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Endovascular treatment of carotid injury

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Abstract. – This is a systematic review of the International Literature regarding the role of endovascular treatment in cases of carotid injury.

Injury to the carotid artery is not very common but is a serious consequence associated with either blunt or penetrating cervical trauma. They are difficult to evaluate due to associated injuries. The frequent coexistence of traumatic brain injuries seems to obscure its presentation and concurrent systemic injuries make the management somewhat challenging from the perspective of both diagnosis and treatment. Although bleeding is a serious and potentially fatal complication of these injuries, the main concern should be the impairment of cerebral blood supply. In the modern era of increasing usage of minimally invasive treatment options and technological advances, endovascular approach seems to gain acceptance as a sufficient alternative treatment modality in carefully selected groups of these trauma population. Interesting issues facing this emerging technology include the adequate definition of the types of injuries ideally indicated for endovascular treatment. Those traumatic carotid lesions located proximal to aortic arch or near the skull base are particularly hazardous to approach and difficult to repair surgically and may benefit of an endovascular approach. Specifically, iatrogenic injuries of carotid vessels are often occur in patients with significant comorbidities that make their management challenging.

Key Words:

Carotid injury, Carotid blunt trauma, Acute carotid injury, Endovascular treatment, Iatrogenic carotid injury, Carotid artery stenting.

Introduction

Carotid artery injuries are difficult to evaluate and treat owing to very complex anatomy confined to a relatively narrow anatomic space. Trauma in this anatomic region can be result of blunt, penetrating or iatrogenic injury. The first documentation of carotid artery injury was done in 1552 by Ambroise Paré, who reported repair of carotid laceration from a sword fight with cotton packing and suture[1]. Verniuel gave the first pathologic description of blunt injury in 1872[2].

The prevalence of penetrating carotid artery injuries, in civilian series, ranges from 12% to 20%, of total penetrating neck injuries. Compared to military injuries, civilian carotid trauma tends to be blunt or stabbing. Blunt carotid artery injury (BCI) has been reported with an overall percentage ranging from 0.08% to 0.38%[3-5]. The majority of patients with BCI have no signs of cervical trauma nor neurological deficits at presentation[3-5]. The BCI is usually detected when delayed focal neurological deficits become apparent.

The initial evaluation is usually complicated because of associated injuries in the head, chest, abdomen, or the limbs. A serious complication in penetrating injury is external bleeding that needs immediate management. However, in carotid trauma, the main concern is cerebral blood supply derangement[6-8].

The appropriate evaluation and management of carotid injury have been controversial and continue to evolve. Technological advances in noninvasive imaging have revolutionized the evaluation of stable patients with cervical vascular injuries, aerodigestive injuries, and associated fractures. Endovascular surgery has added another facet to the management of these trauma patients. Injuries to the distal internal carotid, proximal common carotid, are now amenable to endovascular adjuncts to arrest hemorrhage, exclude dissections or pseudoaneurysms, or assist with open repair.

The aim of this study is to review the available medical literature about the role of endovascular management of carotid artery injuries.

Anatomic Considerations

The anatomic region of neck has been divided into three zones that are useful for diagnosis and treatment[9-10]:

- **Zone I:** Below the cricoid cartilage–proximal control obtained in the chest.

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- **Zone II**: Between the cricoid cartilage and the angle of the mandible-proximal and distal control obtained in the neck.
- **Zone III:** Above the angle of the mandible–distal control difficult to obtain.

Mechanisms of Carotid Injury

Blood vessels are the most frequently injured structures in the neck after cervical trauma. The account for 7% to 27% stroke rate and 7% to 50% mortality rate[11]. The most commonly injured is zone II (47%), followed by zone III (19%) and zone I (18%). It is not uncommon for an injury to traverse two zones of the neck[12]. Gunshot wounds are more likely to cause a large neck hematoma and vascular injury than are stab wounds. Gunshot wounds, especially transcervical, and blast injuries have a higher rate of vascular injury.

Three basic mechanisms of BCI are: (1) extreme hyperextension and rotation, (2) direct blow to the vessel, and (3) vessel laceration by adjacent bone fractures[13]. The most common mechanism of BCI is hyperextension of the carotid vessels over the lateral articular processes of C1-C3 at the base of the skull, which is typically a result of high-speed automobile crashes[14]. There are also scattered case reports of BCVIs resulting from chiropractic manipulation[15] and rapid head turning with exercise. A direct blow to the artery typically occurs in the setting of a misplaced seat belt across the neck during a motor vehicle crash or in the setting of hanging[14]. This injury pattern typically occurs in the proximal internal carotid artery as opposed to the distal aspect[14]. Furthermore, blunt carotid trauma after strangulation or choking has been described[16]. Bilateral BCI ranges from 20.9% to 37.5% of carotid trauma[15].

Iatrogenic Carotid Injury

Iatrogenic injuries of the carotid artery are not common but represent unique operative challenges with associated high morbidity and mortality. Although they are relatively rare, the incidence is increasing, most likely as a result of increasing utilization of percutaneous techniques[16-18]. Most frequent cause is an inadvertent central venous catheter puncture. Arterial puncture occurs in approximately 0.5% to 3.7% of all central venous catheterizations, with a higher incidence after internal jugular compared with subclavian central venous approaches[21,22]. Iatrogenic dissection of the internal carotid artery (ICA) during cerebral angiography or other cerebrovascular interventions may occur in 0.007% to 0.4% of all neuroradiologic procedures[23-25]. Certainly, these injuries typically occur in the sickest of patients, and their comorbidities often make their management challenging. Iatrogenic vascular injuries are associated with increased mortality compared with blunt or penetrating traumatic vascular injuries[26]. These traumatic lesions may consist of carotid artery dissection, arteriovenous fistula, carotid artery perforation and pseudoaneurysm formation.

Clinical Presentation – Screening

In addition to location, the physical examination in penetrating carotid trauma triages patients based on hard signs (mandating exploration) and soft signs (observation or further diagnostic evaluation) of vascular injury (Table I). Approximately 97% of patients with hard signs have a vascular injury; as opposed to only 3% of those with soft signs[12]. A negative physical examination with observation has negative predictive value of 90% to 100% for vascular injuries.

