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REVIEW

Endovascular reconstruction of extracranial traumatic internal carotid artery dissections: a systematic review

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Abstract

Extracranial internal carotid artery dissection (ICAD) is a potential source of morbidity and mortality in trauma patients and requires high degree of suspicion for diagnosis after the initial presentation. Occasionally, if standard therapy is contraindicated, endovascular reconstruction is a treatment option. The aim of this systematic review was to report clinical and radiographic outcomes following endovascular repair of ICAD of traumatic and iatrogenic etiology. A comprehensive systematic review was performed according to the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines. PubMed and Cochrane Library databases were searched. Twenty-four studies comprising 191 patients (204 lesions) were included; 179 underwent traditional carotid artery stenting (CAS), whereas 12 patients underwent flow diversion with the pipeline embolization device (PED). In total, 75.7% of the CAS group and 66.6% of the PED group presented with ICAD-related symptomatology. Concomitant pseudoaneurysms were identified in 61.9% and 78.5% of lesions in the CAS and PED group, respectively. Adverse event rates among CAS-treated lesions after 30-day follow-up were below 2.2% for stroke, transient ischemic attack, and mortality. During follow-up in the CAS group, there was no incidence of ICAD-related stroke or death and 2.2% of patients underwent a repeat CAS procedure. In the PED group, no patient suffered stroke or death in the reported follow-up. In the PED cohort, there was an adequate occlusion rate and no patient had to be retreated. Endovascular reconstruction of traumatic or iatrogenic ICAD appears safe. This approach demonstrated acceptable short- and long-term clinical and radiographic outcomes in both groups.

Keywords Carotid dissection · Trauma · Iatrogenic · Stent · Flow diversion

Introduction

Internal carotid artery dissection (ICAD) is defined as an intimal splitting that can allow blood to enter the artery wall cleft and potentially lead to aneurysmal dilatation or mural hematoma [16, 23, 46]. ICAD can occur spontaneously or as a consequence of trauma [53]. The most common cause of traumatic extracranial ICAD is blunt neck trauma. Preliminary reports have shown that the incidence of ICAD among blunt trauma victims ranges from 0.08 to 0.33%; however, it is believed that the true incidence is underestimated [15, 20]. Patients with ICAD have a broad clinical presentation including stroke, transient ischemic attack (TIA), headache, face or neck pain and Horner syndrome; however, many cases remain asymptomatic [17]. Importantly, delayed appearance of focal neurologic deficits can occur in blunt trauma victims and should prompt cerebrovascular imaging [14].

ICAD accounts for approximately 20% of strokes for patients younger than 45 years old [8]. Strokes are believed to be caused by distal embolization of a thrombus that is created at

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the dissection site [6, 37]. The treatment of choice includes early systemic anticoagulation or antiplatelet therapy; in the majority of cases, this leads to resolution of the neurologic symptoms and a 50–70% recanalization rate of the carotid artery [29, 34]. However, medical management of ICAD might be contraindicated in patients with a high risk of bleeding, intracranial hematomas, penetrating injuries, expansion of an intramural hematoma, persistent or worsening neurologic symptoms, and severe carotid luminal stenosis with abnormal perfusion brain imaging; these various pathologies can often occur in traumatic ICAD cases [38]. Patients with traumatic ICAD and any of the aforementioned pathologies often require endovascular repair [12, 38]. The purpose of this systematic literature review is to collect and analyze all the published carotid dissection cases treated with an endovascular approach in order to better define the typical indications, presentations, treatment, and outcomes.

Methods

Search strategy and selection criteria

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [32]. Eligible articles were identified through search of the PubMed and Cochrane databases up to May 2018 by two independent reviewers (TK, AT). The following terms were utilized: carotid artery dissection, carotid dissection, trauma, traumatic, injury, iatrogenic, endovascular, stenting, stent, and pipeline. A study was included in this systematic review if it fulfilled the following predefined criteria: (i) randomized controlled trials (RCTs) or prospective or retrospective observational analyses on patients with traumatic ICAD, (ii) studies published up to May 2018, and (iii) studies reporting clinical or radiographic outcomes following endovascular repair of ICAD. Excluded studies met at least one of the following criteria: (i) case reports, (ii) dissections identified solely in the intracranial carotid artery segments, (iii) animal studies, (iv) patient population < 16 years old, and (v) reviews, meta-analyses, letters to the editor, or editorials.

