The management of vertebral artery injury in anterior cervical spine operation: a systematic review of published cases

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Abstract

Purpose Anterior cervical spine operations (ACSO) are generally considered to be safe and effective, but the vertebral artery (VA) is at risk during the procedure. Because the consequences of VA injury can be catastrophic, properly managing a VA injury is very important. However, due to the rarity of these injuries, there is no agreed upon treatment strategy.

Methods Studies were identified for inclusion in the review via sensitive searches of electronic databases through 31 December 2011. All cases included in the review were qualitatively analyzed to explore the relationship between type of VA injury management and neurological complications.

Results Seventeen articles describing 39 cases of VA injury during ACSO were included in this study. Seven patients (17.9 %) had neurological complications followed by VA insufficiency. Two patients (5.1 %) had root damage due to ligation. One case (2.6 %) resulted in intraoperative death due to fatal bleeding. Delayed vascular complications were identified in nine (45.0 %) of the 20 patients that underwent only tamponade or hemostatic agent during the operation. Four patients underwent intraoperative endovascular treatment, and three of these patients had a cerebral

infarction. All three patients who underwent clipping also had neurological complications. The five patients treated by direct repair did not have any complications.

Conclusion Our review suggests the management of VA injury should be considered in order listed: (1) performing tamponade with a hemostatic agent, (2) direct repair, (3) postoperative endovascular procedures to prevent delayed complications. If tamponade fails to achieve proper hemostasis, additional procedures as endovascular embolization, clipping and ligation should be considered but carry the risk of neurological complications. Because of the limitations of this review, further studies are recommended with larger sample sizes.

Keywords Vertebral artery injury · Cervical spine · Anterior operation · Management

Introduction

Anterior approaches to cervical spine pathology are used frequently and allow for direct decompression of the nerve root and spinal cord with an excellent success rate [3, 23, 43]. Although anterior cervical spine operations (ACSO) are generally considered to be safe and effective, the vertebral artery (VA) is at risk during the procedure because of its location adjacent to the neural foramen [5, 38]. The largest series of these injuries cite the incidence of injury as approximately 0.3–0.5 % [4, 35]. Although VA injury is uncommon, the consequences can be catastrophic as it is associated with serious complications such as arteriovenous fistula (AVF), pseudoaneurysm, late-onset hemorrhage, thrombosis, embolism, cerebral ischemia, and death [20, 25, 28]. Advances in ACSO and VA injury management should make an effort to reduce these complications. Occurrence of VA injuries can be

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reduced by understanding the mechanisms of the injury [14, 20]. Moreover, properly managing the complications can reduce patient mortality and morbidity from VA injury [10]. Numerous studies have focused on the avoidance of VA injury during ACSO, and there is now a general consensus regarding the best methods for avoiding VA injury [12, 14, 22, 26–28, 31, 33, 38]. However, there is not yet an established strategy or consensus for managing VA injury in ACSO, although previous reports indicate that successful management of the injury is possible [4–6, 9, 13, 16, 18, 19, 24, 25, 29, 35, 39]. It is difficult to determine which management strategy is likely to result in a favorable outcome because VA injury in ACSO is unexpected and very rare. Most evidence available on VA injury is class III, based on case series from individual institutions. Also, it is extremely difficult to conduct a prospective clinical trial to compare the outcomes of various procedures in cases that occur rarely and incidentally.

The aim of this systematic review was to identify consequences according to type of VA injury management. This study combined all VA injury cases published to date in order to describe and assess a strategy for adequate management of VA injury during ACSO.

Methods

Search strategy

Studies were identified for inclusion in the review via sensitive searches of electronic databases. PubMed, EMBASE, and Google Scholar were searched through 31 December 2011. The articles were retrieved for review if they described both the cervical spine operation and the VA injury. To maximize the inclusion of eligible articles, we used the search term: vertebral artery or vertebral artery injury, cervical or cervical spine, operation or surgery or iatrogenic, and/or complication or surgical result or outcome. Additional studies were sought from the references of all retrieved articles.

Inclusion criteria

Studies were included if they satisfied all of the following criteria.

- The studies must describe VA injury during ACSO.
- VA injury was identified during operation.

Exclusion criteria

- The studies were not written in English.
- Papers did not have the sufficient description of clinical features, management, and outcomes for data extraction.

