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A comparison of different transarterial embolization techniques for direct carotid cavernous fistulas: a single center experience in 32 patients

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Abstract

Objective—Transarterial treatment of direct carotid cavernous fistulas (DCCF) via embolic materials has been well documented. This study reports, validates, and compares with existing literature our experience treating DCCFs via endovascular approaches by using detachable balloons, coils, and covered stents.

Methods—Between June 2006 to October 2011, 32 patients (21 male, 11 female) with 32 DCCFs (30 traumatic, 2 spontaneous cavernous ICA aneurysms) were embolized endovascularly. Followup was performed for at least 6 months.

Results—Among the 32 DCCFs, 21 (65.6%) were embolized using detachable balloons, eight (25.0%) with coils, one (3.1%) with balloons and coils, and two (6.3%) with covered stents. Complete DCCF obliteration was achieved in 31 (96.9%) cases. One fistula failed to respond due to premature balloon detachment. Intracranial bruit in 31 (100%) chemosis and exophthalmos in 28 (100%) cases resolved after embolization. Visual acuity and oculomotor palsy improved in 18 (90%) and 18 (69.2%) cases, respectively. There was no evidence of DCCF recurrence. Thirteen DCCFs were followed up by MRI and five by DSA. In these cases, four (4/13, 30.8%) balloon-embolized DCCFs showed pseudoaneurysms. Three patients were asymptomatic; one had minor left oculomotor palsy.

Conclusions—Our results correlate and reinforce literature regarding endovascular treatment of DCCFs. Application of Transarterial embolization with detachable balloons, despite extensive use has been decreasing. Coil embolization is an effective and safe alternative for treatment, especially when balloon embolization fails. Covered stent placement may be used as another alternative for selected cases.

Keywords

Carotid cavernous fistula; embolization; detachable balloon; coil; covered stent

Introduction

Carotid cavernous fistulas (CCFs) in general, represent an aberrant communication between carotid arteries and the cavernous sinus. A large amount of literature exists on the various subtypes of CCFs and their respective treatment with the latter showing constant evolution, with each treatment modality having a different degree of efficacy and safety profile. The CCFs are often subdivided based on flow rates, etiology, and source of feeder vessels as per the Barrow classification into Types A, B, C, and D [3]. Type A CCFs, also referred to as direct carotid cavernous fistulas (DCCFs) represent an abnormally high flow arteriovenous communication between internal carotid artery (ICA) and cavernous sinus (CS), usually resulting from a single, endothelialized tear in

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the carotid wall [3,33]. Types B, C, and D CCFs, also referred to as cavernous dural fistulas represent indirect lesions that have a low flow rate [3]. For instance, Type B lesions originate from the smaller branches of the cavernous carotid artery, type C arise from the dural branches of external carotid whereas type D CCF arise from a combination of external and internal carotid artery branches [3].

Unlike most dural CCFs (Barrow types B, C, and D) that emanate from preexisting microscopic communications between dural arteries and venous sinuses, most DCCFs arise from a traumatic tear of the cavernous ICA caused by, for instance, motor vehicle accidents or penetrating injuries [36]. A Majority of DCCFs result from head trauma with one study documenting occurrence in up to 4% of patients who sustained a basilar skull fracture [15,25]. In addition, DCCFs arising secondary to trauma may also be found bilaterally in 1%–2% of patients [25]. Epidemiologically, as with most traumatic injuries, DCCFs are most often encountered in young men [13,25,43]. It is hypothesized that DCCFs may arise secondary to sudden neck flexion during a traumatic event that leads to compression of the carotid artery increasing intraluminal pressure inside the vessel causing an arterial tear in addition to the external shearing forces on the vessel itself [15,36]. DCCFs arising as complications from surgical procedures such as postcarotid endarterectomies or transsphenoidal pituitary surgery have also been documented in the literature [24,34,39]. In addition, DCCFs may also arise from rupture of pre-existing cavernous sinus aneurysms [3,25]. For instance, Van Rooij *et al* found in their analysis of 51 pre-existing carotid sinus aneurysms a total of 10 aneurysms (24%) that eventually presented with a CCF [41]. On the other hand, certain genetic conditions lead to weakening of the vessel wall predisposing it to rupture secondary to minor trauma such as coughing or Valsalva maneuvers. Such conditions include fibromuscular dysplasia, pseudoxanthoma elasticum, and Ehlers-Danlos syndrome, all of which have been associated less commonly with spontaneous DCCFs [9,18,19,21,23,41].

The various advances in the realm of endovascular technology have given rise to a number of different treatment options for CCFs [23]. Subsequently, endovascular modalities have become the primary treatment option in clinical emergencies and following the failure of conservative therapy [23]. The various treatment options for DCCFs in turn have a varying profile of safety and efficacy. The overall treatment for DCCFs ranges from conservative management comprising of medical management and manual compression therapy to more advanced surgical management, stereotactic radiosurgery as well as endovascular applications [23]. Selecting the exact treatment modality requires a multimodal approach encompassing classifying the CCF according to its angioarchitecture, the neurological morbidity it poses, as well as the nature of symptoms [23]. In this paper, we have sought to compare the results of our single center experience with endovascular modalities encompassing transarterial embolization of DCCFs in 32 patients with the use of detachable balloons, coils, and covered stents with results already established in the literature. Endovascular therapy, though accompanied by complications such as ICA occlusion and cerebral infarction has shown to have successful closure rates in 55%–99% of reported cases of DCCFs [10,13,25,43]. Through this paper we aim to validate, review, and reinforce the existing data on the optimal treatment modality of DCCFs, encompassing techniques of transarterial embolization using detachable balloon coils, liquid adhesives, or covered stents.

Patients and methods

Patient population

Between June 2006 and October 2011, a total of 32 patients with 32 DCCFs were treated by endovascular embolization via a transarterial approach at our institution. Of these patients, 21 were male and 11 were female, with a mean age of 32.3 years (range 15–68). All patients had signs and symptoms related to DCCFs, the most common being intracranial bruit (n = 31), chemosis (n = 28), exophthalmos (n = 28), decreased visual acuity (n = 20), oculomotor palsy (n = 26), or intracranial hemorrhage (n = 2). Etiologically, 30 patients had a history of trauma and two were spontaneous with large pre-existing cavernous ICA aneurysms (Table 1).

