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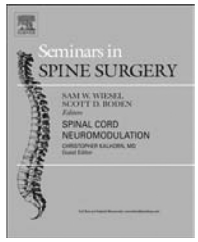

# Vascular complications in spine surgery

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A B S T R A C T

Vascular complications in spine surgery are rare but potentially devastating events. They may occur during surgery in the cervical, thoracic, and lumbo-sacral regions of the spine, and all operative approaches present at least some risk. Some complications are highly specific to various approaches and/or procedures. Meticulous surgical technique, careful preoperative planning, and familiarity with normal and anomalous vascular anatomy may minimize the risk of complications. Spine surgeons should be knowledgeable regarding specific and general vascular complications as early recognition and timely treatment may prevent poor patient outcomes.



## 1. Introduction

Vascular complications may occur directly or indirectly from spine surgery. While all surgical approaches to the spine are associated with some risk of vascular injury, many complications are specific to various anatomic locations, surgical approaches, and procedures. Vascular problems are diverse and may include laceration, hemorrhage, aneurism, arteriovenous fistula, thrombosis, embolization, and instrumentation-related vessel wall erosion.[1–4] While major vascular complications following spine surgery are thought to be relatively rare, they may be substantially under-reported.[3] Furthermore, major vascular injuries may result in catastrophic complications, poor patient outcomes, and increased utilization of finite hospital resources following spine surgery.[3] Surgeons should be well-versed in best practices for both the prevention and timely treatment of vascular complications in the spine.

## 2. Cervical spine

Both anterior and posterior approaches to the cervical spine present the potential for life-threatening vascular complications including rapid hemorrhage, stroke, hematoma, paralysis, and death. Combined anterior-posterior procedures appear to present especially high risk.[5] Knowledge of normal anatomy and common variants, as well as careful and deliberate surgical technique, are important for the prevention of such injuries.

### 2.1. *Vascular complications associated with anterior cervical spine approaches*

The most common approach to the subaxial anterior cervical spine utilizes an anterolateral (Smith-Robinson) interval.[6,7] While the incidence of significant vascular injury during

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https://doi.org/10.1016/j.semss.2019.100756
1040-7383/

anterior cervical approaches is known to be quite rare,[8–10] the consequences may be devastating and include blood loss, hematoma, stroke, permanent neurologic sequelae, and death.[11,12] Both the carotid and vertebral arteries may be damaged during surgical approach, discectomy, bony resection, or instrumentation.

#### 2.1.1. Carotid artery

While the occurrence of carotid artery injury during the anterior approach to the cervical spine has traditionally been thought to be extremely low, the true incidence of this complication may be underreported.[10] This may be because small carotid artery lacerations repaired in the operating room without further sequelae may not be reported as complications. Furthermore, it is likely that carotid artery injury due to prolonged retraction is substantially more common than direct laceration. Overaggressive retraction may lead to decreased carotid blood flow, carotid artery thrombosis, or dislodgment of atherosclerotic plaques.[12–14] This risk may be dramatically higher in patients with prior diagnosis of carotid artery stenosis: one recent study estimated a 6.6% early postoperative incidence of stroke following ACDF in patients with a preoperative diagnosis of carotid artery stenosis, versus a 0.0% incidence in a propensity-matched cohort of patients without carotid artery stenosis.[12] Carotid artery identification via palpation or direct visualization in addition to meticulous dissection during surgical approach may minimize the risk of direct injury. Additionally, avoidance of overaggressive retraction may reduce the incidence of indirect injury. Some authors recommend occasional relaxation of retraction in order to minimize ischemic time;[15] however, it should be noted that aggressive retractor repositioning in patients with preexisting carotid artery stenosis may theoretically result in embolism of plaques.

