



# Pre-Therapeutic Vascular Anatomical Evaluation in Penetrating Cerebrovascular Injuries: Insights from Two Cases

Jinwei LEI, Gongbin WEI

Chongqing University Central Hospital, Chongqing Emergency Medical Center, Department of Traumatology, Chongqing 400000, China

This study has been presented at the 27<sup>th</sup> Annual Congress of Chinese Society of Emergency Medicine, between November 29 and December 1, 2024 at Shenyang, Liaoning Province, China.

**Corresponding author:** Gongbin WEI ✉ weigb2000@163.com

## ABSTRACT

Penetrating cerebrovascular injuries (PCVIs) are often life-threatening, with trauma to the carotid or vertebral arteries potentially causing severe neurological deficits. This study aimed to retrospectively examine two cases of severe penetrating cerebrovascular injury with unstable hemodynamics that resulted in markedly different neurological outcomes. The first patient was struck by a high-speed metal rod, sustained injuries to the right common carotid and right vertebral arteries and was admitted to our hospital 10 h after the trauma. The second patient, who was stabbed, sustained an injury to the right vertebral artery and was admitted to our hospital 1 h after the trauma. Both patients had injuries in zone II of the right lateral neck. The first patient underwent ligation of the right vertebral artery and anastomosis of the right common carotid artery using an interposition graft from the autologous great saphenous vein, resulting in an asymptomatic infarction of the ipsilateral frontal lobe. The second patient only underwent ligation of the right vertebral artery, which ultimately led to an occipital lobe infarction and subsequent visual field deficits. These contrasting outcomes underscore the critical influence of cerebrovascular anatomical variations. Penetrating cerebrovascular injuries may pose significant risks of neurological impairment, particularly in the presence of important vascular anatomical variants. Revascularization should be considered as a primary treatment option for patients with cerebral vessel malformations.

**KEYWORDS:** Cerebrovascular trauma, Carotid artery injuries, Traumatic vertebral artery dissection, Neurologic deficits, Anatomic variation

**ABBREVIATIONS:** **BP:** Blood pressure, **CCA:** Common carotid artery, **CT:** Computed tomography; **CTA:** CT angiography, **DSA:** Digital subtraction angiography, **PCVI:** Penetrating cerebrovascular injury, **PComA:** Posterior communicating artery, **PRBC:** Packed red blood cells, **VA:** Vertebral artery

## INTRODUCTION

Penetrating cerebrovascular injury (PCVI) is an uncommon, but fatal condition (4,23). The common carotid artery (CCA), a major conduit of blood to the head and neck, and the vertebral artery (VA), which is responsible for supplying the posterior part of the brain, are crucial components of the cervical vascular system. Injuries to these arteries, whether blunt or penetrating, carry high morbidity and mortality rates (16,25).

For penetrating neck injuries, clinicians typically opt for selective surgical interventions following a thorough examination, particularly to assess digestive and respiratory functions (21,25). Surgical exploration becomes mandatory in patients with hemodynamic instability, whereas a selective treatment strategy is employed for stable patients, reducing unnecessary surgeries by approximately 59% (21). Studies have primarily reported general treatment outcomes, indicating that these approaches are safe (17).



However, few investigations have examined the relationship between neurological dysfunction, the severity of penetrating cerebrovascular injuries, and cerebrovascular anatomy. This study aimed to analyze the treatment outcomes in two PCVI cases, with a particular focus on neurological deficit complications.

**■ CASE REPORT**

**Case 1**

A 57-year-old female was struck on the right lateral neck (zone II) by a high-speed, 10 cm metal rod (Figure 1A and 1B). Upon admission to a local hospital, computed tomography (CT) angiography (CTA) indicated suspected perforations of the CCA and VA (Figure 1C). An initial exploratory surgery failed to control the bleeding. The patient was intubated, sedated, maintained on the vasopressor norepinephrine, and transferred to our emergency room approximately 10 h post-injury. Exploratory surgery was immediately performed again in the operating room.

Intraoperatively, both the right CCA and VA were found to be lacerated with near-complete transection (both Biffi grade V) (Figure 2A, Table I) (2,6). The VA was ligated first. The CCA was debrided and temporarily shunted using a modified T-tube,