Data extraction

Two reviewers (TK, AT) independently reviewed the included studies and extracted data. All disagreements were resolved with consensus by the addition of a third reviewer (PT). Data extraction was based on a predefined excel spreadsheet with the following variables: first author, year of publication, country and institution, study design and study period, sample size, patient baseline demographics, type of trauma, presenting symptoms, pharmacologic regimen used before, during and after endovascular treatment, follow-up period, related periprocedural and long-term adverse events, and morbidity and mortality rates. Categorical variables were summarized as frequencies and percentages and continuous variables as mean and standard deviations (SD) when available. For studies that reported continuous data as medians and range, the method proposed by Hozo et al. was utilized [24].

Risk of bias assessment

Risk of bias was assessed by two investigators (PT and SG). Non-randomized trials were evaluated according to the criteria proposed by the Cochrane tool for observational studies (ACROBAT) for the following domains: (i) confounding, (ii) selection, (iii) measurement of interventions, (iv) deviations from intended interventions, (v) missing data, (vi) measurement of outcomes, and (vii) selection of the reported result. Studies were assessed as low, moderate, or high risk of bias in every domain.

Results

Search results

The initial literature search yielded 506 potentially relevant records after duplicate studies were removed. After title and abstract screening, 107 articles were retrieved for full-text evaluation. Ultimately, 24 studies satisfied the predetermined search criteria and were included in this systematic review as shown in the PRISMA flow diagram (Fig. 1).

Characteristics of the studies and patients

All the included studies were observational cohort analyses or case-series [1–3, 7, 10, 11, 14, 22, 25–28, 31, 33, 35, 36, 38, 43, 47–49, 51, 52, 54]. Overall, 21 studies included 179 patients who underwent 190 carotid artery stenting (CAS) procedures; three studies comprising 12 patients who underwent 14 endovascular reconstruction procedures with the flow diverting pipeline embolization device (PED) were also included. Important patient and study characteristics, including preprocedural antiplatelet duration and type, are presented in Table 1. Different indications used for the endovascular revascularization procedures by each included study are summarized in Supplementary Table 1. None of the included studies were assessed as having high risk of bias. A more detailed assessment for the risk of bias can be found in Supplementary Table 2.