#### 2.1.2. Vertebral artery

Classically, the vertebral arteries pass anterior to the transverse process of C7, enter the transverse foramen of C6, proceed cranially through the transverse foramen of C6 to C1, and ultimately combine to become the basilar artery, supplying blood to the brainstem and cerebellum.[15] Importantly, despite this well-described classic anatomy, a number of studies have found significant anatomic variability between patients, with anomalous vertebral artery anatomy placing it at risk during anterior cervical surgery.[11,16–19] Anomalous vertebral artery location anterior to the transverse process or medial in the vertebral body places it at significant risk during surgery. Such anomalous anatomy should be identified prior to surgery on the MRI/CT imaging to minimize the risk of intraoperative injury (Fig. 1). In contrast to the carotid artery, most documented injuries to the vertebral artery are thought to result from direct insult. Furthermore, such injuries may result in irreversible complications including bleeding, stroke, neurologic deficit, and death.[11,19,20] Thus, understanding of individual patient anatomy prior to surgical intervention is paramount for prevention of this complication.

During anterior approaches, the vertebral artery is generally placed at greatest risk with overlateralization, either during dissection of the longus coli muscles or by overaggressive discectomy/corpectomy lateral to the uncinate processes. A recent systematic review of vertebral artery injuries during anterior cervical surgery found that injuries were most common when utilizing high speed drilling for bony resection during discectomy or corpectomy.[19] A recent survey of cervical spine surgeons identified cervical corpectomy as the second most likely procedure to result in vertebral artery injury after posterior instrumentation of the upper cervical spine.[21] Generally, avoiding resection of bone or disc material lateral to the uncinate processes will avoid injury to the vertebral arteries.[22] However, surgeons may experience difficulty identifying bony landmarks in degenerative cases with substantial osteophytosis. Furthermore, anomalous vertebral arteries which deviate more medial than normal have been described.[16–18,23–25] Such anatomic variability has led some authors to suggest preoperative CT angiography for complex anterior cases including corpectomies.[25]

Should the vertebral artery inadvertently be injured during the anterior cervical approach, direct pressure should immediately be applied. This often will require additional dissection lateral to the vertebral body to access the artery both inferior and superior to the site of injury. At this point, depending upon the experience of the primary surgeon, availability of an experienced vascular surgeon or interventional radiologist, and facility resources, a decision regarding primary repair, ligation, or endovascular procedure should be made. Most patients may be able to tolerate unilateral vertebral artery occlusion without significant permanent neurologic sequelae,[26] however some reports note symptoms of vertebrobasilar ischemia.[20] Continued bleeding from the site of injury after clamping the artery distal to the site of injury (i.e. between the site of injury and the subclavian artery) suggests adequate collateral blood flow, suggesting that ligation of the artery may be tolerated. While controversy exists regarding the optimal treatment of vertebral artery injuries, endovascular techniques allow for evaluation of collateral circulation are becoming substantially more common.[19,20,23,27]

### 2.2. Vascular complications associated with posterior cervical spine approaches

The primary vascular structures at risk during posterior cervical surgery are the vertebral arteries and venous plexus, particularly in the upper cervical spine and cranial base. However, other vascular injuries including carotid artery injury secondary to malpositioned instrumentation have been reported.[28]

#### 2.2.1. Vertebral artery

While thought to be rare overall, a number of cases of vertebral artery injury during posterior cervical spine surgery have been reported.[21,29–32] Significant anatomic variation as well as the particular anatomy in the upper cervical spine place the vertebral artery at especially high risk during instrumentation from C2 to the occiput. From C2 to C1, the vertebral artery typically takes an anterior to posterior pathway, followed by a lateral to medial pathway over the posterior arch of C1.[33] The artery may be particularly susceptible to injury in these locations. Posterior instrumentation of the upper

