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REVIEWS

Damage control in penetrating carotid artery trauma: changing a 100-year paradigm

Control de daños en el trauma penetrante de la arteria carótida: cambiando un paradigma de 100 años

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Neck injuries, vascular system injuries, carotid artery injuries, advanced trauma life support care, endovascular procedures, stents, carotid artery, angioplasty

Abstract

Carotid artery trauma carries a high risk of neurological sequelae and death. Surgical management of these injuries has been controversial because it entails deciding between repair or ligation of the vessel, for which there is still no true consensus either way. This article proposes a new management strategy for carotid artery injuries based on the principles of damage control surgery which include endovascular and/or traditional open repair techniques. The decision to operate immediately or to perform further imaging studies will depend on the patient's hemodynamic status. If the patient presents with massive bleeding, an expanding neck hematoma or refractory hypovolemic shock, urgent surgical intervention is indicated. An altered mental status upon arrival is a potentially poor prognosis marker and should be taken into account in the therapeutic decision-making. We describe a step-by-step algorithmic approach to these injuries, including open and endovascular techniques. In addition, conservative non-operative management has also been included as a potentially viable strategy in selected patients, which avoids unnecessary surgery in many cases.

Palabras clave:

Lesiones de cuello, lesiones del sistema vascular, lesiones de la arteria carótida, arteria carótida, atención de soporte vital avanzado para traumatismos, procedimientos endovasculares, stents, angioplastia.

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Conflicts of interest:

The authors declare that they have no conflict of interest.

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Resumen

El trauma de la arteria carótida tiene una alta probabilidad de muerte y de secuelas neurológicas. El manejo quirúrgico es objeto de controversia porque se tiene que decidir entre reparar la arteria carótida o ligarla, para lo cual aún no existe un consenso. El objetivo de este artículo es proponer una nueva estrategia de manejo para el trauma de la arteria carótida con los principios de la cirugía de control de daños y el uso de técnicas como el reparo endovascular o el manejo conservador. La decisión de operar al paciente inmediatamente o realizar estudios imagenológicos dependerá del estado hemodinámico del paciente. Si el paciente presenta sangrado masivo, hematoma expansivo o choque hipovolémico refractario, una intervención quirúrgica urgente está indicada. Un déficit del estado neurológico al ingreso es un marcador de mal pronóstico en estos casos e influye en la toma de decisiones. Se describe el paso a paso del reparo vascular abierto y se incluye las estrategias de manejo tanto endovasculares como abiertas. Adicionalmente, el manejo conservador también ha sido incluido como una estrategia viable en pacientes seleccionados, evitando cirugías innecesarias.

Remark

1) Why was this study conducted?

The aim of this article is to propose a new management strategy for carotid artery injuries based on the principles of damage control surgery which include endovascular and/or traditional open repair techniques.

2) What were the most relevant results of the study?

If the patient presents with massive bleeding, an expanding neck hematoma or refractory hypovolemic shock, then urgent surgical intervention is indicated. An altered mental status upon arrival is a potential poor prognosis marker and should be considered in the therapeutic decision making. We describe a step by step algorithmic approach to these injuries which include both open and endovascular techniques. In addition, conservative non-operative management has also been included as a potential viable strategy in selected patients, which in turn avoids unnecessary surgery in many cases.

3) What do these results contribute?

Open surgical exploration has been the prevailing paradigm in the management of penetrating carotid trauma. However, endovascular management can be applied in selected patients also following damage control principles and performing less invasive interventions to repair and/or control vascular injuries.

Introduction

Carotid artery trauma carries a high risk of neurological sequelae and death ¹. Carotid artery injuries occur in approximately 3-11% of cases of penetrating neck trauma ^{1,2}. Carotid vascular trauma varies in the spectrum from life-threatening to subtle injuries, but all can generate neurological sequelae ³. Therefore, the surgeon must decide expeditiously on the appropriate management strategy to optimize the outcome, especially in hemodynamically unstable patients ^{4,5}. The traditional surgical strategies for severe carotid injuries have been limited to primary open vascular repair or ligation of the vessel ^{6,8}. However, new imaging and endovascular technologies have provided opportunities for earlier diagnosis and alternative treatment modalities ^{7,9}. This article proposes a new management algorithm for penetrating carotid artery trauma based on the principles of damage control surgery, including non-operative, endovascular, and traditional open repair techniques.