Diagnosis of DCCFs

Initial studies undertaken at our institution consisted of brain computed tomography (CT) without contrast and magnetic resonance imaging (MRI). The utility of a brain CT lies in its ability to reveal skull base fractures, thick extraocular muscles, asymmetrically enlarged cavernous sinus (CS), or superior ophthalmic veins (SOV).

An MRI, though less sensitive than CT for visualizing skull fractures, is helpful in viewing expansion of the CS, SOV as well as enlargement of extra ocular muscles and proptosis [7]. MRI may show an abnormal cavernous sinus flow void, a finding specific to CCF [17]. The MRI findings were similar to those seen on CT scans, with the addition of abnormal flow void in the affected CS [17]. Cerebral digital subtraction angiogra-

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Table 1. Patient demographics: 32 patients with 32 CCFs.

Demographic data	Values (*n*) ,%
Total no. of patients	32
Male	21 (65.7%)
Female	11 (34.3%)
Average age (year)	32.3 (range, 15–68)
Symptomatic	32
Intracranial bruit	31 (96.9%)
Chemosis	28 (87.5%)
Exophthalmos	28 (87.5%)
Visual impairment	20 (62.5%)
Oculomotor palsy	26 (81.3%)
Intracranial hemorrhage	2 (6.3%)
Etiology	
Trauma	30 (93.7%)
ICA aneurysms	2 (6.3%)

phy (DSA), which remains gold standard, was also used in our patient population to confirm the diagnosis and prepare the next stages of treatment. DSA can identify the site of ICA tear, flow rate of fistulas, the patterns of venous drainage, and steal flow phenomena. According to the classification of van Rooij *et al* [41], DCCFs were classified into three categories: high, intermediate, or low flow. In high-flow DCCFs, all the blood form the ICA entered the fistula without filling of intracranial vessels. In intermediate-flow DCCFs, both the fistula and intracranial vessels received blood from the ICA, and in the low-flow DCCFs only slow and sluggish filling of the cavernous sinus was apparent. For those high-flow DCCFs, compressing ipsilateral common carotid artery (CCA) was necessary to visualize the site and size of ICA tears and ipsilateral cerebral compensatory circulation through the anterior communicating artery (AComA) or the posterior communicating artery (PComA).

Endovascular treatment

The choice of treatment modality for DCCFs is made according to the type, exact anatomy of the fistula, size of the arterial defect and operator/institutional preferences [23]. Indications for endovascular treatment used in our setting for DCCFs included presence of cortical venous drainage, rapidly progressive exophthalmos, oculomotor palsy, decreasing visual acuity, bleeding episode (otorrhagia, intracranial hemorrhage), and cavernous sinus varix:

A. Endovascular treatment using detachable balloons

Endovascular procedures using detachable balloons were performed under local anesthesia. Systemic heparinization was achieved by administering an intravenous bolus of heparin (5000 IU) and maintained by a continuous intravenous infusion of heparin (1000 IU/h). A 8F guiding catheter (Envoy; Cordis, Miami Lakes, FL, USA) was positioned in the involved ICA .Then a detachable balloon (Goldbal, Balt Extrusion, France) mounted on a wire-guided microcatheter (Magic BD-TE, Balt Extrusion, France) was advanced coaxially under roadmap guidance through the tear of the cavernous ICA, inflated using standard hypertonic, water-soluble contrast material and deployed in the CS. If one balloon could not completely occlude the fistula, then a subsequent second or more balloons would be deployed until the DCCF was obliterated.

B. Endovascular treatment using coils

All coil embolization procedures were performed under general anesthesia. A 6F Envoy guiding catheter was positioned in the cervical ICA and then a wire-guided microcatheter (Excelsior microcatheter, Boston Scientific, Natick, MA, USA) entered coaxially into the CS through the fistula under the guidance of roadmap. Coils (Hydrocoil or Microplex coil, Microvention, Aliso Viejo, CA, USA) were rendered and detached into the CS sequentially until the DCCF was occluded. During embolization, usually a protective balloon (HyperGlide 4 × 20 mm, ev3, Plymouth, Minnesota, USA) was placed in the ICA to avoid coil extrusion.

C. Endovascular treatment using covered stents

Before covered stent placement, clopidogrel (75 mg/day) and aspirin (300 mg/day) were administered for at least 3 days. Under general anesthesia, a 6F guiding catheter was positioned in the cervical ICA. Next, a 0.014-in exchange microguidewire (300 cm in length, Transend Floppy; Boston Scientific, Natick, Mss) was navigated into a distal branch of the middle cerebral artery. Then a covered stent (Jostent graft, GraftMaster, Abbott Vascular, IL, USA) was placed over the wire under roadmap guidance to the diseased segment of the ICA. Multiple control angiograms were obtained to confirm the correct position. Then the stent was inflated slowly up to the nominal pressure. Instant angiography was employed after deflating the balloon to confirm the

Table 2. Image results of 32 patients.

Patient	Examination	Location of CCF	Volume of flow	Drainage
1	CT, DSA	HS	Intermediate	SOV, IPS, ICS
2	DSA	HS	Intermediate	IPS, CV
3	CT, DSA	HS	High	SOV, IPS, ICS, PP, CV
4	CT, DSA	HS	Intermediate	SOV, IOV, IPS, ICS, PP
5	DSA	HS	Intermediate	SOV, IPS, PP, ICS
6	CT, DSA	VS	Low	ICS
7	CT, DSA	VS	High	SOV, IPS
8	DSA	HS	Intermediate	SOV, IPS, ICS
9	MRI, DSA	PG	Intermediate	SOV, IOV, BV, IPS
10	CT, DSA	PG	Intermediate	SOV, IOV, IPS, ICS
11	CT, DSA	HS	Intermediate	SOV, IPS, ICS
12	CT, DSA	VS	Intermediate	SOV, IPS, PP, ICS
13	CT, DSA	HS	High	SOV, IPS, PP, CV, ICS
14	DSA	PG	Intermediate	SOV, IOV, IPS, PP
15	MRI, DSA	VS	High	SOV, IPS, CV, ICS
16	CT, DSA	HS	High	SOV, IPS, PP, ICS
17	CT, DSA	VS	Intermediate	SOV
18	DSA	VS	Low	IPS
19	CT, DSA	HS	Intermediate	SOV, SPS, IPS
20	CT, DSA	PG	High	SOV, IPS, ICS
21	MRI, DSA	VS	Intermediate	SOV
22	CT, MRI, DSA	PG	Intermediate	SOV
23	DSA	HS	High	SOV, CV, ICS
24	CT, DSA	VS	Intermediate	SOV, IOV, PP
25	MRI, DSA	HS	High	SOV, IPS, ICS, CV
26	DSA	HS	High	SOV, IPS, ICS, PP, CV
27	CT, DSA	HS	Intermediate	SOV, IPS, ICS
28	CT, DSA	PG	Intermediate	SOV, IPS, PP, ICS
29	CT, DSA	PG	Intermediate	SOV, IPS, ICS
30	DSA	VS	Intermediate	SOV, IPS, PP
31	CT, DSA	VS	Intermediate	SOV, IPS, PP, ICS
32	DSA	HS	Intermediate	SOV

