

Expert Advice Forum of AOSpine International

“Dangerously positioned but asymptomatic pedicle screws”

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Introduction:

Pedicle screw (PS) placement is the most commonly used technique to achieve fixation and fusion in spine surgery. It was first introduced by Harrington and Tullos in 1969¹ and further development of the technique has made it a mainstay of spinal instrumentation. This technique is used for various types of spinal deformities, degenerative spinal disorders, and neoplastic or infectious pathologies associated with spinal instability. Although many technical advances have been made in this area, dangerous complications can occur, with the most common one being screw malpositioning.^{2,3,4} Numerous published reports have focused mainly on symptomatic malpositioned screws, but there remains a lack of consensus on how to deal with asymptomatic malpositioned pedicle screws. These screws in asymptomatic patients may be identified early in postoperative images or several years later in the due course of clinical follow-up. The percentage rate of cervical pedicle screw malposition varies from 5.3% to 19.5%^{5,6,7,8} while that of thoracolumbar pedicle screw malposition varies from 1.2% to 65%.^{3,9} Asymptomatic malpositioned pedicle screws have been described in many reports, but when and how to revise them is not clearly indicated.

In order to ascertain the appropriate management of asymptomatic malpositioned pedicle screws, identified either early or late, the senior author (MI) contacted six spine experts from around the world (Emiliano Viale (EV), Ferran Pellise (FP), Steve Lewis (SL), David Polly (DP), JB Park (JB), and Samir Dalvie (SD)) to find how different their ideology is in dealing with these cases. In this forum, we have discussed five different case scenarios where patients are

completely asymptomatic but the postoperative imaging studies identified dangerously positioned pedicle screws. The following 5 questions were given to the 6 experts for their opinions in each case.

1. Do you choose surgical revision or conservative management for malpositioned pedicle screws?
2. If you choose surgical revision, please describe the surgical indications (canal occupation ratio or magnitude of vessel protrusion), and when and how to salvage malpositioned screws.
3. Do you perform any imaging or other studies before salvage surgery? Or any consultation with other specialists such as cardiovascular surgeons?
4. If you choose conservative management, please describe the details of your conservative management.
5. Any special considerations for the explanation of the risks related either to the malpositioned screws or the salvage surgery to the patients and their family? These patients are asymptomatic to the malpositioned screws.

Expert opinions related to the selection of conservative or operative management and final solutions given by the case providers to these patients are also documented in this manuscript. Further discussion on how to handle asymptomatic malpositioned pedicle screws is presented based on the review of previous publications regarding malpositioned pedicle screws.

Case 1: Malpositioned PS into the spinal canal in the cervical spine (65yo. M) (Figure 1)

Comments from experts

EV:

This case shows medially placed pedicle screws at the cervical spine, in a patient who is asymptomatic. It is not clear whether these screws are at the top, bottom, or center of the construct, and the importance of the fixation at this level for the spine's stability. The option of leaving the screws in this position is not viable due to the following reasons: 1) they are reducing the space for the spinal cord; 2) they are biomechanically ineffective, acting as a foreign body. The strategy for this case would be to define the importance of this fixation point. If it is really relevant, the medially placed screws can act as guides for new screw trajectories, followed by removal of the screws. Direct visualization is recommended for screw removal to avoid further nerve root damage, dural injury, and for hemostatic control of potential epidural bleeding.

FP:

Yes. I would reoperate and replace the malpositioned screws. We have experienced at least 2 cases of late neurologic deterioration associated with intracanal asymptomatic screws. I would probably not remove an asymptomatic screw with a medial breach <3-4mm, with part of the screw in the canal.

SL:

- A. A view of the remaining construct would be helpful to determine whether this implant is at the proximal or distal end of the construct or whether it is central in the construct.
- B. While the patient is described as neurologically intact, if the patient has complaints of dysesthesia or stenosis, I would offer a revision or removal of these implants. If the construct is already fused or these implants are not end screws, I would recommend removing the screws. If the screws were essential to the construct, I would recommend

to revise the screws. Considerations upon removal of these screws is the possibility of a persistent cerebrospinal fluid leak. Plugging the screw holes with gelatinous foam, bone wax, and fibrin sealant would be methods utilized to minimize this risk. If these screws were essential to the construct, careful examination of the imaging should be performed to plan the best way to revise the screws. The main issue in this case is the choice of start points that are too medial. Lateralizing the start points and choosing a slightly less medialized trajectory should provide successful placement of the screws.

- C. If conservative management is chosen, I would discuss potential neurological symptoms that include vague dysesthesia, Lhermitte's sign, positional headaches, or even stenosis symptoms that may be a result of these screws. Should they experience these symptoms to a significant degree, surgical options may be considered.
- D. The risk of chronic CSF leak would be the most likely complication incurred should they choose removal of the screws.

DP:

1. I would strongly consider removal and replacement of the screws in this case. The patient is rheumatoid so healing is an issue. The screws as currently placed have very little purchase (only dorsal and ventral lamina, no pedicle purchase, and minimal vertebral body purchase). It is highly likely that they will toggle and become loose, especially in a rheumatoid patient with soft bone and poor healing.
2. The indication for revision is to obtain adequate fixation. I would get a myelogram CT to assess if there is dural violation as preparation for the surgery. It is quite possible that the patient may require a lumbar CSF drain if there is a ventral dural tear as it is unlikely that a watertight repair could be achieved.
4. If the patient were to be managed non-operatively, I would specifically look for signs of pseudarthrosis and signs of a CSF leak within the spinal canal.
5. I would explain the risks of pseudarthrosis and CSF leak to the patient and family.

JB:

1. Conservative treatment. Despite the medial cortical violation of C6 both pedicles into the spinal canal, the patient has no clinical or neurologic symptoms. Removing malpositioned pedicle screws can cause catastrophic spinal cord injury and/or dural tear with CSF leakage.
4. Just careful follow-up. If necessary, CT myelogram can be performed.
5. Since the patient is a rheumatoid patient, it should be noted that over time the bones may weaken and cause nerve damage.

SD:

I would need further case details, such as indication for surgery, pre-op imaging, and post-operative x-rays. The only issue here is how important this level of fixation is to the overall construct and stability of the cervical spine. By themselves these screws are not dangerous as they are asymptomatic. If these screws are not too important to stability, and a good fusion technique has been used, the construct can be protected in external orthosis, such as a collar or even a Halo vest, and monitored till fusion. In this instance a revision is not required unless there is evidence of loosening or pseudarthrosis. If these screws are important to the stability, I would consider the risks versus benefits of revision surgery, as opposed to getting a fusion with external support. The relatives would be counseled about implant loosening and pseudarthrosis as a

potential complication of conservative care.

What was done to this patient

Removal of the malpositioned pedicle screws was conducted at 9 months after the first surgery when the patient underwent another lumbar surgery. Neither CSF leak nor dural tear was observed during salvage surgery for the malpositioned cervical pedicle screws.