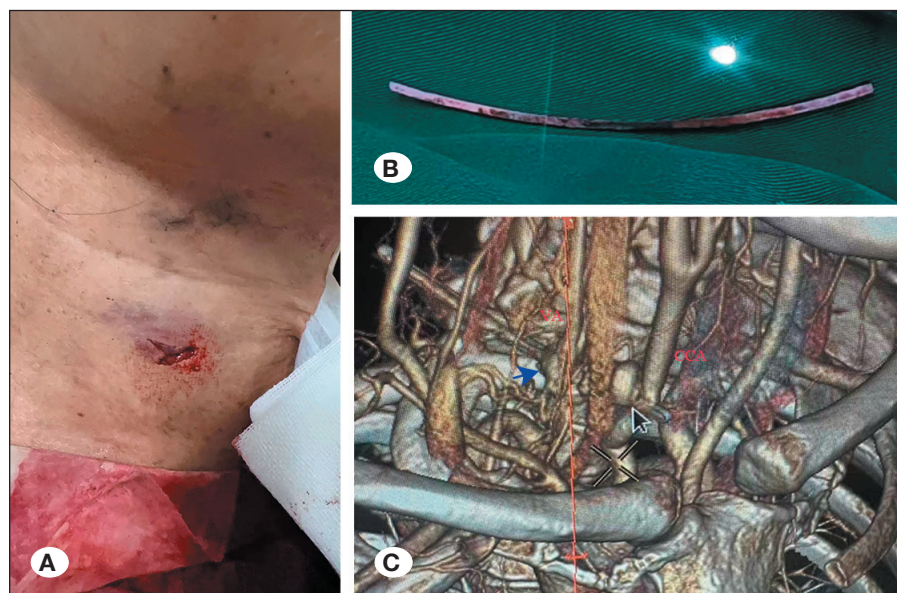
followed by definitive reconstruction with an autologous great saphenous vein graft harvested from the contralateral thigh (Figure 2B-D). CCA repair was completed in approximately 30 min, after which the patient’s hemodynamics stabilized. The total intraoperative blood loss was 1,500 mL, requiring transfusion of 6 units of packed red blood cells (PRBCs) and 950 mL of autologous whole blood.

Postoperatively, non-contrast cranial CT revealed a small ipsilateral frontal lobe infarction (Figure 3A), although the patient remained neurologically intact. Routine Doppler ultrasonography revealed thrombosis at the CCA anastomotic site. A subsequent CTA revealed vascular occlusions measuring 5 cm in the right CCA and 3.5 cm in the right VA (Figure 3B and 3C). Although stent graft placement via digital subtraction angiography (DSA) was attempted, contralateral CCA stenosis precluded this intervention. The patient received dual antiplatelet therapy (aspirin 100 mg/day and clopidogrel 75 mg/day) for 3 months along with a therapeutic dose of enoxaparin (4,000 AXaIU/day).

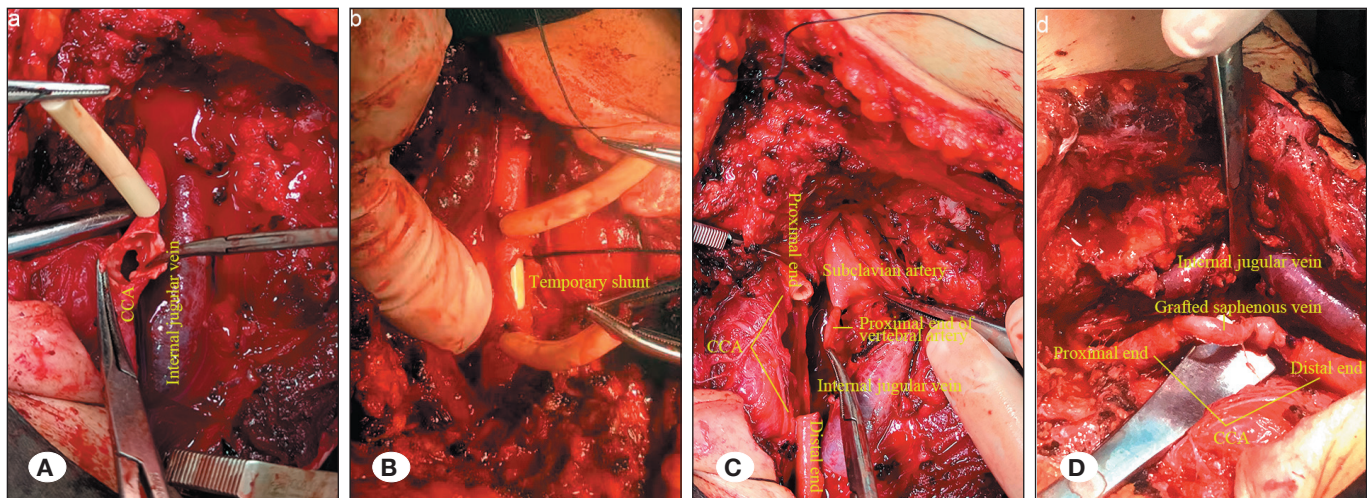
The patient developed a midsternal wound infection that resolved following debridement and negative pressure wound therapy. In addition, the patient experienced hoarseness, and ipsilateral vocal cord paralysis was detected via laryngoscopy. The patient ultimately achieved complete recovery and was discharged without any residual complications.