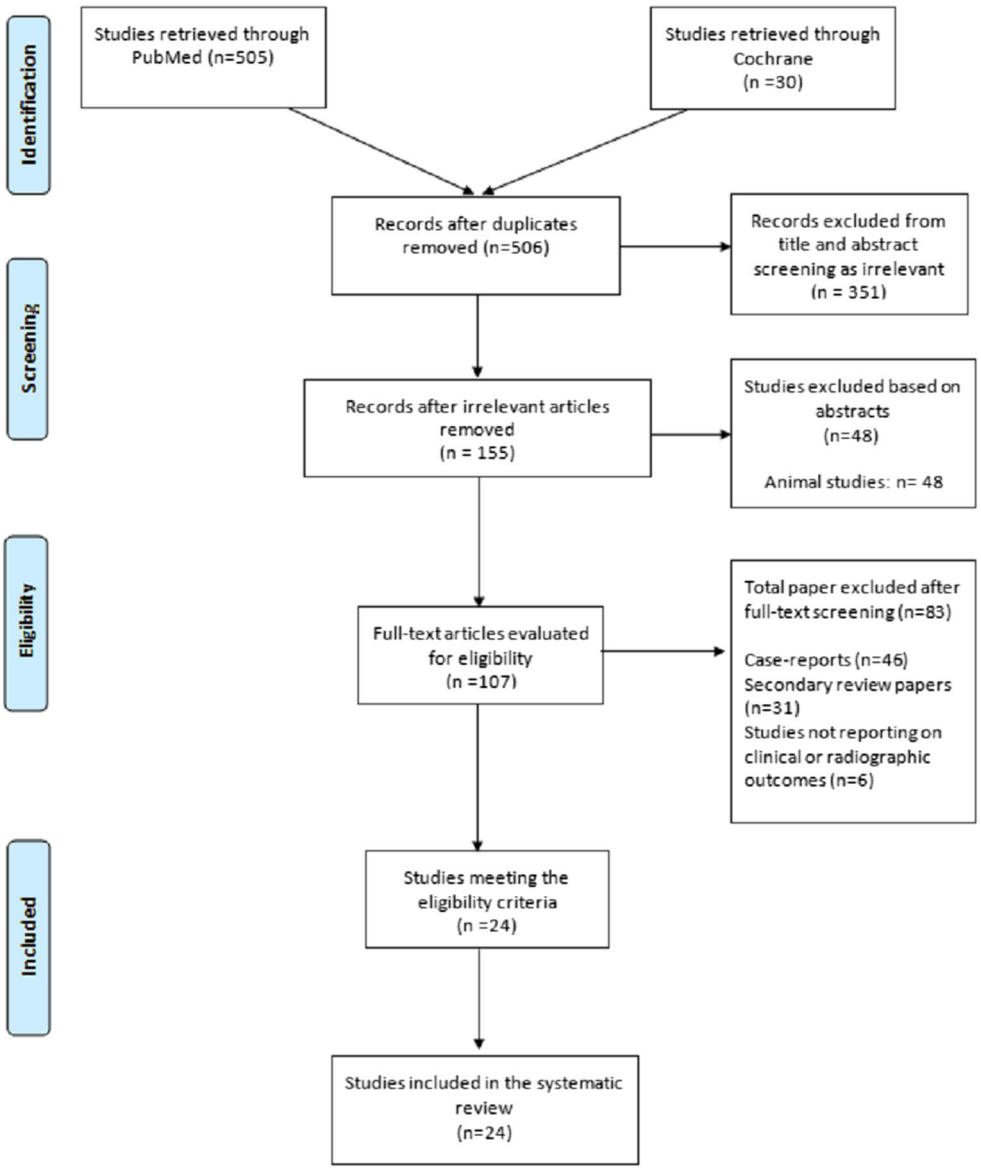

Fig. 1 PRISMA search flow diagram

Endovascular repair with CAS: baseline characteristics, etiology, pre-operative imaging, and procedural details

The majority of the patients who underwent traditional stenting for traumatic ICAD were male (70%), and the overall age range was 19–77 years old. Most of the patients (75.7%) presented with at least one symptom or sign related to the ICAD. The most common presentation among symptomatic patients was stroke (Fig. 2). Sixteen out of 154 patients (10.3%) with available data sustained bilateral traumatic ICAD; interestingly, imaging in one of the patients showed proximal irregularity of the vessels consistent with fibromuscular dysplasia [49]. ICAD was traumatic and iatrogenic in 82.2% and 17.8% of patients, respectively. The vast majority of traumatic ICAD was induced by blunt neck trauma (94.3%), whereas only 5.7% was due to penetrating neck injuries. Details on the mechanism of blunt trauma causing ICAD are illustrated in Fig. 3. Pre-operative imaging with computed tomography angiography (CTA), magnetic resonance angiography (MRA), digital subtraction angiography (DSA), or conventional angiography demonstrated that 58.5% of the lesions were associated with 70–99% carotid artery stenosis, whereas total carotid occlusion was seen in 6.8% of the lesions. Also, pre-operative imaging identified concomitant pseudoaneurysms in 61.9% ($N = 83/134$) of the ICAD lesions. Importantly, two studies excluded patients with pseudoaneurysms from their analyses [14, 48]. Anatomic location of the dissections varied from the common carotid artery proximally to the high cervical segment distally. Single or dual antiplatelet therapy (APT) and heparin were consistently used by most studies. The type of anesthesia varied and