Case 2: Malpositioned PS into the spinal canal in the thoracic spine and lumbar spine (26yo, F) (Figure 2)

EV:

Medially placed screws in the thoracic and lumbar spine. For the thoracic screw, there is no clear spinal cord compromise or screw loosening that might indicate the need for removal. The only indication for removal, besides the two previously mentioned, would be that the neurologic symptoms are on the right side. For the lumbar screw, which crosses the midline, thus leaving the vertebral body on the contralateral side, the need for removal is the same as for any symptomatic canal stenosis, especially if the symptoms are progressive. In this case, fusion should be assessed to determine the need for repositioning the screw or extending the fixation to other levels if the pedicle is not viable. Direct visualization reduces the risk of root adhesion and further injury. Surgeons should be prepared for dural repair, both ventral and dorsal. If dural penetration is evident, increasing the dural defect will reduce further damage and facilitate the repair.

FP:

Yes, I would reoperate and remove both screws. A case was published in The Lancet several years ago: an asymptomatic neurologically intact patient had a knife blade penetrating the thoracic spinal cord at its midline. Blade removal ended in paraplegia. T7 medial screw removal may have some risk of deterioration?? Neuromonitoring.

SL:

- A. I would discuss with the patient their symptoms, specifically related to postural headaches, neural claudication, and radicular leg pain, numbness, weakness. Should these symptoms be sufficiently bothersome to the patient, I would recommend surgical revision.
- B. Both screws demonstrate significant canal compromise, and while they may not be causing severe neurological symptoms, they are likely associated with stenosis and possibly with dural related symptoms. This patient has already undergone a CT myelogram. I would feel that a plain CT would have been sufficient. I would look for CSF extravasation on the myelogram that was performed. I would expect a CSF leak upon screw removal. I would not involve neurosurgery as I would plan on managing this on my own.
- C. Should the patient prefer non-surgical care, regular clinical follow-up both for the construct and the malpositioned screws would be recommended every 6 to 12 months.
- D. I would discuss the risk of early +/- chronic CSF leak related to removing the screw. I would fill the screw site with gelfoam and other sealants, and plug the bone with wax and structural bone graft. I would discuss as well the possibility of irritating the nerve

roots with screw removal. There would be a possibility of being worse after removing the screws in terms of both dural and radicular symptoms.

DP:

This is my case and I will choose not to answer.

JB:

1. Conservative treatment. Despite the medial cortical violation of both pedicles into the spinal canal, the patient has no clinical or neurologic symptoms. Removing malpositioned pedicles screws can cause catastrophic spinal cord injury and/or dural tear with CSF leakage.
4. Regular outpatient follow-up checks for the occurrence of new symptoms or neurologic deficits, and check follow-up radiographs. Follow-up CT myelogram scan is helpful.
5. Explain the presence of asymptomatic malpositioned screws and that careful observation is required. Sometimes, the policy of “Don’t ask and don’t tell” might be the best choice for patients and their families.

SD:

I would need further clinical details. The side of the weakness is not known, nor is the grade of power and whether it has been static since surgery or progressive.

The fact that it has been ‘several years’ since the surgery means that the prognosis for neural recovery is poor if it is screw related. It is surprising that this screw malposition was not dealt with earlier.

I would tell the patient that there is no benefit in revision now, and that it would be an extensive surgical exercise.

What was done to this patient

Surgical revision was conducted several months after these images were obtained.

Case 3: Malpositioned PS into the transverse foramen in the cervical spine a risk to the vertebral artery (VA) (48yo. M) (Figure 3)

EV:

The screw crosses the vertebral artery foramen, and it is very likely that the vertebral artery is injured, and that this artery is not dominant. The strategy depends on arteriography, showing the presence of residual flow and the possibility of later thromboembolic events. If residual flow is present, there are two strategies: 1) to occlude the artery by means of catheterization, leaving the screw in place; 2) exposure of the vertebral artery above and below the screw for direct ligation. The second option is technically demanding and only recommended as a last resort.

FP:

I would remove it if there is a risk of stroke. I am not aware of late complications in such a case. If no late complication should be expected, I would not remove the screw. Neurologists/neurosurgeons and vascular surgeons should participate in the decision. Risk of vascular dissection/stroke? Angiography.

SL:

- A. I would choose conservative management in this case. I would expect the right vertebral artery to be injured by the screws, and that removing the screws would not change this situation. The spine was very unstable and the screws are required to maintain stability.
- B. If surgical revision is considered, an angiogram would be recommended to assess the arterial anatomy prior to removal. If there was partial injury to the right vertebral artery, consideration can be made to embolize the remnants of the artery.
- C. Conservative treatment would entail a referral to a neurologist for ongoing follow-up.
- D. The patient and the family should be informed that an injury to the right vertebral artery occurred. They should be instructed that should further cervical spine surgery be required, an injury to the left vertebral artery could be fatal. They should notify their future surgeon of this issue.

DP:

1. I would manage this patient non-operatively. The screws have reasonable purchase. The fracture is reduced and well aligned. With no cranial symptoms, the risk of screw removal and vertebral artery bleeding is real.
2. No revision.
4. Serial neurological evaluations by a neurologist to watch for stroke symptoms would be appropriate. Given the Asia C status I would have concerns if the patient needs chronic anticoagulation. Presumptively this patient has a patent circle of Willis. If there are concerns down the road, vascular imaging could be helpful.
5. I would specifically discuss the above concerns with the family and with the physical medicine doctor managing the spinal cord injury care.

JB:

1. Conservative treatment
3. Just careful follow-up. If necessary, neck angio-CT can be performed.
5. Explain the presence of asymptomatic malpositioned screws and that careful observation is required. Sometimes, the policy of “Don’t ask and don’t tell” may be the best choice for patients and their families.

SD:

Investigations of the vascular anatomy are indicated. This may be a CT angiography or a conventional angiography. Hopefully, pre-operative studies are also available to compare and look for the dominant side.

There may be 3 scenarios:

- A. If the screw does not affect the flow at all, it may be left alone.
- B. There is a thrombus on either side of the screw and there is no flow in the blocked area. In this case, as the patient has not suffered any injury due to the thrombosis, it does not require intervention. Careful observation may be necessary. A call may have to be made on the risks vs benefits of anticoagulation.
- C. If there is leakage of contrast (blood) from the screw puncture, one has to consider revising the screw. One would need input from a specialist in vascular surgery. Removing the screw would also have considerable risk from torrential bleeding, and adequate preparation should be made for this eventuality.

If the vessel is non dominant or co-dominant, a pre-operative occlusion on both sides by coiling can be performed. The screw can then be safely revised to a safer and better position.

The relatives have to be counseled about the potentially fatal condition or morbidity due to stroke, and this would hopefully be done prior to the operation.

What was done to this patient

Surgical revision was conducted by a different surgeon from the first surgeon at postoperative several months. There was no arterial bleeding when the malpositioned pedicle screw was removed during revision surgery.

Case 4: Malpositioned PS pushing the aorta (28yo. F) (Figure 4)

EV:

In this case, none of the exams were able to prove that there was a breach of the artery wall. As there are several reports of late injury, pseudoaneurysms, and mycotic aneurysms due to pedicle screw encroachment into the aorta, removal is mandatory. The two options are: 1) to perform an endovascular procedure with the placement of a stent followed by removal of the screw, which would have the consequence of long-term anticoagulation in a young patient; 2) to remove the screw under direct visualization, with a small thoracotomy, positioning of vessel loops cranially and caudally at the aorta, and simultaneous removal of the screw on lateral decubitus. If bleeding occurs, the breach is minor and can be directly repaired.