BCIs typically present with contralateral sensory or motor deficit, decreased mental status, or neurologic deficits not explained by closed head injury. Patients typically have coexisting traumatic brain injuries that may mask signs and symptoms of blunt cerebrovascular injuries[14]. Furthermore, many patients are initially asymptomatic and develop symptoms after a latent period, ranging from 1 hour to several weeks after injury[27,28]. Berne et al[29] found a median time to diagnosis of 12.5 hours for survivors of BCVI and 19.5 hours for nonsurvivors, suggesting a sufficient window of opportunity for diagnosis and treatment. Neither admission Glasgow Coma Scale score nor baseline neurologic examination correlates with the subsequent development of symptoms attributed to BCVI[14].

Table I. Classification of signs in penetrating carotid trauma.

Hard signs	Soft signs
Shock	History of bleeding (scene of injury)
Refractory hypotension	Stable hematoma
Pulsatile bleeding	Nerve injury
Enlarging hematoma	Proximity of the injury track
Bruit	Unequal upper extremity blood pressure measurements
Loss of pulse with stable or evolving neurologic deficit	

The first and most comprehensive screening protocol was initiated at Denver Health Medical Center (Table II)[30,31] where the s reported an overall BCVI incidence of 0.86%. Using the Memphis criteria (Table II), the incidence of BCI was 1.03%, Both screening regimens mandate four-vessel cerebral angiography if the patient meets at least one of the screening criteria[14]. A cervical seat-belt sign has been evaluated in several prospective studies but was not found to be predictive of BCVI[32]. Biffl et al[33] performed a multivariate analysis on a prospectively screened population and found four clinical findings predictive of BCVI (listed in Table II). Patients with one finding had a 41% risk of BCVI; two findings, 56% to 74%; three findings, 80% to 88%; and all four, 93%; however, 20% of patients with BCVI did not have any of the findings[14].

Diagnostic Evaluation

Patients with hard signs of carotid injury should proceed to the operative suite. There have been several advances in the treatment of penetrating neck injuries, and there are now sufficient data to support selective exploration in hemodynamically stable patients who have no hard signs of vascular or tracheobronchial injury. Exploration of cervical injuries based on platysma muscle penetration carries an unacceptably high negative exploration rate of 50% to 90%[34].

Computed tomography is a modern imaging tool for trauma evaluation and should be the initial diagnostic step in patients with penetrating neck injuries but without hard signs. Computed tomographic angiography (CTA) has 90% sensitivity and 100% specificity for vascular injuries[35,36]. CTA may be limited in the setting of missile fragments (shotgun injuries) or bone fragments obscuring the cervical vasculature; arteriography should be used for these patients as confirmatory study[14]. Duplex Ultrasonography (DU) has been used for penetrating neck trauma, but its utility is limited to zone II neck injuries[37]. As opposed to penetrating cervical trauma, selective digital subtraction angiography (DSA) is the diagnostic "gold standard" for the diagnosis of BCI. The Denver group proposed an angiographic grading system as the standard for reporting BCI[38]. This grading scale has prognostic value for patients' risk of subsequent stroke. Although it's an invasive modality associated to a stroke-risk (<1%)[30], not only depict the extent and the severity of the vessel injury, but also qualifies the adequacy of cerebral circulation.

Duplex Ultrasound has limited usefulness to identify patients with BCI as often cannot identify small intimal tears or nonocclusive dissections.

Table II. Comparison of measured variables before and after intervention in plasma.

Denver criteria*	Memphis criteria†	Biffl's modified criteria‡
Signs and symptoms	**Signs and symptoms**	**Signs and symptoms**
Arterial hemorrhage or expanding hematoma	Neurologic exam not explained by brain imaging	GCS < 6 (1.98)
Cervical bruit	Horner's syndrome	
Neurologic exam inconsistent with head CT findings	Neck soft tissue injury (seat-belt sign, hanging, or hematoma)	
Stroke on follow-up head CT		
Focal neurologic deficit		
Risk factors	**Risk factors**	**Risk factors**
Le Fort II or III fracture pattern	Le Fort II or III fracture pattern	Le fort II or III fracture pattern (3.7)
Basilar skull fracture with involvement of carotid canal	Basilar skull fracture with involvement of carotid canal	Petrous fracture (2.64)
Diffuse axonal injury with GCS < 6		Diffuse axonal injury (3.09)
Cervical spine fracture	Cervical spine fracture	
Near-hanging with anoxic brain injury		

CT: computed tomography; GCS: Glasgow Coma Scale score. *Adapted from Biffl WL, Moore EE, Ryu RK, et al. The unrecognized epidemic of blunt carotid arterial injuries: early diagnosis improves neurologic outcome. Ann Surg 1998; 228(4): 462-470. †Adapted from Miller PR, Fabian TC, Croce MA, et al. Prospective screening for blunt cerebrovascular injuries: analysis of diagnostic modalities and outcomes. Ann Surg 2002; 236(3): 386-393; discussion 393-395. ‡Adapted from Biffl WL, Moore EE, Offner PJ, et al. Optimizing screening for blunt cerebrovascular injuries. Am J Surg 1999; 178: 517-522.

Furthermore, it has an inability to directly evaluate carotid vessels in neck zones I and III. However, DU may offer as follow-up evaluation tool in these patients[39], CTA offers several advantages over DSA. It is a noninvasive study that can be obtained quickly and, as opposed to cerebral angiography, CTA obtains three-dimensional images of the vessel wall. However, the adequacy of CTA in BCI diagnosis is controversial. Several studies emphasizing the effectiveness of 16-channel multislice CTA as diagnostic modality of BCI[40,41], while others support that CTA not as reliable and as accurate as DSA, because underestimates the severity of the injury and has significant false-negative rate[42,43]. Magnetic resonance angiography (MRA) is an attractive safe noninvasive modality because of image resolution obtained, the infinite number of projections of the vessel, and ability to assess the intracranial architecture for signs of stroke[44]. A recent review supports equivalence between MRA and CTA in diagnosing carotid dissection[45]. Limitations include high cost, availability and time required for image acquisition.

