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Epidemiology and Management of Iatrogenic Vertebral Artery Injury Associated With Cervical Spine Surgery

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Conflict of Interest
The author has no financial conflicts of interest.

ABSTRACT

Iatrogenic vertebral artery injury (VAI) caused by surgical interventions involving the cervical spine is an uncommon but catastrophic complication associated with high morbidity or mortality due to ischemic stroke, intra- or extra-dural hemorrhage, and the formation of pseudoaneurysm or arteriovenous fistulae. In cervical spine surgeries, VAI may occur during the peri- or postoperative period. This may be induced by an anterior or posterior surgical approach. Despite advanced imaging techniques and increased anatomical knowledge, VAI during cervical spinal surgery remains a challenge. Techniques for managing VAI include hemostatic tamponade, ligation, microvascular repair or anastomosis, and endovascular management. We need to consider the risk of iatrogenic VAI as a complication in patients undergoing cervical spine surgeries and a better understanding of its mechanism and proper management.

Keywords: Cervical spine; Infarction, Surgery; Vertebral artery injury

INTRODUCTION

Cervical spine surgeries are performed to treat various conditions, such as degenerative diseases, trauma, infection, tumors, and deformity.[22,53] Surgical procedures for cervical spine entail anterior, posterior, and combined (anterior and posterior) approaches.[55] The various complications associated with cervical spine surgeries depend on the approach. An anterior approach is associated with dysphagia, esophageal injury, superior and recurrent laryngeal nerve palsy, and Horner's syndrome.[27,33] Dura tearing, epidural hematoma, nerve root damage, and infarction of spinal cord are induced by posterior approaches for cervical spine.[22] In addition, vascular injury due to cervical spine surgeries is rare but fatal, and involve various blood vessels, including vertebral artery (VA), carotid artery, thyroid arteries, or internal jugular vein.[24,45,55,57]

Especially, vertebral artery injury (VAI) is the most common vascular injury in cervical spine surgeries and potentially devastating complication. A recent systematic review by Turgut et al. showed that the most commonly injured vessels during cervical spine surgery were VA (86.6%).[55] VAI can result in severe neurologic damage and even death due to acute and late-onset hemorrhage, arteriovenous fistulae (AVF), pseudoaneurysms, thrombosis, embolism, and cerebral ischemia.[44,45] The incidence of iatrogenic VAI in cervical spine surgeries has yet to

be reported accurately given the case reports or series, and retrospective single- or multi-center studies. The overall incidence of VAI in cervical spine surgery varies from approximately 0.08% to 1.4%.[27,35,41,50] However, the rates vary depending on the approach. VAI is more frequent in the posterior approach to C1-2 (4.1% to 8.2%) than the anterior approach (0.3% to 0.5%).[4,27,45]

Iatrogenic VAI is related to the anatomical characteristics of VA and accompanying anomalies. The VA comprises four segments (V4 to V1): The V1 originates in the subclavian artery, anterior to C7 transverse process, until the C6 transverse foramen.[61] The V2 extends to the transverse foramen of C6–C1, while V3 arises in the superior aspect of the arch of the C1 to the foramen magnum.[26] V4 extends from the intradural foramen magnum to basilar artery, and joins the contralateral VA. The VA and basilar artery provide posterior circulation to the brain. The VA is most vulnerable anterior to C7, lateral to C3-7, and posterior to C1-2.[45] In addition, cadaveric or clinical studies revealed the anomalous course of VA in 2.7% to 5.4%.[8,26] Advances in computed tomography angiography (CTA), magnetic resonance angiography (MRA), and conventional angiography revealed the anatomic features of VA. Assessments prior to cervical spine surgery can facilitate accurate surgical planning, and avoid complications. The review provides an understanding of VAI in cervical spine surgery along with the side effects associated with each surgical procedure, and the management strategy and precautions to prevent such complications.