This article is a consensus that synthesizes the experience earned during the past 30 years in trauma management, general surgery and critical care acquired by the Trauma and Emergency Surgery (CTE) group from Cali, Colombia which is made up of experts from the Hospital Universitario del Valle “Evaristo García”, the Hospital Universitario Fundación Valle del Lili, the Universidad del Valle and Universidad Icesi, and the collaboration of national and international specialists from the Asociación Colombiana de Cirugía and the Pan-American Trauma Society.

Epidemiology

The overall prevalence of carotid injuries is between 6 to 11% ^{1,2}. The most commonly involved anatomical segments are the common carotid and the internal carotid arteries. Previously published case series have reported that approximately half the patients with these injuries are managed non-operatively ⁸. Of the patients that underwent open surgical management, only 20% required vessel ligation due to massive hemorrhage ^{1,6,10-13}. However, endovascular management has evolved, especially during this last decade. A recent analysis of the National Trauma Data Bank reported that 12% of patients undergoing surgical management of carotid artery injuries were treated via endovascular techniques with no significant difference in mortality and/or complications compared to the traditional open surgical approach ¹⁴.

Initial Approach

Initial efforts should be directed towards bleeding control and physiologic stabilization of the patient according to the Advanced Trauma Life Support (ATLS) guidelines and damage control surgery principles ^{15,16}. The decision to operate immediately or to perform imaging studies will depend on the patient’s hemodynamic status upon admission. If the patient presents with massive bleeding, expansive hematoma or hypovolemic shock that persists after resuscitation with blood products, urgent surgical intervention is required. On the other hand, the patient with normal vital signs, a stable hematoma, or hemodynamic instability that responds to resuscitation should be evaluated through complementary studies. An impaired neurological status upon admission is a marker for poor prognosis and should influence intra-operative decision-making ¹⁴ (Table 1).

Table 1. Neurologic Criteria of Poor Prognosis in Penetrating Carotid Trauma.

Neurologic Criteria of Poor Prognosis in Penetrating Carotid Trauma

- Window time > 6 hours
- Coma Status
- Hemiplegia
- Risk of cerebral reperfusion edema
- High risk of hemorrhagic transformation

Table 2. AAST Classification of Cervical Vascular Trauma ¹⁶.

Grade	Description
I	Thyroid vein Common Facial Vein External Jugular Vein Unnominated arterial/venous branches
II	Arterial branches of the external carotid (ascending pharyngeal artery, upper thyroid, lingual, maxillary, facial, occipital, posterior auricular) Thyrocervical trunk or primary branches Internal Jugular Vein External Carotid Artery
III	Subclavian Vein Vertebral Artery Common Carotid Artery
IV	Subclavian Artery
V	Internal Carotid Artery (extracranial portion)

*Increase one grade for multiple grade III or IV injuries involving more than 50% vessel circumference. Decrease one grade for less than 25% vessel circumference disruption for grade IV or V.

Table 3. Denver Grading Scale for Blunt Carotid and Vertebral Artery Injury ¹⁷

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

Penetrating carotid trauma does not have an independent grading system, but it is included in the American Association for the Surgery of Trauma (AAST) classification for cervical vascular trauma (Table 2) ¹⁷. It has been customary to use the blunt trauma classification of these injuries in cases of penetrating trauma. However, our experience is that these two mechanisms of injuries are widely different in their pathophysiology and their management ¹⁸ (Table 3) .

Treatment

The management of carotid artery injuries has evolved over the years. Ligation used to be the only surgical option and today, the carotid artery is repaired with a variety of open and/or endovascular techniques. Open surgical options include temporary vascular shunts, primary repair, patch angioplasty, external carotid artery transposition and ligation. Endovascular surgical options include the placement of covered stents and/or occlusion of injured vessels ¹⁹.