**Table I:** Biffi Classification for Traumatic Cerebrovascular Injury (2)

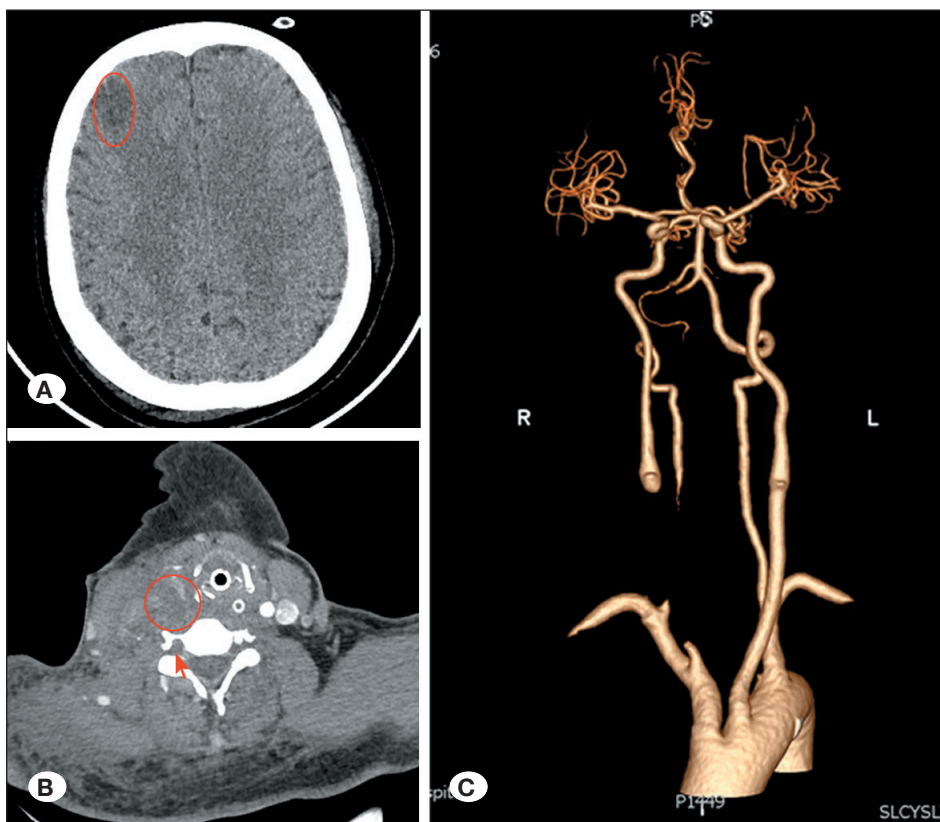
Biffi grade	Description
I	Luminal irregularity or dissection with < 25% luminal narrowing
II	Dissection or intramural hematoma with ≥ 25% luminal narrowing, intraluminal thrombus, or raised intimal flap
III	Pseudoaneurysm
IV	Occlusion
V	Transection with free extravasation



**Figure 1:** Preoperative images of case 1. **A)** The location of penetrating injury in the neck. **B)** Metal rod penetrating the neck. **C)** Preoperative CTA showing injured segments of the right CCA and VA. The blue arrow indicates the injured segment of the right VA and the black arrow indicates the injured segment of the right CCA. **Abbreviations:** CCA: common carotid artery; CTA: computed tomography angiography; VA: vertebral artery.



**Figure 2:** Intraoperative images of case 1. **A)** The laceration site in the right CCA. **B)** Temporary shunting procedure prior to anastomosis. **C)** Trimming the injured right CCA segment. **D)** Anastomosis was performed using a self-great saphenous vein graft from the contralateral thigh. Abbreviations: CCA, common carotid artery.