EPIDEMIOLOGY AND CLINICAL FINDINGS OF VAI

Recent systematic reviews indicate that the most common cause of VAI in cervical spine surgeries was drilling (20.6 to 61%) or instrumentation (16% to 31.44%).[20,55] Other causes of VAI are soft tissue retraction, removal of an ossified posterior longitudinal ligament, dissection with cautery, and VA manipulation. Mechanisms of vascular injury during cervical spine surgery reported by Turgut et al. include laceration (most common, 41.24%), pseudoaneurysm (16.49%), arterial dissection (5.67%), thrombosis, emboli or occlusion (4.64%), and AVF (2.58%).[55] Symptoms after cervical spine surgery for VAI may be immediate or manifest several years later.[27] Clinical findings of iatrogenic VAI include intraoperative bleeding, posterior circulation infarcts, neck swelling, hypotension, dyspnea, altered consciousness, hemorrhagic shock, and death, or may be asymptomatic.[4] The majority of symptoms associated with VAI occur immediately, but delayed symptoms may be associated with hemorrhagic complications due to ruptured pseudoaneurysm or AVF.[45] Furthermore, ischemic complications during the delayed period may be associated with emboli due to partially occluded or damaged VA.[59] Dominant VA (about 42% to 50%) was more frequent on the left side, with diameters of equal size found only in 6%–26%.[25] Therefore, the occurrence of VAI during manipulation on the left side requires increased attention. Furthermore, the patency of posterior inferior cerebellar artery (PICA) originating in VA is important because the VAI induces lateral medullary infarction due to abnormal distribution of the PICA, if it is not compensated by collateral circulation.

IATROGENIC VAI ACCORDING TO SURGICAL APPROACHES

Anterior approach

Anterior cervical discectomy and fusion and anterior cervical corpectomy and fusion

Approximate 0.3% to 0.5% of vascular injuries occur during the anterior cervical approach, and

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the most frequently involved vessel is the VA.[20,28,55] Vaccaro et al. reported that VAI occurred in the more cephalad vertebrae, during excessive lateral drilling, disc removal, placement of the plate and screws out of the midline, and in cases with tumor or infection.[56] Likewise, VAI was related to coarse lateral drilling of the uncovertebral joint or neural foramen for decompression, especially with bone softening secondary to infection or tumor.[32,49,54] Other factors, including instrumentation, probe maneuver for lateral exploration, cautery dissection, and prolonged neck hyperextension induce VAI.[2,34,58] Drilling was the most frequent cause of VAIs in previously reported cases.[20] Therefore, surgeons should be prudent when drilling the uncovertebral joint or neural foramen, and avoid coarse extensive lateral drilling.[52] In addition, exposure of the dural root sleeve should not exceed 5 mm in removal of the Luschka joint.[20] Anatomic variations of VA are associated with increased risk of VAI. Therefore, preoperative computed tomography (CT) and magnetic resonance imaging (MRI) findings should be reviewed carefully to determine the appropriate management strategy and to avoid VAI. In addition, the loss of landmarks during anterior cervical approach is highly associated with VAI.[26,45] The safe limit for drilling is an anatomical landmark, which is the insertion site of the longus colli muscles or the uncovertebral joint and should be maintained.[45]

Posterior approach

C1-2 screw fixation

Most VAIs in the posterior cervical approach are associated with C1-2 fusion. The trans-articular screw fixation involving C1-2, in which a screw is inserted through the C2 pars interarticularis to the facet joint of C1-2, is a popular technique in posterior C1-2 fusion.[23] However, this technique increase the risk of VAI, due to the anatomical proximity and anomaly (high riding) of the VA around cranio-cervical junction.[41,46] The incidence of VAI in C1-2 trans-articular screw fixation was approximately 4.1% to 8.2% in previous studies.[36,59] Before the procedure, surgeons evaluate to the anatomical structures around C1 and C2 via CT and MRI images to determine the correct screw trajectory. Furthermore, CTA or MRA are essential to detect the VA status and accompanying anomalies, such as a high riding VA.[18,40] Other technique, such as the C1 lateral mass with C2 pedicle screw insertion was widely used to decrease the risk of VAI, compared with trans-articular screw.[23]

Posterior subaxial cervical screw fixation

VAI in posterior cervical pedicle screw insertion is rarely reported. Abumi et al.[1] reported only one (0.6%) case of VAI in180 patients with cervical pedicle screw. In addition, posterior cervical lateral mass screw insertion is associated with a low risk of VA and decreased stability, compared with pedicle screw.[12,48]

Posterior cervical laminectomy, laminoplasty, and foraminotomy

VAI in posterior cervical laminectomy, laminoplasty, and foraminotomy is extremely rare. Diao et al.[10] reported pseudoaneurysm at Rt. V3 after C2-7 laminectomy and instrumentation. VAI was triggered by drilling of the C1 posterior arch.[10] Pristley presented a case of AVF after unilateral posterior cervical foraminotomy.[47] Obermüller et al.[42] reported a patient with delayed VAI following dorsal cervical foraminotomy.

