INTRODUCTION

Penetrating neck injuries are a surgical challenge because of the anatomical complexity of this region. The neck contains many important communicating structures between the head and torso, including blood vessels, the aerodigestive tract, vertebrae, and the spinal cord in a small area. In particular, penetrating neck injuries associated with carotid artery injuries are known to have a high mortality rate. Overt external hemorrhage is unanimously considered as an indication for surgical exploration. The authors present a case of successful surgical management for a penetrating common carotid artery injury caused by a metal fragment using a Pruitt-F3 Carotid Shunt (LeMaitre Vascular Inc., Burlington, MA, USA) in a 60-year-old male patient.

CASE REPORT

A 60-year-old male patient was transferred to the regional trauma center due to a metal fragment piercing his neck while working. Active pulsatile bleeding was observed from the 3-cm-long external wound on the anterior neck in zone II. Emergency neck exploration showed near-total transection of the left common carotid artery just below the carotid bifurcation. After a Pruitt-F3 Carotid Shunt was applied to the injured carotid artery as a temporary vascular shunt, artificial graft interposition was performed for the injured common carotid artery. The patient experienced cerebral infarction as a complication caused by ischemia-reperfusion of the common carotid artery but was discharged in a suitable state for rehabilitation therapy.

Keywords: Penetrating wounds; Neck injuries; Carotid artery injuries; Cerebral infarction; Case reports
ma center of Gachon University Gil Medical Center due to a metal fragment piercing his neck while working. Active pulsatile bleeding was observed from a 3-cm-long external wound on the anterior neck (zone II). Endotracheal intubation was performed immediately with manual compression using the second finger. The initial vital signs were a blood pressure of 81/59 mmHg, a heart rate of 51 beats/min, a respiratory rate of 26 breaths/min, and a temperature of 35.6°C. The initial SpO$_2$ was 96%. His mental status was semicomatose.

A decision was made to perform emergent neck exploration. A Pruitt-F3 Carotid Shunt was applied immediately to the injured carotid artery as a temporary vascular shunt (Figs. 1, 2). After applying the Pruitt-F3 Carotid Shunt as a temporary vascular shunt, each end of the transected arteries was trimmed. A proximal and distal occlusion balloon (blue and white) were inserted into the CCA and internal carotid artery (ICA), respectively. After applying the Pruitt-F3 Carotid Shunt to the transected common carotid artery, polytetrafluoroethylene graft interposition was performed because the remaining ends were too short for re-anastomosis (Fig. 3). The transected internal jugular vein was ligated. A metal fragment (1.5 × 0.5 × 0.5 cm) was identified and removed from the neck (Fig. 4). Computed tomography (CT) angiography for the brain and neck was performed 1 day after the operation (Fig. 5A). The repaired carotid artery was patent (Fig. 5A). There were no abnormal findings of the brain parenchyma on CT (Fig. 5B). However, an acute infarction with diffusion restriction in the left middle-cerebral artery territory and right frontal lobe was identified on brain diffusion magnetic resonance imaging that was performed at 3 days postoperatively (Fig. 6). Aspirin and mannitol were administered for the cerebral infarction thereafter. The patient was transferred to the Department of Neurology for management of the cerebral infarction. The Korean National Institute of Health Stroke Scale (NIHSS) score was 23 points at this time. He was discharged to another hospital for rehabilitation on the 15th postoperative day, with an improved NIHSS score (13 points).

**DISCUSSION**

The treatment of penetrating neck injuries has changed from...
mandatory neck exploration to selective nonoperative management [3–5] due to advances in diagnostic modalities. This approach prevents unnecessary complications accompanying mandatory neck exploration [3–5]. Emergent neck exploration is indicated if there are overt symptoms or signs, including airway compromise, massive subcutaneous emphysema, active bleeding, shock, stroke, and expanding hematoma [3–5]. This patient experienced massive external bleeding with shock, which was an indication for emergent surgery.

A penetrating injury to zone II can cause a major vascular injury in up to 50% of cases [6]. Injury of the ICA or CCA is associated with high rates of mortality and central neurologic deficits [1,7].

Previous reports described poorer outcomes for the ligation of ICA or CCA injuries than for the repair of ICA or CCA injuries [3,8–14]. Patients who underwent ligation had higher rates of mortality (22% vs.10%) and stroke (88.9% vs. 33.3%) than those who underwent repair [3]. Therefore, if possible, repair of the injured carotid artery is recommended rather than ligation [3].