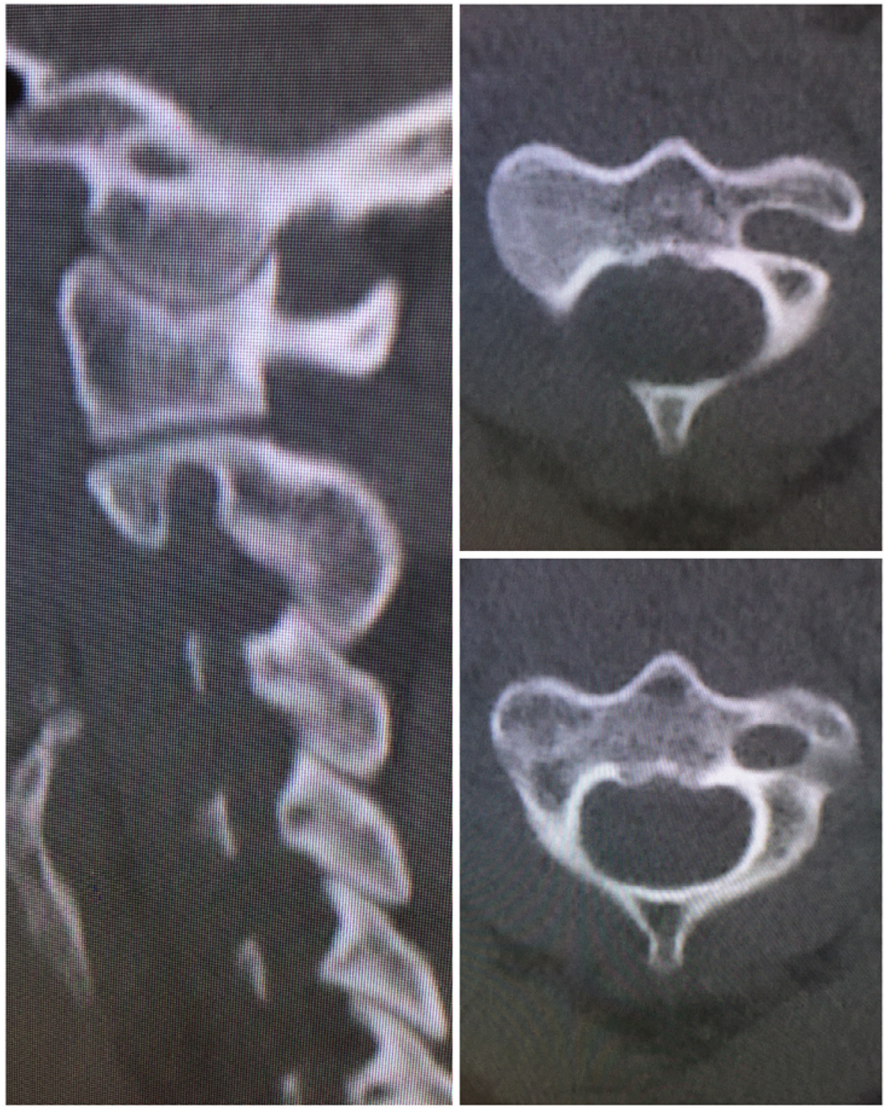

**Fig. 1 – Aberrant left vertebral artery seen on preoperative computed tomography scan. Such anatomy may preclude the placement of safe instrumentation.**

cervical spine has been identified as the most common cause of vertebral artery injury.[21] Intraoperative fluoroscopy or CT is generally indicated during C1 and C2 instrumentation to increase screw accuracy and decrease the risk of vascular injury.[34] It should be noted that about 15% of patients have a bony bridge on C1 covering the vertebral artery called the *ponticulus ponticus*.[34] Generally, this variant is easily identified on preoperative imaging, however failure to recognize it may results in accidental vertebral artery injury during dissection or instrumentation.