MANAGEMENT OF VAI IN CERVICAL SPINE SURGERIES

Most cases of VAI during cervical spine surgery involve sudden, non-pulsatile, copious bright red bleeding, which is different from bone bleeding or injury to the surrounding

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venous plexus.[44] There is still no consensus for the definitive treatment strategy of VAI. However, the three major goals are as follows: 1) control of local hemorrhage, 2) prevention of immediate ischemic complication of vertebra-basilar system, and 3) prevention of other cerebrovascular complications, such as pseudo-aneurysm or emboli. In addition, the management of iatrogenic VAI encompasses both bleeding control with maintenance of patent posterior blood circulation in the acute period, and treatment of additional vascular abnormalities in the delayed phase.[44,45] The treatment strategies for VAI in cervical spine surgeries are summarized in (**FIGURE 1**). In the event of VAI, the surgeon should notify to the anesthesiologist accordingly.[45] Fluid replacement or transfusion is needed to maintain blood flow and volume, and reduce the risk of posterior circulation ischemia and hypovolemia. The next step is VAI management for resuscitation.

Surgical treatment

Intraoperative surgical management of VAI includes hemostatic tamponade, microvascular repair or anastomosis, and ligation of the VA. First, bleeding during VAI should be controlled via direct tamponade with hemostatic agents, such as Gelfoam, Surgicel, or FloSeal (Baxter Biosciences, Vienna, Austria). Control of hemorrhage by direct hemostatic tamponade can be effective and easy, but this technique has several disadvantages, including uncontrolled bleeding with hypovolemic shock, ischemic damage by VA occlusion, delayed hemorrhage or ischemia due to the formation of pseudo-aneurysm or AVF.[9,41,44,45] Therefore, conventional angiography is strongly recommended, when bleeding control is achieved with direct hemostatic tamponade. Fortunately, some studies report good outcomes using only anti-coagulation after tamponade, but almost all cases require further evaluation and management following VAI.[34,37,44] According to the status of VA, secondary management after tamponade should be considered, such as endovascular treatment, surgical clipping,

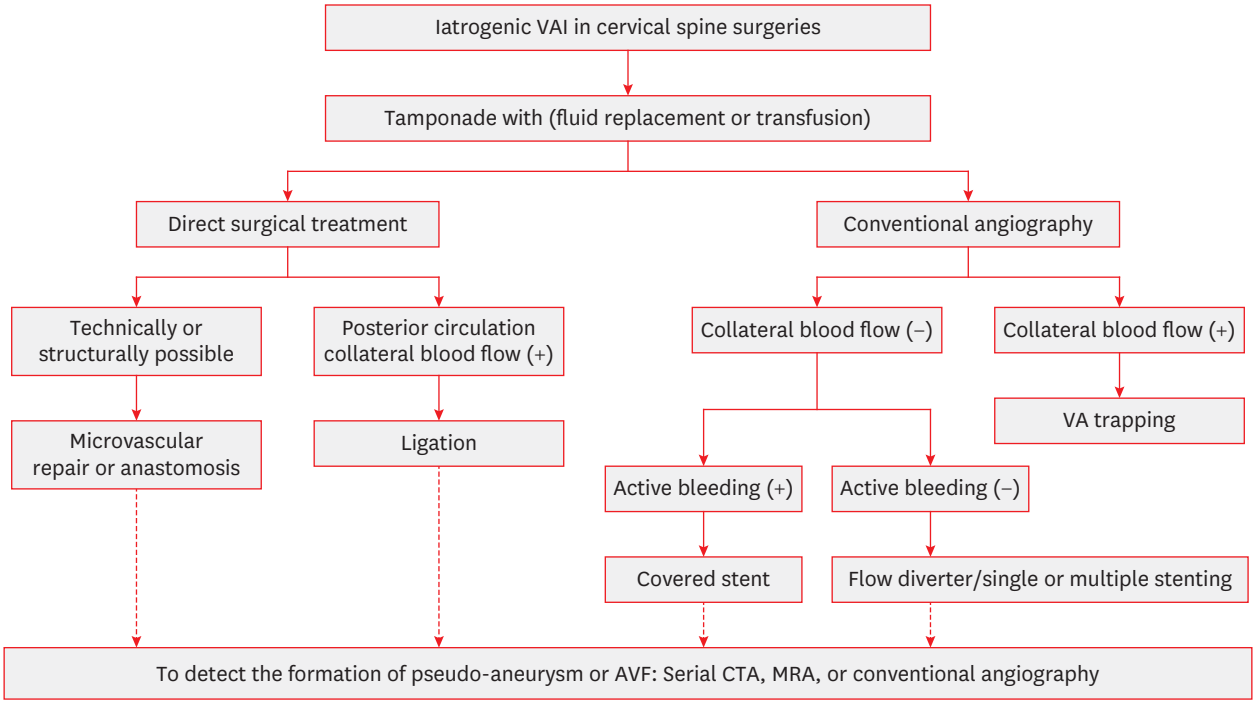

FIGURE 1. Flow sheet for management of iatrogenic vertebral artery injury in cervical spine surgeries.
AVF: arteriovenous fistula, CTA: computed tomography angiography, MRA: magnetic resonance angiography, VAI: vertebral artery injury.