Table 1 Important patient characteristics enrolled in the included studies

Study	Patients (*n*)	Endovascular repair	Etiology (T/I)	Pseudoaneurysms (*n*)	Pre-procedural APT (duration in days/type) (*n* pts)	Stent type
Bejjani 1998	4	CAS	3/1	NR	NR	NR
Butterworth 1999	3	CAS	3/0	NR	None	Wallstent
Liu 1999	4	CAS	2/2	NR	NR	Wallstent, Palmaz
Malek 2000	2	CAS	2/0	NR	NA/dual (1 pt)	Wallstent
Malek 2000	5	CAS	2/3	1	NR	NR
Lee 2001	2	CAS	2/0	1	2d/dual (1 pt)	Wallstent, Nir Primo
Joo 2005	3	CAS	3/0	1	3d/dual (3 pts)	Jostent, AVE S670
Kadkhodayan2005	18	CAS	9/9	15	5d/single or dual (18 pts)	Wallstent, SMART, Precise
Schulte 2008	7	CAS	2/5	0	NA/single (7 pts)	Wallstent, AVE-stent
Berne 2008	8	CAS	8/0	8	1d/dual (7pts)	SMART, Neuroform
Jeon 2010	2	CAS	2/0	0	None	Wallstent
Schirmer 2011	2	CAS	2/0	0	NR	NR
Paramasivam 2011	3	CAS	0/3	0	None	NR
Vidjak 2012	4	CAS	2/2	NR	NR	NR
Seth 2012	47	CAS	47/0	43	Emergent or 5d/single or dual (47 pts)	NR
Cohen 2012	23	CAS	23/0	0	NR	Wallstent, Precise, Wingspan, Bx Sonic
Asif 2014	8	CAS	8/0	2	5d/dual (8 pts)	Wallstent, Xpert, Xact, Nexstent, Precise, Neuroform, Wingspan, Liberte, Veriflex, Enterprise
Juszkat 2015	4	CAS	4/0	1	5d/dual (4 pts)	Wallstent, MER, Precise
Zhengxing 2015	17	CAS	17/0	0	NR	Acculink
Martinelli 2016	6	CAS	6/0	0	None	Wallstent
Simonetti 2017	7	CAS	0/7	0	NR	NR
Brzezicki 2015	7	Flow diversion	7/0	6	Emergent or 7d/dual (7 pts)	PED
Amuluru 2017	2	Flow diversion	2/0	1	NR/dual (1 pt)	PED
Wang 2017	3	Flow diversion	0/3	3	1d/dual (3 pts)	PED

APT antiplatelet therapy, *CAS* carotid artery stenting, *I* iatrogenic, *n* number, *NR* not reported, *PED* pipeline embolization device, *pts*. patients, *T* traumatic

included general or local anesthesia or conscious sedation. The use of open or closed cell stents was mostly based on the interventionalist's preference. Several lesions required the use of multiple stents [14, 48, 49, 54], whereas stent-assisted coiling was reported in 10% of the procedures [49]. Only four studies reported distal filter utilization in CAS, albeit inconsistently in three of them [14, 38, 48, 54].

Endovascular repair with CAS: short- and long-term clinical outcomes and imaging findings

Immediate post-procedural imaging demonstrated a 100% technical success rate with complete or improved luminal restoration and pseudoaneurysm occlusion or minimal filling in all cases. Two patients suffered a stroke (1.1%) and four patients (2.2%) suffered a transient ischemic attack (TIA) within 30 days post-procedure. Routine follow-up CTA imaging identified a total carotid occlusion on the eighth post-operative day in one asymptomatic patient (1%) [49]. Subsequent MRI of this patient demonstrated adequate collateral flow through the circle of Willis without any evidence of ischemia. Two patients had to be retreated: one had persistent filling of the pseudoaneurysm and luminal narrowing; the second patient had development of a new pseudoaneurysm 1 week after CAS. Both patients underwent a second stent-assisted coiling procedure; the first patient had complete pseudoaneurysm occlusion and luminal restoration, and the second patient had near complete occlusion of the pseudoaneurysm sac. The 30-day mortality rate was 2.2% (four patients). The first patient died on post-operative day 4