Even in the subaxial cervical spine, poorly positioned lateral mass screws can injure the vertebral artery in the transverse foramen.[9] An et al. describe a lateral mass screw technique involving a start point near the center of the lateral mass and directed 30° laterally and 15° cephalad.[35] This trajectory minimizes risk of inadvertent injury to the vertebral artery, which generally lies directly anterior or slightly lateral to the middle one third of the lateral mass.[36]

*2.2.2. Carotid artery*

Carotid artery impingement by upper cervical screws has been described.[28,34] Currier et al. in an anatomic study, found that the internal carotid artery lies approximately 2.9 mm anterior to C1 and thus may be at risk during bicortical C1 instrumentation.[97] The authors recommend preoperative CT angiogram prior to C1 instrumentation, with use of unicortical screws or alternate fusion techniques if the artery lies in close proximity to C1.

## 3. Thoracic spine

While rare, major vascular injuries have been reported with both anterior and posterior thoracic approaches to the spine.[37–39] These complications may lead to massive life-threatening hemorrhage and/or thoracic spinal cord ischemia. While prevention is ideal, any spine surgeons operating

on the thoracic spine should be prepared to readily identify and treat such injuries.

### 3.1. Vascular complications associated with anterior thoracic spine approaches

Anterior approaches to the thoracic spine may be performed open or thoracoscopically. A number of important vascular structures are inherently placed at risk during anterior thoracic approaches, and vascular complications have been reported in 1.1% to 13.8% of such cases.[38,40,41] Direct injury to the major vessels and their branches may be encountered, and can result in catastrophic blood loss, paraplegia, and other serious complications. Collaboration with an experienced vascular surgeon during the approach may minimize these risks.[41]

#### 3.1.1. Segmental arteries

The segmental arteries supplying the spinal cord lack substantial anastomoses,[42] and thus either temporary or permanent bilateral segmental artery ligation at multiple levels increases the risk of cord ischemia and neurologic sequalae.[43,44] Cord ischemia secondary to bilateral segmental disruption may also occur indirectly during deformity reduction.[45] While patients appear to tolerate unilateral segmental ligation well with low risk of neurologic complications, bilateral disruption is tolerated poorly.[46] Bilateral disruption is more often the case with revision procedures compared to isolated primary anterior approaches. Furthermore, cases requiring secondary posterior procedures or significant correction of kyphotic deformity may place the cord at particular risk of ischemia. For particularly high risk cases, some authors advocate trial of clamping with subsequent spinal cord monitoring for any signal changes before ligation.[46] Should spinal cord ischemia be suspected, increasing mean systemic blood pressure has been shown to result in increased perfusion to the cord.[46]

#### 3.1.2. Artery of Adamkiewicz

The artery of Adamkiewicz is a well described large segmental artery which supplies the thoracolumbar spinal cord and originates between T8 and L2.[46] While the anterior spinal artery also supplies blood flow to the cord at these levels, it tends to be small or incomplete from T4–9.[46] Additionally, the spinal canal from T4–9 is narrow. These factors in combination may place the cord at high risk of ischemia even with unilateral segmental ligation. If ligation is planned, ischemic risk may be minimized with avoidance of bilateral ligation, ligation on the deformity's convexity, ligation at the mid-body, avoidance of hypotension during surgery, and utilization of neuromonitoring following temporary clamping but prior to permanent ligation.[46–48]

#### 3.1.3. Aorta

While injuries to the aorta are more typical of pedicle screw instrumentation during posterior thoracic approaches, anterior instrumentation may result in aortic erosion, thinning, scarring, and delayed bleeding complications.[49,50]

### 3.2. Vascular complications associated with posterior thoracic spine approaches

While a midline posterior approach to the thoracic spine may result in substantial blood loss, it nonetheless poses minimal risk of catastrophic vascular injury. Instead, malpositioned or inappropriately sized pedicle screws are the primary etiology for life-threatening vascular injury in posterior thoracolumbar spine surgery.[37,51]