FP: Yes. I would definitely remove the screw contacting the aorta. Late complications have been reported. Discuss with vascular surgeons. Angiography.

SL:

- A. I would choose surgical treatment in this case.
- B. I would review the construct on the CT and determine the status of the fusion as well as the position of all the screws. If the fusion is solid, I would consider either removing the screw or replacing it with one 10 mm shorter. With the CT angiogram already performed, I would not need further investigations. I would have a vascular surgeon available for the procedure. I would have an interventional radiologist in the operating room. I would have an ipsilateral femoral arterial line in place for the procedure so that a stent could be placed in the aorta if a major bleed were to occur.
- C. With conservative management, I would do regular ultrasounds of the aorta to ensure that no further injury occurs to the aorta over time.
- D. The risks of delayed aortic rupture would be discussed with the patient

DP:

- A. I would discuss this with the patient. I think that this case could be managed either with surgical revision or continued observation.
- B. There is not clear distortion of the aorta on the aortogram. Perhaps as the radiologist did the study, they might have seen a different projection or disruption of the contrast flow pattern which could change my opinion.
- C. If I were to observe this patient, I would get sequential serial imaging to ensure that no aneurysm/pseudoaneurysm develops.

- D. I would explain to the family both treatment strategies. If I were to do a surgical revision, I would have interventional radiology/endovascular surgery pass a guide wire and have a stent ready to go before removing the screw.

JB:

1. Surgical revision. Because it may cause aortic rupture and sudden death, I think that surgery to remove the pedicle screw after aorta bypass surgery is necessary.
2. The operation strategy may require a two-step approach with a vascular surgery team. In case of violation of the aorta, angiography is considered essential. If there is a suspected or obvious violation of the aorta, a vascular surgeon (general, thoracic surgeon) must be consulted. Even though there is no aorta injury, the screw and aorta are in contact with each other and there is a high possibility of aneurysm due to pulsation of the aorta.
5. These cases might be associated with sudden future mortality because the screws could penetrate the aorta. Therefore, we have to explain the present status and the future risk.

SD:

In this case I would not intervene. The screw has been in the same position since surgery, and hence there is no imminent risk at this point. Any injury or pseudoaneurysm would have presented long ago. It is highly unlikely that any adverse event would occur now. The patient and family would be counseled that there is a very unlikely chance that this screw would cause any problems, and that the risk of revision at this stage is far more than the risk posed by keeping it in place.

What was done to this patient

Surgical revision was conducted with spine surgeons and vascular surgeons.

Case 5: Malpositioned PS deeply inserted into the aorta (28yo. F) (Figure 5)

EV:

The same comments from the case above apply to this one. The added difficulty for the endovascular procedure is the risk of stent damage if the screw is not removed before the stent positioning.

The following references have good technical descriptions about the procedure:

- 1) Clairborne, P. Journal of vascular surgery cases. 1(4):265-267, 2015.
- 2) Freyrie, A. Annals of Vascular surgery. 27(4):499.e1-499.e3, 2013.

FP:

Yes, I would remove the screws. Vascular surgeon absolutely needed.

SL:

- A. I would choose surgical treatment in this case. The indication for surgery would be to prevent the possibility of catastrophic delayed rupture of the aorta.
- B. I would review the construct on the CT and determine the status of the fusion as well as the position of all the screws. If the fusion is solid, I would consider either removing the screw or replacing it with one 10 mm shorter. With the CT angiogram and ultrasound

already performed, I would not need further investigations. During the surgery, I would have a vascular surgeon available for the procedure. I would have an interventional radiologist in the operating room. I would have an ipsilateral femoral arterial line in place for the procedure. An aortic stent would be available for immediate insertion by the interventional radiologist or vascular surgeon should major bleeding occur.

- C. If the patient declined surgery, for conservative management, I would do regular ultrasounds of the aorta to ensure that no further injury occurs to the aorta over time.
- D. The risks of delayed aortic rupture would be discussed with the patient.

DP:

1. I would recommend surgical revision. This screw is clearly in the vessel itself. Concerns are that thrombosis could form on the screw tip or that there could be dissection around the screw.
2. The reason for revision is prevention of thrombosis or dissection. This case would be planned in conjunction with interventional radiology/endovascular surgery and cardiothoracic surgery. If the endovascular approach had a high confidence of success then I would proceed with CT surgery on standby. I would do this case in a lateral position with the thorax draped for a thoracotomy. The CT surgeons may or may not want to do a thoracoscopy before screw removal. If there were uncontrolled bleeding with screw removal, either deploying a stent or temporarily doing a balloon occlusion could control it at least temporarily. This would be the equivalent of an aortic cross clamp with the risk of spinal cord ischemia.
4. If the patient refused surgery, serial imaging to rule out aneurysm formation would be reasonable.
5. Discussion with the family would be detailed about the risk of death due to bleeding, spinal cord ischemia, and the usual surgical risks.

JB:

1. Surgical revision. Because it may cause aortic rupture and sudden death, I think that surgery to remove the pedicle screw after aorta bypass surgery is necessary.
2. The operation strategy may require a two-step approach with a vascular surgery team. In case of violation of the aorta, angiography is considered essential. If there is a suspected or obvious violation of the aorta, a vascular surgeon (general, thoracic surgeon) must be consulted. Even though there is no aorta injury, the screw and aorta are in contact with each other and there is a high possibility of aneurysm due to pulsation of the aorta.
5. These cases might be associated with sudden future mortality because the screws could penetrate the aorta. Therefore, we have to explain the present status and the future risk.

SD:

It would be important to compare with the earlier postoperative films to confirm that the screw has cut out rather than being malpositioned.

Assuming the screws have cut-out, I would recommend a revision. I would involve a vascular surgeon in the case. My plan would be to take this patient for surgery together with a vascular surgeon. It would also have to be ascertained if it was sufficient to remove the offending screw from the construct or if a refixation/extension was required

Patient would be positioned in the lateral position, and as first stage, the vascular anatomy would

be approached from an anterior approach. The screw tip would be visualized as well as the aorta, and it would be evident whether the screw was clear of the vessel or not.

If the screw was separate, then by posterior approach, the offending screw would be removed.

If not, then full preparation for a vascular rescue, clamping of aorta, readiness for by-pass graft, etc. would be made and the screw removed subsequently.

The patient and family would be counseled for a very high risk surgery, with complications such as paraplegia or death. The risk of not doing the surgery would be pseudo-aneurism formation with fatal sequelae.

What was done to this patient

Surgical revision was conducted with spine surgeons and vascular surgeons.

Discussion:

The surgical indications to revise asymptomatic malpositioned pedicle screws are not yet established. The expert forum here discussed 5 different case scenarios where pedicle screws were dangerously malpositioned, but all these patients were asymptomatic. Table 1 shows the opinions from the experts about further actions required in each case. There are large variations among the 5 experts in treatment selection except in case 3 and 5.