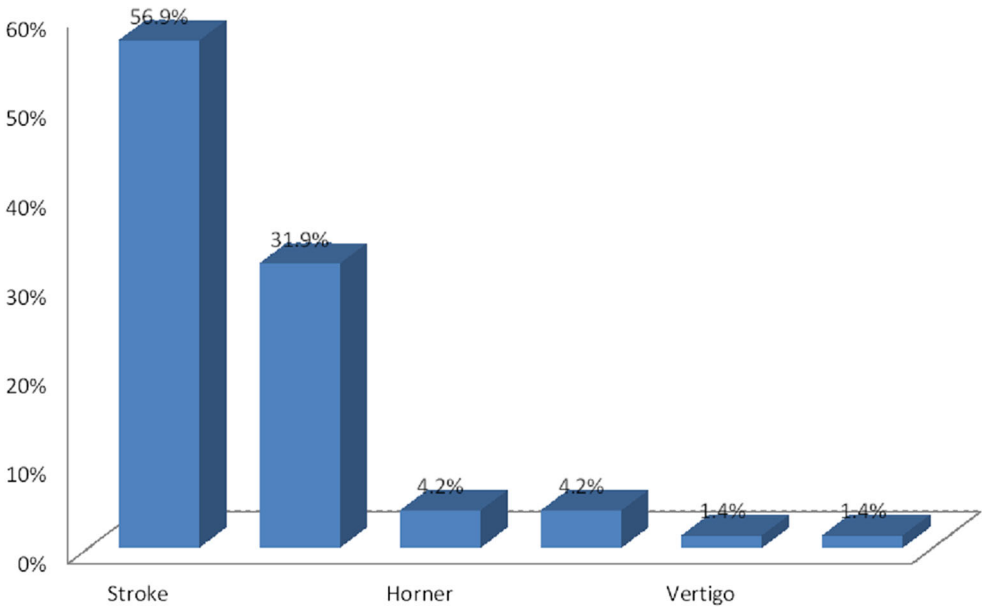

Fig. 2 Presentation of symptomatic patients in the carotid artery stenting group

due to systemic injuries sustained after a motor vehicle accident; the second had a lethal myocardial infarction; and two patients suffered progressive cerebral edema and brain death.

The mean weighted follow-up period was 28.9 months. The majority of patients were prescribed dual APT, although the exact regimen was not available. No incidence of ICAD-related stroke or death was reported within this period. In total, three patients (1.6%) suffered a TIA during the follow-up. Repeat angiography in an asymptomatic patient at 3.5 months demonstrated total carotid occlusion. Overall, two patients (1.1%) had to be retreated during the long-term follow-up period. The 5-week post-operative imaging showed in-stent intimal hyperplasia with 40% carotid luminal narrowing and persistent pseudoaneurysm filling in one patient. This patient underwent an additional CAS procedure with the use of platinum coils. The 15-month post-operative imaging for this patient showed pseudoaneurysm occlusion, but the intimal hyperplasia was unchanged. The second patient underwent a repeat endovascular revascularization procedure after the 6-month post-operative imaging showed intimal hyperplasia and 50% carotid stenosis. Pooled periprocedural and long-term adverse event rates are presented in Table 2.

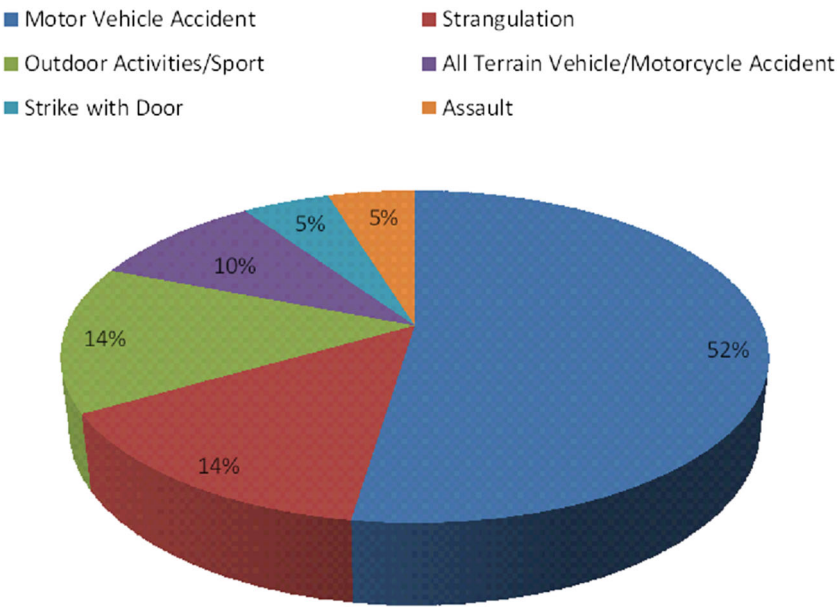

Fig. 3 Different mechanisms of blunt trauma causing carotid artery dissections

Table 2 Pooled short- and long-term adverse event rates, pre-operative imaging, and location of dissection following carotid artery stenting and flow diversion with the pipeline embolization device (PED)