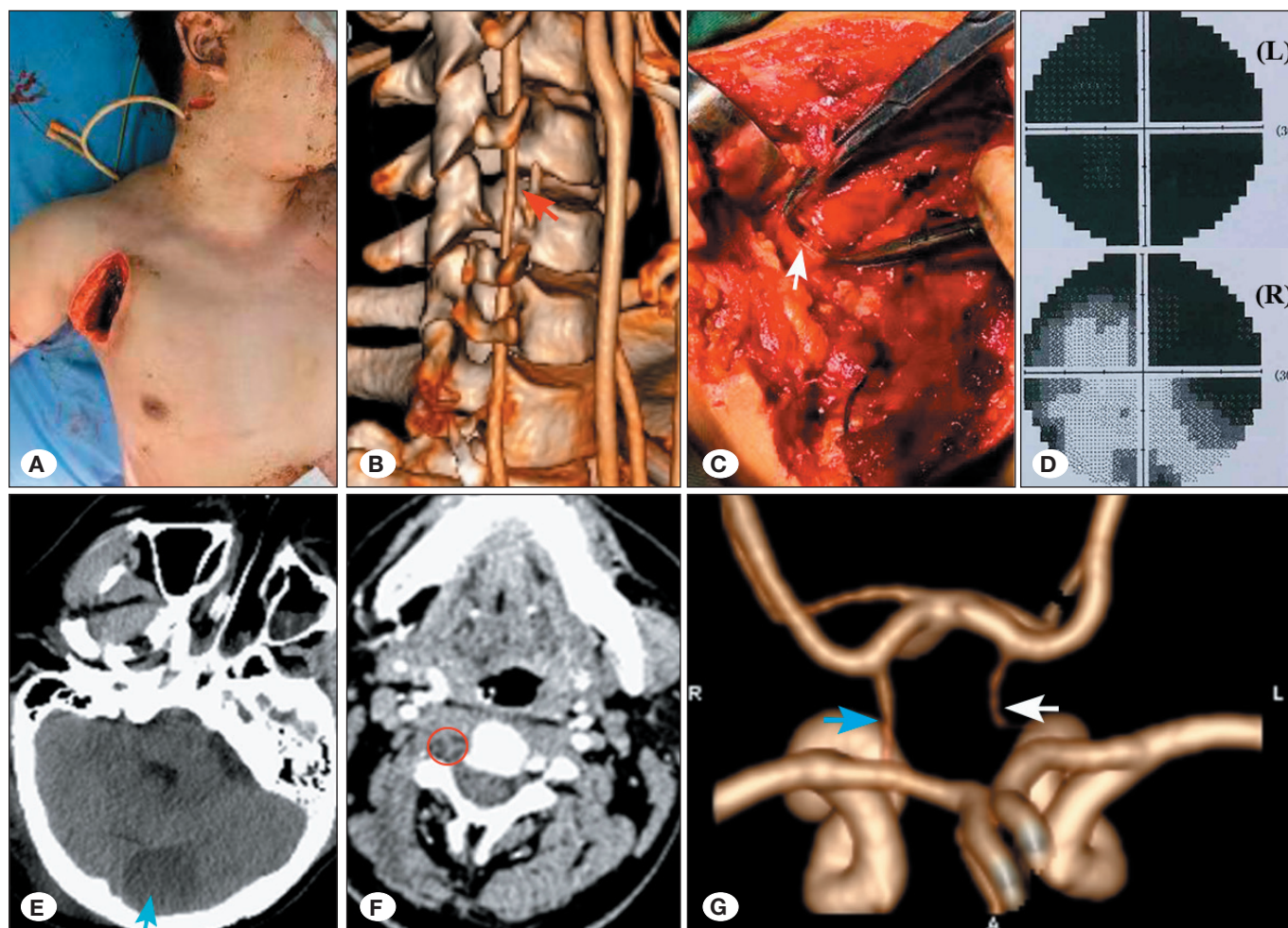


**Figure 3:** Postoperative images of case 1. **A)** Non-contrast cranial CT showing a small ischemic infarction in the ipsilateral frontal cerebral lobe. **B)** Postoperative occlusion of the injured CCA and VA segments. The red circle indicates the occluded right CCA segment. Red arrow indicates an occluded segment of the right VA. **C)** CTA showing the relative occluded lengths of the right CCA and VA. **CCA:** Common carotid artery; **CT:** Computed tomography; **CTA:** computed tomography angiography; **VA:** vertebral artery.

**Case 2**

A 31-year-old male presented to our trauma center approximately 1 h after sustaining multiple stab wounds involving the right lateral neck (zone II), head, right anterior chest, and left elbow. On admission, the patient was conscious but hemodynamically unstable with tachycardia (heart rate, 120 beats per minute), tachypnea (respiratory rate, 24 breaths per min-

ute), and hypotension (blood pressure (BP) 70/50 mmHg). Active hemorrhage from the right neck wound was noted, accompanied by hematemesis. Initial hemorrhage control was achieved using a Foley catheter with balloon tamponade (Figure 4A). Resuscitation included transfusion of 2 units of PRBCs and vasopressor support through a central venous catheter, resulting in hemodynamic improvement (systolic BP > 90 mmHg). Emergency CTA demonstrated luminal narrow-



**Figure 4:** Pre-, intra-, and postoperative images of case 2. **A)** Foley catheter with a balloon tamponade was used to control the hemorrhage. **B)** Preoperative CTA showing injured segments of the right VA (red arrow). **C)** Laceration of proximal esophagus (white arrow). **D)** Grayscale visual field analysis showing complete left eye blindness and right homonymous hemianopsia (upper panel: left eye; lower panel: right eye). **E)** Postoperative non-contrast cranial CT imaging showing an ischemic infarction in the left occipital lobe (blue arrow). **F)** Postoperative occlusion of the injured VA segment (red circles). **G)** CTA showing occlusion of the left PComA (white arrow) and hypoplasia of the right PComA (blue arrow). **CT:** Computed tomography; **CTA:** Computed tomography angiography, **VA:** Vertebral artery; **PComA:** Posterior communicating artery.

ing of the right vertebral artery at the C5 transverse foramen segment, consistent with a vascular injury (Figure 4B). Subsequently, the patient was transported to the operating room for exploratory surgery.