Table 1: Difference between experts on whether to revise the asymptomatic screws

EXPERT	EV	FP	SL	DP	JB	SD	MAJORITY
Case1	R	R	R	R	NR	NR	Surgical revision
Case2	R	R	R	R	NR	NR	Surgical revision
Case3	R/NR	R/NR	NR	NR	NR	R/NR	Conservative
Case4	R	R	R	R/NR	R	NR	Surgical revision
Case5	R	R	R	R	R	R	Surgical revision

Revision(R)/No revision(NR)

There are two scoring systems reported to help surgeons determine which malpositioned screws need surgical revision. In a study published by the McGill Scoliosis and Spine Centre¹⁰, they proposed a new scoring system to predict which screws needs revision. In their scoring system, both symptomatic and asymptomatic screws were taken into account (Table 2).

Table 2: Scoring system for revision of pedicle screw (McGill score)¹⁷

Location of breach	Radiological score based on axial cuts				Symptomatic score	
	>6mm	4-6mm	2-4mm	<2mm		
Medial	4	3	2	1	New radicular pain	4
Inferior	2	2	1	0	New weakness	4
Lateral	2	2	1	0	New sensory loss	1
Superior	1	1	0	0	No symptoms	0
Anterior	1	1	0	0		

Final score = radiological score + symptomatic score. Score>6 considered for revision

An imaging score was added to a symptom score, and a total above 6 was an indication for surgical revision. In another study published by the College of Medicine at Zhejiang University of China (Table 3), there are defined post-operative revision scores for pedicle screw

malpositioning.¹¹ Both radiological and clinical assessment were used to calculate a score. Based on the total score, a protocol was made to decide when to intervene. A score of >5 was considered for surgical revision while a score lower than 5 was an indication for conservative management. An increase in the score during follow-up was taken as an indication for surgical revision. Patients with early neurological symptoms with scores less than 5 were also considered for conservative management. Although these two scoring systems could be used for asymptomatic screws as well, some clinically important variables such as anterior perforation at the thoracolumbar spine and lateral perforation in the cervical spine have not been included in these systems. When these scoring systems were applied to the 5 cases in this forum (Table 4), only one case (Case2) was identified for surgical revision. The main reason for the low scores was the lack of clinical symptoms.

Table 3: Post-operative revision scores of pedicle screw malpositioning assessment (Zejiang score)¹⁶

Objective	Assessment	Score
Medial breach	<2mm	1
	2-4mm	2
	>4mm	3
Inferior breach	Yes	1
	No	0
Neurological status	Unchanged	0
	1 increase in Frankel grade	3
	>1 increase in Frankel grade	5
Visual analogue scale (VAS)	No pain	0
	VAS<3	1
	VAS>3	2
Patient ready to undergo revision surgery	Yes	1
	No	0

Score >5 considered for revision

Table 4: The results of scoring systems and what was done to each patient

	Mcgill score >6 for revision	Zejiang score >5 for revision	What was done to patient
Case1	4	3	Surgical revision
Case2	8(revision)	7(revision)	Surgical revision
Case3	2	0	Surgical revision
Case4	3	0	Surgical revision
Case5	3	0	Surgical revision

Vascular injuries related to malpositioned pedicle screws are relatively infrequent, but potential life-threatening complications that require early recognition with prompt repair of vascular involvement and screw reposition.^{12,13,14,15,16} These injuries may present intraoperatively or in many cases very late, such as several years after the primary surgery as reported by Soutanis et al.¹⁷ In a review article by Kakkos et al, numerous case reports of delayed complication of the aorta by a malpositioned pedicle screw were introduced.¹⁸ On average, these cases presented 18 months after the primary surgery. Pseudoaneurysm was the most common presentation. All these cases needed surgical revision of malpositioned screws and endoarterial repair for the aorta.

Slight erosive lesions of the aorta may not necessarily need removal of screws. Endovascular repair of the aorta without removal of a screw is also possible for these slight lesions to the great vessels.¹⁹ As for the cervical spine, Zhang et al. reported a delayed presentation of cerebrovascular infarction due to misplaced cervical pedicle screws.²⁰ Though common sense indicates that a prompt diagnosis and subsequent revision surgery can help minimize neurological symptoms, Neo et al.²¹ demonstrated that 13 cervical pedicle screws perforated the foramen transversarium more than 2mm without showing discontinuity of the vertebral artery on cervical angiography. If surgical revision is required, removal of malpositioned cervical pedicle screws can cause serious complications as reported by Yang et al.²² Complete understanding of anomalous running of the vertebral artery is mandatory in every cervical spine instrumentation surgery to avoid these catastrophic complications.²³

The necessity to revise medially malpositioned pedicle screws is higher than those malpositioned anteriorly, superiorly, or laterally.¹² This is because medially placed screws tend to cause serious neurological complications. There is a case report²⁴ of delayed CSF leak after medial malposition of thoracic screws in a scoliosis patient who presented with positional headaches and acquired Chiari malformation. Misplaced pedicle screws in the thoracic or the cervical spine can cause complete paraplegia.^{25,26,27} Laterally or anteriorly malpositioned pedicle screws also have risks for vascular complications.^{28,29}

The decision of when and how to revise malpositioned pedicle screws is so complex, with numerous factors to be considered, that a consensus among international spine experts was not achieved in this forum. All the risky malpositioned pedicle screws in the 5 cases ended up with surgical revision after discussion between surgeons and patients (Table 4). Further research is needed to develop a consensus among experts on when and how to deal with malpositioned pedicle screws. Despite all the discussion above, the most effective way to reduce the risks of screw malpositioning is to improve the accuracy of placement of pedicle screws. Many surgical techniques have become available in recent years to decrease the rates of malposition, such as navigation guided placement of pedicle screws.^{30,31}

Tips and tricks:

- The necessity to revise medially malpositioned pedicle screws is greater than for those malpositioned anteriorly, superiorly, or laterally.
- Delayed CSF leak and paraplegia may occur with medially malpositioned pedicle screws into the spinal canal.
- There are many case reports of delayed complication of the aorta by a malpositioned pedicle screw in the thoracic or lumbar spine.
- Delayed presentation of cerebrovascular infarction due to a laterally malpositioned pedicle screw in the cervical spine would be possible.
- There are two scoring systems to evaluate either symptomatic or asymptomatic malpositioned pedicle screws. The scores for asymptomatic malpositioned screws are low, so that many malpositioned screws do not meet the criteria for surgical revision.
- Though the opinions on whether to revise or not revise malpositioned pedicle screws differed among expert spine surgeons, all the risky asymptomatic malpositioned pedicle screws in the 5 cases were surgically revised after discussion between surgeons and patients.

Conclusion:

In this forum, we collected expert opinions from 6 experienced spine surgeons from around the world on 5 cases with asymptomatic malpositioned pedicle screws at different locations of the spine. The opinions were so different among the experts that it was difficult to achieve consensus on when to revise those malpositioned pedicle screws. The 2 scoring systems that currently exist to assess the necessity of revision of malpositioned pedicle screws did not provide surgeons with appropriate suggestions on how to handle asymptomatic malpositioned pedicle screws. Although consensus among experts was not achieved in most cases, the 5 cases presented with asymptomatic malpositioned pedicle screws eventually led to surgical revision after discussion between surgeons and patients.

