Endovascular Management of Neurovascular Arterial Injuries in the Face and Neck

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ABSTRACT

The diagnosis and treatment of traumatic vascular injuries continues to improve as new tools and techniques are developed. In addition to locoregional hemorrhagic complications, injuries to blood vessels in the neck and face can result in ischemic injuries to the brain and cervical spinal cord. Surgical access to these lesions may be difficult, and endovascular techniques, including stenting and embolization, now serve as definitive treatments in many instances. This article reviews the endovascular management of patients with arterial injuries in the neck and face.

KEYWORDS: Trauma, neurointervention, embolization, N-butyl cyanoacrylate, stent

Objectives: Upon completion of the article, the reader should be able to explain the classification of neurovascular trauma in the face and neck, as well as the indications and therapeutic options for endovascular treatment with embolic agents and stents.

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Trauma is the ninth leading cause of death worldwide.¹ In the United States, it remains the leading cause of death in individuals under the age of 45.² The predominant cause of death related to trauma is a central nervous system (CNS) injury.³ In addition to their locoregional repercussions, *e.g.*, massive neck hemorrhages, traumatic injuries to the neck arteries can result in remote complications, in particular ischemic damage to the CNS. In both types of complications, the time factor plays a significant role. The treatment of traumatic arterial injuries in the neck and face can therefore represent a challenging task for the neurointerventionalist.

MECHANISMS OF INJURY

Neurovascular trauma is categorized by its mechanism: either blunt or penetrating. Due to the critical nature of the blood supplied by the carotid and vertebral arteries, injuries to these vital structures account for significant morbidity and mortality. In a study by Landreneau et al,⁴ a mortality rate of 50% was reported when penetrating injuries to both the carotid and vertebral arteries were present.

PENETRATING TRAUMA

For the purposes of prognosis and treatment of penetrating injuries, the neck is traditionally divided into

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three anatomic zones.⁵ Zone I extends inferiorly from the cricoid cartilage. Zone III extends superiorly from the angle of the mandible to the skull base. Zone II includes everything between zones I and III, from the cricoid cartilage to the angle of the mandible. For the sake of discussion, the face is here included in zone III.

Vascular injuries can be categorized based on their appearance on imaging studies. These categories include: (1) intimal and/or medial damage with or without associated narrowing of the vessel lumen and/or dissection of the vessel, (2) aneurysm or pseudoaneurysm, (3) complete occlusion, (4) arteriovenous fistula, and (5) complete transection.⁶ It is important to understand that vascular injuries are dynamic lesions that can combine several of the characteristics described above and, with time, evolve from one category to another. This potential for evolution emphasizes the need for careful follow-up imaging studies, as it will be shown below (see Fig. 2).

In most trauma centers, computed tomographic (CT) angiography is the initial imaging study for clinically stable patients. CT angiography can be rapidly obtained, and CT machines capable of providing good-quality CT angiograms are now widely available, in particular in the emergency departments of most major trauma centers. If a significant vascular injury is suspected or identified by CT angiography, patients are triaged to surgery or catheter angiography for further diagnosis and treatment. Zone II injuries are relatively easy to explore and have traditionally been considered surgical indications. Zone I and III injuries, presenting a more challenging surgical access, are often referred for therapeutic angiography.

BLUNT TRAUMA

In contrast to the generally dramatic appearance of penetrating head and neck trauma, blunt carotid and vertebral injury (BCVI) may present with few physical signs or symptoms. BCVI is responsible for ~10% of all cervical vessel injuries.⁷ Overall, BCVI is associated with a mortality rate of ~30%, with severe neurological morbidity seen in up to 56% of survivors.⁸

Biffi et al⁹ proposed a five-category grading scheme for blunt vascular injuries. In their study, injuries of different grades had different outcomes, and the stroke risk was found to increase with the grade of the initial injury. Grade I injuries are mild intimal injuries with a luminal narrowing of less than 25%. Grade II injuries are intimal injuries, dissections, or intramural hematomas with a luminal stenosis above 25%. Grade III injuries are associated with a pseudoaneurysm, grade IV injuries are vessel occlusions, and grade V injuries are complete transections.