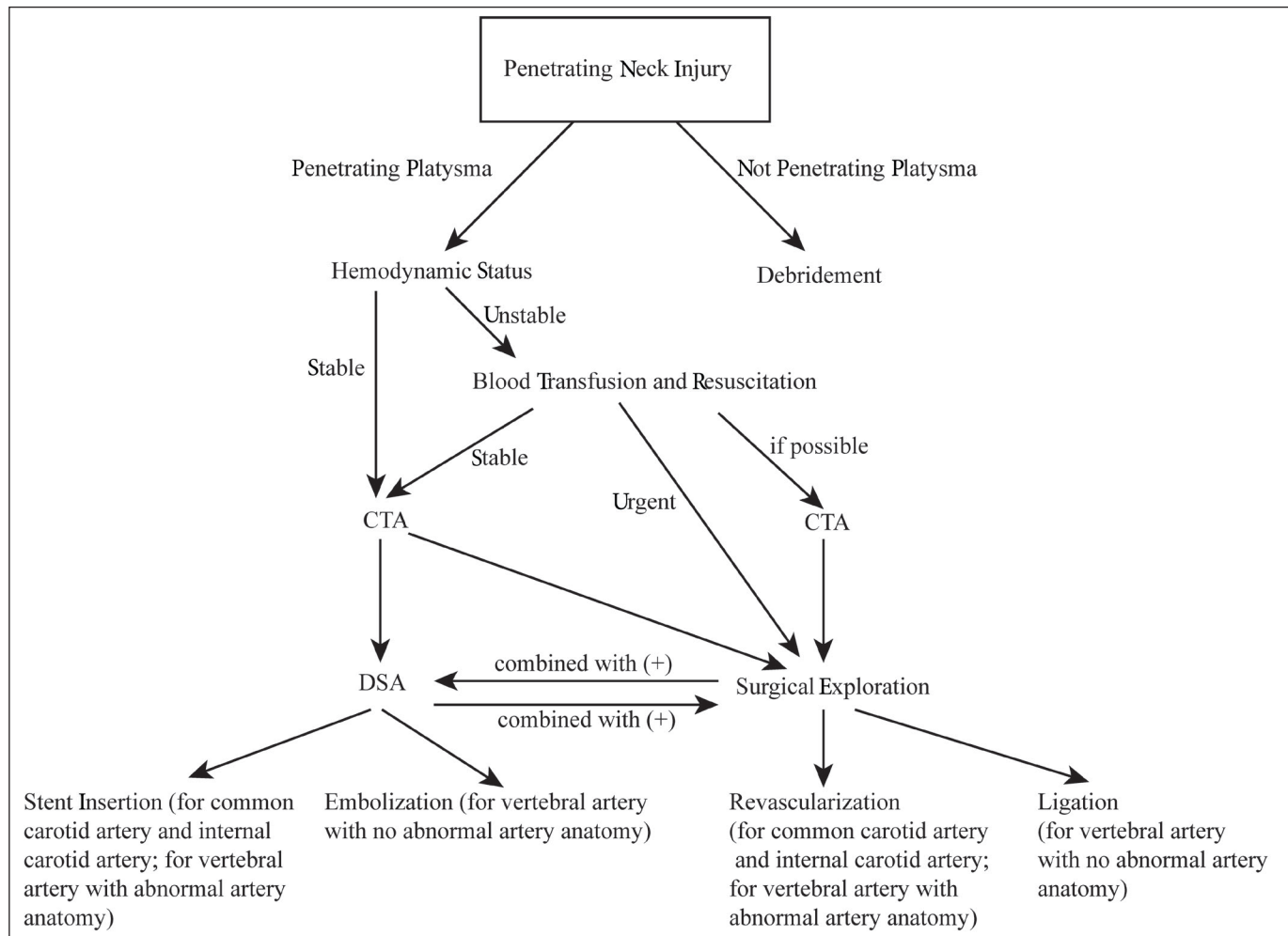
Surgical exploration confirmed complete transection (Biff grade V) of the right VA and the accompanying vein, along with laceration of the proximal esophagus (Figure 4C). The vertebral vessels were surgically ligated and primary esophageal repair was performed by placing a closed suction drain adjacent to the repair site. The procedure resulted in an estimated blood loss of 500 mL, requiring transfusion of 6 units of PRBCs and 350 mL of fresh frozen plasma. The patient received enoxaparin monotherapy (4,000 AXaIU/day) for thromboembolic prophylaxis.

The patient developed almost complete left eye blindness and right homonymous hemianopia postoperatively, with visual

field defects confirmed by standardized ophthalmic perimetry (Figure 4D). Non-contrast cranial CT revealed an acute infarction in the left occipital lobe. Subsequent CTA revealed occlusion of the right VA and left posterior communicating artery (PComA) along with hypoplasia of the right PComA (Figures 4E-G). The patient was discharged with persistent visual field deficit.

## DISCUSSION

PCVI accounts for approximately 25% of penetrating neck injuries, with the carotid artery involved in 80% of cases and the vertebral artery in 43% (13). These injuries carry high risks of hypovolemic shock, ischemic cerebral infarction, and mortality. Reported mortality rates range from 2.6% to 26%, whereas ischemic infarction ranges from 9% to 30% (5,18). Persistent neurological deficits have been reported in up to



**Figure 5:** Treatment algorithm of penetrating neck injury involving cerebrovascular injuries. **CTA:** computed tomography angiography, **DSA:** digital subtraction angiography.