Endovascular Management

Endovascular management has risen during the last two decades, especially using hybrid therapies for post-traumatic pseudoaneurysms and carotid artery dissections ^{14,20,21}. We recently published a case series of 20 patients with penetrating carotid injuries managed from January 2018 until December 2019 ²². Gunshot wounds was the most common mechanism of injury. Open surgical management was performed in 3 patients, endovascular management in 9 (7 required covered stent and two required embolization) and non-operative management in 8. Four patients died (2 from stroke) and 11 were discharged home without neurologic sequelae ²² (Tables 4 and 5).

We were able to determine potential candidates for endovascular management as those who were hemodynamically stable or transient responders to initial damage control resuscitation upon arrival and in whom temporary bleeding was achieved in the Emergency Room (ER). Also, a quick neurological exam should be performed in the ER as an indirect baseline assessment of the patency of the patient's Circle of Willis. If this type of examination is not achievable, then a computed tomographic angiography (CTA) of the neck and brain is recommended.

CTA should be used as the basis for classifying the extent of the injury, which includes partial

or complete loss of vascular continuity, pseudoaneurysm and/or intimal flap, rather than using the traditional AAST blunt trauma grading system. If vessel occlusion with a patent Circle of Willis is identified, then conservative non-operative management is recommended along with antiplatelet/anticoagulant therapy to reduce the risk of cerebral embolism and subsequent stroke. If patency is not detected, then endovascular stent placement should be considered to restore vascular perfusion. Pseudoaneurysms of less than 5 mm should be managed non-operatively, while those greater than 5mm will require repair. Formal angiography is recom-

Table 4. Clinical Characteristics

	Carotid Artery Injury (n = 20)
Gender	
Male	18
Age, years, median (IQR)	34(25-42)
Type of Trauma	
Penetrating	18
Stabbing wounds	2/18
Gunshot wounds	16/18
Blunt, n (%)	2
Status on Admission	
HR, median (IQR)	97(70-117)
GCS, median (IQR)	14(9-15)
SBP, median (IQR)	117 (80-125)
Shock Index, median (IQR)	0.9(0.5-1.5)
Paresis	8
Active bleeding	13
Expansive hematoma	8
Stable hematoma	11
Transfusion	10
Traumatic Brain Injury	19
Surgical Approach	
Raffia	1
Saphenous Graft	1
Ligature	1
No	17
Arteriography	
Diagnostic	6
Therapeutic	9
No	5
Endovascular Management	
Diagnostic	6
Embolisation	2
Stent	7
No	5
Carotid Portion	
Common	5
External	2
Internal	13
Type of Injury	
Dissection < 30%	2
Dissection > 30%	1
Pseudoaneurysm	7
Rupture	3
Amputation	7
Conservative Management	8
Antiaggregation / Anticoagulation Therapy	
No	5
Antiaggregation	7
Anticoagulation	1
Combined	7
Neurological Impairment at Discharge	
None	11
Minor	4
Major	5
Clinical Outcomes	
Hospital stay, days, median (IQR)	5(5-14)
Mortality	4

Table 5. Non-Operative Management (n= 7)

Sex	Age (years)	Admission BP (mm Hg)	Admission GCS	Arteriography	Anatomical Portion of the Carotid Artery	Type of Injury	Other Injuries	Neurological Deficit	Hospital Stay (days)	Death
F	25	140	14	Yes	External	Amputation	Facial	No	3	No
M	43	120	14	Yes	Internal	Dissection < 30	Mandibular	No	10	No
M	51	70	8	Yes	External	Amputation	Vertebral	Major	28	No
M	59	80	7	No	Internal	Amputation	Severe TBI	Major	4	Yes
F	39	135	8	Yes	Internal	Amputation	Petrous Fracture	No	15	No
M	53	157	11	No	Common	Amputation	Facial	Major	5	Yes
M	22	126	15	Yes	Internal	Dissection < 30	Facial	Minor	17	No

BP: Blood Pressure. GCS: Glasgow Coma Scale. TBI: Traumatic Brain Injury.

mended when doubt persists on the extent and type of injury after a CTA and in those patients with persistent subclinical cervical or cerebral bleeding. Patients with intramural thrombus, intimal flap defects and/or vessel dissections with intact distal blood flow are candidates for non-operative management with or without antiplatelet/ anticoagulant therapy depending on each individuals' comorbidities and risk assessment.