CAROTID INJURIES

It is now clear that blunt carotid injuries are much more common than once thought; these lesions are diagnosed in ~1% of patients presenting with blunt trauma.¹⁰ When untreated, carotid artery injuries are associated with a stroke rate directly related to the severity of the injury, reaching up to 50%.¹¹ Aggressive screening, associated with anticoagulation therapy for patients diagnosed with carotid injury, has been shown reduce the risk of stroke.^{10,12,13}

Crissey and Bernstein have identified four fundamental mechanisms of blunt carotid injury.¹⁴ Type I injuries result from a direct blow to the neck and account for a minority of injuries. Type II injuries are the most common and result from hyperextension and contralateral rotation of the head and neck. Type III injuries result from intraoral trauma, and type IV injuries are associated with skull base fractures that involve the sphenoid or petrous bones. Regardless of the type of injury, the mechanism for most of these arterial lesions is intimal disruption, which exposes the thrombogenic subendothelial collagen surface, promoting platelet aggregation with subsequent embolization, partial thrombosis with low flow, or complete thrombosis.¹⁵

VERTEBRAL INJURIES

Blunt vertebral arterial injuries, once thought to be innocuous, have been attributed to 24% of posterior circulation strokes and 8% of deaths in one study.¹⁶ Trauma to the vertebral arteries can occur at several anatomic locations. Compression of muscles and associated tendons can compress the vertebral arteries prior to entering the foramen transversarium of C6.¹⁷ Osteophytic spurs in the midcervical spine can act as fixed points against which the vertebral arteries can be damaged during blunt trauma.¹⁸ The vertebral arteries can also be injured where they run in a fixed position within the transverse foramen of C1–C6. Motion at the atlantoaxial joint, cervical fractures, and dislocations with bony impingements can all lead to intimal and medial injuries. These injuries can produce ischemia from vessel lumen narrowing or complete occlusion, or embolization of thrombus arising from pseudoaneurysms or dissection.¹⁹

TREATMENT

Treatment for neurovascular trauma includes conservative management as well as various surgical and endovascular options. If a patient is medically stable, angiography can be performed to both establish a firm diagnosis and proceed with endovascular treatment when indicated. The location of the injury as well as the collateral cerebral circulation must be evaluated prior to an intervention. Transarterial embolization is a fast and effective method for the treatment of an active

Figure 1 A 25-year-old man with gunshot wound to the face and enlarging hematoma. The patient presented to the emergency department after sustaining gunshot wounds to the face and abdomen. He was taken to the operating room for repair of a colonic injury. His facial hematoma, initially stable, started to enlarge 24 hours after admission. He was brought to the neuroangiography suite. (A) Right common carotid angiography, lateral view, showing injury of the maxillary artery with contrast stagnation, no active leak, and no distal opacification. (B) A 6-French guide catheter (Envoy; Cordis Neurovascular, Miami Lakes, FL) was placed within the origin of the right external carotid artery, and a 2.3-French microcatheter (Prowler Plus, Cordis Neurovascular) advanced into the damaged arterial segment over a 0.014-inch guide wire (Transend, BSC, Fremont, CA). Superselective angiography of the maxillary showed moderate contrast extravasation, indicating partial tamponade of the transected maxillary artery by the closed hematoma. (C) The microcatheter was withdrawn into the maxillary artery stump, proximal to the site of transection. Two detachable microcoils (GDC, BSC) were deployed, followed by several pushable fibered microcoils (Vortex, BSC). (D) Right common carotid angiography, lateral view. This final control angiogram shows the configuration of the coil pack securing the transected arterial segment. Superselective angiography performed prior to the removal of the microcatheter had confirmed the absence of extravasation.

hemorrhage, in particular when the injured vessel is relatively small and the collateral circulation allows for vessel's sacrifice. Endovascular stent placement may be more appropriate for injuries involving large- and medium-size vessels that must remain patent, such as the

common carotid, internal carotid, or vertebral arteries in the absence of adequate collateral circulation.

The treatment algorithm depends upon multiple factors, including the medical and neurological status of the patient and the presence of concomitant vascular