Article inclusion

All titles and abstracts were screened independently by two reviewers (Dr. Park and Dr. Jho). Disagreements regarding whether or not a paper should be included were resolved via consensus. When a disagreement occurred about whether or not to exclude the report, it was retrieved for further review. The articles were also retrieved for review if they described VA injury or complications due to ACSO. Retrieved full text articles were screened independently by two reviewers.

Definition and data extraction

One review author (Dr. Park) extracted the following data from included studies and the second author (Dr. Jho) checked the extracted data. Disagreements were resolved by discussion between the two review authors. Articles were scrutinized for pre-specified features chosen from prior knowledge of literature.

We extracted the following information from the included studies: the diagnosis before surgery, the operation method, the cause of VA injury, the site of VA injury (right or left VA), the management of VA injury (primary and secondary), the angiographic findings of VA (before or after surgery), and neurological complications.

The diagnosis before surgery was defined as one representative disease for operation was recorded. Procedures of management were classified as either primary or secondary. Primary management was defined as a procedure performed during the operation. Secondary management was defined as a procedure performed after surgery for treatment or prevention of delayed complications. If other procedures were performed in addition to tamponade as part of primary management, the additional procedures were recorded as primary management. The complications irrelevant to VA injury were excluded.

Quality assessments for each report were not performed because that was extremely low due to the character of the reports. Quantitative analysis was not feasible because of the lack of appropriate data. All retrieved reports were tabulated and analyzed in a qualitative manner.

Results

Search

From the electronic database search, a total of 2,164 papers were identified (Fig. 1). Seventeen articles describing 42 patients were initially identified based on the aforementioned inclusion criteria. Of these 42 patients, three were excluded due to unclear information regarding management (two patients) or outcome (one patient) of the VA

Fig. 1 Flow chart showing identification and selection of cases with vertebral artery injury in anterior cervical spine operation. *OP* operation, *VAI* vertebral artery injury

injury. Therefore, 39 patients were included in this study (Table 1). No controlled clinical trial or cohort study dealing with the topic could be found. There was one survey study, one retrospective observational study, three retrospective reviews of case series, and 12 case reports (class III).

Patient characteristics

The characteristics of patients with VA injury during ACSO are shown in Table 2. The primary diagnosis of all patients were degenerative disc disease (DDD) (27 patients (69.2 %)), tumor (four patients (10.3 %)), ossification of posterior longitudinal ligament (OPLL) (three patients (7.7 %)), infection [two patients (5.1 %)], pseudoarthrosis [two patients (5.1 %)], and fracture [one patient (2.6 %)]. Of the 39 patients, 35 patients (89.7 %) had the discectomy or corpectomy without or with fusion, and two patients (5.1 %) had foraminotomy. The other two patients had resection of exostosis, and drainage of pus respectively.

Cause and site of injury

Cause of injury was reported for 30 patients (76.9 %); of these, VA injury occurred during drilling in 23 patients (58.9 %), during instrumentation in four patients (10.3 %),

during retraction in two patients (5.1 %) and during dissection in one patient (2.6 %). In the two cases where injury occurred during retraction, one occurred in a patient with plasmacytoma who had undergone prior cervical irradiation treatments, and the other occurred in a patient with abscess formation after a previous operation. Data on site of injury were available for 34 patients (87.2 %). Of these, 19 patients (48.7 %) had injury to the right VA and 15 patients (38.5 %) to the left VA.

Management of VA injury

For primary management, hemostasis was achieved with tamponade or a hemostatic agent in 20 patients (51.2 %), repair in six patients (15.4 %), ligation in five patients (12.8 %), endovascular treatment in four patients (10.3 %), clipping in three patients (7.7 %), and coagulation in one patient (2.6 %). Pseudoaneurysm (six patients) or AVF (three patients) occurred in nine (45.0 %) of the patients who had been treated by tamponade or hemostatic agent as part of primary management. Seven patients had an embolization, and two patients were treated by direct repair and ligation as a secondary management approach. One patient had an embolization via intraoperative hemostasis.