More than 30 studies have analyzed the use of a temporary vascular shunt during the operation [3,15]. Nonetheless, there is still no definite indication for using a temporary vascular shunt during surgery, because most of the studies were small case series.
The largest retrospective study was published by Asensio et al. [3] in 2020. Their study was conducted using 32 articles performed between 1960 and 2018 [3]. The researchers found 973 patients with penetrating ICA and CCA injuries, of whom 136 (14%) underwent ligation and were excluded from the analysis [3]. Of the remaining 837 patients, 126 (15.1%) were treated with shunts (WS) and 711 (84.9%) without shunts (WOS) [3]. They concluded that patients with penetrating ICA and CCA injuries repaired with temporary shunts had a slightly lower mortality rate (WS, 5.6% vs. WOS, 11.1%; P = 0.058) and similar or unchanged neurological outcomes versus those repaired without shunts (neurological improvement rate: WS, 14.2% vs. WOS, 13.7%; P = 0.8; neurological worsening rate: WS, 3.4% vs. WOS, 9.0%; P = 0.038) [3]. Summarizing the above results, a temporary intraoperative shunt is recommended for patients requiring complex vascular anastomosis. A temporary shunt should be applied according to the situation. For a tiny injury that can be repaired simply and primarily, primary repair without a shunt is considered first. However, according to our experiences, most carotid artery injuries are accompanied by atheromatous changes of the arteries and severe dissection of the intima. We think that the high pressure of the CCA coming directly from the aorta may inflict additional damage. We usually perform segmental resection and anastomosis in a short segmental injury with clean endothelium, but this patient had a long segmental injury and dirty atheromatous endothelium. We resected extensively to see a clean and healthy endothelium and interposed the graft. Therefore, surgeons should always consider using a shunt if a procedure becomes complicated.

The Pruitt-F3 Carotid Shunt is commonly used for carotid endarterectomy. There is no consensus on which shunt is best. There are two occlusion balloons in the Pruitt-F3 Carotid Shunt, which prevent additional vascular injury with no need for a vascular clamp. Identification of backflow is possible due to the presence of the middle channel in the Pruitt-F3 Carotid Shunt. We think that this shunt is usable for most peripheral artery injuries, including those affecting the carotid and femoral arteries.

The latest and largest study supports using a temporary shunt [3]; therefore, we decided to use a temporary vascular shunt during the operation. However, in our case, the patient did not avoid cerebral infarction as a complication of carotid injury, which may have been due to the ischemic time.

In conclusion, emergent surgery is mandatory for cases of a penetrating neck injury with overt signs. Repair of the injured CCA should be considered first if it is possible. The use of a temporary vascular shunt during the operation is recommended for penetrating carotid artery injuries, depending on the intraoperative circumstances.

NOTES

Ethical statements
This study was approved by the Institutional Review Board of the Gachon University Gil Medical Center, Gachon University College of Medicine, Incheon, Korea (No. GDIRB 2022-142). Informed consent for publication of the research details and clinical images was obtained from the patient.

Conflicts of interest
Min A Lee is the Associate Editor and Kang Kook Choi and Jayun Cho are Editorial Board members of Journal of Trauma and Injury, but were not involved in the peer reviewer selection, evaluation, or decision process of this article. The authors have no other conflicts of interest to declare.

Funding
None.

Author contributions
Conceptualization: MAL, KKC, JC, YBJ; Visualization: SME, KKC, MAL; Investigation: SME, KKC, MAL; Resources: all authors; Supervision: YBJ; Writing–original draft: KKC, JC, YBJ; Writing–review & editing: JC, YBJ, SME.

All authors read and approved the final manuscript.

REFERENCES

1. Burgess CA, Dale OT, Almeyda R, Corbridge RJ. An evidence based review of the assessment and management of penetrating neck trauma. Clin Otolaryngol 2012;37:44–52.
2. DeBakey ME, Simeone FA. Battle injuries of the arteries in World War II: an analysis of 2,471 cases. Ann Surg 1946;123:534–79.
3. Asensio JA, Kessler JJ 2nd, Kotaru TR, Kalamchi LD, Miljkovic SS, Dabestani PJ. Penetrating internal and common carotid artery injuries shunts versus no shunts during repair effect on neurological outcomes. Injury 2021;52:266–73.
4. Prichayudh S, Choadrachata-anun J, Sruissadaporn S, et al. Selective management of penetrating neck injuries using “no zone” approach. Injury 2015;46:1720–5.
5. Teixeira F, Menegozzo CA, Netto SD, et al. Safety in selective

[3. The largest retrospective study was published by Asensio et al. [3] in 2020. Their study was conducted using 32 articles performed between 1960 and 2018 [3]. The researchers found 973 patients with penetrating ICA and CCA injuries, of whom 136 (14%) underwent ligation and were excluded from the analysis [3]. Of the remaining 837 patients, 126 (15.1%) were treated with shunts (WS) and 711 (84.9%) without shunts (WOS) [3]. They concluded that patients with penetrating ICA and CCA injuries repaired with temporary shunts had a slightly lower mortality rate (WS, 5.6% vs. WOS, 11.1%; P = 0.058) and similar or unchanged neurological outcomes versus those repaired without shunts (neurological improvement rate: WS, 14.2% vs. WOS, 13.7%; P = 0.8; neurological worsening rate: WS, 3.4% vs. WOS, 9.0%; P = 0.038) [3]. Summarizing the above results, a temporary intraoperative shunt is recommended for patients requiring complex vascular anastomosis. A temporary shunt should be applied according to the situation. For a tiny injury that can be repaired simply and primarily, primary repair without a shunt is considered first. However, according to our experiences, most carotid artery injuries are accompanied by atheromatous changes of the arteries and severe dissection of the intima. We think that the high pressure of the CCA coming directly from the aorta may inflict additional damage. We usually perform segmental resection and anastomosis in a short segmental injury with clean endothelium, but this patient had a long segmental injury and dirty atheromatous endothelium. We resected extensively to see a clean and healthy endothelium and interposed the graft. Therefore, surgeons should always consider using a shunt if a procedure becomes complicated.