Carotid Injuries – Treatment

Penetrating

Patients with penetrating carotid injury (PCI) presenting with coma, dense hemispheric stroke, or documented carotid thrombosis, need special consideration. The treatment of this specific injury pattern has come full circle: from revascularization in the 1950s to routine ligation in the 1970s and back to revascularization as the current mainstay of treatment. However, to date, there is no preoperative marker other than time (>24 hours from the time of injury) that predicts which patients are unlikely to benefit from revascularization. Early revascularization has consistently demonstrated improvement or stabilization of neurologic symptoms in patients with dense hemispheric strokes (100%), even in those who present obtunded (50%)[11].

Occult injuries (intimal flaps, dissections, pseudoaneurysms) identified during evaluation for penetrating cervical injury are managed, initially, the same as those caused by blunt trauma. Isolated intimal flaps are rare in penetrating trauma, and dissections occur in only 2%. Pseudoaneurysms are the most common occult injury identified. Large pseudoaneurysms should be considered for early intervention, whereas small pseudoaneurysms should be treated with antithrombotic therapy and early follow-up imaging. The natural history of these lesions is unknown. However, patients should be closely monitored for the development of embolic symptoms.

Blunt

The cornerstone of treatment for BCI is antithrombotic therapy. However, there are no randomized controlled trials to support this recommendation. Fabian et al[5] reported the first prospective observational study demonstrating improved neurologic outcome associated with the early use of antithrombotic therapy. Their analysis revealed the benefit of heparin therapy for decreasing the rate of neurologic deterioration after the development of symptoms and for decreasing the rate of new neurologic events. Heparin therapy was associated with dramatic reduction in neurologic morbidity (29%) compared with no treatment (73%). Biffl et al[30] confirmed that patients benefit from early anticoagulation, documenting the greatest benefit among those who were asymptomatic at the time heparinization. Analyzing the symptomatic cohort, 93% of patients had improvement in their neurologic deficits with anticoagulation, compared with only 67% without anticoagulation. Based on these studies, anticoagulation became the first-line treatment for BCI.

Complications associated with anticoagulation occur in 25% to 54% of trauma population. Most concerning is intracranial hemorrhage, but more common are gastrointestinal bleeding, retroperitoneal hemorrhage, blunt solid organ injury, and rebleeding from surgical wounds. Eachempati et al[46] noted that few patients were able to receive heparin therapy at the time of BCVI diagnosis (14%), and found complication rate of 16% among those who received heparin therapy.

Because of the complication profile of full anticoagulation therapy, several Authors have focused on antiplatelet therapy as an alternative. A prospective comparison of antiplatelet therapy versus anticoagulation for BCI does not exist. Biffl et al[39] reported that anticoagulation was superior to antiplatelet therapy, with stroke rates of 1% versus 9%. Several follow-up studies have failed to confirm this result. Miller et al[47] found similar resultant stroke rates after BCVI treated with heparin and with antiplatelet therapy (5% and 3%, respectively). In addition, Biffl and Cothren suggest heparinisation as first-line therapy for BCI, reserving antiplatelet agents for patients not deemed to be candidates for full anticoagulation[31,40,48].

A retrospective study, in 2008, by Stein et al[49], emphasizes the need to promptly identify and treat BCI, because 25.8% of untreated patients developed stoke compared to 3.9% of those received treatment. Pseudoaneurysms are unlikely to resolve with medical management, and 33% of acute non-occlusive dissections treated with anticoagulation develop pseudoaneurysms on follow-up arteriography[5]. These lesions have very low rupture-risk, but act as nidus of chronic embolic events or thrombosis[50]. About those patients with bilateral BCI, some studies suggest conservative anti-thrombotic therapy while more recently, some Authors propose early carotid artery stenting[17].

Iatrogenic

These injuries have traditionally been managed surgically. Surgical management of iatrogenic traumatic carotid injuries, under the best circumstances, carries the potential for significant morbidity and mortality related to blood loss, cranial nerve injury, and stroke. Endovascular treatment using stent-grafts and arterial access remote from injury site has been described previously[51,52]. For patients who have undergone previous neck surgery or extensive head and neck radiation therapy, there are additional difficulties of surgical exposure and reliable vascular control. These considerations make endovascular treatment an attractive alternative for them. Moreover, with improvements in stent-graft design and availability, these approaches are possible via percutaneous femoral access, even in emergent situations. Because of the low incidence of iatrogenic vascular injuries, the literature consists mostly of case reports, optimal management remains unclear[53].

Methods

A systematic electronic health database search was conducted using PubMed, Ovid, Medline, Embase and the Cochrane Database, on all accessible published articles between January 1997 and December 2010, referring to BCI. An unrestricted search strategy was used using terms such as, “carotid”, “injury”, “blunt injury”, “penetrating injury”, “cerebrovascular injury”, “endovascular management”, “stent”, “stent-graft”, “covered stent”, “coil embolization”, “iatrogenic injury”. Thirty-seven studies were included in this review, with a total of 158 patients.

Results

The endovascular management of carotid artery injury was described in 158 patients (Tables III, IV, V), which were divided to, 95 patients with BCI, 47 patients with PCI and 16 patients with iatrogenic injury. Age ranged from 16 to 82 years for overall carotid trauma, but according to distinct type of injury the age spectrum was, 15-81 years for BCI, 18-67 years for PCI and 58-82 years. 76.4% were male and 24.6% female. In the study of Edwards et al[54] there were no sufficient data about the gender, and the anatomic distribution of the injuries. The distribution of lesion was unilateral in all patients with penetrating and all except one in iatrogenic trauma, whereas from 77 patients (with full and sufficient data) 73 presented with unilateral lesions and only 5 with bilateral (Table VI). Anatomic distribution of these lesions can be seen in Table VI. Injuries treated included dissection, pseudoaneurysm with or without hemorrhage, arteriovenous fistula and laceration of carotid wall (Table VII). Time interval between injury and implementation of endovascular therapy seems to be variable and ranges from hours to even years. The majority of BCI patients treated endovascular with self-expanding stents and the most PCI managed endoluminally with self-expanding stent-grafts (Table VIII).

