Anterior spine fusion; *PSF,* posterior spine fusion; *NA,* not applicable; *NK,* not known; *NS,* not specified.
[a]Performed 3 weeks before aortic operation.

bral surgery to reduce the risk of potential vessel damage during a revision surgery. The use of this patch might reduce the incidence of aortic injury by orthopedic hardware.

In summary, aortic penetration by orthopedic hardware is a serious, most likely under-reported complication of instrumentation on the spine. Because of treatment implications, orthopedic and vascular surgeons should be aware of this entity.

REFERENCES

1. Papadoulas S, Konstantinou D, Kourea HP, Kritikos N, Haftouras N, Tsolakis JA. Vascular injury complicating lumbar disc surgery. A systematic review. Eur J Vasc Endovasc Surg 2002;24:189-95.
2. Faciszewski T, Winter RB, Lonstein JE, Denis F, Johnson L. The surgical and medical perioperative complications of anterior spinal fusion surgery in the thoracic and lumbar spine in adults. A review of 1223 procedures. Spine 1995;20:1592-9.
3. Woolsey RM. Aortic laceration after anterior spinal fusion. Surg Neurol 1986;25:267-8.
4. Jendrisak MD. Spontaneous abdominal aortic rupture from erosion by a lumbar spine fixation device: a case report. Surgery 1986;99:631-3.
5. Sokolic J, Sosa T, Ugljen R, Biocina B, Simunic S, Slobodnjak Z. Extrinsic erosion of the descending aorta by a vertebral fixator. Tex Heart Inst J 1991;18:136-9.
6. Matsuzaki H, Tokuhashi Y, Wakabayashi K, Kitamura S. Penetration of a screw into the thoracic aorta in anterior spinal instrumentation. A case report. Spine 1993;18:2327-31.
7. Ohnishi T, Neo M, Matsushita M, Komeda M, Koyama T, Nakamura T. Delayed aortic rupture caused by an implanted anterior spinal device. Case report. J Neurosurg 2001;95(2 suppl):253-6.
8. Choi JB, Han JO, Jeong JW. False aneurysm of the thoracic aorta associated with an aorto-chest wall fistula after spinal instrumentation. J Trauma 2001;50:140-3.
9. Minor ME, Morrissey NJ, Peress R, Carroccio A, Ellozy S, Agarwal G, et al. Endovascular treatment of an iatrogenic thoracic aortic injury after spinal instrumentation: case report. J Vasc Surg 2004;39:893-6.
10. Been HD, Kerkhoffs GM, Balm R. Endovascular graft for late iatrogenic vascular complication after anterior spinal instrumentation: a case report. Spine 2006;31:E856-8.
11. Lim KE, Fan KF, Wong YC, Hsu YY. Iatrogenic upper abdominal aortic injury with pseudoaneurysm during spinal surgery. J Trauma 1999;46: 729-31.
12. Aydinli U, Ozturk C, Saba D, Ersozlu S. Neglected major vessel injury after anterior spinal surgery: a case report. Spine 2004;29:E318-20.
13. Huitema GC, Cornips EM, Castelijns MH, van Ooij A, van Santbrink H, van Rhijn LW. The position of the aorta relative to the spine: is it mobile or not? Spine 2007;32:1259-64.
14. Floch NR, Harvey JC, Beattie EJ Jr. Aortoesophageal fistula after reconstruction of the thoracic spine. Ann Thorac Surg 1995;60:191-2.
15. Baker JK, Reardon PR, Reardon MJ, Heggeness MH. Vascular injury in anterior lumbar surgery. Spine 1993;18:2227-30.
16. Brau SA, Delamarter RB, Schiffman ML, Williams LA, Watkins RG. Vascular injury during anterior lumbar surgery. Spine J 2004;4:409-12.
17. Sasso RC, Best NM, Mummaneni PV, Reilly TM, Hussain SM. Analysis of operative complications in a series of 471 anterior lumbar interbody fusion procedures. Spine 2005;30:670-4.
18. Chase CW, Layman TS, Barker DE, Clements JB. Traumatic abdominal aortic pseudoaneurysm causing biliary obstruction: a case report and review of the literature. J Vasc Surg 1997;25:936-40.
19. Verdant A. Chronic traumatic aneurysm of the descending thoracic aorta with compression of the tracheobronchial tree. Can J Surg 1984; 27:278-9.
20. Andrassy J, Weidenhagen R, Meimarakis G, Lauterjung L, Jauch KW, Kopp R. Stent versus open surgery for acute and chronic traumatic injury of the thoracic aorta: a single-center experience. J Trauma 2006; 60:765-72.
21. Raghavendran K, Singh G, Arnoldo B, Flynn WJ. Delayed development of infrarenal abdominal aortic pseudoaneurysm after blunt trauma: a case report and review of the literature. J Trauma 2004;57:1111-4.
22. Dregelid E, Jenssen G, Jonung T, Braaten A. Pseudoaneurysm of the abdominal aorta due to a needle-like osteophyte on the first lumbar vertebra. J Vasc Surg 2007;45:1059-61.