80% of cases (26). Both cases in this study involved severe Biffl grade V cerebrovascular injuries. Previous studies have consistently demonstrated that higher Biffl grades are strongly correlated with an increased incidence of in-hospital stroke (22,26).

The CCA and internal carotid artery serve as the principal conduits for the anterior cerebral circulation. As such, injuries to these arteries are particularly threatening to cerebral perfusion. Current management protocols recommend DSA for hemodynamically stable patients with zone I (between the cricoid cartilage and clavicle) or zone III (above the mandible) injuries, where the anatomical complexity favors endovascular approaches (18). In contrast, hemodynamically unstable patients require immediate surgical exploration regardless of the injury location. Both cases presented here involved zone II injuries (between the mandible and the cricoid cartilage) that necessitated open surgical intervention.

Revascularization of the CCA or internal carotid artery remains the preferred treatment for eligible patients, except in cases of preoperative neurological deficits, in which arterial ligation may be required (7,18). Current evidence suggests that CCA

ligation should be considered only in comatose patients with prograde flow during surgical exploration, as documented in a previous study (12). The available revascularization options include primary repair and interposition grafting when anatomically feasible. Temporary intravascular shunt placement, while serving as a damage-control technique, has been associated with an increased risk of stroke and mortality (5).

The unique hemodynamic characteristics of the circle of Willis predispose patients to cerebral infarction when ipsilateral arterial supply is diminished or absent (19). In the first case, the patient was sedated upon arrival at the emergency department, which prevented immediate neurological assessments. Despite a 10-h delay from injury to treatment, successful interposition grafting was achieved using the contralateral great saphenous vein. Postoperative imaging revealed thrombosis at the anastomotic site with subsequent development of a small, asymptomatic right frontal lobe infarction. The likely pathophysiological mechanisms include: (a) cerebral hypoperfusion secondary to hemorrhagic shock and (b) thromboembolic events originating from the injured right CCA. The preserved blood flow through the contralateral CCA and VA (Figure 3C) likely limited the extent of the cerebral infarction.

Literature typically recommends ligation or embolization for unilateral VA injuries (10,18,21). VA ligation is generally considered to carry minimal risk of cerebral complications, particularly unilateral injuries (10). Notably, bilateral VA injuries require prompt intervention through endovascular techniques or cervical immobilization to maintain adequate posterior circulation perfusion and prevent catastrophic neurological outcomes (9). Hypotension has been found to increase the risk of stroke by 1.32-fold compared to patients without hypotension, particularly in those with internal watershed infarctions (3,22). In case 2, the patient developed a left occipital lobe infarction and bilateral visual field defects after the injury. Left occipital lobe infarction may partially contribute to the bilateral visual field defects. However, near-blindness of the left eye cannot be explained only by left occipital lobe infarction and requires further investigation. The infarction area is always ipsilateral to the injured vertebral artery; however, this was not the case here (1). The infarction likely resulted from multiple contributing mechanisms: (a) cerebral hypoperfusion secondary to hypotensive shock, leading to a critical reduction in effective cerebral blood flow; (b) ligation of the right VA, which significantly diminished posterior circulation; (c) occlusion of the left PComA combined with hypoplasia of the right PComA, further limiting collateral perfusion to the posterior cerebral circulation and exacerbating ischemia in the left occipital lobe; and (d) thromboembolism originating from the site of injury to the right VA. A previous study also revealed that small (<1 mm in diameter) or absent ipsilateral PComAs contribute to the occurrence of ischemic infarction (19). This finding underscores the need for a cautious approach to VA injury management, particularly in cases of hypovolemic shock and vascular anatomical variants.

Preoperative CTA plays a critical role in detecting circles of Willis abnormalities, including stenoses or congenital malformations, which may worsen cerebral ischemia during hypotensive shock or reduced arterial flow. Research has highlighted several aspects of the risks associated with VA injuries. Anatomical predispositions to injury, such as artery placement relative to cervical structures, increase susceptibility to trauma-induced vertebrobasilar insufficiency (15). Even when ligation appears successful, pseudoaneurysms and thromboembolisms have been reported, necessitating long-term monitoring (14). Preoperative CTA is particularly valuable for evaluating potential collateral pathways, including deep cervical arterial networks, which may significantly influence post-ligation ischemic outcomes (20). Studies have also confirmed that unilateral vertebral artery ligation can be performed safely only when preoperative evaluations demonstrate adequate compensatory flow from the contralateral artery (8). Thus, the second patient's severe neurological deficits following VA ligation directly correlated with the preexisting circle of Willis abnormalities. Occlusion of the left PComA in case 2 further contributed to decreased blood flow in the posterior cerebral circulation, particularly on the left side. In contrast, the first patient avoided major complications despite combined carotid and vertebral injuries, probably because of the preserved normal vascular anatomy.

The revascularization of VA injuries typically involves the use of endovascular stents (17). A significant limitation was the lack of suitable-caliber stents (11). Embolization is a viable salvage option when distal stent deployment is not feasible. The complex anatomical course of the VA through the transverse foramina and cervical plexus makes open surgical repair particularly demanding. However, innovative techniques show promise. V3 segment-deep cervical artery anastomosis may effectively restore posterior circulation perfusion (24), whereas bypass grafting from the ipsilateral external carotid artery to the VA at the C1 level has demonstrated clinical efficacy (8).