After stent placement the majority of patients received some form of antithrombotic regimen and underwent documented follow-up. Usually this follow-up was achieved by DSA and alternative imaging modalities such as, DU, CTA which usage has been raised recently. Four of these trauma patients suffered a post-procedural stroke while an uneventful stent occlusion happened in twelve patients (two with penetrating, eight with blunt and two with iatrogenic injuries).

Endovascular Treatment of Carotid Trauma

The outset of endovascular treatment of carotid artery injuries began in the mid-1990s after successful interventions of coronary artery rupture[55,56]. An endoluminal approach to neck injuries may avoid the morbidity of a median sternotomy, high thoracic incision, or difficult dissection at the base of the skull. Furthermore, endovascular techniques offer potential benefit in cases of distal internal carotid artery injury, where surgical exposure is complicated[57] by the need for extensive dissection or mandible sublux-

Table III. Endovascular management of blunt carotid injury in published studies.

Year	Author – Study	Patients (n)	Gender (n)	Age	Type of injury (n)	Location (n)	Endovascular treatment (n)	Injury- treatment interval	Follow-up/ outcome
1997	Klein et al.- AJNR	1	F (1)	30	Pseudoaneurysm (1)	Unilateral ICA (1)	Coiling + Stent (SE) (1)	14 years	Uncomplicated 6 months follow-up (DSA)
1997	Matsuura et al. - J Endovasc Surg	1	F (1)	20	Pseudoaneurysm (1)	Unilateral ICA (1)	"Stent-assisted" (SE) coiling (1)	3 days	Uncomplicated 12 months follow-up (DU)
1999	Simionato et al. - Neuroradiology	1	M (1)	39	Pseudoaneurysm (1)	Unilateral ICA (1)	Stent (SE) (1)	6 weeks	Uncomplicated 2 months (DU)
2000	Kerby et al. - J Trauma	1	F (1)	37	Dissection - Intimal flap (2)	Bilateral ICA	Angioplasty with) Stenting (2)	2 days	Uncomplicated 12 months At 6 months: (DSA)
2000	Coldwell et al. - J Trauma	14	M (7) F (7)	Avg 27	Pseudoaneurysm (16)	Unilateral ICA (12) Bilateral ICA (2)	Stent (SE) (14)		Uncomplicated 16 months mean follow-up (DSA)
2000	Simionato et al. - J Endovasc Surg	1	M (1)	50	Pseudoaneurysm (1)	Unilateral ICA (1)	Stent-graft (BE) (1)	3 years	Uncomplicated 12 months follow-up (DU)
2001	Bush et al. - J Endovasc Surg	5	M (4) F (1)	Avg 43	Pseudoaneurysm (5)	Unilateral ICA (5)	"Stent-assisted" (SE) coiling (5)	3 days - 10 years	Uncomplicated 8,4 months mean follow-up (DSA)
2004	Fusonie et al. - Ann Vasc Surg	1	M (1)	37	Pseudoaneurysm (1)	Unilateral ICA (1)	Stent-graft (SE) (1)	15 years	Uncomplicated 3 months (DU)
2005	Joo et al. - J Trauma	9	M (8) F (1)	Avg 36,7	Pseudoaneurysm (4) Fistula (5)	Unilateral ICA (8) Unilateral ECA (1)	**Pseudoaneurysm:** Stent (SE) (2) Double-stent (SE) (1) Coils+glue in ECA (1) **Fistula**: Balloon embolization (3) Stent-assisted coiling (3)		ICA-ICA thrombosis due to coil migration (1 pt.) Uncomplicated 12 months (DSA) (8 pts)
2005	Cothren et al. - Arch Surg	23	M (15) F (8)	Avg 32	Pseudoaneurysm (23)	Unilateral ICA (22) Bilateral ICA (1)	Stent (SE) (23)	Mean of 6 days	Immediate: Strokes (3), Subclavian dissection (1) Uncomplicated mean 2,4 month follow-up (DSA) (8)

Table continued

Table III *(Continued)*. Endovascular management of blunt carotid injury in published studies.

Year	Author – Study	Patients (n)	Gender (n)	Age	Type of injury (n)	Location (n)	Endovascular treatment (n)	Injury- treatment interval	Follow-up/ outcome
2005	Cohen et al. - Stroke	10	M (8) F (2)	Avg 42,7	Dissection - Intimal flap (10)	Unilateral ICA (10)	Stent (SE) (3) Multiple Stents (SE) (7)	Mean of 6 hours	Uncomplicated 17,2 months mean follow-up (DU)
2005	Salerno et al. - Injury Extra	1	M (1)	48	Pseudoaneurysm (1)	Unilateral CCA (1)	Stent-graft (SE) (1)	36 hours	Uncomplicated 4 months follow-up (DU)
2006	Maras et al. - Cardiovasc Interv Radiol	1	M (1)	22	Pseudoaneurysm (1)	Unilateral CCA (1)	Stent-graft (BE) (1)	8 months	Uncomplicated 30 months follow-up (CTA)
2007	Edwards et al. - J Am Coll Surg	18		Avg 37	Dissection (4) Pseudoaneurysm (14)		Stent	7-10 days	**Before Discharge:** Stroke and Death (1) Death due Pulmonary Failure (1) **After Discharge:** Death AIDS-related (1) Uncomplicated mean 8 months follow-up (DSA)
2007	Schulte et al. - Cardiovasc Interv Radiol	2	M (1) F (1)		Dissection (2)	Unilateral ICA (2)	Stent (2)	3 months	Uncomplicated mean 12 months follow-up (CTA/ DU)
2008	Yi et al. - AJNR	4	M (2) F (2)	Avg 35	Pseudoaneurysm (4)	Unilateral ICA (4)	Stent-graft (SE) (3) Stent-graft (BE) (2)		**Before Discharge:** Death due to multiple trauma(1) **After Discharge:** Uncomplicated mean 8 months follow-up (DSA)
2010	Stager et al. - J Vasc Surg	1	F (1)	55	Pseudoaneurysm (1)	Unilateral ICA (1)	Double-stent technique (overlapping bare SE stents)		Uncomplicated 12 months follow-up (CTA)
2010	Keilani et al. - J Vasc Surg	1	F (1)	52	Dissection (1) Pseudoaneurysm (1)	Bilateral ICA	Stent (SE) (2)	9 days	Uncomplicated 3 months follow-up (DSA)

SE: Self-expanding; BE: Balloon-expandable.