#### 3.2.1. Aorta

The incidence of significant aortic injury secondary to thoracic pedicle screws is rare. One recent CT study of 2020 pedicle screws placed for correction of adolescent idiopathic scoliosis identified 4 anterior perforations abutting the aorta, with no associated major aortic injuries.[52] Another evaluation of 964 patients receiving 6816 free hand pedicle screws noted 10 screws (0.29%) encroaching upon the aorta.[53] Only 2 patients required revision surgery and no major vascular injuries were reported. Nonetheless, multiple case reports of aortic artery injury from thoracic pedicle screws have been published,[51,54–56] and surgeons should be prepared to recognize and treat such injuries in a timely manner. Aortic injuries may be recognized immediately or in a delayed fashion, with multiple reports of late presentations of aortic erosion, pseudoaneurysm, or perforation.[51,56–60] While prevention by utilizing careful technique and intraoperative radiography is ideal, should a thoracic aortic disruption be encountered, consultation with an experienced cardiothoracic or vascular surgeon followed by open or endovascular aortic repair may be indicated.[56,58,59,61]

## 4. Lumbar spine

While anterior lumbar approaches are particularly high-risk, major life-threatening vascular injuries have been reported with all known approaches to the lumbar spine. Even still, the overall rates of vascular complications are likely under-reported.[3] At-risk structures include the aorta, vena cava, common iliac artery and vein, middle sacral vessel, iliolumbar vein.

### 4.1. Vascular complications associated with anterior and lateral lumbar spine approaches

Multiple approaches to the anterior lumbar spine have been described, and all place major vascular structures at risk including the aorta, vena cava, iliolumbar vein common iliac artery and vein, and middle sacral arteries.[3] Meticulous dissection, often with the assistance of a vascular or general surgeon, is important for prevention of vascular injuries. Anterior lumbar approaches confer an especially high risk of vascular injury, with estimated incidence of up to 15.6%, most often involving venous structures.[62] Furthermore, such injuries may be under-reported, especially in cases involving early recognition and repair without permanent deficits. The most common vascular injuries associated with anterior abdominal approaches include left common iliac vein laceration, inferior vena cava laceration, and left common iliac

artery/vein thrombosis.[3] Given the extensive anatomical variation between patients, careful preoperative imaging of the aorta and inferior vena cava bifurcation as well as any potential vascular anomalies is an important part of the preoperative planning process.

#### 4.1.1. Aorta and vena cava

For access to the disc space of interest via the anterior approach, the aorta and vena cava may be mobilized together or independently contingent on the level of bifurcation.[63] Generally, mobilization is performed from left to right in order to preferentially retract against the more robust aorta versus the fragile vena cava. Multilevel anterior procedures often require several vascular approaches. Generally, anterior abdominal approaches to the lumbar spine are best when working at the L3–S1 levels, however this varies based upon patient anatomy. Anterior column pathology above the L3–S1 level is best performed via anterolateral or direct lateral approaches, which may also place the great vessels at risk.[63] Regardless of level, all anterior approaches to the lumbar spine require retraction of the great vessels after ligation of segmentals. While adequate exposure is imperative, it is important that any retractors used avoid over-retraction and complete occlusion of the great vessels.[3]

#### 4.1.2. Common iliac artery of vein

Inadvertent laceration of the left common iliac vein is thought to be the most common vascular injury associated with anterior lumbar approaches.[64] Still, early or delayed venous or arterial thrombosis may occur anywhere from a few hours to up to a few days following surgery.[65,66] As with many vascular problems, smoking and a history of peripheral vascular disease may increase the risk of this complication. Acute thrombosis of the common iliac artery or vein may result in loss of life or limb, and is generally considered a vascular emergency.[67] Early thrombectomy or stenting may be required, and delay in diagnosis or treatment may result in major complications including rhabdomyolysis, reperfusion syndrome, compartment syndrome, and loss of the leg. While some surgeons monitor for such changes using great toe pulse oximetry,[68] nearly all recommend close neurovascular evaluations of the left leg following surgery.[3]

#### 4.1.3. Middle sacral vessels and iliolumbar vein

The middle sacral vessels traverse caudally from the aortocaval bifurcation and must be sacrificed for adequate exposure to the L5–S1 disc space. These vessels should be identified and ligated appropriately to prevent accidental tearing which may result in substantial blood loss and poor visualization. The left recurrent iliolumbar vein branches off of the left common iliac vein and, due to substantial anatomic variability, is at high risk of injury with left sided retroperitoneal approaches. Generally, this vessel branches either posteriorly off the superolateral margin of the left common iliac vein.[3] It should be carefully identified and either preserved or sacrificed in order to avoid accidental tearing or laceration.