HS: horizontal segment of cavernous ICA, VS: vertical segment, PG: posteriot genu, SOV: superior ophthalmic vein, IOV: inferior ophthalmic vein, SPS: superior petrosal sinus, IPS: inferior petrosal sinus, CV: cortical venous, PP: pterygoid plexus, ICS: intercavernous sinus, BV: basal vein.

obliteration of the DCCF. The deflated balloon was then gently and carefully pulled out to deploy the stent. Heparin was not antagonized at the end of stent deployment. Low molecular weight (5000 IU) heparin was given subcutaneously every 12 h for 72 h, clopidogrel (75 mg/day) was administered for at least 12 weeks, and aspirin (100 mg/day) was continued for life.

Follow up

Detailed clinical evaluations were performed before treatment, immediately after treatment and later during followup. Either an MRA or a DSA was performed to assess the occlusion of the fistula, ICA patency, and any pseudoaneurysm formation.

Results

Imaging results

Among the 32 cases, 19 (59.4%) received CT scan without contrast and 5 (15.6%) received MRI scan before admission. Brain CT showed skull base fractures in 15 cases and exophthalmos with dilated SOV in 18 cases. MRI in all five cases showed abnormal flow void in the affected CS in addition to findings seen on CT scan. Cerebral DSA confirmed the diagnosis of DCCFs, with 15 (46.9%) of fistulas located at the horizontal segment and 21 (53.1%) at the vertical segment or posterior flexure of the cavernous ICA. In all of the 32 DCCFs, nine (28.1%) were characterized as high flow, 21 (65.6%) were intermediate, and two (6.3%) were low flow. Twenty-nine (90.6%) fistulas showed anterior venous drainage into SOV or inferior ophthalmic vein (IOV), 25 (70.1%) showed posterior drainage through the inferior petrosal sinus (IPS), superior petrosal sinus (SPS), or basal vein (BV), seven (21.9%) had superior drainage through cortical venous (CV), 20 (62.5%) had contralateral venous drainage to the opposite cavernous sinus through the intracavernous sinus, and 12 (37.5%) had inferior drainage via pterygoid plexus (Table 2).

Interventional results

A total of 97% (31/32) DCCFs were completely obliterated via transarterial endovascular approach at the end of treatment. Among 32 DCCFs, 21 (65.6%) were embolized only with detachable balloons, one case (3.1%) was treated with both detachable balloons and coils, eight (25.0%) only with coils, and two (6.3%) with covered stents.