Figure 2 A 27-year-old man with gunshot wounds to the neck. The patient presented to the emergency department with neck, chest, and abdomen gunshot wounds. Computed tomographic (CT) angiography documented a left vertebral artery occlusion. The patient became hemodynamically unstable and was taken to the operating room where he underwent small bowel resection. (A) CT angiography, coronal reconstruction, obtained at admission, immediately prior to abdominal surgery. The left vertebral artery is opacified proximally (V1 segment, arrow), but the V2 and V3 segments are absent. Note the metallic artifacts related to bullet fragments at C2. Comminuted left facet fractures of C2 and C3 were noted as well (not shown). (B) Left vertebral artery injection, anteroposterior view. A diagnostic angiogram was prompted by the documentation of a small left cerebellar stroke on a skull base CT obtained 24 hours after admission. The angiogram showed that the previously occluded segment of the left vertebral artery had recanalized. The V2 and V3 segments were markedly irregular, with two pseudoaneurysms (only one visible in this projection, white arrow). In addition, an arteriovenous fistula draining into the vertebral epidural plexus (white arrowheads) was present. Note the large bullet fragment (black arrow) and a prominent anterior spinal artery originating from the V2 segment (artery of the cervical enlargement, black arrowheads). (C) The decision was made to sacrifice the left vertebral artery. A compliant microballoon (Hyperform 7 × 7 mm, eV3 Irvine, CA; arrowheads) was inflated within the V2 segment, distal to the takeoff of the anterior spinal artery (black arrowheads), and a 1.7-French microcatheter (Echelon 10, eV3) was placed distally within the damaged segment of the vertebral artery. The balloon and the microcatheter were advanced coaxially within the same 6-French guide catheter (Envoy, Cordis Neurovascular, Bridgewater, NJ). (D) The V2 and V3 segments were then embolized with 37 detachable coils (GDC 10 and 18, BSC, Fremont, CA). (E) Left vertebral artery injection, anteroposterior view after embolization, confirming the patency of the anterior spinal artery and the absence of opacification of the damaged portion of the left vertebral artery. (F) Right vertebral artery injection, anteroposterior view, showing collateral flow to the left V4 segment and the left posterior inferior cerebellar artery (PICA) via the right vertebral artery, but no retrograde opacification of the damaged segment or the arteriovenous fistula.

and nonvascular injuries. The neurological status is a critical factor when evaluating treatment strategies for a patient with neurovascular trauma. Several studies have shown that patient outcomes are associated with the severity of existing neurological deficits at the time of treatment, for both blunt and penetrating trauma.^{20–22}

A balloon occlusion test can be performed prior to vessel sacrifice in patients with significant associated injuries that preclude the anticoagulation required after stent placement.²³ If the patient's clinical status allows for it, the neurological exam is closely evaluated in addition to the pattern of collateral circulation as a balloon is inflated proximal to the injured vascular

Figure 3 A 22-year-old man with gunshot wound to the face and massive nasopharyngeal hemorrhage. The patient arrived to the emergency department bleeding profusely; he had a large facial wound with maxillary and hard palate defects and several disrupted teeth. Emergent tracheostomy was performed, and a Foley balloon catheter was inflated in each nasal cavity, providing only partial hemostasis. The patient was sent to the neuroangiography suite. (A) Left external carotid artery injection, oblique view, showing brisk contrast extravasation from a severed left superior alveolar artery. Note the presence of diffuse arterial vasospasm typically associated with gunshot injuries. (B) A 1.7-French microcatheter (Prowler 10, Cordis Neurovascular, Miami Lakes, FL) was advanced into the superior alveolar artery through the 5-French diagnostic catheter (JB-1, Terumo, Piscataway, NJ). Superselective angiography confirmed the site of extravasation. (C) N-butyl cyanoacrylate (NBCA) glue was injected through the microcatheter (mixture of 1 mL of Ethiodol for 1 mL of NBCA). (D) Left external carotid artery injection, oblique view, obtained after withdrawal of the microcatheter, confirming that hemostasis has been achieved.

segment. If a neurological deficit develops or worsens during the temporary balloon occlusion, the collateral circulation is considered inadequate for vessel sacrifice. If a reliable neurological evaluation cannot be obtained, various adjunct tests can be performed during a balloon occlusion test, such as electroencephalogram monitoring or nuclear medicine studies.^{24–27} These additional tests are, however, often difficult to arrange in the emergent context of trauma management.

MEDICAL THERAPY

It is always important to consider the role of anticoagulation and observation before embarking upon com-

plex endovascular procedures. One should as much as possible resist the temptation to treat neurovascular trauma patients with stents and stent grafts to achieve gratifying immediate angiographic results. Several studies have shown that neurologically intact patients with low-grade injuries have good outcomes with observation and anticoagulation.^{28–30} A recent study comparing outcomes in patients with carotid artery injury treated with anticoagulation/antiplatelet therapy versus patients undergoing carotid stenting has demonstrated a significantly higher rate of vessel occlusion in the stent group (45%) when compared with the antithrombotic therapy group (5%).³¹ This is particularly true for arterial dissection, which responds favorably to anticoagulation/