Outcome

A definitive follow-up period was not described for most patients. Of the 39 patients, 29 (76.4 %) had no neurological complications. Seven patients (17.9 %) had neurological complications after VA insufficiency. Two patients (5.1 %) had root damage due to ligation, although it was not directly caused by VA injury. One case (2.6 %) resulted in intraoperative death due to fatal bleeding.

Outcome by management type

Figure 2 shows the outcome of VA injury according to type of management in ACSO. Of the cases managed by tamponade or hemostatic agent, one patient had a cerebral infarction, and one case resulted in death due to fatal bleeding. Delayed vascular complications were identified in nine of these cases (45.0 %). These patients were treated without complication by secondary management methods. Of the five patients who underwent ligation, two had root damage. Of the four patients who underwent endovascular treatment as primary management, three had cerebral infarctions. All three patients underwent clipping had neurological complications. Five patients treated by direct repair did not have any complications.

Table 1 Summary of cases of vertebral artery injury during anterior cervical spine operation

References	Description of study	No. of cases	Disease	Op method	Cause	Site of injury	Management		Neurological sequelae	Status of VA
							Primary procedure	Secondary procedure		
Weinberg et al. [42]	Case report	1	DDD	ACDF	NA	Lt. VA	Tam/Hem	Ligation	No	Postop 1 mon: AVF VA: occlusion
Cosgrove et al. [6]	Cases report	1	DDD	ACDF	NA	Lt. VA	Tam/Hem	Endovascular Tx (embolized)	No	Postop 1 yr: AVF VA: normal flow
de los Reyes et al. [9]	Case report	2	DDD	Discectomy	NA	Rt. VA	Tam/Hem	Endovascular Tx (balloon)	No	Postop 6 days: AVF VA: normal flow
Smith et al. [35]	Case report	1	OPLL	DC and fusion	Drilling	Rt. VA	Tam/Hem	Repair	No	Postop 3 days: PA VA: decreased flow
A retrospective review of case series		1	Aneurysmal bone cyst	Corpectomy	Instrument	Rt. VA	Tam/Hem	No	No	VA: normal flow
		2	DDD	Corpectomy	Drilling	Rt. VA	Coagulation	No	No	NA
		3	C2 Fx	Corpectomy	Drilling	Lt. VA	Clipping ^a	No	Cerebellar infarction	Collateral flow present, NA
		4	Infection	Corpectomy	Instrument	Rt. VA	Tam/Hem	No	No	NA
		5	DDD	ACDF	Instrument	Lt. VA	Clipping ^a	No	Transient dysphagia	Persistent PSI
		6	OPLL	Corpectomy	Drilling	Lt. VA	Clipping ^a	No	Quadruparesis	NA
		7	DDD	Corpectomy	Drilling	Rt. VA	Ligation	No	C5 root damage	NA
		8	Metastases	Corpectomy	Drilling	Rt. VA	Ligation	No	No	NA
		9	PA	Corpectomy	Drilling	Rt. VA	Ligation	No	C5 root damage	NA
		10	PA	Corpectomy	Drilling	Rt. VA	Tam/Hem	No	No	NA
Pfeifer et al. [29]	Case report	1	DDD	Corpectomy	Drilling	Lt. VA	Repair	No	No	VA; symmetry, normal flow
Golfinos et al. [19]	A retrospective review of case series	1	DDD	DC	Drilling	Rt. VA	Repair	No	No	Tortuous VA
Daentzer et al. [7]	Case report	2	DDD	DC	Drilling	Lt. VA	Repair	No	No	VA: normal flow
		3	DDD	DC	Tapping	Rt. VA	Repair	No	No	VA: normal flow
		4	Plasmacytoma	DC	Soft tissue retraction	Rt. VA	Ligation	No	No	NA
									No	Previous irradiation
Epstein [13]	Case report	1	DDD	ACDF	Drilling	Lt. VA	Tam/Hem	Endovascular Tx (coil)	No	Postop 2 dys: PA VA: normal flow
Tumialan et al. [39]	Case report	1	RA, DDD	Corpectomy and fusion	Dissection	Lt. VA	Tam/Hem	Endovascular Tx (coil)	No	Postop: Lt. VA occlusion
		1			Drilling	Lt. VA	Tam/Hem	No	Extensive infarction	Lt VA dominant. Tortuous VA
										Postop: occlusion