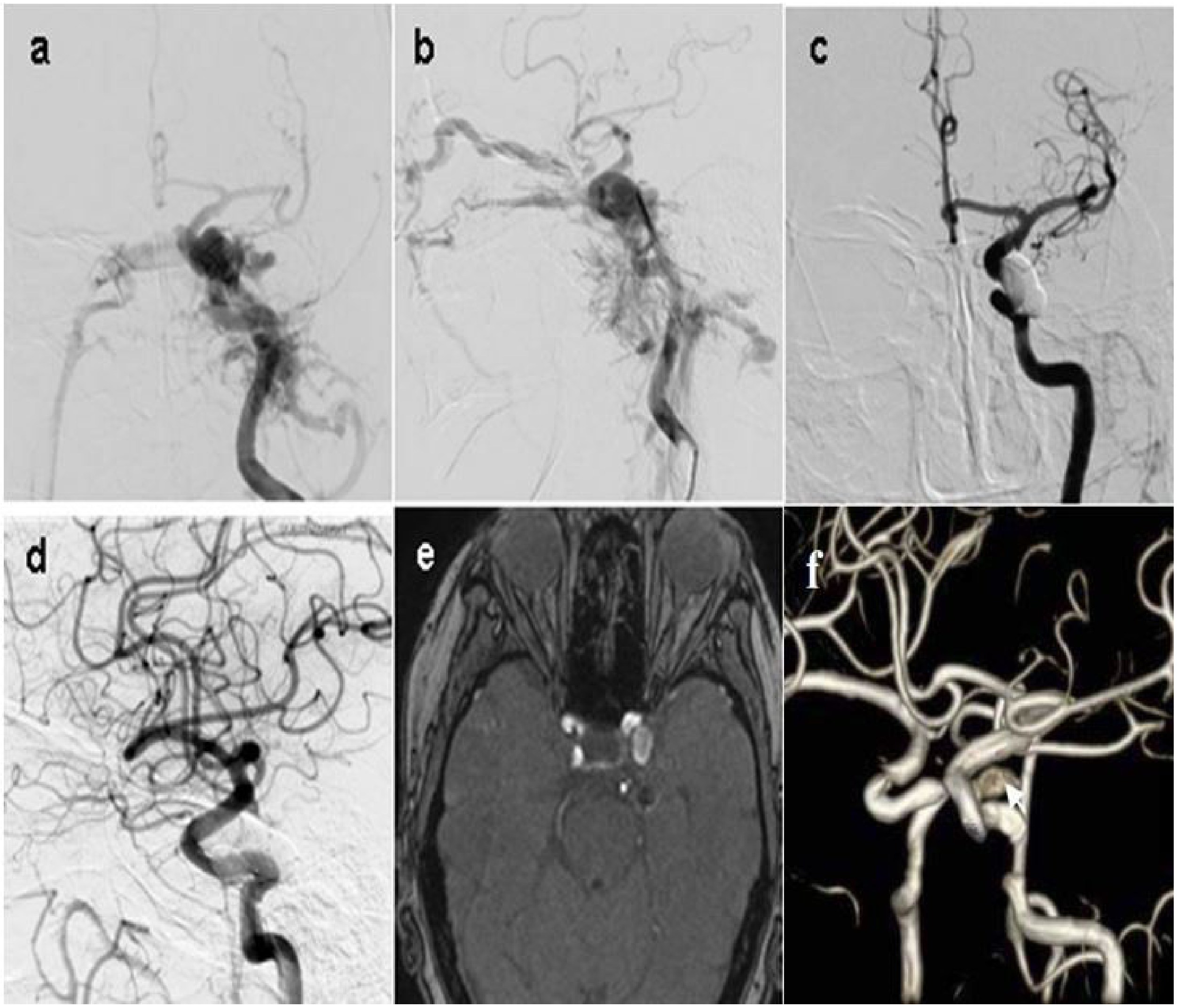

Figure 1. **Case 4 (a)(b) Left ICA angiogram shows a left DCCF. (c)(d) Left ICA angiogram shows the fistula is completely occluded by two detachable balloons. (e)(f) Followup MRA after 12 months shows an asymptomatic pseudoaneurysm in the left cavernous ICA.**

A. Endovascular treatment with detachable balloons

Twenty-two DCCFs were initially only treated with detachable balloons (Figure 1); however, two fistulas failed to occlude because of either premature detachment in one case or repeated puncture of the balloon by bony fragments in the other case. We only encountered one procedure-related complication using balloon alone which involved the accidental occlusion of the proximal ICA because of premature balloon detachment. The patient had good collateral arterial supply and consequently suffered no neurological deficit. Finally, the fistula was treated by a craniotomy with clipping of the C5 segment of the ICA distal to the ophthalmic artery. For the other aforementioned DCCF that had the obstructing bony fragments, further endovascular treatment using coils was performed to obliterate the fistula. Therefore, 90.9% (20/22) of the DCCFs were successfully treated with occlusion of the fistula using detachable balloon(s) alone. Thirteen fistulas required the endovascular application of only one balloon, with only one requiring two balloons, and six requiring three or more balloons. Before discharge, it was found that two DCCFs reoccurred at the 2^{nd} and 7^{th} day post-treatment, respectively, secondary to premature balloon deflation. As a result, subsequent detachable balloons were used to retreat these aforementioned two DCCFs successfully via a transarterial endovascular approach. Among the 20

DCCFs that were occluded with balloons, patency of the ICA was preserved in 17 (85.0%, 17/20) cases.

B. Endovascular treatment with coiling

Coiling alone was performed as the initial modality of treatment in eight DCCFs with low and intermediate flow fistulas (Figure 2). In one particular aforementioned DCCF with bony fragments, there was rupture of the detachable balloon secondary to puncture and therefore, coiling was done as an alternative to occlude the fistula. In that particular case, five coils were used to occlude the fistula with a subsequent application of a second detachable balloon that eventually led to the total occlusion of the residual fistula (Figure 3). Complete obliteration with preservation of the ICA was achieved in all patients undergoing coiling. On average, five coils were used for each coil-only treated fistulas. No procedure-related neurological complications occurred in any of these patients.

C. Endovascular treatment with stents

Covered stents were used in two DCCFs with a straighter or less tortuous carotid artery. Complete occlusion of the fistula was achieved in one patient immediately after stent deployment. Endoleak (representing blood flow outside the stent-graft lumen but within the confines of the fistula) was observed in another patient, thus re-dilation of the stent with a larger of diameter was performed, resulting in a complete occlusion of the fistula (Figure 4). There were no procedure-related complications seen within this subgroup of DCCF patients.

Clinical outcomes

Intracranial bruit that was present in 31 (100%) cases completely disappeared at the end of the embolization. Other symptoms documented such as chemosis and exophthalmos that were present in 28 (100%) cases gradually resolved within the next few days post treatment. Before discharge, 18 (90%) cases that were experiencing decreased visual acuity had improvement in symptoms with two other cases being unchanged. In addition, 18 (69.2%) cases with oculomotor palsy showed recovery along various degrees.

Follow-up results

All cases that underwent endovascular treatment and showed symptomatic improvement were followed up clinically. The followup ranged from 6 to 20 months, with a mean of 11.8 months. Among these patients who were followed, there was no recurrence of symptoms, including intracranial bruit, chemosis, exophthalmos, or intracranial hemorrhage. Oculomotor palsy recovered in various degrees in all of the 26 (100%) cases. However, two cases that presented with initial blindness in one eye showed no improvement in their visual acuity (Table 3).

A total of 18 DCCFs were followed up by MRA (n = 13) or DSA (n = 5). None of the 18 DCCFs showed abnormal flow void at CSs or dilated SOVs. However, pseudoaneurysms in the cavernous ICA were found in 4 (4/13, 30.8%) balloon-embolized cases with an average size of 5.8 mm (ranging from 2.9 to 9.5 mm) (Figure 4). Three of four pseudoaneurysm cases were asymptomatic with the fourth case exhibiting a mild degree of left oculomotor palsy. These patients were still followed up without any further treatment.

Discussion

Various treatment modalities have been documented in the literature for treatment of CCFs, in general. These range from conservative management, which consists of medical management and manual compression therapy; surgical management; stereotactic radiosurgery; and endovascular repair via a transarterial or transvenous route [23]. Recent advances in the endovascular technology have enabled this mode of treatment to be a primary treatment option after conservative therapies have failed [23]. The exact mode of treatment, as mentioned previously, is made from a combination of factors when a DCCF presents to the hospital that includes the type, exact anatomy of the fistula, size of the arterial defect, and operator/institutional preferences [23]. In turn, the treatment options for DCCFs have mainly centered on transarterial obliteration of the fistula with a detachable balloon, transarterial/transvenous obliteration of the ipsilateral cavernous sinus with coils or other embolic material, or deployment of a covered stent across the fistula [23]. Treatment at times may require more than one procedure as has been exemplified in the literature with the successful application of stenting with coil placement for DCCFs [27,43]. We will discuss the results of the endovascular techniques on DCCF obliteration individually in the following subsections and will compare the results with what has been established in the literature.