Figure 4 A 43-year-old man with enlarging neck hematoma. This patient admitted for relapsing acute leukemia with kidney failure and disseminated intravascular coagulation presented an enlarging neck hematoma shortly after placement of a central venous line. (A) Computed tomographic angiography revealed that the 7-French triple lumen catheter (arrowhead) had been mistakenly inserted into a branch of the right subclavian artery (arrow), with its distal tip lying within the aortic arch. (B) Right subclavian artery injection, oblique view, confirming the presence of the 7-French catheter within the subclavian artery (arrowheads). (C) An attempt at keeping percutaneous access to the injured artery by passing an exchange-length guide wire through the 7-French catheter failed as the latter was withdrawn. The access was lost, and a pulsatile neck hemorrhage started. A 6-French guiding catheter with a distal balloon (Corail, Balt, Montmorency, France) previously placed at the origin of the right subclavian artery as a safety measure was immediately inflated, achieving partial control of the hemorrhage. (D) A 2.3-French microcatheter (Prowler Plus, Cordis Neurovascular, Bridgewater, NJ), which was already parked within the 6-French guide catheter, was advanced into the stump of the damaged subclavian branch, and embolization was performed with N-butyl cyanoacrylate (NBCA) glue (mixture of 0.5 mL of Ethiodol and 1.0 mL of NBCA). The microcatheter was withdrawn, and the hemorrhage had stopped. (E) Right subclavian artery injection, oblique view, after embolization, confirming the absence of extravasation. Note the subtraction artifact related to the NBCA glue deposit (arrowheads).

antiplatelet therapy in most cases. In our practice, only patients with symptomatic stenosis/occlusion or patients with an enlarging pseudoaneurysm are treated endovascularly (see below).

ENDOVASCULAR THERAPY

Minimally invasive endovascular techniques can be used alone or in combination with medical therapy and/or traditional surgical techniques to stabilize patients, control blood loss, and prevent or limit further

injury, in particular secondary neurological damage. The strength of endovascular approaches lies in their ability to provide rapid access to surgically inaccessible vessels.

EMBOLIZATION THERAPY

Embolization therapy aims at occluding injured blood vessels to either control an active hemorrhage or secure a damaged vessel not actively bleeding. Numerous agents can be used for embolization therapy.

Figure 5 An 18-year-old man with gunshot wound to the face and active hemorrhage. A massive hemorrhage was controlled in the emergency department by inflation of a Foley balloon catheter in the bullet entry wound, and the patient was sent to the neuroangiography suite. (A) Right external carotid angiography, lateral view. After initial four-vessel diagnostic angiography, a 6-French guiding catheter with a low-pressure distal balloon (Corail, Balt, Montmorency, France) was advanced into the origin of the right external carotid artery. The Foley catheter was deflated and selective angiography obtained, showing massive contrast extravasation through a maxillary artery transected by a large bullet fragment. (B) Right external carotid angiography (N-butyl cyanoacrylate [NBCA] injection), lateral view. Control of the extravasation was obtained by inflating the distal balloon of the guide catheter. A 1.9-French microcatheter (Echelon 10, eV3 Irvine, CA) already present within the guide catheter was advanced over a 0.014-inch guide wire (Transend 14, BSC, Fremont, CA) into the stump of the transected artery. Three detachable microcoils (GDC 10, BSC) were deployed at the site of the transection. The balloon was slightly deflated and a control angiogram performed, showing persistent extravasation. The balloon was reinflated. NBCA glue was prepared (fast polymerization mixture with 0.1 mL of Ethiodol, 1.0 mL of NBCA, and tantalum powder) and injected through the coil pack. The microcatheter and the guide catheter were both removed at the end of the glue injection. (C) Right common carotid angiography, lateral view. The final angiogram confirms that control of the hemorrhage has been achieved. Note vasospasm of the internal carotid artery, a finding typically observed in arteries located nearby the bullet path.

GELFOAM

The most commonly used agents are Gelfoam (Upjohn, Inc., Kalamazoo, MI) and metallic coils. The choice of embolic material must be determined on a case-by-case basis. There are two simple questions that can help guide this decision-making process. First, is the targeted vessel large or small? Second, is a permanent occlusion desired? If the vessel to be embolized is large, then larger embolic agents (Gelfoam sponge, coils) are appropriate. The decision of temporary occlusion versus permanent occlusion will dictate the use of Gelfoam versus coils. In many cases of vascular injury leading to active hemorrhage, temporary embolization is all that is needed. In such cases, Gelfoam pledgets or slurry may be used to control the bleeding; the pledgets or slurry create a cast that mechanically occludes the vessel.