Table IV. Endovascular management of penetrating carotid injury in published studies.

Year	Author – Study	Patients (n)	Gender (n)	Age	Type of injury (n)	Location (n)	Endovascular treatment (n)	Injury- treatment interval	Follow-up/ outcome
2000	du Toit et al. - EJVES	2	M (2)	Avg 35	Arteriovenous fistula (2)	Unilateral CCA (2) in Zone I	Stent-graft (SE) (2)	24 h -2 yrs	Uncomplicated 7 months follow-up (DU)
2002	McNeil et al. - J Vasc Surg	1	M (1)	18	Pseudoaneurysm (1)	Unilateral ICA (1) in Zone III	Stent-graft (SE) (1)	12 hours	50% asymptomatic stenosis in 10 months follow-up (DU)
2003	Diaz - Daza et al. - Cardiovasc Interv Radiol	7	M (6) F (1)	Avg 38	Fistula (1) Pseudoaneurysm (7)	Unilateral ICA (5) in Zone III Branches of ECA(2)	**Embolization:** (coils, gelfoam) (7) Stent-assisted coiling (1) Repair: Stent-graft (SE) (1)		Uncomplicated up to 8 months follow-up
2003	Kubaska et al.- J Endovasc Ther	2	M (2)	Avg 40	Pseudoaneurysm (2)	Unilateral ICA (2) in Zone III	Stent-graft (SE) (2)	Immediate	**1st pt:** seizure in postop day 4 due to VA pseudoaneurysm - Then uncomplicated for 2 years follow-up (CTA, DU) **2nd pt:** uncomplicated 20 months follow-up (CTA, DU)
2005	Joo et al. - J Trauma	1	M (1)	32	Fistula (1) Pseudoaneurysm (2)	Unilateral ICA (1) in Zone III	Stent-graft (SE) (1)		Uncomplicated 10 months follow-up (DU)
2006	Witz et al. - Eur Spine J	1	M (1)	16	Pseudoaneurysm (1)	Unilateral ICA (1) in Zone II	Stent-graft (SE) (1)		Uncomplicated 12 months follow-up (DU)
2007	Feuger et al. - EJVES	1	M (1)	44	Pseudoaneurysm (1)	Unilateral ICA (1) in Zone III	Stent-graft (SE) (1)	8 hours	Uncomplicated 24 months follow-up (DU)
2007	Cox et al. - J Vasc Surg	8	M (8)		Pseudoaneurysm (8)	Unilateral ICA (1) in Zone III - ECA (7)	Coil-embolization (7) Stent-graft (SE) (1)		Uncomplicated short-term (at discharge) follow-up (CTA, DU)
2008	Yi et al. - AJNR	2	M (2)	Avg 34	Pseudoaneurysm (2)	Unilateral ICA (1) in Zone III Unilateral CCA (1) in Zone I	Stent-graft (SE) (2)		Uncomplicated short-term (14 days) follow-up (CTA, DU)
2008	Rangaka et al. - EJVES Extra	3	M (3)	Avg 25,7	Fistula (2) Pseudoaneurysm (2)	Unilateral CCA (3) in Zone II	Stent-graft (SE) (3)	Avg 30,7 hours	Uncomplicated 9 months follow-up (DU)
2009	du Toit et al. - EJVES	19	M (19)	Avg 30	Fistula (9) Pseudoaneurysm (10)	Unilateral ICA (5) in Zone III Unilateral CCA (14) in Zone I	Stent-graft (SE) (18) Stent-graft (BE) (1)	Avg 26 hours	**Before Discharge:** Death (1) (brain herniation) **After Discharge:** Stent occlusion (1) at 30 days - (1) at 25 months (DSA) **Uncomplicated** (14 pts) mean 44 months follow-up (DU)

Table V. Endovascular management of iatrogenic carotid injury in published studies.