A. Endovascular treatment with Detachable balloons

Transarterial embolization with detachable balloons used to be the preferred method for treating DCCFs, however, due to issues with migration and premature detachment its use has decreased relatively [6,13,16,25]. In addition, the lack of availability of detachable bal-

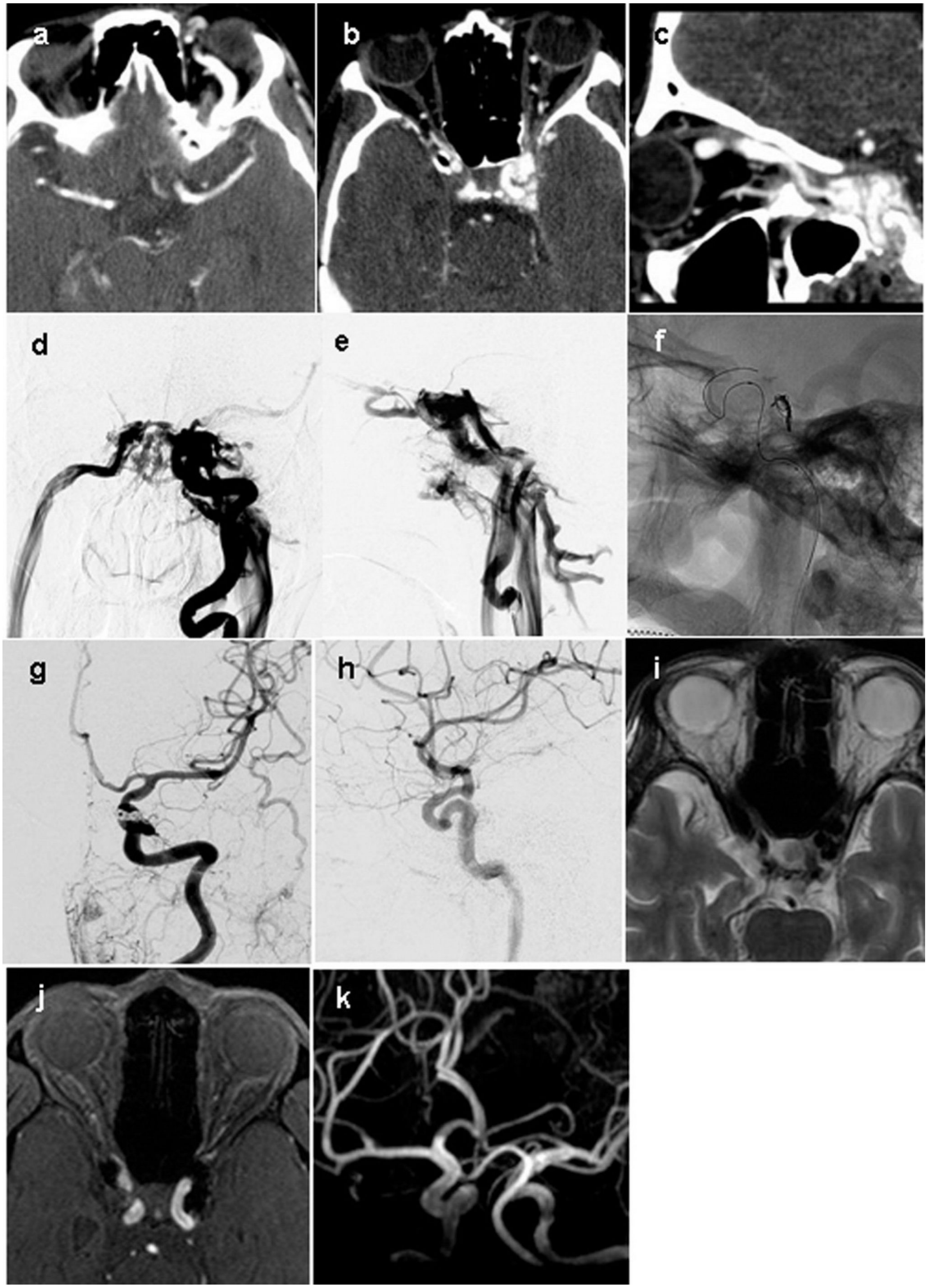

Figure 2. Case 12 (a)(b)(c) Enhanced CT scan shows a left DCCF with a dilated SOV. (d)(e) Left ICA angiogram confirms the diagnosis of CCF. (f)(g)(h) The CCF is completely occluded by four coils. (i)(j)(k) Followup MRA after 20 months show the obliteration of the CCF without any pseudoaneurysms.