	Carotid artery stenting cohort		Flow diversion with the PED cohort	
ICAD location	Varied from CCA to high cervical segment		High cervical or skull base segment	
Pre-operative imaging	• 70–99% stenosis: 58.5% of lesions • Occlusion: 6.8% of lesions • Pseudoaneurysms: 61.9%		• Stenosis%: not consistently reported • Pseudoaneurysms: 78.5%	
Adverse event	Within 30 days % (*n*/*N*)	Long-term follow-up (mean 28.9 months)% (*n*/*N*)	Within 30 days % (*n*/*N*)	Long-term follow-up (mean 5.2 months)% (*n*/*N*)
Stroke	1.1% (2/179)	0 (0/179)	0% (0/12)	0 (0/12)
TIA	2.2% (4/179)	1.6% (3/179)	8.3% (1/12)	0% (0/12)
Carotid occlusion	0.55% (1/179)	0.55% (1/179)	0% (0/12)	0% (0/12)
Death	2.2% (4/179)	0 (0/179)	0% (0/12)	0% (0/12)
Retreatment	1.1% (2/179)	1.1% (2/179)	0% (0/12)	0% (0/12)

n number of patients with event, *N* patients in the cohort, *TIA* transient ischemic attack

Endovascular repair with the PED: baseline characteristics, etiology, pre-operative imaging, and procedural details

Twelve patients underwent 14 endovascular carotid reconstruction procedures with use of the PED. Two of them were found to have bilateral ICAD. Eight patients (66.6%) presented with ICAD-related symptomatology. The majority of symptomatic patients presented with signs of stroke and Horner syndrome (Fig. 4). All 14 dissections were located in the high cervical or skull base segment of the internal carotid artery. Only the study by Brzezicki et al. specifically reported the pre-operative degree of luminal stenosis of nine ICAD cases [10]. Interestingly, two out of the nine dissections did not show any degree of stenosis; however, the rest of the cases demonstrated a mean stenosis degree of 82% (standard deviation (SD) 16). Also, pre-operative imaging identified concomitant pseudoaneurysms in 78.5% ($N = 11/14$) of the ICAD lesions. The ICAD etiology for the PED cohort was 75% traumatic and 25% iatrogenic. A more detailed report of the mechanism of the sustained injuries, including whether the injury was blunt or penetrating, was not available for these studies. Dual APT and intraprocedural heparin were administered to all patients before the endovascular procedure. In six ICAD cases (42.8%), balloon angioplasty was used with the PED to achieve revascularization. One patient received a combination of the PED and carotid Wallstent in order to achieve better apposition of the PED construct to the vessel wall [1].

Endovascular repair with the PED: short- and long-term clinical outcomes and imaging findings

All ICAD reconstructions with the PED were technically successful. Immediate post-operative imaging with CTA showed complete radiographic obliteration of the pseudoaneurysm sac or contrast stagnation [10], while DSA results demonstrated improved vessel caliber (majority < 10% stenosis) and decreased pseudoaneurysm filling [1, 52]. There were no incidents of 30-day stroke or death. One patient reported transient weakness and, however, had negative imaging studies.

All patients were prescribed aspirin 325 mg indefinitely and clopidogrel 75 mg for 6 months post-operatively. None of the patients suffered stroke, TIA, or death during the follow-up period (5.2 months). Routine imaging of the patients with available data showed complete pseudoaneurysm occlusion in 66.6% ($N = 6/9$), whereas 33.3% ($N = 3/9$) demonstrated minimal residual filling. Imaging of the luminal stenosis demonstrated complete revascularization in 87.5% of the cases ($N = 7/8$), while one patient had 20% stable residual stenosis during the follow-up. No patient during the follow-up had to be retreated. Pooled periprocedural and long-term adverse event rates are presented in Table 2.

Discussion

This systematic review investigated the short- and long-term clinical and radiographic outcomes following endovascular reconstruction of ICAD of traumatic or iatrogenic etiology. The most common dissection mechanism was blunt neck trauma. The most prevalent ICAD-related presentations were sensory or motor deficits, although approximately 25% of patients in the CAS group and 33% of patients in the PED group were still asymptomatic at presentation. Our results indicate that the endovascular approach has a 100% technical success rate. No procedure-related major cardiovascular events occurred in the traditional CAS or the flow-diverting PED groups in the 30-day interval. During the long-term follow-up, endovascular treatment with either CAS or PED demonstrated excellent recanalization and pseudoaneurysm occlusion rates with very low retreatment rates. Only four patients