Major vessel lacerations without complete disruption or pseudoaneurysms larger than 5 mm are candidates for endovascular stent management. In cases in which the vessel is completely thrombosed or a larger injury with an inherently high risk of re-bleeding that is not amenable to stent placement, the contralateral blood flow should be evaluated along with the possibility of reinforcing the occlusion with endovascular coil embolization. All of these patients will require close neurologic monitoring in the intensive care unit (ICU) postoperatively.

Non-operative management

Non-operative management is the therapy of choice in well-selected cases. The aim is to avoid unnecessary morbidity. Indications include: patients with signs of cerebral ischemia but are not candidates for endovascular therapy, vessel occlusion with a patent Circle of Willis, those with pseudoaneurysms less than 5 mm and those who present with a significant neurological deficit and an inherent poor prognosis^{23,24}.

Operative management

The following is a step-by-step management algorithm for hemodynamically unstable patients with hard signs of carotid artery injury:

STEP 1: Control of immediate surgical hemorrhage should be initiated in the Emergency Room (ER) via direct compression. The patient is typed and crossed and the institutions massive transfusion protocol (MTP) is activated. The patient is then transferred to the operating room (OR)^{25,26}. The initial surgical approach is via a right or left neck incision according to the injury site. Considering that an expanding hematoma may obscure the anatomical reference of the anterior edge of the sternocleidomastoid muscle, we recommend an imaginary line between the earlobe crease and the sternal notch as a guide for the initial incision.

STEP 2: Proximal and distal control of the injured vessel is of upmost importance:

Carotid Common Artery: If the injury to the vessel is at its origin, then an extension of the incision towards a median sternotomy may be required to achieve proximal control.

External Carotid Artery: Proximal control may require dissection of the bifurcation of the common carotid artery.

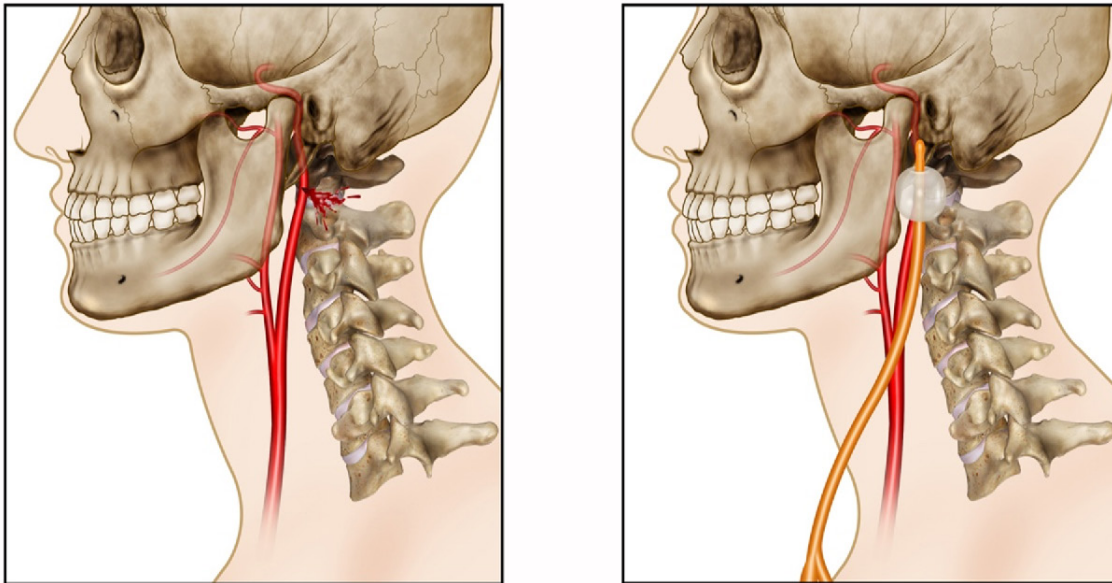


Figure 1. Temporary Hemorrhage Control of the Internal Carotid Artery. A. Distal internal carotid artery injury. B. Maneuver to stop distal internal carotid artery bleeding by placing a Foley catheter into the track of the wound.