Year	Author – Study	Patients (n)	Gender (n)	Age	Iatrogenic injury	Type of injury (n)	Location (n)	Endovascular treatment (n)	Follow-up/ outcome
2000	Martin et al. - Cardiovasc Surg	1	M (1)	59	Ca oropharynx - Biopsy	Pseudoaneurysm (2) with hemorrhage	Bilateral carotid bifurcation (1)	Vein-covered (BE) stents (3) + coils	After discharge: at 3 weeks due to massive bleeding, re-intervention with 2 more vein-covered stents (DSA)
2002	Kocer et al. - AJNR	1	F (1)	58	Transsphenoidal surgery for pituitary adenoma	Laceration of cavernou s ICA with CCF	Unilateral ICA (1)	Stent-graft (BE) (1)	Uncomplicated 3 months follow-up (DSA)
2003	Kubaska et al.- J Endovasc Ther	1	M (1)	67	Previous CEA in an irradiated hostile neck	Pseudoaneurysm (1)	Unilateral ICA (1)	Stent-graft (SE) (2)	Uncomplicated 6 months follow-up (CTA, DU)
2004	Wyers et al. - J Vasc Surg	2	M (2)	Avg 72	Biopsy of neck mass (1) - Reoperation in Hostile neck (1)	Pseudoaneurysm (2) with hemorrhage	Unilateral: carotid bifurcation (1) - CCA (1)	Stent-graft (SE) (1)	**1st pt:** Death at 2 months from heart attack **2nd pt:** Uncomplicated 12 months follow-up
2005	Nemes et al. - EJVES Extra	2	M (2)	Avg 78,5	US-guided aspiration cytology (1) - History of CEA (1)	Pseudoaneurysm (2)	Unilateral carotid bifurcation (2)	Stent-graft (SE) (2)	**1st pt:** Uncomplicated 12 months follow-up (DU) **2nd pt:** Stent occlusion postop day 5 (DU)
2007	Bogaerde et al. - Clin Neurol and Neurosurg	1	M (1)	60	Cervical spine surgery	Pseudoaneurysm (1)	Unilateral ICA (1) Zone III	Stent (1)	Uncomplicated
2008	Schulte et al. - Cardiovasc Interv Radiol	5	M (3) F (2)	Avg 65,3	**Postoperative:** CEEA (3) - CAS (2)	Dissection (5)	Unilateral ICA (1)	Stent (5) mostly (BE)	(1) Asymptomatic stent occlusion 22 months (DU) (1) Restenosis - 48 months (3) Uncomplicated mean 12 month follow-up (DU)
2009	Park et al. - Surgical Neurogly	1	M (1)	61	Transsphenoidal surgery	Laceration (1)	Unilateral ICA (1)	Stent-graft (BE) (1) + adjunctive coiling	Uncomplicated 1 month follow-up (DSA)
2010	Ellens et al. - Am J Otolaryng	1	F (1)	68	Cervical radiotherapy - Hostile neck	Pseudoaneurysm (1)	Unilateral CCA (1)	Stent-graft (SE) in CCA (1) - Bare stent in ICA (1)	Uncomplicated 5 month follow-up (CTA)
2010	Loffroy et al. - J Vasc Surg	1	F (1)	82	During jugular vein catheter insertion	Pseudoaneurysm (1)	Unilateral CCA (1)	Superselective coil embolization	Uncomplicated 12 month follow-up (DU)

Table VI. Anatomic distribution of carotid inuries.

	BCI (n)	PCI (n)	Iatrogenic (n)
Unilateral	73	47	15
Bilateral	4	–	1
ICA	79	18	9
CCA	2	20	3
ECA	1	9	–
Carotid Bifurcation	–	–	4

BCI: Blunt carotid injury; PCI: Penetrating carotid injury; ICA: Internal carotid artery; CCA: Common carotid artery; ECA: External carotid artery; n: number of patients.

Table VII. Type of carotid injuries.

	BCI (n)	PCI (n)	Iatrogenic (n)
Dissection	18	–	5
Pseudoaneurysm	75	36	10
with hemorrhage			4
without hemorrhage			6
A-V fistula	5	15	–
Laceration	–	5	–

A-V: Arteriovenous.

Table VIII. Endovascular treatment modalities.

	BCI (n)	PCI (n)	Iatrogenic (n)
Coil embolization	1	7	3
Stent-assisted coiling	10	8	
Stent	74		7
SE	68		4
BE	1		1
Stent-graft	9	34	8
SE	5	33	6
BE	4	1	2
Vein-covered stent (BE)			5

SE: Self-expanding; BE: Balloon-expandable.

ation to gain exposure and by 9% perioperative stroke[58] rate. Another benefit is that endoluminal therapy can be performed with local anesthesia, allowing direct assessment of the patient's neurologic status. The use of stents, coils or even stent-grafts, can protect blood vessel both against lumen and wall complications, such as dissection, thrombosis, pseudo-aneurysm and hemorrhage.

Although multiple trials are ongoing to evaluate carotid stenting for carotid stenoses due to atherosclerosis, or intimal hyperplasia after carotid endarterectomy, very few studies have examined the role of endovascular techniques for traumatic injuries to the carotid arteries. Therefore, the evidence base for this modality is in its infancy, and these small studies offer results too conflicting to make any single consensus.

The current standard of care for blunt carotid injuries involves antiplatelet therapy (either aspirin or clopidogrel) with or without the addition of anticoagulation (heparin or warfarin), depending on a patient's associated injuries and any contraindications that exist. Endovascular therapy has been proposed to treat carotid injury in order to decrease risk of embolization from, or rupture of, pseudoaneurysms, with concomitant severe neurologic sequelae[59,60]. Endovascular treatment options may include either vessel occlusion with detachable balloons[61], glue or coil embolization 62 or repair with preservation of carotid flow with stenting. An uncovered carotid stent achieves this goal through the following mechanisms: (1) acts as a filter to trap any thrombus within the pseudoaneurysm; (2) decreases flow into the pseudoaneurysm by increasing laminar flow within the stent; and (3) allows endothelial cells to grow in the stent interstices[60]. An additional benefit of endovascular techniques is the exclusion of the pseudo-aneurysm with use of a bare (uncovered) stent and catheter-directed coil (with/without thrombogetic agents) delivery through the interstices of the stent[63,64]. The stent acts as a barrier, confining the coils to the pseudo-aneurysm, ensuring its adequate embolism and preventing the outflow of these materials into the vital carotid artery[58,63]. Indications for stenting in the setting of carotid injury include contraindication to coagulation, enlarging pseudoaneurysm, progressive dissection and high inaccessible operatively lesions[63].

As with currently accepted applications for bare metal carotid stents, the use of covered stents (stent-grafts) in carotid arteries is reserved for patients who are at high risk for complications with open surgical management of their specific problem. Similarly, patients may be considered high risk due to anatomic factors (such as cervical wounds, infections, tracheostomy, and inaccessible lesion location) or physiologic factors (cardiac, pulmonary, or other systemic disease). For zones I

and III injuries, endovascular exclusion of a pseudoaneurysm, partial transection, or arteriovenous fistula remains a viable option, depending on the location of the injury and the patient's clinical status. Self-expanding covered stents can be safely delivered to these locations with limited morbidity[65,66]. The list of potential uses for covered stents in carotid arteries is similar to covered stent applications in other vessels, including management of traumatic injury, pseudoaneurysm, dissection, and in-stent restenosis.