The two cases in this series collectively demonstrate that revascularization should constitute the primary treatment strategy for both CCA and VA injuries. Methods such as open surgical ligation or embolization may be acceptable under specific circumstances as mentioned above. Based on these findings, we proposed a promising treatment algorithm (Figure 5). A critical component of this approach is comprehensive preoperative vascular imaging (initially with CTA, and DSA if necessary) of the carotid arterial and vertebral arterial systems to identify potentially compromising anatomical variants before ligation of the great vessels. Therefore, DSA may be an option for the diagnosis, treatment, and follow-up of patients with stable disease. Careful consideration should be given to avoid ligation or embolization to minimize the risk of symptomatic cerebral infarction in certain cases. Additionally, the anatomical zone of neck injury should be considered when selecting the appropriate treatment strategy.

## CONCLUSION

Anatomic variation is a critical determinant of outcomes in penetrating cerebrovascular injury. Revascularization is essential to prevent cerebral infarction and permanent neurologic impairment when treating patients with significant cerebrovascular variants.

### Declarations

**Funding:** This work was supported by a grant from Chongqing University Central Hospital (Grant No. SYRCCY20230315).

**Availability of data and materials:** The datasets generated and/or analyzed during the current study are available from the corresponding author by reasonable request.

**Disclosure:** The authors declare no competing interests.

**Informed consent:** We obtained written informed consent from patients for the publication of this case report.

### AUTHORSHIP CONTRIBUTION

Study conception and design: JL, GW

Data collection: JL

Analysis and interpretation of results: JL, GW

Draft manuscript preparation: JL

Critical revision of the article: JL, GW

Other (study supervision, fundings, materials, etc.): JL, GW

All authors (JL, GW) reviewed the results and approved the final version of the manuscript.