Internal Carotid Artery: Only its extra-cranial portion is amenable to surgical repair. Proximal control can be achieved at the level of the common carotid artery or the proximal internal carotid artery. If distal control is technically difficult via your initial incision, then an anterior mandibular dislocation may be necessary to obtain better exposure of the distal vessel. This maneuver can expose approximately 2 cm more of the distal vessel in most patients. In cases where distal vascular control is still not obtainable, we recommend placing a Foley catheter into the wound and inflating the balloon until hemorrhage control is achieved (Figure 1). Another alternative is placing a Fogarty catheter into the injured vessel and achieving distal control by advancing the catheter beyond the injury site and inflating the balloon^{19,27}.

STEP 3: Once hemorrhage control has been achieved, the surgeon must determine the appropriate surgical repair approach of the injury. Suppose the patient has an overall poor prognosis upon arrival (Table 1), absence of distal reflux bleeding from the injured vessel (Figure 2), and/or an external carotid artery injury associated with hemodynamic instability. In that case, we recommend ligating the vessel as a definitive surgical therapy (Figure 3). Otherwise, we recommend primary repair of the vessel. Common and internal carotid arteries injuries should be repaired using a synthetic [Goretex or PTFE (polytetrafluoroethylene)] interposition graft, rather than an autologous reverse saphenous vein graft which requires a separate incision, prolonged surgical time and is not conducive to damage control management principles (Figure 4).

STEP 4: For distal internal carotid injuries, where hemorrhage control requires Foley or Fogarty catheter balloon placement (Figure 1), we recommend the immediate transfer of the patient to a hybrid or angiography suite for endovascular stent placement (Figure 5).

STEP 5: Surgical field hemostasis should be carefully verified and in cases of ongoing non-surgical bleeding due to coagulopathy persists, then the wound should be packed, and a negative pressure dressing placed. The patient should then be transferred to the Intensive Care Unit (ICU) to continue with rewarming, correction of coagulopathy and damage control resuscitation²⁸. Close neurologic monitoring should be performed in the ICU and a 24 hour follow-up CTA of the head and neck should be done to evaluate arterial blood flow and secondary tissue injury.

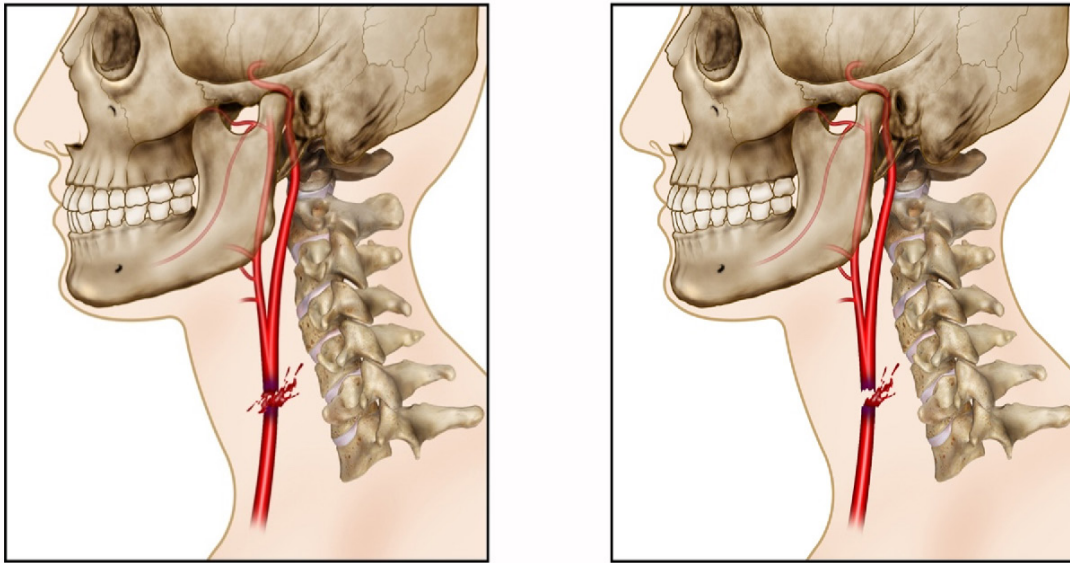


Figure 2. Common Carotid Artery Injury. A. Proximal and distal flow present. B. Proximal flow but no reflux flow from the distal end.