Discussion

This literature review yielded 158 patients and studied demographic data, mechanisms of injury, type of injury, anatomic location of the lesion, endovascular treatment, time of treatment and follow-up. The treatment and outcome of traumatic carotid injuries are influenced by many of these factors; including the mechanism, type of injury, and associated neurologic function.

Endovascular approaches to carotid injuries have seen increasing utilization. Borrowing on the expanding experience with the use of endovascular stents for cerebrovascular disease[67], stenting has most commonly been used for high extracranial internal carotid lesions[58]. These types of interventions are ideally suited for this region, where surgical approaches are most difficult, and are associated with a high rate of local and cerebrovascular complications. An endovascular approach may also prove particularly useful in the treatment of select types internal carotid injuries, as surgical resection or repair of internal carotid pseudoaneurysms in particular, are associated with a high mortality rate (30%) and high incidence of cerebral complications.

Several types of injuries may result from carotid trauma, regardless of mechanism. Those that do not commonly result in the operative indications of expanding hematoma or hemorrhage include intimal flaps, dissections, and pseudoaneurysms. The natural history and appropriate management of these injuries remains ill-defined. In a recent review study, Moulakakis et al[63] proposed an algorithm for management on BCI, as surveillance with anticoagulation or anti-platelet regimens remains the first management approach in preventing cerebral infarction. It seems that in selected patients, especially in those with pseudoaneurysms, the endovascular techniques could have a beneficial role.

Important requirements when considering stent repair of blunt carotid injury (BCI), are the time of stenting and the ideal post-intervention antithrombotic therapy[83]. The exact timing of stenting is an ill-defined issue in literature. Some Authors suggest delay of carotid stenting, thus decreasing the risk of thrombotic and embolic adverse events related to catheter manipulation in the acutely injured artery, while others recommend delaying carotid stenting until approximately 1 week[63,64]. The appropriate post-stenting anti-thrombotic therapy remains also ambiguous; the decision-making balances among the risk of anti-platelet regimens administration in trauma patients and, on the other hand, the risk of an early stent occlusion. Many Authors[58,68] advocate dual anti-platelet therapy (clopidogrel 75 mg and aspirin 80 mg, daily) at least for 3 months while others[69] suggest solid anti-platelet therapy lifelong. Thus, Biffl et al[30] emphasized that careful risk-benefit analysis must be performed before placing stents in the acutely injured carotid artery, while Hershberger et al[70] suggest that protocols for long-term follow-up should be developed before routine use of stents for the treatment of carotid artery trauma.

Joo et al[62] evaluated ten patient with carotid injuries (nine BCI, one PCI) (Tables III, IV) treated with endovascular techniques during a 7-year period (5 carotid-cavernous fistulas, 4 pseudoaneurysms, and 1 carotid-jugular fistula). Their treatment consisted of embolization with coils, glue, or detachable balloons, stents, and stent-assisted coil embolization. In one patient with a penetrating carotid injury a stent-graft was applied to exclude a false aneurysm. Mean clinical follow-up was 20 months, and imaging studies (eight angiograms, one magnetic resonance angiogram) were performed an average of 4 to 12 months post-procedure. They observed one ICA thrombosis due to coil embolisation. There were no infections, vessel ruptures, new neurologic deficits, or access site complications. They concluded that the endovascular management of carotid injury is safe and feasible.

A larger study by Cothren et al[68] revealed the opposite conclusion: that stenting, in fact, cannot be considered a safe alternative to anti-thrombotic alone management. In this study, 46 patients was diagnosed with BCI (grade III: pseudoaneurysm) in a period of 8.5 years and most of them[42] were asymptomatic at the time of diagnosis. Twenty-three patients were treated with anti-thrombotic therapy (anticoagulation/antiplatelets) and the re-

mained 23 with stents. There were four complications in the stent group: three strokes and one subclavian artery dissection; 45% of patients (8 of 18) had occluded arteries on follow-up imaging studies. There was only one complication (stroke) in the no-stent group, and only 5% of patients (1 of 20) had an occluded artery in follow-up. The Authors concluded that stents carried a higher complication rate as well as a higher long-term occlusion rate, and recommended antithrombotic therapy as the mainstay of treatment. However, this report had some limitations. First, there were no selection criteria for the selection of one treatment over another. Second, in the treatment period (1996-2001) there was a lack of recommendation for dual anti-platelet administration, which could interpret the high rate of stent thrombosis. Finally, there is little data in the study concerning follow-up. There are numerous reports of patients treated with anti-thrombotic therapy alone and presenting weeks to a year later with life-threatening hemorrhage or other complications from untreated pseudoaneurysms. This may advocate that anti-thrombotic therapy alone may not be the best treatment for BCI and pseudo-aneurysm.

In another study by Edwards et al[69] 18 patients were treated by endovascular means. Fourteen of them were available for a long-term follow-up (mean: 29.7 months). Angiographic follow-up revealed that all patients had patent stents without adverse effects or complications. They concluded that in selected patients with severe dissections and pseudoaneurysms, endovascular stent therapy is both safe and effective. Cohen et al[68] reported their experience with the endovascular treatment of ten patients with traumatic carotid dissection. They used a total of 22 stents as seven patients needed multiple stents to treat dissection. No peri-procedural complication was observed. Stenting reduced mean dissection stenosis from 69% to 8%. At follow-up up to 28 months, no in-stent thrombosis was noted. All patients were under dual anti-platelet therapy for 3 months. The Authors concluded that stenting seems a rationale and effective way to restore the artery lumen in selected patients.

Nowadays, there is an increasing use of endovascular procedures with either bare or covered stents, in the management of carotid injuries as it appears in Table VIII. However, no commercially available covered stent is FDA-approved for carotid artery applications, but use of several different devices has been reported in the literature. Except, perhaps, when a very short stent will suffice, balloon-expandable (BE) covered stents should be used with caution in mobile segments because they may be permanently deformed by compression or kinking due to movement. Use of more flexible self-expanding (SE) stent designs has been favored.