References:

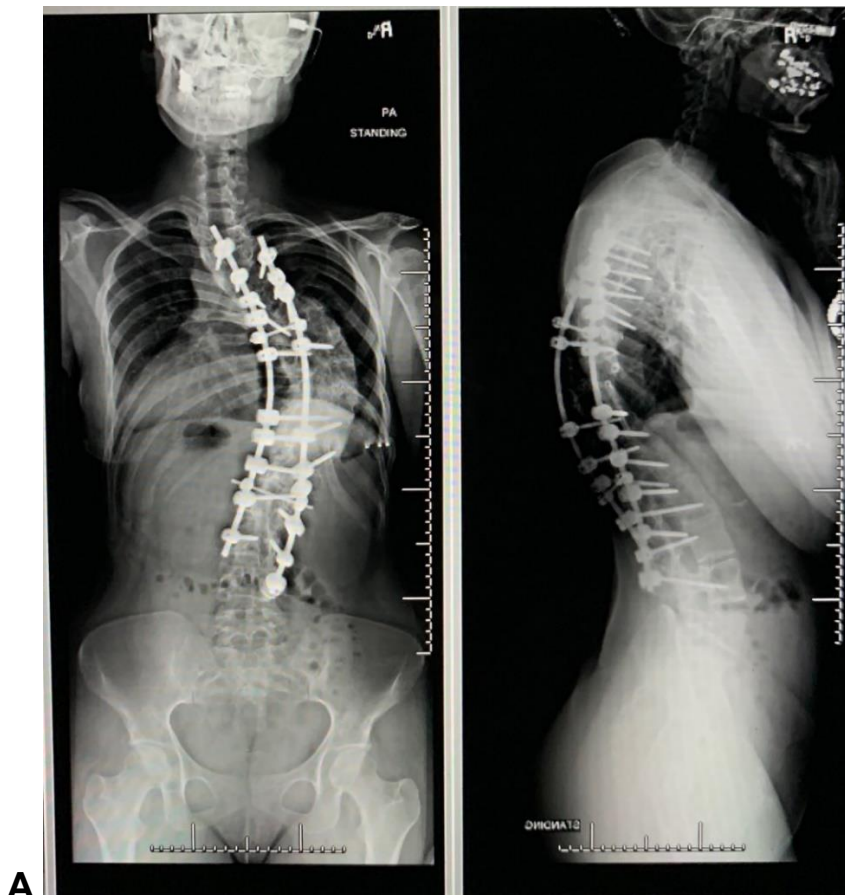
1. Harrington PR, Tullos HS. Reduction of severe spondylolisthesis in children. *South Med J.* 62:1-7, 1969.
2. Gautschi O, Schatlo B, Schaller K, Tessitore E. Clinically relevant complications related to pedicle screw placement in thoracolumbar surgery and their management: a literature review of 35,630 pedicle screws. *Neurosurg Focus.* 31 (4):E8, 2011.
3. Hicks JM, Singla A, Shen FH, Arlet V. Complications of pedicle screw fixation in scoliosis surgery: a systematic review. *Spine (Phila Pa 1976)*, 35:E465–E470, 2010.
4. Merloz P, Tonetti J, Pittet L, Coulomb M, Lavalleyé S, Sautot P. Pedicle screw placement using image guided techniques. *Clin Orthop Relat Res.* 354:39–48, 1998.
5. Nakashima H, Yukawa Y, Imagama S, Kanemura T, Kamiya M, Yanase M, Ito K, Machino M, Yoshida G, Ishikawa Y, Matsuyama Y, Ishiguro N, Kato F. Complications of cervical pedicle screw fixation for nontraumatic lesions: a multicenter study of 84 patients. *J Neurosurg Spine.* 16(3):238-47, 2012.
6. Abumi K, Kaneda K, Shono Y, Fujiya M. One-stage posterior decompression and reconstruction of the cervical spine by using pedicle screw fixation systems. *J Neurosurg.* 90(1 Suppl):19-26, 1999.
7. Abumi K, Shono Y, Ito M, Taneichi H, Kotani Y, Kaneda K. Complications of pedicle screw fixation in reconstructive surgery of the cervical spine. *Spine (Phila Pa 1976)*. 25(8):962-9, 2000.
8. Yukawa Y, Kato F, Ito K, Horie Y, Hida T, Nakashima H, Machino M. Placement and complications of cervical pedicle screws in 144 cervical trauma patients using pedicle axis view techniques by fluoroscope. *Eur Spine J.* 18(9): 1293–1299, 2009.
9. Chan CYW, Kwan MK. Safety of Pedicle Screws in Adolescent Idiopathic Scoliosis Surgery. *Asian Spine J.* 11(6):998-1007, 2017.
10. Aoude A, Ghadakzadeh S, Alhamzah H, Fortin M, Jarzem P, Ouellet JA, Weber MH. Postoperative Assessment of Pedicle Screws and Management of Breaches: A Survey among Canadian Spine Surgeons and a New Scoring System. *Asian Spine J.* 12(1): 37-46, 2018.
11. Du JY, Wu JS, Wen ZQ, Lin XJ. Treatment strategies for early neurological deficits related to malpositioned pedicle screws in the lumbosacral canal: A pilot study. *Bone Joint Res.* 5:46–51, 2016.
12. Pesenti S, Bartoli MA, Blondel B, Peltier E, Adetchessi T, Fuentes S. Endovascular aortic injury repair after thoracic pedicle screw placement. *Orthop Traumatol Surg Res.* 100(5):569-73, 2014.
13. Foxx KC, Kwak RC, Latzman JM, Samadani U. A retrospective analysis of pedicle screws in contact with the great vessels. *J Neurosurg Spine.* 13(3):403-6, 2010.
14. Klodell CT, Vlasak R, Martin TD, Janelle G, Beaver TM. Impending aortic penetration following thoracolumbar spinal fixation: a case study. *J Long Term Eff Med Implants.* 17(1):55-8, 2007.
15. Vanichkachorn JS, Vaccaro AR, Cohen MJ, Cotler JM. Potential large vessel injury during thoracolumbar pedicle screw removal. A case report. *Spine (Phila Pa 1976)*. 22(1):110-3, 1997.
16. Lopera JE, Restrepo CS, Gonzales A, Trimmer CK, Arko F. Aortoiliac vascular injuries after misplacement of fixation screws. *J Trauma.* 69(4):870-5, 2010.
17. Soultanis KC, Sakellariou VI, Starantzis KA, Papagelopoulos PJ. Late diagnosis of perforation of the aorta by a pedicle screw. *Acta Orthop Belg.* 79:361-367, 2013.