Table 1 continued

References	Description of study	No. of cases	Disease	Op method	Cause	Site of injury	Management		Neurological sequelae	Status of VA
							Primary procedure	Secondary procedure		
Burke et al. [4]	A retrospective review of case series	1	DDD	Corpectomy, fusion	NA	Lt. VA	Repair	No	No	NA
		2	DDD	ACDF	NA	Lt. VA	Ligation	No	No	NA
		3	DDD	Corpectomy, fusion	NA	Lt. VA	Repair	No	No	NA
		4	DDD	Corpectomy	NA	Lt. VA	Tam/Hem	No	Intraoperative death	NA
		5	DDD	Corpectomy	NA	Rt. VA	Tam/Hem	No	No	NA
Garcia Alzamora et al. [18]	Case report	1	DDD	Foraminotomy	Drilling	Lt. VA	Tam/Hem	Endovascular Tx (stent)	No	Postop 2nd day: hematoma, PA
Choi et al. [5]	Cases report	1	Infection	Irrigation and drainage	Soft tissue retraction	Lt. VA	Tam/Hem	Endovascular Tx (Golden valve)	No	Postop 10 days: PA VA: occlusion
		2	DDD	ACDF	Drilling	Rt. VA	Tam/Hem	Endovascular Tx (coil)	No	Postop 4 days: PA VA: occlusion
Neo et al. [25]	A retrospective survey	1	DDD, OPLL	ACDF	Drilling	NA	Endovascular Tx (embolized)	No	No	NA
		2	DDD	ACDF	Drilling	NA	Tam/Hem	No	No	Postop: PA VA: patent
		3	C4 TP exostosis	Resection	Drilling	NA	Tam/Hem	No	No	Postop: occlusion
		4	DDD	ACDF	NA	NA	Tam/Hem	No	No	NA
		5	DDD	Foraminotomy	Drilling	NA	Tam/Hem	No	No	VA: patent
Eskander et al. [14]	Case report	1	DDD	ACDF	Drilling	Lt. VA	Endovascular Tx (embolized)	No	Lateral medullary stroke	Lt. Aberrant VA
Gantwerker et al. [17]	Case report	1	DDD	ACDF	Drilling	Lt. VA	Tam/Hem	Endovascular Tx (coil)	No	Postop: occlusion
									Anomalous VA	Postop 4 days: PA VA: occlusion
Bilbao et al. [2]	A retrospective observation study	1	DDD	Corpectomy	Drilling	Lt. VA	Endovascular Tx (embolized)	No	Multiple infarction, Tetraparesis	Postop: occlusion
Jung et al. [21]	Case report	1	DDD	ACDF	Drilling	Rt. VA	Endovascular Tx (embolized)	No	Rt cerebellar infarction ^b	Postop: occlusion

VA vertebral artery, DDD degenerative disc disease, ACDF anterior cervical discectomy and fusion, NA not available, Tam/Hem tamponade or hemostatic agent, OPLL ossification of posterior longitudinal ligament, DC decompression, PA pseudoaneurysm, PSI posterior circulation insufficiency, RA rheumatoid arthritis, TP transverse process

^a Proximal and distal vascular clips

^b No neurologic sequelae

Table 2 Characteristics of vertebral artery injury during anterior cervical spine operation

Primary diagnosis	39 (100)
Degenerative disc disease	27 (69.2)
Tumor	4 (10.3)
OPLL	3 (7.7)
Infection	2 (5.1)
Pseudoarthrosis	2 (5.1)
Fracture	1 (2.6)
Type of surgical procedure	39 (100)
Anterior decompression	35 (89.7)
Foraminotomy	2 (5.1)
Resection of exostosis	1 (2.6)
Drainage of pus	1 (2.6)
Cause of vertebral artery injury	39 (100)
Drilling	23 (58.9)
Instrumentation	4 (10.3)
Retraction	2 (5.1)
Dissection	1 (2.6)
Not described	9 (23.1)
Injury site	39 (100)
Right vertebral artery	19 (48.7)
Left vertebral artery	15 (38.5)
Not described	5 (12.8)
Type of management	
Primary	39 (100)
Tamponade/hemostatic agent ^a	20 (51.2)
Repair	6 (15.4)
Ligation	5 (12.8)
Endovascular Tx	4 (10.4)
Clipping	3 (7.7)
Coagulation	1 (2.6)
Secondary	10 (100)
Tamp/hemo → endovascular Tx	8 (80.0)
Tamp/hemo → repair	1 (10.0)
Tamp/hemo → ligation	1 (10.0)
Delayed vascular complication ^b	20 (100) ^b
None	11 (55.0)
Pseudoaneurysm	6 (30.0)
AVF	3 (15.0)
Neurological sequence	39 (100)
None	29 (76.4)
Cerebral infarction	7 (17.9)
Root damage	2 (5.1)
Death	1 (2.6)