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repair, anastomosis or ligation. Even in non-dominant VA injury and the ipsilateral PICA flow is adequately filled by the contralateral VA, a more reliable treatment such as ligation or clipping rather than a hemostatic tamponade is better to prevent delayed hemorrhage or pseudo-aneurysm. Microvascular primary repair or anastomosis restores normal blood flow and minimizes the risk of immediate or delayed complications.[39,44] However, it is technically difficulty to suture given the extensive VAI site. The suture of damaged VA requires a sharp margin. Massive bleeding, VAI within the bony canal and surrounding venous plexus, and prolonged hemodynamic instability can hinder the management.[3,13,16] Therefore, microvascular primary repair or anastomosis is indicated when it is technically feasible in cases of dominant VAI involving hemodynamically stable patients without interference from the surrounding structures.

Permanent occlusion with surgical ligation or clipping is another option for iatrogenic VAI. This technique can diminish the risk of hemorrhagic complications, but it is associated with significant morbidities of cerebellar infarction, lower cranial nerve paresis, hemiplegia, altered consciousness, and high mortality rate.[37,45] Therefore, it should be performed only when blood supply to the posterior circulation by the contralateral VA is sufficient.[14,19,25] In addition, ligation of VA should be done at both proximal and distal, because only proximal ligation can induce formation of pseudo-aneurysm or AVF, and delayed embolic infarct.[45] As mentioned before, more than 50% of population is left dominance and about 25% is co-dominance, so more attention should be paid to ligation of left VA.[16] The risk of brain stem infarction following VA occlusion was estimated at 3.1% in the left side and 1.8% in the right, and mortality rate associated with unilateral VA ligation was 12%.[9,45] Furthermore, hypoplasia and aplasia of VA should be an obstacle for ligation or clipping of VA. In the normal population, 5.7% of hypoplasia and 1.8% of aplasia in left VA were reported compared with 8.8% of hypoplasia and 3.1% of aplasia in right VA.[14] However, the VA status might facilitate in decision making in VA ligation, but cannot guarantee a favorable outcome. Furthermore, VA ligation is associated with the risk of nerve root injury due to poor visualization of operative field.

Endovascular treatment

Nowadays, endovascular management for VAI is widely facilitated by its advances in techniques and devices. In case of iatrogenic VAI, intra-operative or urgent conventional angiography along with emergent bleeding control is recommended. Conventional angiography in VAI can identify the exact injury mechanism and site, and evaluate the status of bilateral VA and collateral circulation. Actually, there may be limitation to get a trained endovascular team and equipment as soon as hemodynamic instability is discovered. However, recent trends suggest that the popularization of endovascular treatment for cerebrovascular disease has led to increased availability of experienced interventionists with well-equipped angio-suites or hybrid operating rooms at several institutions, and improved access to angiography with endovascular treatment for VAI.[60] VA occlusion with coil is an option in VAI if a patent contralateral VA or sufficient collateral posterior circulation blood flow is identified in conventional angiography.[30,37,46] Destructive intervention, complete occlusion of VA with coil has benefits in bleeding control, reduces recurrence and emboli, compared with other VA saving endovascular techniques.[37,43] However, insufficient blood flow of the contralateral VA can lead to ischemic strokes in brain stem and cerebellum.[44] Therefore, permanent VA occlusion with coil should be considered carefully to uncontrolled bleeding, in patients with tolerable collateral flow in posterior circulation and patent contralateral VA. Furthermore, VA trapping with coil embolization should be performed

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at both proximal and distal portions of the VAI segment to reduce pseudo-aneurysm or recurrence. Simple coiling or stent assisted coiling can be performed in patients with pseudo-aneurysm without active bleeding via adequate hemostasis.[37]