18. Kakkos SK, Shepard, AD. Delayed presentation of aortic injury by pedicle screws: Report of two cases and review of the literature. *J Vasc Surg.* 47:1074-82, 2008.
19. Zerati AE, Leiderman DB, Teixeira WG, Narazaki DK, Cristante AF, Wolosker N, de Luccia N, Barros Filho TE. Endovascular Treatment of Late Aortic Erosive Lesion by Pedicle Screw without Screw Removal: Case Report and Literature Review. *Ann Vasc Surg.* 39:285.e17, 2017.
20. Zhang J, Xu R, Li Z, Zha W. Cerebral infarction due to malposition of cervical pedicle screw: A case report. *Medicine (Baltimore).* 97(7):e9937, 2018.
21. Neo M, Sakamoto T, Fujibayashi S, Nakamura T. The clinical risk of vertebral artery injury from cervical pedicle screws inserted in degenerative vertebrae. *Spine (Phila Pa 1976).* 30(24):2800-5, 2005.
22. Yang Y, Liu H, Ma L, Zeng J, Song Y, Xie X. Sudden cerebral infarction after interventional vertebral artery embolism for vertebral artery injury during removal of C1-C2 pedicle screw fixation: a case report. *Int J Clin Exp Med.* 8(9):16803-7, 2015.
23. Akinduro OO, Baum GR, Howard BM, Pradilla G, Grossberg JA, Rodts GE Jr, Ahmad FU. Neurological outcomes following iatrogenic vascular injury during posterior atlanto-axial instrumentation. *Clin Neurol Neurosurg.* 150:110-116, 2016.
24. Floccari LV, Larson AN, Stans AA, Fogelson J, Helenius I. Delayed Dural Leak Following Posterior Spinal Fusion for Idiopathic Scoliosis Using All Posterior Pedicle Screw Technique. *J Pediatr Orthop.* 37(7):e415-e420, 2017.
25. Leroy A, Kabbaj R, Dubory A, Bachy M, Vermersch AI, Vialle R. The Indian Basket Trick: a case of delayed paraplegia with complete recovery, caused by misplaced thoracic pedicle screw. *Springerplus.* 30;5(1):944, 2016.
26. Sarlak AY, Tosun B, Atmaca H, Sarisoy HT, Buluç L. Evaluation of thoracic pedicle screw placement in adolescent idiopathic Scoliosis. *Eur Spine J.* 18(12):1892-7, 2009.
27. Mac-Thiong JM, Parent S, Poitras B, Joncas J, Hubert L. Neurological outcome and management of pedicle screws misplaced totally within the spinal canal. *Spine (Phila Pa 1976).* 38(3):229-37, 2013.
28. Hojo Y, Ito M, Suda K, Oda I, Yoshimoto H, Abumi K. A multicenter study on accuracy and complications of freehand placement of cervical pedicle screws under lateral fluoroscopy in different pathological conditions: CT-based evaluation of more than 1,000 screws. *Eur Spine J.* 23(10):2166-74, 2014.
29. Ryabykh SO, Pavlova OM, Savin DM, Khomchenkov MV, Ochirova PV, Hartmann S, Gubin AV. Malpositioned Pedicle Screw Compressed Thoracic Aorta of a Patient With Adolescent Idiopathic Scoliosis: Case Report and Literature Review. *Techniques in Orthopaedics.* 32(4):277-82, 2017.
30. Tian NF, Huang QS, Zhou P, Zhou Y, Wu RK, Lou Y, Xu HZ. Pedicle screw insertion accuracy with different assisted methods: a systematic review and meta-analysis of comparative studies. *Eur Spine J.* 20:846–859, 2011.
31. Rajasekaran S, Vidyadhara S, Ramesh P, Shetty AP. Randomized clinical study to compare the accuracy of navigated and nonnavigated thoracic pedicle screws in deformity correction surgeries. *Spine (Phila Pa 1976),* 32:E56–E64, 2007.

Figures:



Figure 1: Case 1: Malpositioned pedicle screws at C6; 65 year-old male, rheumatoid arthritis. Postoperative CT (1 day after surgery); 2 pedicle screws were medially misplaced. No neurological signs.



A

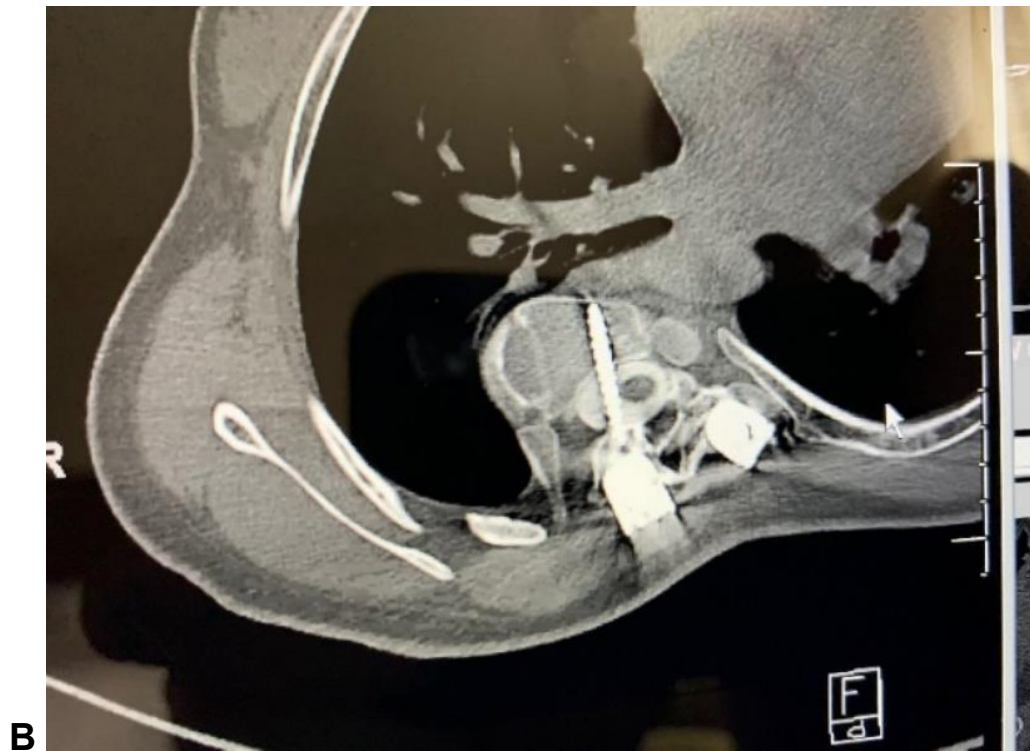


Figure 2: Case 2. 26 year-old female. Congenital scoliosis. Operated several years ago. She has some pain and very little motor weakness in her unilateral leg. (Courtesy of David W. Polly, MD).