OPLL ossification of posterior longitudinal ligament, *AVF* arteriovenous fistula

^a Eight of these patients had vascular complications of arteriovenous fistula or pseudoaneurysm

^b Total number of patients is the group that was treated by tamponade or hemostatic agent in primary management

Discussion

The current systematic review shows that, when managing VA injury during ACSO, hemostasis achieved by tamponade or hemostatic agent carries a risk of postoperative hemorrhage, AVF, or pseudoaneurysm formation. Embolization or clipping for hemostasis as a form of primary management also carries a risk of neurological complications that should not be overlooked. Ligation as primary management of hemostasis was related to nerve root damage. On the other hand, primary repair does not appear to be associated with any neurologic complications.

Causes

The VA is critical to perfusion of the brainstem and cerebellum. VA injury is a rare but profound complication of ACSO [2, 17, 25, 35]. The reports included in this study presented several mechanisms or risk factors of VA injury in ACSO. The mechanisms of injury include performance of an excessively wide corpectomy as well as loss of the vertebral midline or orientation, leading to an off-center or oblique corpectomy [4, 21]. Unrecognized VA tortuosity or other anomalies, such as a VA located anterior to the transverse process, may also result in intraoperative injury [4, 15, 17, 39]. The presence of a softened lateral cortex due to tumor or infection has been implicated in VA injury during operation [4, 5, 19, 35]. In addition, a VA weakened by radiation or infection is also at risk for injury [5, 19]. The most common cause of VA injury was drilling (23 patients, 58.9 % of cases). Therefore, careful attention should be paid during drilling. It is clear that prevention of the problem is the best option, and therefore, it is important to understand these mechanisms and risk factors so that VA injury can be avoided when possible. However, if VA injury occurs despite the best preventative efforts, an effective management plan must be in place.

Management

The therapeutic goals for treating VA injury are threefold and progressive: (1) obtain control of local hemorrhage, (2) prevent immediate vertebrobasilar ischemia, and (3) prevent cerebrovascular complications [20, 28]. When VA injury occurs, there usually is a sudden, copious bright red bleeding, which is different from bone bleeding [28]. VA bleeding should be controlled with direct tamponade followed by hemostatic agents, although an effort should be made to accomplish a more effective means of control [8, 20, 25, 28]. Control of hemorrhage by direct hemostatic tamponade can be effective and easy, but this review

Fig. 2 Flow chart showing treatment outcomes according to type of management of vertebral artery injury in anterior cervical spine operation. *Numbers* represent the number of cases.

AVF arteriovenous fistula,
PA pseudoaneurysm,
Endo endovascular treatment,
Embo embolization

showed that there remains a potential risk of cerebral ischemia due to VA occlusion, hypovolemic shock due to insufficient hemostasis, or delayed hemorrhage due to pseudoaneurysm or AVF formation. Having said that, the cases of delayed hemorrhage were treated without complication using secondary management methods such as endovascular procedures, ligation or repair. Therefore, once tamponade followed by hemostatic agents, has provided some degree of hemostasis, more effective procedure such as repair, clipping, or ligation should be considered with resuscitation. This step should help prevent immediate vertebrobasilar ischemia. Some surgeons advocate direct primary repair of the injured vessel as an optimal management strategy if it is technically feasible [9, 17, 19, 24, 29]. Primary repair could restore normal blood flow and minimize the risk of hemorrhagic or ischemic complications; therefore, it should especially be considered when injury occurs in the dominant VA [9, 19, 20, 24, 29]. This review found that the six cases of VA injury managed by primary repair had favorable outcomes. However, direct exposure and suture repair of a VA laceration is not always feasible because of copious bleeding within the bony canal and surrounding venous plexus and hemodynamic instability [13, 17]. If the VA is lacerated or perforated with good margin, it can be repaired by primary suture [24]. Direct tamponade followed by endovascular investigation can help assess the patency of the vessel and also permits repair during the same procedure [17]. Repair should be considered for preventing vertebrobasilar ischemia.