23. Pisters PW, Heslin MJ, Riles TS. Abdominal aortic pseudoaneurysm after blunt trauma. J Vasc Surg 1993;18:307-9.
24. Kaminishi Y, Saito T, Kato M, Kamisawa O, Misawa Y, Fuse K. Successful surgical treatment of chronic traumatic thoracic aneurysm in two patients. Jpn J Thorac Cardiovasc Surg 2002;50:375-7.
25. Hinchliffe RJ, Yung M, Hopkinson BR. Endovascular exclusion of a ruptured pseudoaneurysm of the infrarenal abdominal aorta secondary to pancreatitis. J Endovasc Ther 2002;9:590-2.
26. Cherry JK, Bennett DE. False aneurysm of the aorta following penetrating trauma. Report of a case with secondary infection and delayed rupture. Arch Surg 1966;93:404-8.
27. Liljenqvist UR, Halm HF, Link TM. Pedicle screw instrumentation of the thoracic spine in idiopathic scoliosis. Spine 1997;22:2239-45.
28. Suk SI, Kim WJ, Lee SM, Kim JH, Chung ER. Thoracic pedicle screw fixation in spinal deformities: are they really safe? Spine 2001; 26:2049-57.
29. Wiesner L, Kothe R, Schulitz KP, Ruther W. Clinical evaluation and computed tomography scan analysis of screw tracts after percutaneous insertion of pedicle screws in the lumbar spine. Spine 2000;25:615-21.
30. Sjostrom L, Jacobsson O, Karlstrom G, Pech P, Rauschning W. CT analysis of pedicles and screw tracts after implant removal in thoracolumbar fractures. J Spinal Disord 1993;6:225-31.
31. Kuklo TR, Lenke LG, O'Brien MF, Lehman RA Jr, Polly DW Jr, Schroeder TM. Accuracy and efficacy of thoracic pedicle screws in curves more than 90 degrees. Spine 2005;30:222-6.
32. Faro FD, Farnsworth CL, Shapiro GS, Mohamad F, White KK, Breisch E, et al. Thoracic vertebral screw impingement on the aorta in an in vivo bovine model. Spine 2005;30:2406-13.
33. Smorgick Y, Millgram MA, Anekstein Y, Floman Y, Mirovsky Y. Accuracy and safety of thoracic pedicle screw placement in spinal deformities. J Spinal Disord Tech 2005;18:522-6.
34. Sucato DJ, Kassab F, Dempsey M. Analysis of screw placement relative to the aorta and spinal canal following anterior instrumentation for thoracic idiopathic scoliosis. Spine 2004;29:554-9.
35. Huitema GC, van Rhijn LW, van Ooij A. Screw position after double-rod anterior spinal fusion in idiopathic scoliosis: an evaluation using computerized tomography. Spine 2006;31:1734-9.
36. Maruyama T, Takeshita K, Nakamura K, Kitagawa T. Spatial relations between the vertebral body and the thoracic aorta in adolescent idiopathic scoliosis. Spine 2004;29:2067-9.
37. Kuklo TR, Lehman RA Jr, Lenke LG. Structures at risk following anterior instrumented spinal fusion for thoracic adolescent idiopathic scoliosis. J Spinal Disord Tech 2005;18(suppl 1):S58-64.
38. Sucato DJ, Duchene C. The position of the aorta relative to the spine: a comparison of patients with and without idiopathic scoliosis. J Bone Joint Surg Am 2003;85:1461-9.
39. Milbrandt TA, Sucato DJ. The position of the aorta relative to the spine in patients with left thoracic scoliosis: a comparison with normal patients. Spine 2007;32:E348-53.
40. Bullmann V, Fallenberg EM, Meier N, Fischbach R, Lerner T, Schulte TL, et al. The position of the aorta relative to the spine before and after anterior instrumentation in right thoracic scoliosis. Spine 2006;31: 1706-13.
41. Miller JS, Wall MJ Jr, Mattox KL. Ruptured aortic pseudoaneurysm 28 years after gunshot wound: case report and review of the literature. J Trauma 1998;44:214-6.
42. Yeh MW, Horn JK, Schecter WP, Chuter TA, Lane JS. Endovascular repair of an actively hemorrhaging gunshot injury to the abdominal aorta. J Vasc Surg 2005;42:1007-9.
43. Borioni R, Garofalo M, Seddio F, Colagrande L, Marino B, Albano P. Posttraumatic infrarenal abdominal aortic pseudoaneurysm. Tex Heart Inst J 1999;26:312-4.
44. Falkensammer J, Behensky H, Gruber H, Prodinger WM, Fraedrich G. Successful treatment of a tuberculous vertebral osteomyelitis eroding the thoracoabdominal aorta: a case report. J Vasc Surg 2005;42: 1010-3.
45. Safi HJ, Miller CC 3rd, Huynh TT, Estrera AL, Porat EE, Winnerkvist AN, et al. Distal aortic perfusion and cerebrospinal fluid drainage for thoracoabdominal and descending thoracic aortic repair: ten years of organ protection. Ann Surg 2003;238:372-81.
46. Moore EE, Burch JM, Moore JB. Repair of the torn descending thoracic aorta using the centrifugal pump for partial left heart bypass. Ann Surg 2004;240:38-43.