## ■ REFERENCES

- AlBayar A, Sullivan PZ, Blue R, Leonard J, Kung DK, Ozturk AK, Chen HI, Schuster JM: Risk of vertebral artery injury and stroke following blunt and penetrating cervical spine trauma: A retrospective review of 729 patients. *World Neurosurg* 130:e672-e679, 2019. <https://doi.org/10.1016/j.wneu.2019.06.187>
- Biffi WL, Moore EE, Offner PJ, Brega KE, Franciose RJ, Burch JM: Blunt carotid arterial injuries: Implications of a new grading scale. *J Trauma* 47:845-853, 1999. <https://doi.org/10.1097/00005373-199911000-00004>
- Bladin CF, Chambers BR: Clinical features, pathogenesis, and computed tomographic characteristics of internal watershed infarction. *Stroke* 24:1925-1932, 1993. <https://doi.org/10.1161/01.STR.24.12.1925>
- Boggs HK, Kiang SC, Tran Z, Mukherjee K, Tomihama RT: Analysis of extracranial cerebrovascular injuries: Clinical predictors of management and outcomes. *Ann Vasc Surg* 100:53-59, 2024. <https://doi.org/10.1016/j.avsg.2023.10.022>
- DiBartolomeo AD, Williams B, Weaver FA, Matsushima K, Martin M, Schellenberg M, Inaba K, Magee GA: Risk factors for stroke in penetrating cerebrovascular injuries. *J Vasc Surg* 80:1064-1070, 2024. <https://doi.org/10.1016/j.jvs.2024.05.061>
- Foreman PM, Griessenauer CJ, Kicielinski KP, Schmalz PGR, Rocque BG, Fusco MR, Sullivan JC, Deveikis JP, Harrigan MR: Reliability assessment of the Biffi Scale for blunt traumatic cerebrovascular injury as detected on computer tomography angiography. *J Neurosurg* 127:32-35, 2017. <https://doi.org/10.3171/2016.7.JNS16849>
- Halpern AL, Burton CR, Steward LT: Ligation of common carotid artery after penetrating neck trauma. *J Trauma Acute Care Surg* 87:505-507, 2019. <https://doi.org/10.1097/TA.0000000000002289>
- Hoshino Y, Kurokawa T, Nakamura K, Seichi A, Mamada T, Saita K, Miyoshi K: A report on the safety of unilateral vertebral artery ligation during cervical spine surgery. *Spine (Phila Pa 1976)* 21:1454-1457, 1996. <https://doi.org/10.1097/00007632-199606150-00011>
- Irawany V, Nasution VAF, Amalia N: Bilateral vertebral artery injury leads to brain death following traumatic brain injury: A case report. *J Med Case Rep* 18:106, 2024. <https://doi.org/10.1186/s13256-024-04432-3>
- Koh DH, Choi HC, Shin HS, Baek HJ, Koh EH, Park MJ, Choi DS: Endovascular treatment of traumatic vascular injuries in the head and neck region. *Medicina (Kaunas)* 60:269, 2024. <https://doi.org/10.3390/medicina60020269>
- Leiderman DBD, Zerati AE, Wolosker N, Hoffmann Melo HA, da Silva ES, De Luccia N: Endovascular treatment of penetrating injury to the vertebral artery by a stab wound: Case report and literature review. *Ann Vasc Surg* 45:267.e261-267.e265, 2017. <https://doi.org/10.1016/j.avsg.2017.06.145>
- Liekweg WG, Greenfield LJ: Management of penetrating carotid arterial injury. *Ann Surg* 188:587-592, 1978. <https://doi.org/10.1097/0000658-197811000-00001>
- Lodhia J, Chugulu S, Wampembe E, Chilonga K, Msuya D: Traumatic left common carotid artery thrombosis with ischemic brain injury: A case report. *Int J Surg Case Rep* 111:108891, 2023. <https://doi.org/10.1016/j.ijscr.2023.108891>
- Meier DE, Brink BE, Fry WJ: Vertebral artery trauma: Acute recognition and treatment. *Arch Surg* 116:236-239, 1981. <https://doi.org/10.1001/archsurg.1981.01380140082021>
- Moskopp ML, Sannwald LW, Burbelko M, Moskopp D: Operative V2 decompression for traumatic vertebrobasilar insufficiency: Illustrative case. *J Neurosurg Case Lessons* 5:CASE2358, 2023. <https://doi.org/10.3171/CASE2358>
- Nagatomo K, Tsutsumi Y, Tsuchiya A, Togo M, Ishigami K, Soma Y, Sato M, Yasuda S: Right proximal common carotid artery injury. *J Trauma Acute Care Surg* 91:e18-e20, 2021. <https://doi.org/10.1097/TA.0000000000003223>
- Piper K, Rabil M, Ciesla D, Agazzi S, Ren Z, Mokin M, Guerrero WR: Penetrating vertebral artery injuries: A literature review and proposed treatment algorithm. *World Neurosurg* 148:e518-e526, 2021. <https://doi.org/10.1016/j.wneu.2021.01.021>
- Roon AJ, Christensen N: Evaluation and treatment of penetrating cervical injuries. *J Trauma* 19:391-397, 1979. <https://doi.org/10.1097/00005373-197906000-00001>
- Schomer DF, Marks MP, Steinberg GK, Johnstone IM, Boothroyd DB, Ross MR, Pelc NJ, Enzmann DR: The anatomy of the posterior communicating artery as a risk factor for ischemic cerebral infarction. *N Engl J Med* 330:1565-1570, 1994. <https://doi.org/10.1056/NEJM199406023302204>
- Son JI, An TY, Ko MJ, Park SW, Lee YS: Occlusion of both vertebral arteries with development of collateral circulation from the deep cervical artery after cervical spine trauma. *Korean J Neurotrauma* 18:374-379, 2022. <https://doi.org/10.13004/kjnt.2022.18.e57>
- Teixeira F, Metidieri Menegozzo CA, do Couto Netto SD, Poggetti RS, de Sales Collet E Silva F, Birolini D, de Oliveira Bernini C, Utiyama EM: Safety in selective surgical exploration in penetrating neck trauma. *World J Emerg Surg* 11:32, 2016. <https://doi.org/10.1186/s13017-016-0091-4>
- Tran A, Fernando SM, Rochweg B, Hawes H, Hameed MS, Dawe P, Garraway N, Evans DC, Kim D, Biffi WL, Inaba K, Engels PT, Vogt K, Kubelik D, Petrosioniak A, Joos E: Prognostic factors associated with risk of stroke following blunt cerebrovascular injury: A systematic review and meta-analysis. *Injury* 55:111319, 2024. <https://doi.org/10.1016/j.injury.2024.111319>
- Tunthanathip T, Phuenpathom N, Saehaeng S, Oearsakul T, Sakarunchai I, Kaewborisutsakul A: Traumatic cerebrovascular injury: Prevalence and risk factors. *Am J Emergency Med* 38:182-186, 2020. <https://doi.org/10.1016/j.ajem.2019.01.055>
- Vetter M, Iwanaga J, Choi PJ, Yilmaz E, Oskouian RJ, Tubbs RS: A novel microsurgical procedure for revascularization of the vertebral artery. *World Neurosurg* 122:e302-e306, 2019. <https://doi.org/10.1016/j.wneu.2018.10.026>
- Wang D, Zhao Y, Cha B, Fang P, Liu Y: Penetrating neck trauma with common carotid artery injury caused by a percussive drill: A case report. *Medicine (Baltimore)* 98:e15750, 2019. <https://doi.org/10.1097/MD.00000000000015750>
- Wathen C, Santangelo G, Muhammad N, Ellens N, Catanzaro S, Singh A, Dagli MM, Petrov D, Ozturk AK, Bender M, Stone JJ, Schuster J: Management and outcomes of cerebrovascular injuries after gunshot wounds to the cervical spine. *Clin Neurol Neurosurg* 243:108376, 2024. <https://doi.org/10.1016/j.clineuro.2024.108376>