Permanent occlusion by ligation or clipping is another available option. This type of management can decrease the risk of delayed hemorrhage and insufficient hemostasis related to tamponade. However, it should only be attempted if the patient has a patent contralateral VA or sufficient collateral posterior circulation [14, 20, 24, 28]. The left VA is hypoplastic in 5.7 % and absent entirely in 1.8 % of the general population, while the right VA is hypoplastic in 8.8 % and absent in 3.1 % [14]. Attempted unilateral ligation of the VA has a reported mortality rate of 12 % [34]. The risk of brain stem infarction following VA occlusion is estimated to be 3.1 % on the left side and 1.8 % on the right [8]. The left VA is dominant in 50–60 % of the population, whereas the right VA is dominant in approximately 25 %. The remaining 25 % of the population have co-dominant VAs [17]. Of the six patients with cerebral infarctions that were included in the current review, information about VA dominance was only available for one patient, and this patient had injury to the dominant VA. However, these suggestions might be helpful in making a treatment decision but cannot guarantee a favorable outcome. This study showed that ligation of the VA involves risk of nerve root damage due to poor visualization, and clipping resulted in significant morbidities due to occlusion of the VA. Although coagulation resulted in a favorable outcome in the one case reviewed in this study, electrocautery as a means to control bleeding should be avoided, as it is generally ineffective and may cause injury to the cervical roots [8]. Endovascular treatments are another primary management method for achieving

hemostasis. Some authors suggest that intraoperative endovascular treatment is effective in both checking the blood flow of the contralateral VA and stopping bleeding from the injured VA [13, 25]. In actuality, intraoperative angiography can assist with urgent evaluation of the injury site and identification of the contralateral VA status. If a patent contralateral VA or a sufficient collateral posterior circulation is present, direct occlusion of an injured VA is justified. However, if the patient has a hypoplastic contralateral VA, then vessel repair or stenting is preferred [18, 32, 37]. That said, intraoperative embolization has several limitations. First, it is not always possible to obtain a trained endovascular team and equipment as soon as hemodynamic instability is discovered. Furthermore, insufficient blood flow of the contralateral VA can result in significant complications [15, 25], leaving medical personnel no choice but to occlude the VA in cases of uncontrolled bleeding of VA. In this review, three of four cases developed a lateral medullary stroke and multiple cerebral infarctions after VA injury and subsequent intraoperative embolization. Ligation, clipping, coagulation, and embolization as primary management tools all carry a risk of neurological complication that cannot be overlooked. These procedures should be considered carefully as a means of arresting VA bleeding that cannot be controlled with tamponade and a hemostatic agent.

Secondary management is used in the case of delayed complications or insufficient hemostasis after operation. Nine patients had delayed hemorrhage due to pseudoaneurysm or AVF. All underwent tamponade in primary management. Seven of the nine underwent endovascular treatment without complications as a form of secondary management. One of the remaining patients had ligation, and the other underwent VA repair. This review shows that endovascular treatment as a form of secondary management typically results in a favorable outcome. Reports of endovascular management for trauma-related VA injuries have shown similar results [11, 32, 41]. Desouza et al. [11] performed a clinical review focusing on blunt VA injury and recommended that high-grade and symptomatic VA injuries be treated by endovascular approaches. Endovascular techniques include stenting, VA occlusion, and coil embolization, either individually or in combination [11, 32]. The choice of technique depends on the grade of the VA injury, the site of the injury, and the presence of collateral circulation and a dominant vertebral artery [5, 11, 32]. Transvenous treatment and embolization of iatrogenic vertebral AVF have also been reported [5, 16]. Some authors describe a stenting technique without coils that successfully treated a pseudoaneurysm and AVF of VA [18, 32], which has the potential to assure VA patency. Although some studies report favorable outcomes for endovascular treatment, long-term studies with large sample sizes are needed to confirm

long-term outcomes and complications of endovascular treatment for VA injury in ACSO. The present review suggests that endovascular treatment as secondary management typically results in favorable outcomes, in contrast to using endovascular treatment as a primary management approach.