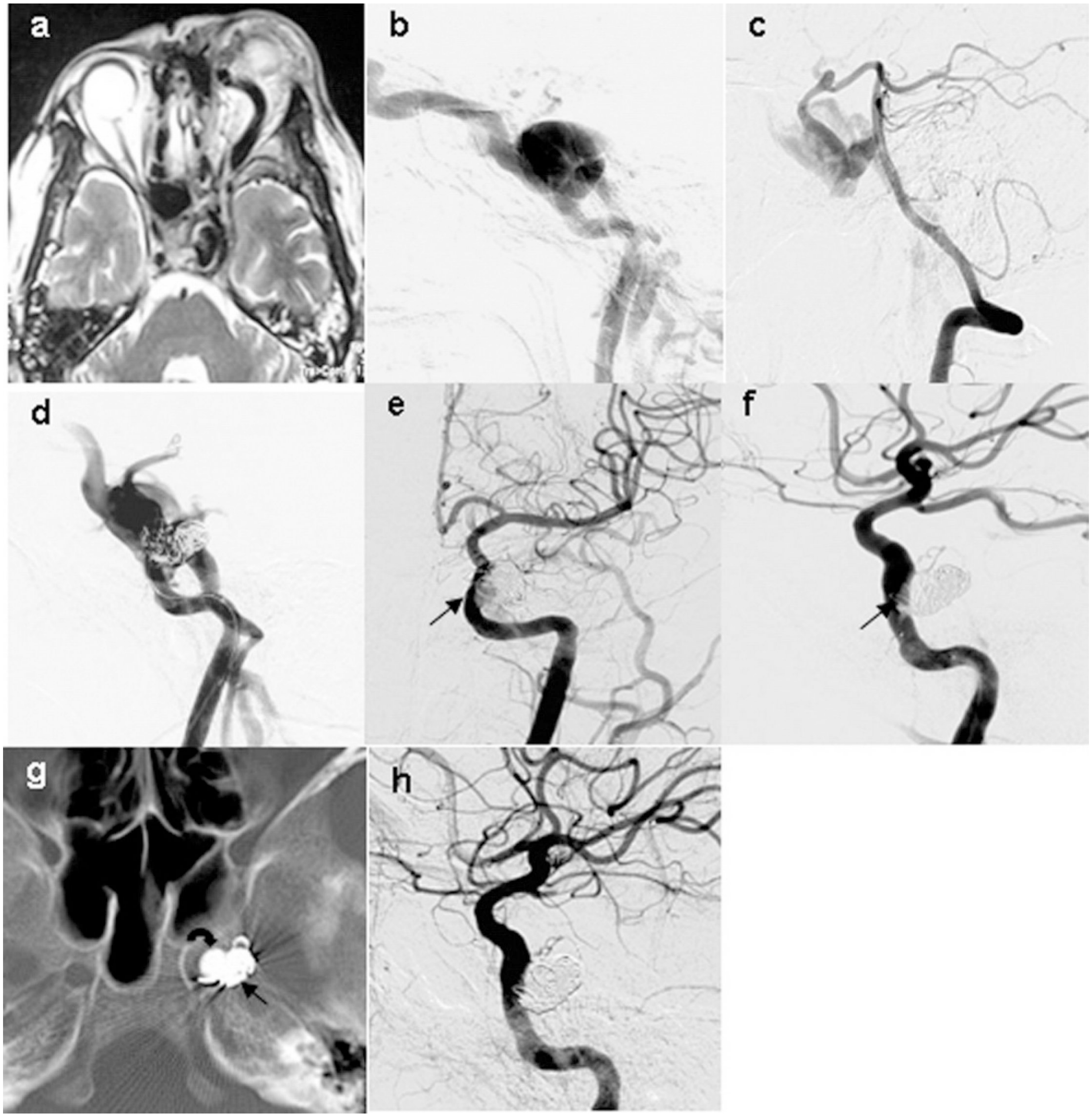

Figure 3. Case 15 (a)(b)(c) Left ICA angiogram shows a left DCCF with high-flow. (d) The fistula is still opacified after five coils was placed. (e)(f) The fistula is completely obliterated by placement of a detachable balloon between the coils mass and the tear of ICA. (g) CT scan after 5 days shows the balloon (curve arrow) and coil mass (arrow) in the left CS. (h) Follow-up DSA after 14 months shows the obliteration the CCF without any pseudoaneurysms or stenosis of right ICA.

loons eventually led to the adoption of both transarterial and transvenous coil embolization with adjunctive techniques of parent vessel protection [8]. The application of balloon catheter to occlude CCFs was first described by Prolo and Hanberry in 1971 followed by Serbinenko *et al* who reported the first case of a CCF embolization using a detachable silicone balloon with simultaneous preservation of the ICA [7,20]. The application of transarterial balloon detachment had been the accepted standard for endovascular treatment of DCCFs since 1980s. The majority of patients who are successfully treated using this technology show postoperative ICA patency