47. Mitra A, Mitra A, Harlin S. Treatment of massive thoracolumbar wounds and vertebral osteomyelitis following scoliosis surgery. Plast Reconstr Surg 2004;113:206-13.
48. Harrington DP, Barth KH, White RI Jr, Brawley RK. Traumatic pseudoaneurysm of the thoracic aorta in close proximity to the anterior spinal artery: a therapeutic dilemma. Surgery 1980;87:153-6.
49. Qiu Y, He YX, Wang B, Zhu F, Wang WJ. The anatomical relationship between the aorta and the thoracic vertebral bodies and its importance in the placement of the screw in thoracoscopic correction of scoliosis. Eur Spine J 2007;16:1367-72.
50. Jang JS, Lee SH, Lim SR. Guide device for percutaneous placement of translaminar facet screws after anterior lumbar interbody fusion. Technical note. J Neurosurg 2003;98(1 suppl):100-3.
51. Shim CS, Lee SH, Jung B, Sivasabaapathi P, Park SH, Shin SW. Fluoroscopically assisted percutaneous translaminar facet screw fixation following anterior lumbar interbody fusion: technical report. Spine 2005;30:838-43.
52. Kang HY, Lee SH, Jeon SH, Shin SW. Computed tomography-guided percutaneous facet screw fixation in the lumbar spine. Technical note. J Neurosurg Spine 2007;7:95-8.
53. Papadopoulos EC, Girardi FP, Sama A, Sandhu HS, Cammisa FP Jr. Accuracy of single-time, multilevel registration in image-guided spinal surgery. Spine J 2005;5:263-8.
54. Lieberman IH, Togawa D, Kayanja MM, Reinhardt MK, Friedlander A, Knoller N, et al. Bone-mounted miniature robotic guidance for pedicle screw and translaminar facet screw placement: part I–technical development and a test case result. Neurosurgery 2006; 59:641-50.
55. Togawa D, Kayanja MM, Reinhardt MK, Shoham M, Balter A, Friedlander A, et al. Bone-mounted miniature robotic guidance for pedicle screw and translaminar facet screw placement: part 2–evaluation of system accuracy. Neurosurgery 2007;60(suppl 1):ONS129-39.
56. Barzilay Y, Liebergall M, Fridlander A, Knoller N. Miniature robotic guidance for spine surgery–introduction of a novel system and analysis of challenges encountered during the clinical development phase at two spine centres. Int J Med Robot 2006;2:146-53.
57. Sukovich W, Brink-Danan S, Hardenbrook M. Miniature robotic guidance for pedicle screw placement in posterior spinal fusion: early clinical experience with the SpineAssist. Int J Med Robot 2006;2: 114-22.
58. Dunn HK. Anterior spine stabilization and decompression for thoracolumbar injuries. Orthop Clin North Am 1986;17:113-9.

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