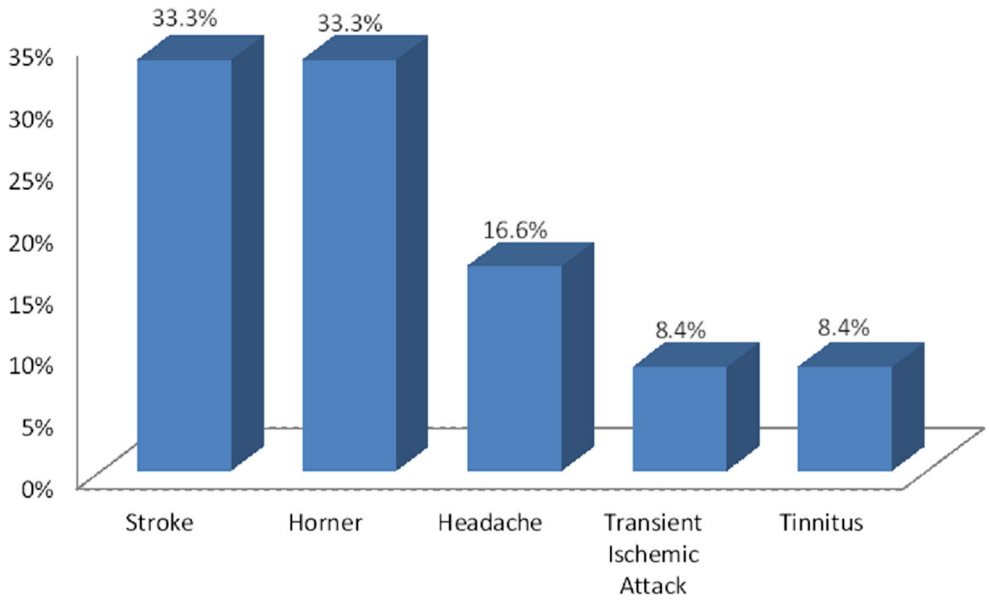

Fig. 4 Presentation of symptomatic patients in the flow diversion group

from the entire 191-patient cohort had to be retreated due to residual stenosis or persistent pseudoaneurysm filling 1 week (two patients), 5 weeks (one patient), and 6 months (one patient) after the procedure.

The major cause of traumatic extracranial ICAD is blunt neck trauma. Preliminary reports have shown that the incidence of ICAD among blunt trauma victims ranges from 0.08 to 0.33% [15, 20]. Before CTA was incorporated into the routine screening practice of patients with craniocervical trauma or traumatic brain injury, ICAD was typically diagnosed only after the development of ICAD-related symptomatology [4, 36]. Therefore, it is believed that the incidence of ICAD among blunt trauma victims may be underestimated [18, 30]. Interestingly, in this study, we report that ICAD was diagnosed incidentally in a significant subset of patients (25% of patients in the CAS and 33% of patients in the PED group). Future prospectively designed studies with standardized CTA screening in blunt trauma patients would be helpful to show the true incidence of traumatic ICAD. Importantly, delayed appearance of focal neurologic deficits in blunt trauma victims should always raise suspicion for ICAD and lead to prompt cerebrovascular imaging [14].

Several studies have suggested that the mechanism of ICAD-related stroke is thromboembolic [5, 6]. Currently, anticoagulant or antiplatelet medications are considered the standard of care in order to prevent a distal embolization phenomenon [37, 55]. More specifically, the 2011 AHA/ASA guidelines recommend treatment with either an anticoagulant or an antiplatelet medication for at least 3 to 6 months when an ICAD-related stroke or TIA has occurred [9]. However, these guidelines do not specifically report which is the preferred regimen. Supportive of this parity, the randomized Cervical Artery Dissection in Stroke Study (CADISS) showed that both anticoagulants and antiplatelets are similarly effective at stroke and death prevention in ICAD patients [55].

The vast majority of traumatic dissections can be safely treated with antiplatelet or anticoagulation. However, during the past two decades, endovascular repair of ICAD has emerged as a viable treatment approach [4, 39, 41, 50]. Of note, this strategy should only be reserved for select cases. Specifically, several indications for endovascular reconstruction have been proposed by a number of studies. Indications for endovascular repair include patients with (i) dissections associated with significant flow restriction, (ii) any contraindication to the use of anticoagulation (e.g., intracerebral or systemic hemorrhage), (iii) recurrent stroke or TIA despite medical therapy, and (iv) expanding or symptomatic pseudoaneurysms [16, 21, 40]. It is important to note that persistent pseudoaneurysms are thought to pose a long-term risk for distal thromboembolism [18, 45]. Nevertheless, the management of concurrent ICAD and pseudoaneurysm is still controversial [19, 44]. In fact, in this review, only four studies used the presence of a pseudoaneurysm as part of the inclusion criteria for endovascular repair [2, 7, 33, 49]. Our study shows that CAS was associated with excellent clinical and radiographic outcomes and efficiently prevented recurrent stroke and TIA following traumatic ICAD with or without concurrent pseudoaneurysms.