Descriptions of "homemade" covered stents for carotid applications have included PTFE or saphenous vein segments sutured to balloon-expandable Palmaz stents or attached to nitinol stents[71]. Vein stent grafts may be less likely to become infected, but they are cumbersome to construct and challenging to deliver. Martin et al[72] reported a case of bilateral location of pseudoaneurym at carotid bifurcation in a patient with oropharynx cancer, that was successfully treated with multiple autologous vein-covered stents. Vein as covering material was chosen due to its lower risk for thrombo-embolism. Post-therapeutic anticoagulation regimen could thus be avoided, since the risk for recurrent bleeding was regarded very high. At 8 months follow up outcome was judged as excellent, without any thrombo-embolic episodes and with permeable carotid arteries bilaterally. With the variety of PTFE-covered, balloon-expandable, and self-expanding stents now commercially available (Table IX), the homemade versions are essentially obsolete, except perhaps for use in a potentially infected site or in other unusual cases.

In a series of six patients with covered stents placed for internal carotid dissections (both spontaneous and posttraumatic), Assadian et al[73] reported no late complications out to 6 months, although one patient had a periprocedural transient ischemic attack. In their report and literature review that included 20 patients treated (in a 16-year period) with covered stents for traumatic extracranial internal carotid artery pseudoaneurysms due to penetrating craniocervical injuries or skull base fractures, Maras et al[57] reported a 15% occlusion rate (3 asymptomatic stent-graft occlusions) during follow-up, which they considered acceptable due to the complexity of the injuries. According to Redekop et al[74] aggressive management of these lesions is generally warranted to prevent life-threatening hemorrhage and thromboembolic complications.

Recently, du Toit et al[75] revealed nineteen patients with penetrating carotid injuries (PCI) in zone I and III, which were treated with stent-grafts, during a 10.5-year period. One patient died on post-operative day 3 despite confirmed DU patency of the repaired artery, due to his

Table IX. Commercially produced covered stents currently available in the us with potential off – label applications managing carotid artery pathology.

Covered stent	Manufacturer	Approved indications	Stent design	Stent material	Covering material	Sheath size required (F)	Guidewire size (inch)	Diameters or expansion range (mm)	Available lengths (mm)
Fluency plus	Bard peripheral	Tracheobroncial vascular	SE*	Nitinol†	ePTFE‡	8, 9		0.035	40, 60, 80
Jostent Graft-Master	Abbott Vascular	Coronary or Saphenous graft perforation	BE§	Stainless steel 316L	ePTFE		7	0.014	12, 16, 19, 26
iCast	Atrium medical	Tracheobroncial	BE	Stainless steel 316L	ePTFE	6, 7		0.035	16, 22, 38, 59
Viabahn	Gore & associates	Superficial femoral artery, Tracheobroncial	SE		ePTFE	8-12		0.025, 0.035	25, 50, 100, 150
Wallgraft	Boston scientific	Tracheobroncial	SE	Elgiloy**	PET††	9-12		0.035	20, 30, 50, 70

*SE: self-expanding; †Nitinol: nickel/titanium alloy; ‡ePTFE: expanded polytetrafluoroethylene; §BE: balloon-expandable; **Elgiloy: nonferromagnetic alloy composed of cobalt, chromium, nickel, and molybdenum; ††PET: polyethylene terapthalate.

traumatic brain injury. Four patients were lost to follow-up. The 14 remaining patients had a mean follow-up of 44 months. In total, two (14%) of the patients that were available for follow-up had occluded stent-grafts, of which one (7%) resulted in a stroke. The 30 day stroke and mortality rate for the whole group were both 5% and no graft sepsis or other stent-graft related complications were reported. The Authors[75] concluded that endovascular treatment of PCI in selected patients is a safe and effective treatment modality, as it was examined in a relative long-term follow-up.

There are several unique complications to be considered when using endovascular approaches. Local access site complications after these types of percutaneous .interventions have been shown to occur in 3% of elective cases in the treatment of cerebrovascular disease[76]. Several other factors may also adversely affect the placement and patency rates of these devices. Technical inexperience and anatomic difficulties may preclude effective placement. Redekop et al[74] have shown that small vessel size, proximal or distal dissection, and under dilation of the stent have all been associated with a higher probability of carotid stent thrombosis after placement. Additionally, as no device is currently FDA approved for this indication, the limitations of available stents types that may be used for these approaches remain largely unknown. Even if these devices are effectively placed for initial treatment, no consensus agreement as of yet exists to provide guidance for the need and type of adjunctive anticoagulation that should be used or ideal type or interval for subsequent follow-up. The usage of embolic cerebral protection devices has not been studied in large series and from the articles studied only Schultze et al[77] used such a device in 5 of totally 7 patients with carotid dissections.

The long-term follow-up of patients with BCAI also appears confusing in literature. The optimal radiologic follow-up for these lesions has not been determined and will require further studies[63]. DU is simple, cheap and easily repeatable, but it may miss carotid injuries within the bone canal at the base of the skull. DSA may represent the optimal imaging technique at the moment. However, it is not an examination of choice for follow-up due to its invasive nature. CTA may be the technique of choice in the follow-up of these patients, but concern for the effects of contrast-induced complications and radiation may not justify the benefit[63].

Conclusions

Despite these uncertainties, the role of endovascular stenting after carotid trauma warrants further investigation. Unresolved issues facing this emerging technology include the adequate definition of the types of injuries ideally indicated for endovascular approach. The need for emergent operation in many penetrating carotid injuries, for example, confounds the ability to appropriately compare outcomes after these mechanisms of injury. Better definition of the optimal blunt injuries likely to benefit is, likewise, lacking. The ideal adjunctive anticoagulation regimens and appropriate follow-up protocols must also be defined. Documentation of long-term outcomes also remains among the most important concerns, particularly given the relative young age of the patients for whom these devices are used. From initially published reports, endovascular treatment appears to have comparable stroke rates and lower associated mortality compared with traditional surgical approaches. Comparisons between patients requiring surgical intervention and those undergoing stenting are problematic, however, because these populations may represent groups that are not similar. For all of these reasons, further prospective analysis of the role for endovascular treatment of carotid injuries is warranted.

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