### 4.2. Vascular complications associated with posterior lumbar spine approaches

#### 4.2.1. Aorta, vena cava, common iliac vessels

The great vessels may be inadvertently injured during routine posterior lumbar spine procedures. This can result in major complications including massive blood loss, hypovolemic shock and death. Lumbar discectomies may result in major vessel injury from overaggressive use of the pituitary rongeur in the anterior disc space.[69] While an intact anterior annulus and anterior longitudinal ligament may protect against this complication, these structures may be weak in degenerative in revision cases. The most commonly injured vascular structures at L4–5 are the left common iliac vessels, however injury to the aorta, vena cava, and common iliacs are also possible[70] (Fig. 2). Known risk factors for major vascular injury during posterior lumbar discectomy include degenerative disc, retroperitoneal adhesions, increased intraabdominal pressure, revision discectomy, and overaggressive primary discectomy.[70] Positioning with the abdomen free and careful surgical technique may reduce the risk of vascular injury.[71,72] Additionally, overaggressive complete discectomies with blind pituitary use in the anterior disc space should be avoided.[73] The safe depth for pituitary use is controversial and varies based upon patient size. Intraoperative radiographs may be helpful.[1] Furthermore, the surgeon should maintain an adequate “feel” of the vertebral endplates with all instruments in order to avoid anterior extrusion.[74] Similar to the thoracic spine, pedicle screws in the lumbar spine may place the major vessels at risk if inappropriate trajectories or screw sizes are utilized. While early recognition and treatment of such injuries is paramount for avoiding catastrophic patient outcomes, less than 50% of such cases are recognized initially.[71,75–78] Bleeding in the disc space, hypotension, tachycardia, and abdominal rigidity may be early signs of a major vessel injury. Should this be suspected, anesthesia and vascular surgery should be immediately notified, blood transfusions and volume expanders should be initiated promptly, and the wound should be packed and sterilely dressed. The patient should be flipped into the supine position, and open or endovascular aortic repair should be performed by a general or vascular surgeon judiciously.[71,79]

## 5. Other

Additional vascular complications may occur following spine surgery and affect patient outcomes. These complications include but are not limited to epidural hematomas, venous thromboembolism, superior mesenteric artery syndrome, and post-operative blindness.

### 5.1. Epidural hematoma

The development of a postoperative epidural hematoma is a clinically significant complication which may result in permanent neurologic injury following spine surgery.[80–82] Known risk factors include anticoagulation, thrombocytopenia, coagulopathy, poor hemostasis, osteotomy or corpectomy, more extensive surgery, and ankylosing spondylitis.[83]