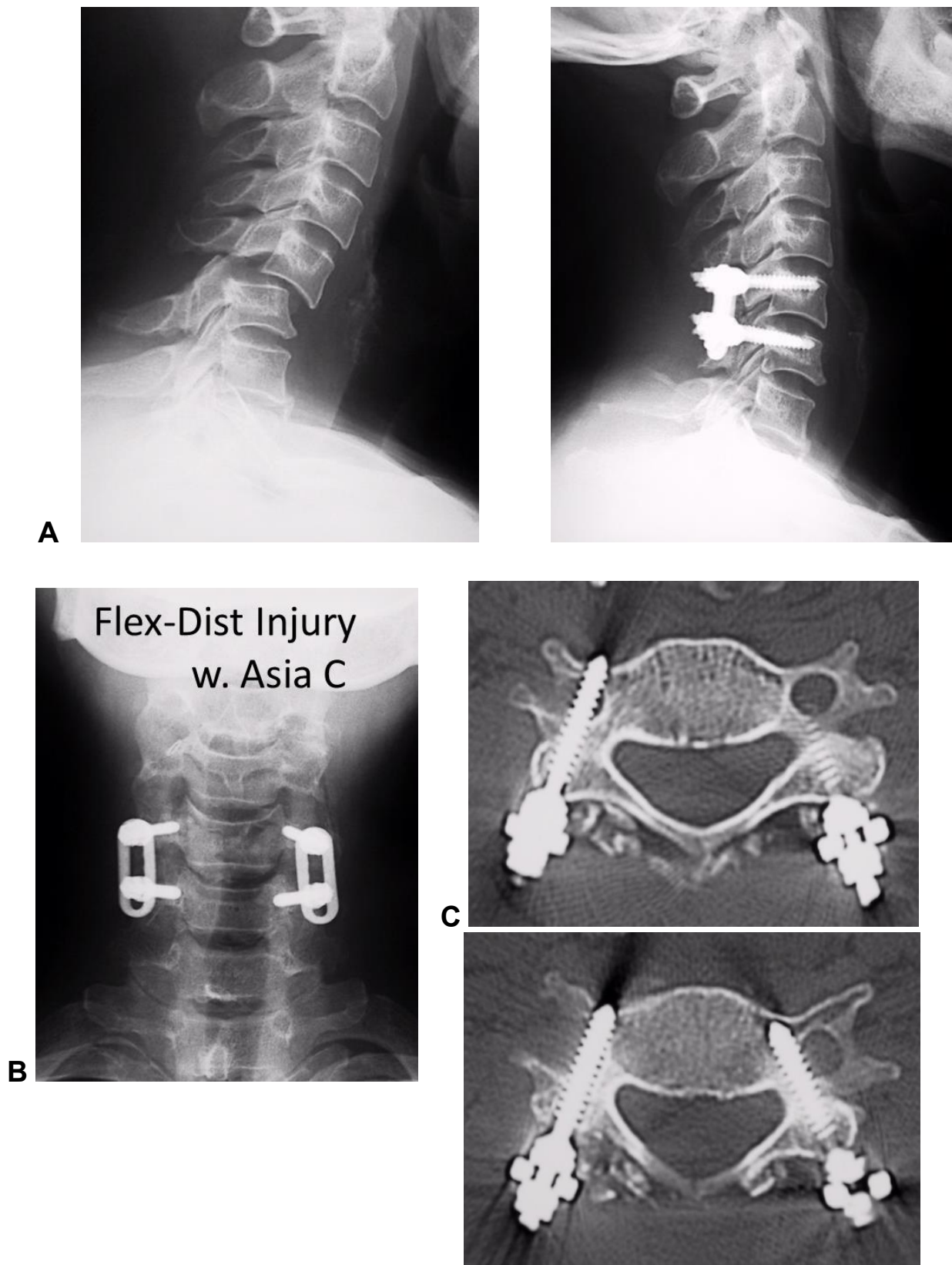


Figure 3: Case 3. 48 year-old male. No intraoperative bleeding from VA, no brain symptoms. Postop 1w CT (Courtesy of Kuniyoshi Abumi, MD).



A



B

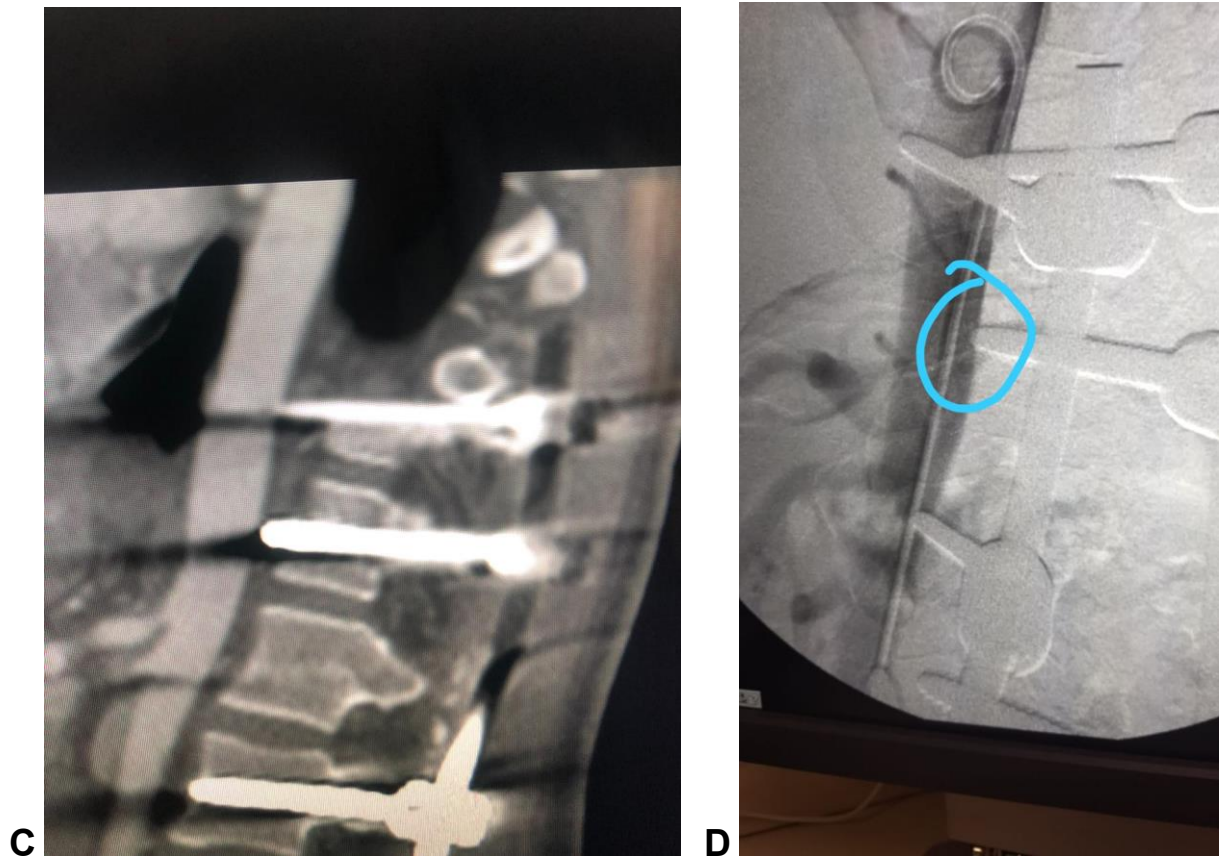
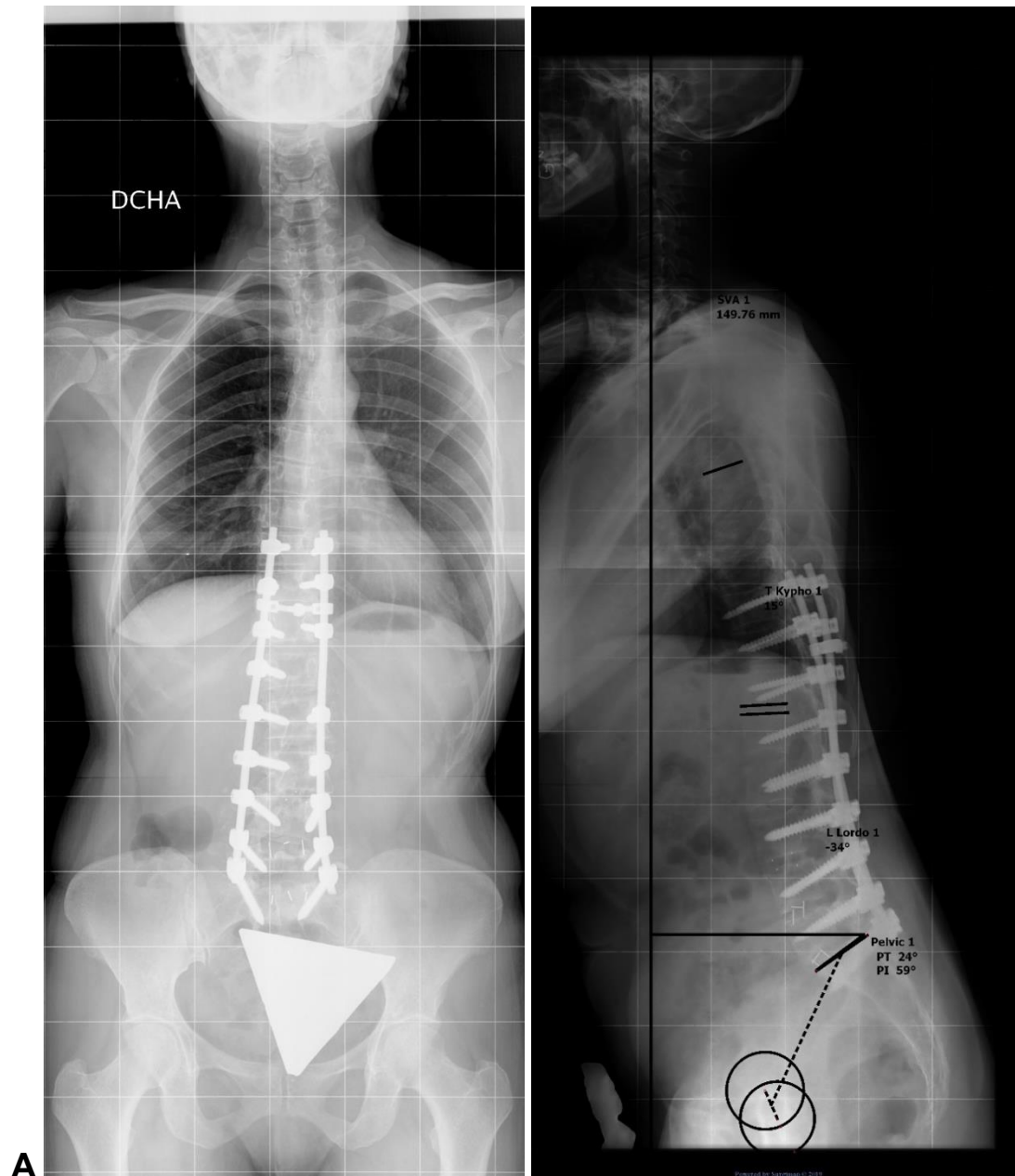