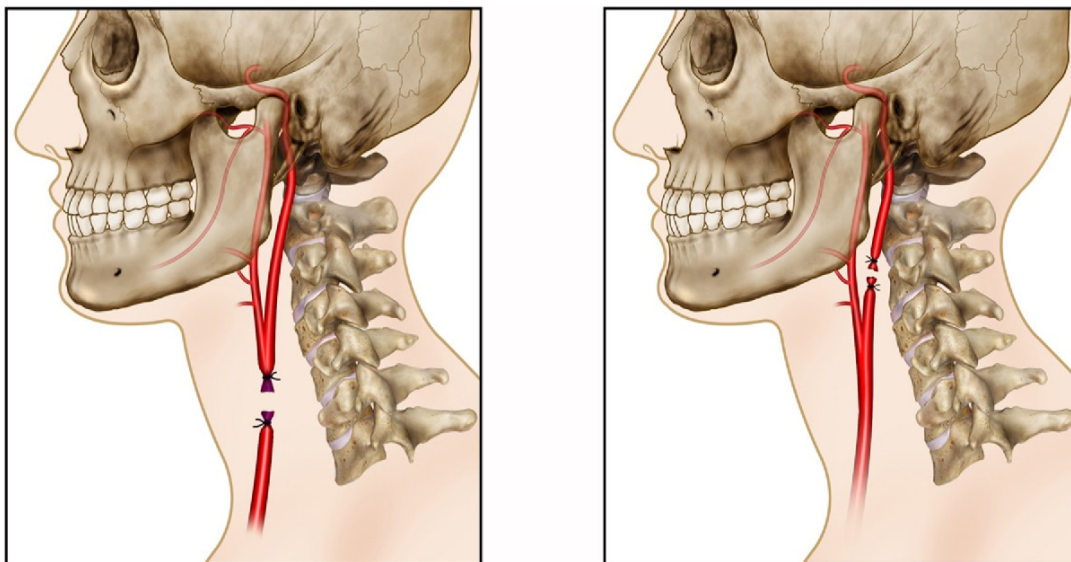


Figure 3. Carotid Artery Ligation. A. Common carotid artery ligation. B. Internal carotid artery ligation.

Discussion

Studies have shown that protocol-driven management of penetrating neck trauma avoids unnecessary surgical interventions^{2,29}. Primary repair, vein patches, Goretex/PTFE or reverse saphenous vein grafts, and even external carotid artery transposition are the most common surgical therapies for managing carotid artery injuries²⁴. However, in our series, endovascular management was the most frequently used therapy for penetrating carotid trauma with similar outcomes to those reported who applied open surgical repair²². Herrera et al. described the angiographic features of 36 traumatic injuries of the carotid artery during 12 years and found that the injury resulted in a pseudoaneurysm in 24 (66.7%) of instances and an arteriovenous fistula in 7 (19.4%) which correlate with the findings in our series²¹. During the surgical procedure, the priority is to restore cerebral blood flow. However, in the absence of distal arterial injury reflux