The Pruitt-F3 Carotid Shunt is commonly used for carotid endarterectomy. There is no consensus on which shunt is best. There are two occlusion balloons in the Pruitt-F3 Carotid Shunt, which prevent additional vascular injury with no need for a vascular clamp. Identification of backflow is possible due to the presence of the middle channel in the Pruitt-F3 Carotid Shunt. We think that this shunt is usable for most peripheral artery injuries, including those affecting the carotid and femoral arteries.

The latest and largest study supports using a temporary shunt [3]; therefore, we decided to use a temporary vascular shunt during the operation. However, in our case, the patient did not avoid cerebral infarction as a complication of carotid injury, which may have been due to the ischemic time.

In conclusion, emergent surgery is mandatory for cases of a penetrating neck injury with overt signs. Repair of the injured CCA should be considered first if it is possible. The use of a temporary vascular shunt during the operation is recommended for penetrating carotid artery injuries, depending on the intraoperative circumstances.

NOTES

Ethical statements
This study was approved by the Institutional Review Board of the Gachon University Gil Medical Center, Gachon University College of Medicine, Incheon, Korea (No. GDIRB 2022-142). Informed consent for publication of the research details and clinical images was obtained from the patient.

Conflicts of interest
Min A Lee is the Associate Editor and Kang Kook Choi and Jayun Cho are Editorial Board members of Journal of Trauma and Injury, but were not involved in the peer reviewer selection, evaluation, or decision process of this article. The authors have no other conflicts of interest to declare.

Funding
None.

Author contributions
Conceptualization: MAL, KKC, JC, YBJ; Visualization: SME, KKC, MAL; Investigation: SME, KKC, MAL; Resources: all authors; Supervision: YBJ; Writing–original draft: KKC, JC, YBJ; Writing–review & editing: JC, YBJ, SME.

All authors read and approved the final manuscript.

REFERENCES

1. Burgess CA, Dale OT, Almeyda R, Corbridge RJ. An evidence based review of the assessment and management of penetrating neck trauma. Clin Otolaryngol 2012;37:44–52.
2. DeBakey ME, Simeone FA. Battle injuries of the arteries in World War II: an analysis of 2,471 cases. Ann Surg 1946;123:534–79.
3. Asensio JA, Kessler JJ 2nd, Kotaru TR, Kalamchi LD, Miljkovic SS, Dabestani PJ. Penetrating internal and common carotid artery injuries shunts versus no shunts during repair effect on neurological outcomes. Injury 2021;52:266–73.
4. Prichayudh S, Choadrachata-anun J, Sruissadaporn S, et al. Selective management of penetrating neck injuries using “no zone” approach. Injury 2015;46:1720–5.
5. Teixeira F, Menegozzo CA, Netto SD, et al. Safety in selective
surgical exploration in penetrating neck trauma. World J Emerg Surg 2016;11:32.
6. Bladergroen M, Brockman R, Luna G, Kohler T, Johansen K. A twelve-year survey of cervicothoracic vascular injuries. Am J Surg 1989;157:483–6.
7. Fox CJ, Gillespie DL, Weber MA, et al. Delayed evaluation of combat-related penetrating neck trauma. J Vasc Surg 2006;44:86–93.
8. du Toit DF, van Schalkwyk GD, Wadee SA, Warren BL. Neurologic outcome after penetrating extracranial arterial trauma. J Vasc Surg 2003;38:257–62.
9. Fabian TC, George SM Jr, Mangiante EC, Voeller GR, Kudsk KA. Carotid artery trauma: management based on mechanism of injury. J Trauma 1990;30:953–61.
10. Feliciano DV. Management of penetrating injuries to carotid artery. World J Surg 2001;25:1028–35.
11. Lawrence KB, Shefts LM, McDaniel JR. Wounds of common carotid arteries; report of 17 cases from World War II. Am J Surg 1948;76:29–37.
12. Ledgerwood AM, Mullins RJ, Lucas CE. Primary repair vs ligation for carotid artery injuries. Arch Surg 1980;115:488–93.
13. Liekweg WG Jr, Greenfield LJ. Management of penetrating carotid arterial injury. Ann Surg 1978;188:587–92.
14. Reva VA, Pronchenko AA, Samokhvalov IM. Operative management of penetrating carotid artery injuries. Eur J Vasc Endovasc Surg 2011;42:16–20.
15. Lee TS, Ducic Y, Gordin E, Stroman D. Management of carotid artery trauma. Craniomaxillofac Trauma Reconstr 2014;7:175–89.