Figure 4: Case 4. 28 year-old female, 3 years after correction of lumbar scoliosis due to hemivertebra. Postop CT scan showed a pedicle screw touching the aorta at T10. CT angio and arteriography could not identify or exclude the presence of a breach.





B



C

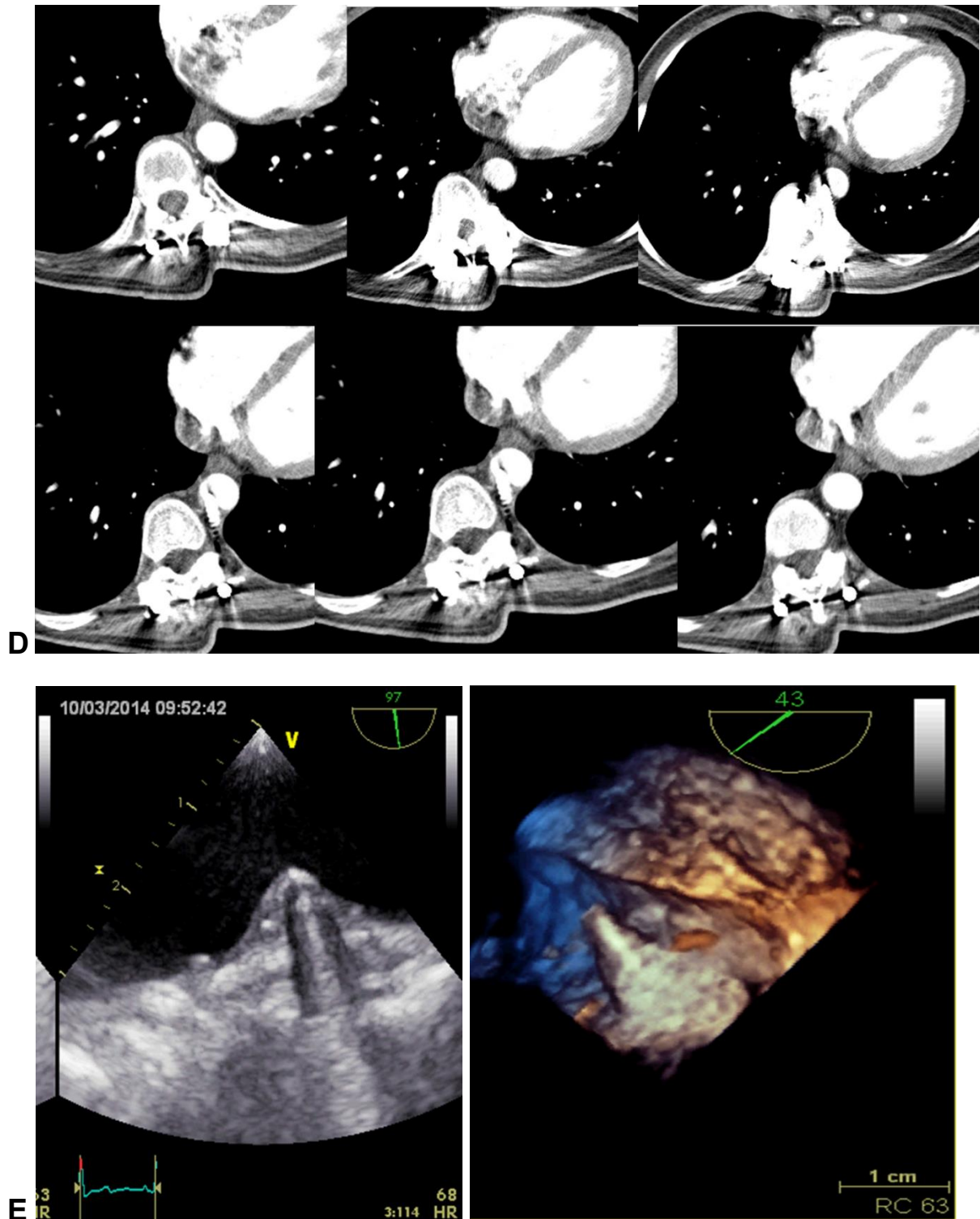


Figure 5: Case 5. 48 year-old female. Second surgery of thoraco-lumbar degenerative scoliosis with fusion from T10 to S1. She had good clinical outcomes for 4 postoperative years, but complained of lumbosacral pain after fall. D: Plain CT. E: Sonogram.