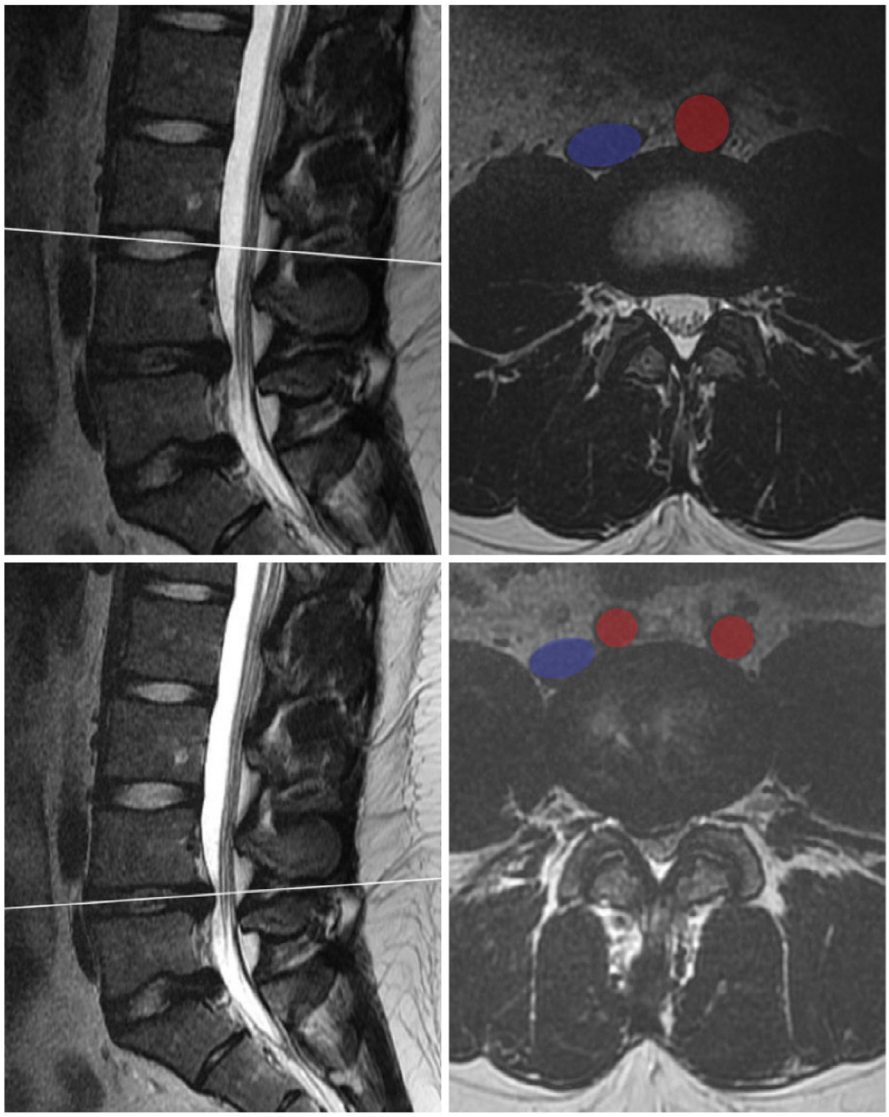

**Fig. 2 – Representative axial and sagittal MRI cuts of a patient undergoing L4–5 discectomy. The aorta (at L3–4 level) and common iliac arteries (at L4–5 level) are highlighted in red. The inferior venae cava is highlighted in blue. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)**

The diagnosis can be made by clinical examination with confirmation by MRI of CT myelography.[82] Generally, early decompression of the hematoma is recommended to prevent poor neurologic outcomes.[84,85] Reversal of anticoagulation should also be initiated. Most spine surgeons avoid routine use of chemical DVT prophylaxis in the perioperative period to avoid this complication.

### 5.2. *Thrombosis, thromboembolism*

While chemical anticoagulation has traditionally been minimized after spine surgery to minimize the risk of epidural hematoma,[86] the incidence of venous thromboembolism may be increased with this practice.[87] Aspirin (81 mg) has been shown to have a low risk of hematoma formation when utilized as DVT prophylaxis.[83] Furthermore, some new evidence suggest no increased risk of epidural hematoma when using heparin prophylaxis following spine surgery.[87] Non-chemical preventative measures including mechanical compression, early mobilization, and IVC filters are also options in patients at high risk for clots.[86]

### 5.3. *Superior mesenteric artery syndrome*

Superior mesenteric artery (SMA) syndrome occurs secondary to mechanical compression of the third part of the duodenum between the SMA and aorta.[88–90] This may be caused by correction of kyphotic deformity during surgery for adult or pediatric scoliosis. SMA syndrome is estimated to occur following approximately 2 in 1000 spinal deformity cases.[89] Known risk factors for SMA syndrome include substantial deformity correction and low body mass index.[91] The symptoms generally follow a nonspecific pattern of gastrointestinal distress in the early