COILS

When permanent occlusion is desired, coils provide a readily available embolic material. Coil embolization relies both on a mechanical action (the coil mass itself) and a thrombogenic action (clot forming within the coil pack). Some coils designed for peripheral use have Dacron or nylon fibers that enhance the thrombogenic response (Fig. 1). However, it can be difficult to obtain

dense coil pack, and the occlusion of an artery of the size of a carotid or vertebral artery can necessitate the use of a large number of coils (Fig. 2). In addition, the obliteration of the vessel is incomplete until thrombus forms within the coil pack. The volume of coil material in a “dense packing” situation represents at best only ~35% of the total volume treated, the rest being filled with clot.³² This mechanism may be compromised in trauma patients who have received large volumes of packed red blood cells, have consumed most of their clotting factors, and may therefore not be able to form adequate thrombus. In addition, when treating patients with neurovascular trauma, clot migration into the cerebrovascular circulation represents a very significant risk of complication by distal thromboembolic events leading to stroke. For this reason, coil embolization of a carotid or vertebral artery with persistent antegrade flow should be performed under flow-controlled condition: we use nondetachable compliant balloons for this purpose (Fig. 2). If a coil packing dense enough to stop antegrade blood flow cannot be obtained with the coils that are readily available, coils may be combined with Gelfoam, to create a coil and Gelfoam sandwich. Several coils may be placed to create a plug. Subsequently, large Gelfoam pledgets may then be placed, which will be retained by the coils. Additional coils can then be deployed

Figure 6 A 44-year-old man with traumatic carotid pseudoaneurysm. This patient presented with right-sided weakness and aphasia and was diagnosed with bilateral carotid pseudoaneurysms, for which he was started on warfarin. After 2 years of conservative management, the right-sided pseudoaneurysm has regressed, and the left-sided one remained unchanged in size. (A) Left common carotid artery injection, oblique view. A large pseudoaneurysm arises from the proximal segment of the left internal carotid artery. (B) A 5-French guide catheter (Envoy, Cordis Neurovascular, Miami Lakes, FL) is placed in the common carotid artery, and a 1.9-French microcatheter (Echelon 14, eV3 Irvine, CA) advanced into the aneurysmal cavity, which was first framed with 0.018-inch microcoils (GDC 18, BSC, Fremont, CA). (C) A dense coil pack was achieved by the combination of 0.010 ($\times 18$) and 0.018 ($\times 10$) microcoils (GDC 360 10 and 18, BSC). (D) Left common carotid artery injection, oblique view obtained immediately after coiling, showing residual opacification of the proximal component of the pseudoaneurysm. However, it was decided to stop the procedure at this point rather attempt more complex maneuvers (stent or balloon-assisted coiling) in a sinuous vessel prone to dissection. The patient was discharged on aspirin and clopidogrel and scheduled for follow-up angiography 6 months later. (E) Left common carotid artery injection, oblique view, obtained 6 months later, showing complete obliteration of the pseudoaneurysm with reconstitution of a normal-looking internal carotid artery.

to trap the Gelfoam. This can be repeated to create a dense mechanical barrier and promote thrombosis.

Coils designed for neurovascular applications do not have fibers. They are much softer than coils designed for peripheral use and can they can be packed much tighter (Fig. 1A–C). One other advantage to these coils is the ability to retrieve them, even after they have been completely deployed outside of the catheter.

N-BUTYL CYANOACRYLATE

N-butyl cyanoacrylate (NBCA) is a liquid embolic agent that polymerizes immediately upon contact with an ionic

solution (i.e., blood or saline) and forms a cast that obliterates the vessel lumen and controls the bleeding. When combined with superselective catheter techniques, NBCA allows for fast and precise embolization and bleeding control while maintaining patency in undamaged vessels. Although NBCA is approved in the United States only for the preoperative embolization of cerebral arteriovenous malformations³³ (TRUFILL[®], Cordis, Miami Lakes, FL), it has been used in Europe for over 25 years to treat a wide range of peripheral and neurovascular conditions, including acute hemorrhage from visceral trauma^{34,35} as well as bleeding from external carotid artery blowout syndrome.³⁶