Both CAS and flow diversion have several advantages over medical therapy. First, the true and false lumens can be identified [53]. Second, blood flow through the dissected carotid is immediately restored after stent deployment [13]. Third, any co-existent pseudoaneurysm can be concurrently treated by coil embolization during the same procedure or obliterated by the stent itself [14]. In addition, anticoagulation cannot improve a hemodynamically significant carotid stenosis, which will continue to pose a long-term risk for

thromboembolic or ischemic events [14]. In fact, several studies reported that approximately 40% of traumatic ICADs along with their associated pseudoaneurysms did not heal during the mean 4-month follow-up [18, 20]. However, endovascular reconstruction of the ICAD has several pitfalls including the fact that microcatheterization of the true carotid lumen may be technically challenging [53]. Microcatheterization of complex dissections may worsen the dissection, release thrombus or the microcatheter may accidentally remain in the false lumen. Therefore, a microcatheter angiogram should be performed in order to ensure that catheterization of the true lumen has been achieved.

High cervical and skull base dissections can be challenging to treat with traditional carotid or intracranial stents due to a number of reasons. First, tortuosity of the carotid artery makes this location difficult to access with the inflexible carotid stent delivery system. Even though intracranial stents can be used for this indication, they may not provide enough flow diversion to promote pseudoaneurysm thrombosis because of their large cell design [10]. In contrast, flow diverters are low porosity woven tubes which can significantly increase vessel coverage compared to intracranial stents [34]. In theory, this also allows for better containment of the mural thrombus between the stent and vessel wall; this, in turn, could decrease the potential of spontaneous distal embolization. In addition, the pipeline embolization device is flexible which enables the device to more efficiently conform to vessel curves. The authors believe that flow diverters may have an improved pseudoaneurysm healing rate and may be a more suitable choice for high cervical or skull base carotid dissections due to the vessel tortuosity at this location. However, future studies with larger patient samples would be needed to confirm this hypothesis. Of note, several reports have suggested that ICAD can be effectively treated with vein graft replacement, thromboendarterectomy, or carotid bypass to prevent thromboembolic complications when medical therapy fails [38, 42]. However, studies comparing the surgical and endovascular approach for traumatic ICAD are lacking in the literature. Future studies could be conducted to evaluate whether the endovascular approach is associated with superior short- and long-term post-operative outcomes.

There is no consensus on whether embolic protection devices (EPD) should be used in CAS for ICAD. Only four studies in this review reported use of distal filters in CAS [14, 38, 48, 54]. In theory, distal protection devices may reduce the probability that an ICAD-related embolus reaches the intracranial circulation. However, distal filters could potentially propagate a dissection or create a new intimal flap; therefore, given the very low periprocedural complication risk in traumatic ICAD cases managed with unprotected CAS, EPD use may be reserved only for patients with high risk of stroke including those with concurrent carotid atherosclerosis or patients with confirmed ICAD-related thrombus [48, 54].

Limitations

To our knowledge, this is the first systematic review focusing only on traumatic ICAD cases treated with the endovascular approach. However, a number of limitations exist.

First, most of the included studies are case series including only small number of patients. The non-randomized observational nature of these studies limits the generalizability of our results as it is possible that only cases with favorable outcomes were reported. Second, heterogeneity in patient selection, imaging modalities used, and clinical/radiographic follow-up is another limitation of the current review.

Conclusions

Endovascular reconstruction of traumatic or iatrogenic ICAD when medical treatment is contraindicated is a safe and feasible treatment strategy. This approach demonstrated acceptable short- and long-term clinical and radiographic outcomes with either the stenting technique or with flow diversion. Prospective cohorts or RCTs specifically designed for this patient population are lacking in the literature and can further help validate our results.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval For this type of study, formal consent is not required.

Informed consent Not applicable.

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