Moreover, modern techniques like endovascular stenting and new hemostatic agent can be considered in managing VA injury. Actually, improvements in stent technology may expand the population that may be eligible for endovascular treatment [30]. The use of new hemostatic agent as FloSeal (Baxter Biosciences, Vienna, Austria) could provides a quick and effective method of hemostasis in the bleeding by VA injury [1].

Outcome

Although successful surgical or endovascular treatment of a VA injury is usually possible, the surgeon must remain vigilant for delayed complications. Careful attention must be paid to potential complications such as late-onset hemorrhages, thrombosis with embolic incidents, and vertebrobasilar ischemia [4, 5, 17, 20, 25, 28, 35, 42]. Therefore, the patient should be postoperatively admitted to an intensive care unit for close monitoring of neurologic functions. When hemostasis by tamponade is used to treat VA injury, some authors strongly recommend an immediate angiography to detect vascular complications and confirm adequate collateral circulation to the brain [5, 13]. Further management (such as reoperation, embolization, or anticoagulation) would be based upon the etiology of any abnormalities detected by these tests [4, 28]. Bleeding may occur at variable intervals from the time of injury, making it difficult to promptly diagnose a false VA aneurysm [5, 6, 9, 16, 18, 25, 35]. In addition, a normal angiography after a surgery complicated with VA injury does not rule out later formation of a pseudoaneurysm, since re-bleeding has been observed days to years after surgery. In this situation, patient follow-up should include an MR angiography or CT angiography to evaluate the vessel situation and to exclude a growing pseudoaneurysm [5, 20, 25, 28].

Anticoagulation is generally indicated when neurological deficits occur due to thromboembolic phenomena. Heparin is immediately started and then an antiplatelet agent is used for 3 months postoperatively. Anticoagulation carries some risk of local re-bleeding or conversion of a recent brain infarct to a hemorrhagic infarct requiring evacuation [4, 28].

Summary

Based on the research reviewed for this study, the following strategy is recommended for treatment of VA injury in ACSO (Fig. 3). When the VA is injured during ACSO,

Fig. 3 Flow chart showing strategies for management of vertebral artery injury in anterior cervical spine operation. Stent or repair can be considered when bleeding is temporally controlled by intraoperative endovascular procedures

the primary goal is to achieve hemostasis by packing (but not forcing) thrombogenic materials into the area of injury. After hemostasis, repair should be considered first. If repair is not feasible, after tamponade with a hemostatic agent, postoperative endovascular procedures should be performed to prevent delayed complications. If tamponade fails to achieve proper hemostasis, additional treatments such as intraoperative endovascular procedures, clipping, and ligation should be considered after the patient is resuscitated. These procedures are effective for stopping fatal intraoperative bleeding but carry the risk of neurological complications. In cases when proper hemostasis is achieved through intraoperative endovascular procedures, if collateral circulation is not adequate, the possibility of repair or stent should be considered again.

Limitation

As with any systematic review, the results may be biased if the included cases are a biased sample of cases in general (publication bias). The lack of randomization for treatment could have resulted in a biased outcome. In addition, cases with a negative outcome may not have been published, thus creating a significant reporting bias. Because this study includes only case reports and case series, publication biases could exaggerate clinical effects resulting in potentially erroneous clinical decision making [36]. It is important to assess the likely extent of the bias and its potential impact on the conclusions. Nevertheless, for extremely rare complications such as VA injury, it is sometimes impossible to obtain class I or II evidence, and therefore, a systematic review of existing cases is the only

option [40]. This review helps clarify management strategies for VA injury during ACSO.

Conclusion

This review included 39 cases of VA injury in ACSO. Our review suggests the management of VA injury should be considered in order listed: (1) performing tamponade with a hemostatic agent, (2) direct repair, (3) postoperative endovascular procedures to prevent delayed complications. If tamponade fails to achieve proper hemostasis, additional procedures as intraoperative endovascular embolization, clipping and ligation should be considered but carry the risk of neurological complications. Because of the limitations of this review, further studies are recommended with larger sample sizes.

Conflict of interest The authors have no personal, financial or institutional interest in any of the drugs, materials, or devices described in this article.

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