Figure 7 A 53-year-old man with traumatic carotid pseudoaneurysms and multiple transient ischemic attacks. This patient with known fibromuscular dysplasia and bilateral carotid dissections sustained while being assaulted with a nunchaku was admitted for recurrent right hemispheric transient ischemic attacks occurring despite antiplatelet therapy. (A) Right common carotid artery injection, lateral view, showing a sinuous and irregular cervical segment, with a wide-necked pseudoaneurysm located immediately below the skull base (arrow), and a second, more proximal, and smaller lesion (arrowhead). Note the presence of fibromuscular dysplasia in the vessel (also noted on the opposite side as well as in both vertebral arteries). (B) Right internal carotid artery injection, unsubtracted lateral view obtained after stent deployment (Acculink 6 × 40 mm, Abbott Vascular, Redwood City, CA), and placement of two microcoils (GDC, BSC, Fremont, CA). Note how the stent keeps the coils within the pseudoaneurysm cavity despite the absence of true aneurysmal neck. (C) Right common carotid artery injection, lateral view, obtained after placement of 10 coils. Note complete occlusion of the pseudoaneurysm and reconstitution of regular luminal contour. The stent also covers the smaller aneurysm, which now shows significantly delayed opacification and stagnation as an effect of the hemodynamic change resulting from the stent placement and parent artery straightening.

NBCA shows several major advantages that makes it our agent of choice in the trauma setting: (1) It can be quickly prepared and delivered and provides prompt, selective vessel occlusion (Figs. 3 and 4). (2) It does not rely on the patient's intrinsic clotting system to occlude the vessel lumen. (3) It can be combined with coils in cases of persistent bleeding after coil embolization (Fig. 5).

ENDOVASCULAR STENTING

Stents have been used to treat vascular injuries in trauma patients when there is a need to preserve patency of the damaged vessel. Although there are many different types of stents, the two basic distinctions are: (1) balloon expandable versus self-expanding stents and (2) bare metal versus covered stents. Balloon-expandable stents are preferred when precise placement is needed and there is no risk of extrinsic stent compression, such as at the origin of the supra-aortic trunks. Self-expanding stents are more difficult to place precisely but tolerate compression better, and are therefore preferred for the treatment of cervical lesions.

Bare metal stents have been used to treat arterial dissections and pseudoaneurysms.^{37–39} The placement of a bare stent helps “tack down” the dissection flap and prevent worsening of the dissection. Bare stent placement is now the treatment of choice for patients with

arterial dissections who are failing medical therapy.⁴⁰ Pseudoaneurysms can be treated by either coiling (Fig. 6) or stent placement (Fig. 7), or by a combination of the two techniques (stent-assisted coiling; Fig. 7). After a bare metal stent is placed across the pseudoaneurysm neck, a microcatheter is advanced through the stent struts and coils are deployed within the pseudoaneurysm. The stent acts as a barrier that keeps the coils within the aneurysmal space, preventing protrusion into the parent vessel lumen and possible coil migration. During the last decade, covered stents, known as stent grafts, have become available. These may be beneficial in cases involving pseudoaneurysms or arteriovenous fistulas. The potential benefit of covered stents lies in their ability to treat a pseudoaneurysm or an arteriovenous fistula without additional procedures. Their drawback, on the other hand, is the presence of a significant amount of foreign body within the arterial lumen, the need for long-term antiplatelet therapy, and the still unclear long-term outcome, particularly in regard to the patency of the parent artery.

Stent platforms also differ by their guide wire profile. Systems that rely on 0.035-inch guide wires are often too stiff to negotiate safely the tortuous anatomy of the internal carotid artery, especially near or at the skull base. More recently developed systems that utilize 0.018-inch and 0.014-inch guide wires are able to overcome these limitations in most instances.

Stent placement is not without risk. Potential long-term complications of stent placement include restenosis due to intimal hyperplasia, acute and subacute thrombus formation, distal stent migration, narrowing and restenosis of the parent artery, and further injury to the vessel.⁴¹ A recent study by Cothren et al⁴² has demonstrated a 45% occlusion rate for carotid stents placed in the setting of trauma. It is therefore recommended to first try treating the lesion with coiling and rely on the assistance of a stent only when coiling alone is not feasible.

CONCLUSION

The use of endovascular therapy in the treatment of cerebrovascular trauma continues to evolve as new techniques and equipment become available. These techniques have the potential to provide less invasive therapies to a patient population that is already compromised as a result of trauma. However, as with all new techniques that show promise, these new techniques and tools need to be critically evaluated before definitive recommendations can be made in favor of one therapy over another, in particular regarding the use of stents. The role of NBCA glue as a fast, precise, and safe embolic agent in the setting of traumatic injury with life-threatening hemorrhage is emphasized. This indication currently represents an off-label use of NBCA in the United States.

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