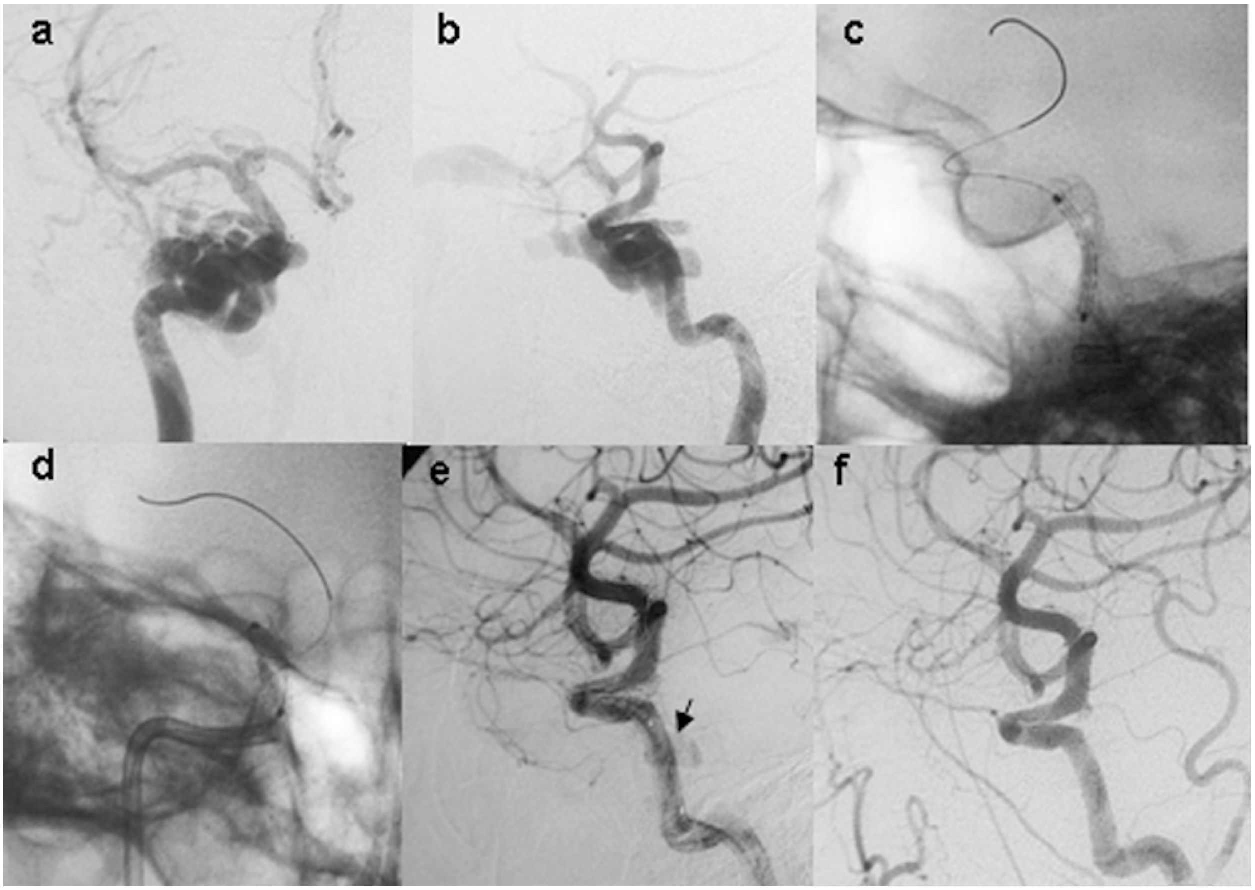

Figure 4. Case 21 (a)(b) Right ICA angiogram shows a right CCF with the tear locating at the vertical segment of cavernous ICA. (c)(d) A covered stent (Jostent 4 × 16mm) is deployed in the ICA over the fistula. (e) The stent is dilated with the nominated pressure (16 atm), but the endoleak (arrow) is still visualized. (f) The CCF is completely occluded with the patency of the involved ICA until the dilating pressure is up to 19 atm.

ranging from 59% to 88% [25,29]. However more recently the application of additional endovascular modalities such as coiling and stent application have added more options. The beneficial aspects of balloon-assisted DCCF treatment involve the easily flow-guided access into the cavernous sinus through the fistula. In addition, before detachment, it can be inflated, deflated and repositioned repeatedly. Direct CCFs are usually commonly accompanied by large carotid defects which frequently permit transarterial balloon occlusion of the fistula with preservation of the ICA [3,26]. Moreover, the application of detachable balloons is also relatively inexpensive. Therefore, balloon occlusion of the fistula was the most commonly used mode of treatment in our series. Using this technique alone, the occlusion rate of the fistula with preservation of the ICA was 85.0%, similar to other studies that documented a rate of 75%–88% [6,16,25]. For example, Plasencia and Santillan reported in their recent experience of using detachable balloons in 13 DCCF cases in Peru a cure rate of 92.3%, with ICA lumen preservation in 80% of patients [35].

Despite the benefits mentioned, the use of balloons in DCCF treatment also has established difficulties that may or may not be due to the balloon itself. For instance, the anatomy of the cavernous sinus and the size of the fistula itself can limit the success rate of detachable balloon embolization [37]. The cause of the failure to occlude the fistula by detachable balloons in our cases included premature detachment, premature deflation and migration, and puncture of the balloon by bony fragments, all of which have been documented in the literature [25,26,43]. In one particularly unsuccessful case, the first balloon could not completely occlude the fistula. However, the second balloon was prematurely detached at the tear of ICA during deployment. Despite occluding the proximal ICA, the fistula was still supplied by blood flow from posterior circulation. As a

Table 3. Endovascular treatment outcomes of all patients.

Patient	Embolic material	Immediate outcome	ICA patency	Retreatment	Clinical FU (month)	Image FU
1	DB	Cured	Yes	No	TR (14)	DSA
2	DB	Cured	Yes	No	TR (8)	No
3	DB	Failure	No	craniotomy	NA	NA
4	DB	Cured	Yes	No	OP (12)	MRA (Pseudo AN)
5	DB	Cured	Yes	No	TR (12)	No
6	Coil	Cured	Yes	No	TR (7)	MRA
7	DB	Cured	Yes	No	TR (13)	MRA
8	DB	Cured	Yes	No	One eye blind (8)	No
9	DB	Cured	Yes	No	TR (18)	DSA (Pseudo AN)
10	DB	Cured	No	No	TR (6)	No
11	DB	Cured	No	No	OP (13)	No
12	Coil	Cured	Yes	No	TR (20)	MRA
13	DB	Cured	Yes	No	TR (15)	MRA
14	DB	Cured	Yes	No	TR (12)	MRA
15	Coil, DB	Cured	Yes	No	TR(14)	DSA
16	DB	Cured	Yes	No	OP (9)	MRA
17	Coil	Cured	Yes	No	TR (13)	No
18	Coil	Cured	Yes	No	TR (8)	MRA
19	Coil	Cured	Yes	No	TR (13)	No
20	DB	Cured	No	No	TR(13)	MRA
21	Stent	Cured	Yes	No	One eye blind (11)	No
22	Stent	Cured	Yes	No	TR (12)	No
23	DB	Cured	Yes	Yes	TR (12)	DSA
24	Coil	Cured	Yes	No	TR (14)	No
25	DB	Cured	Yes	No	TR (12)	DSA (Pseudo AN)
26	DB	Cured	Yes	Yes	TR (14)	No
27	DB	Cured	Yes	No	TR (12)	MRA (Pseudo AN)
28	DB	Cured	Yes	No	TR (10)	No
29	DB	Cured	Yes	No	TR (9)	MRA
30	Coil	Cured	Yes	No	TR (13)	MRA
31	DB	Cured	Yes	No	TR (10)	MRA
32	Coil	Cured	Yes	No	OP (9)	No

ICA: internal carotid artery, DB: detachable balloons, Stent: covered stent, FU: followup, AN: aneurysm, TR: totally recovery, OP: oculomotor palsy, NA: not available.

result, the patient underwent a craniotomy with clipping of the C5 segment of the ICA distal to the ophthalmic artery. Premature balloon deflation and migration have been the most common causes attributed to recurrence of DCCFs in the literature [29]. This observation was validated in our series that showed the recurrence of two DCCFs before discharge that were secondary to premature balloon deflation. Both of these cases underwent a successful application of a second round of detachable balloons without sacrificing the ICA. We also encountered one case with repeated rupture of detachable balloons resulting from puncture by bony fractures. Further alternative treatment was undertaken by coil application for this case.

Besides the aforementioned disadvantages , there are some limitations of embolization of DCCFs by using detachable balloons. As mentioned above, the size of the fistula and the cavernous sinus may affect the success of balloon embolization of DCCFs. If the fistula is too small, it does not allow entry and inflation of the balloon. Similarly, the cavernous sinus should be large enough to accommodate the balloon for occlusion of the fistula. However, if the cavernous sinus is markedly enlarged, it cannot be completely filled even with multiple balloons. In other situations including a tortuous ICA or transection of the ICA, the use of balloon is also limited [2].