A covered stent, single or multiple stent, and flow diverter can be considered as treatments to maintain the patency of damaged VA. The covered stent for VAI can completely seal the laceration by wrapping the membrane, and stop active bleeding.[58] However, most covered stents are rigid and have limited application in neurovascular disease. The rigidity of the covered stent makes to hard its passage and acquire adequate wall apposition at curved vessel, such as V3 and V4 segment.[31] Therefore, covered stent can be a treatment option for injuries of V1 or V2 segment with its straight course. Single or multiple stenting with self-expandable stents can be considered for the treatment of pseudoaneurysm or dissection accompanying VA laceration, rather than active bleeding status. Flow diverter application has been reported recently for VAI, and in most cases it was used to treat the pseudo-aneurysm rather than active bleeding.[11,51] A flow diverter in VAI is effective for treatment of non-active bleeding pseudoaneurysm, but the application of flow diverter in VAI is restricted in Korea due to the medical insurance system. A covered stent is recommended for the control of active bleeding in non-curved portions, whereas a self-expandable stent or flow diverter is preferred in curved vessels without active bleeding.

Although successful surgical or endovascular treatment for VAI was achieved in acute phase, serial follow up imaging studies for vascular status are essential to evaluate the delayed hemorrhagic or ischemic complications due to the formation of pseudo-aneurysms or AVF during the post-operative periods.[20] Likewise, postoperative angiography without abnormal findings during the acute phase does not rule out subsequent pseudoaneurysm or AVF. The pseudoaneurysm was not apparent in early postoperative CTA or MRA, but can occur later and result in bleeding or AVF formation. Delayed hemorrhagic or embolic infarcts due to these vascular abnormalities appear days or years post-VAI.[6,7,29,34] Therefore, patients with suspected or definitive VAI should be evaluated via CTA, MRA, or conventional angiography to determine the vascular status of VAI during late periods. A pseudoaneurysm or AVF can be treated with the endovascular techniques including coil embolization, stent-assist coil embolization, self-expandable stenting, covered stents, or flow diverter.[17,34,38,47,51,55] Spinal AVF can be treated with as usual manner, such as coil, isobutyl cyanoacrylate, or ONYX embolization by trans-arterial or venous approach.

STRATEGIES FOR PREVENTION OF VAI

CT and MRI images should be carefully reviewed in the pre-operative period. If necessary, additional imaging studies including CTA, MRA, and conventional angiography should be considered for further evaluation. The location of the VA and its association with bone and surrounding structures should be demonstrated.[45] It is important to identify the VA status including ectasia, tortuosity, and anomaly. Based on these images, the surgeon should determine the precise extent of dissection and decompression. Especially in posterior approach, the safe trajectory for screw placement as well as the dimensions of the pedicles or lateral masses should be reviewed to avoid VAI. If there is VA anomaly, additional prophylactic procedures such as exposure of the VA for proximal and distal placement of encircling vascular loops or sutures may be considered.[54] In addition, alternative surgical approaches, including anterior to posterior or posterior to anterior strategies, should be

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considered. During the peri-operative period, identification of midline and other anatomic landmarks is important for safe dissection and instrumentation. A blunt dissection, coarse and extensive drilling should be avoided. Intraoperative imaging techniques such as fluoroscopy, CT, or navigation may be useful, especially in difficult cases.[5,15,21] Surgeons should minimize intraoperative manipulation and/or retraction of the vascular structures to avoid VAI in cervical spine surgeries.[24,57] Furthermore, an experienced neurovascular surgeon, and a neuro-interventionist with endovascular equipment are essential to provide immediate conventional angiography and prompt management for VAI in cervical spine surgery.

CONCLUSIONS

Nowadays, cervical spine surgeries for various pathologies are commonly performed with advanced imaging techniques and increased anatomical knowledge. However, they are associated with a potential risk of iatrogenic VAI which is a rare but fatal complication. Therefore, all of surgeons should remember that VAI can occur any time during or after the surgery regardless of the surgical approach (anterior and/or posterior) for the cervical spine. Prevention is the best strategy for any iatrogenic VAI. Every effort should be made to prevent VAI, including understanding the vascular status, identification of anatomical anomaly, proper surgical planning, and closed monitoring peri/post- operative periods. Furthermore, surgeons should be aware of the possibility and appropriate management strategies for VAI. Hemostatic tamponade, microvascular repair or anastomosis can be performed as needed. Surgical ligation or permanent clipping should only be attempted if the contralateral VA provides adequate collateral circulation. Recent advances in endovascular treatment have led to increased interventions in iatrogenic VAI. In the event of VAI, local bleeding control is the first step. An immediate conventional angiography is recommended, followed by serial endovascular treatment and closed monitoring of the patient.

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