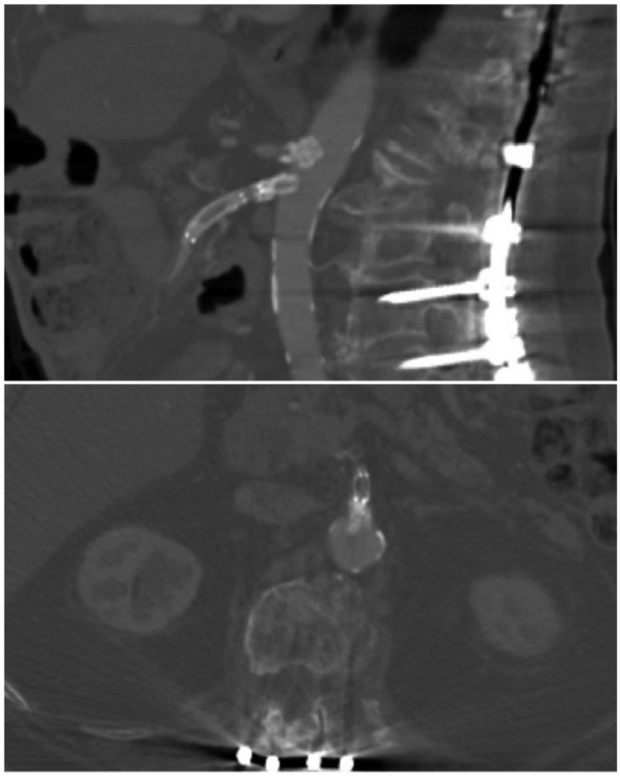

**Fig. 3 – Representative sagittal and axial CT cuts of a 69 year old man who sustained an acute superior mesenteric artery thrombosis following adult spinal deformity correction with 3-column osteotomy. The SMA is visualized here following stenting. The lumen of the duodenum is seen anterior to the aorta and inferior to the SMA on the sagittal view. This patient sustained an ischemic bowel injury, ultimately requiring partial bowel excision.**

postoperative period. While many deformity cases are followed by postoperative ileus of varying degrees, SMA syndrome should be considered in cases of patients with low BMI. In rare cases, thrombosis of the SMA may occur, resulting in bowel ischemia (Fig. 3). Plain abdominal films, CT, MRI, or MRA can confirm diagnosis, and treatment may consist of dietary restriction, nasogastric tube and intravenous fluid resuscitation. Attention to electrolytes and nutrition should be prioritized in order to maximize healing and minimize complications. Should this syndrome fail to resolve with conservative management, general surgical intervention may be indicated.[88,89]

### 5.4. *Blindness*

Postoperative blindness is a rare but devastating complication following spine surgery with an estimated incidence of 0.16%.[92] This dreaded complication has been associated with prone positioning for posterior spine surgery,[92–95] and is thought to be vascular in nature. Hypothesized etiologies include retinal thromboembolism, central retinal vein or artery occlusion, or embolic phenomena which may ultimately result in a form of optic compartment syndrome and permanent blindness.[92] Risk factors for sudden postoperative blindness include peripheral vascular disease, direct ocular pressure, hypotensive anesthesia, increased operative time, and increased blood loss.[92,96] Reverse Trendelenberg positioning, avoidance of intraoperative hypotension, and prevention of orbital pressure may decrease the risk of this often irreversible complication.

## 6. Conclusion

Vascular complications may occur during or following spine surgery. Surgeons should be aware of best practices for prevention, diagnosis, or treatment of such injuries. Preoperative care, meticulous surgical technique, and attentive care in the postoperative period may minimize complications and result in improved patient outcomes.

## Disclosure

None.

## Acknowledgment

None.

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