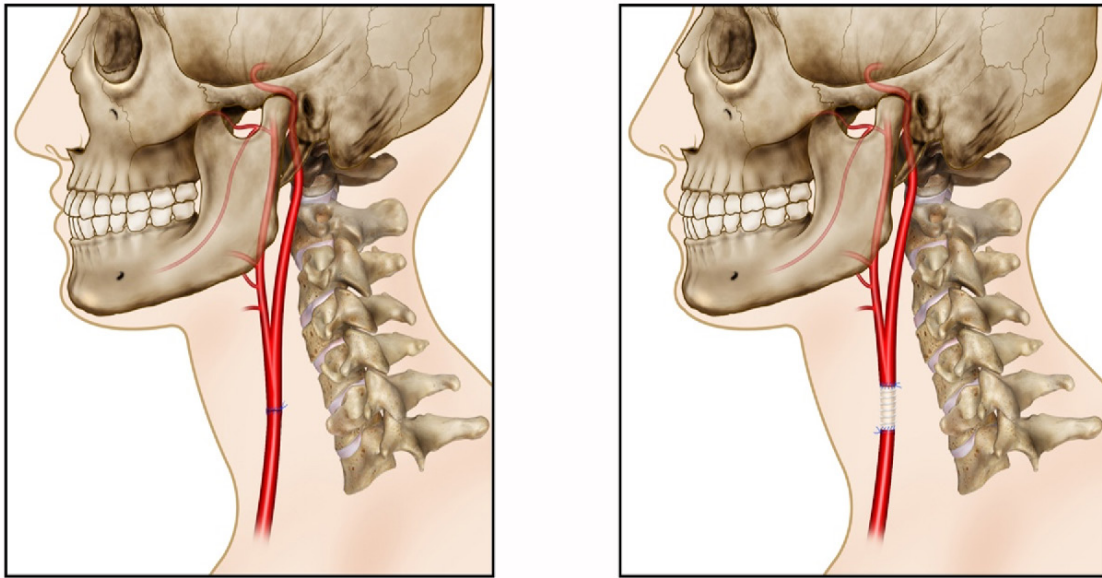


Figure 4. Open Surgical Repair of the Common Carotid Artery . A. Common carotid artery anastomosis. B. PTFE interposition graft.

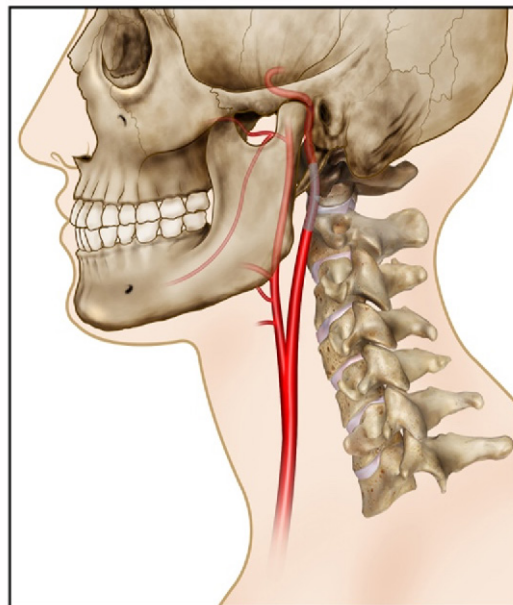


Figure 5. Endovascular Repair of the Internal Carotid Artery. A. Endovascular Stent placement.

bleeding (Figure 2) or in cases of poor overall prognosis upon arrival (Table 1), arterial ligation becomes the strategy of choice to achieve definitive hemorrhage control. White et al. reported that patients who underwent common or internal carotid artery ligation had a mortality rate of 22% and a stroke rate of 89% with permanent long-term neurologic sequelae³⁰.

There has been insufficient reported data to determine the effectiveness of restoring blood flow in cases of complete traumatic occlusion of the injured carotid vessels. Neurologic recovery has been reported between 42% and 64% in those patients managed via primary repair, and 14% in those in which the vessel was ligated¹³. With these findings in mind, we recommend that at-

tempts should be made when possible to restore blood flow via an open or endovascular repair. Primary suture repair is the ideal technique for low-grade injuries and interposition grafts for larger ones. Our general recommendation is to use readily available synthetic (PTFE/Goretex) grafts and autologous vein grafts as a secondary option, especially in cases that require the implementation of a damage control strategy^{31,32}.

Conclusion

Open surgical exploration has been the prevailing paradigm in the management of penetrating carotid trauma. However, endovascular management can be applied in selected patients, following damage control principles and performing less invasive interventions to repair and/or control vascular injuries.

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