Moreover, delayed cavernous ICA pseudoaneurysm formations are frequently associated with balloon-occluded DCCFs with a reported rate of 30%–91% [29,31]. Because of the defective/weakening of the wall of the ICA once a fistula is potentially fixed, there is an increasing predilection for pseudoaneurysms to form after the detachable balloon deflates. Most pseudoaneurysms are asymptomatic, less life-threatening and with a progressive decrease in size over time and as such, conservative observation is reasonable. Nevertheless, a pseudoaneurysm in the CS may enlarge to exert mass effect on the surrounding structures, such as the oculomotor nerve, which may warrant further treatment. In our patient series that were followed up by angiography, four cases (36.4%) were found to have pseudoaneurysms after embolization with balloons. However, only one of these four cases exhibited a mild degree of oculomotor palsy. Thus these four patients were still followed up conservatively without any further treatment.

B. Endovascular treatment with coils

Transarterial cavernous sinus packing with coils is an alternate treatment for DCCFs [12,14,28,38]. This is especially true for the small to medium fistulas of 2–3 mm diameter [38]. The application of coils in transarterial embolization has now become a mainstay for high flow DCCFs as established in [43]. Embolization has been performed using both detachable platinum coils as well as silk/liquid embolic agents such as n-butyl cyanoacrylate (n-BCA), and ethylene-vinyl alcohol copolymer (EVOH) [25]. A microcatheter can be navigated into the cavernous sinus through a small tear that does not allow the passage of the balloon, allowing microcoils to be placed into the cavernous sinus resulting in occlusion of the fistula. The advantageous aspect of coil application is its easy retrievability, ability to be repositioned and better controllability. Before detachment, the coils can be adjusted easily or even removed if placement is not optimal [14]. In addition, factors such as the ease of access and availability of a variety of sizes of embolic device also favor the application of coils [26]. Using longer and thicker coils such as the HydroCoils may also reduce the total number of coils used [30,42].

In our series, we used coils alone to occlude eight DCCFs that presented with low to intermediate flow dynamics. It should be noted that this method still has some disadvantages for embolization of high-flow fistulas with large CS that encompass not only the element of high cost but also difficulties in determining the optimal volume of coils, coil protrusion, and migration into the ICA as well as failure of certain symptoms such as oculomotor palsy to be resolved secondary to residual mass effect [5]. Additional documented disadvantages include an overall slower/gradual occlusion of the fistula, which increases procedure time and the risk of incomplete fistula occlusion with the risk of losing transarterial access [26]. Balloon-assisted or stent-assisted techniques for coil placement may be effective for preservation of the parent artery [1,4,32]. In addition, the application of balloon assisted technique/stenting may also be needed to prevent retrograde herniation of embolic material into the parent artery and distal intracranial circulation [25,26]. Interestingly, sometimes the use of balloons can also reduce the total coil numbers used for embolization. It should be noted that in our first coiling case, the DCCF was not occluded during the attempted balloon procedure secondary to repeated puncture by the bony structures. Subsequently, five coils were deployed that alleviated the problem, however the fistula still remained open. A detachable balloon was used again after the coiling process to occlude the residual fistula. The balloon passed the site of the repeated tears and detached smoothly without early deflation and migration. Postprocedural angiograms showed the eventual obliteration of the fistula. In this way, a 3-D reconstruction angiography may help not only understand the structure of DCCFs, but also provide an objective assessment of the degree to which the fistulas are obliterated safely and effectively [20].

C. Endovascular treatment by stents

Recently, covered stents have become a promising therapeutic alternative for treatment of DCCFs and giant intracranial aneurysms [2,11,30,40,44]. Covered stents are considered extremely useful in the immediate obliteration of DCCF while simultaneously preserving the parent ICA patency thus reducing risk of ischemic stroke [25,43]. The stent is placed across the ostium of the fistula with preservation or reconstruction of the parent artery. Currently, the Jostent GraftMaster coronary stent has been the most commonly applied stent in literature [2,11]. The Jostent graft, composed of an ultrathin polytetrafluoro-ethylene (ePTFE) layer between two stainless steel stents, offers the potential advantage of immediate hermetic exclusion of a defect in the target vessel segment from the circulation without sacrificing the parent vessel itself, even in the setting of requisite anticoagulation or antiplatelet therapy [2,11]. However, owing to its limited longitudinal flexibility, the stent cannot be navigated in tortuous segments of the ICA. In addition, periprocedural arterial spasm and dissections have also been documented owing to the ends of the stents [6].

In our series of patients, the Jostent graft was used in the two DCCFs that had a straighter or less tortuous carotid artery. Complete occlusion of the fistula was achieved in one patient immediately after stent deployment. Endoleak was observed in another patient, thus re-dilation of the stent to a larger of diameter was performed to successfully eliminate the endoleak. One foreseeable explanation to the endoleak arises from the mismatch of the ICA and stent diameters. The Jostent graft used in this patient is 4 mm in diameter. Although the ICA diameter is usually on average <5 mm, it can ultimately be widened secondary to sustained long standing high-flow dynamics [2].

This leads to the ICA at the fistula exceeding the stent diameter causing the endoleak. Adjusting the stent size accordingly can minimize such occurrences [40]. Nevertheless, placing a longer stent to reduce endoleak adds more difficulty in maneuvering the stent towards the lesion owing to the increased stiffness of the stent thus adding difficulty in the treatment. This issue would be offset by the application of a more flexible covered stent in treating DCCFs.

Even though there is a limited amount of experience in literature on using covered stents, we do not consider it as the first choice for treating DCCFs. Their use is further limited due to lack of configurations compatible with intracranial use as well as long-term safety data [43]. If a DCCF is presented with a high flow, no tears at curved parts of the cavernous ICA and no tortuous arteries in the delivery pathway, then a covered stent may be considered applicable to maintain the patency of ICA. Nevertheless, the disadvantages stem from its dual concentric stent design, with the covered stent offering longitudinal stiffness and hence proving difficult to maneuver in tortuous vessels of the intracranial circulation. If a vessel tear is present at the curved parts of ICA (such as anterior and posterior genu of cavernous ICA), expansion of the covered stent becomes more difficult, which often leads to the failure of treatment. Moreover, long-term artery patency is an important issue. Although some authors reported satisfactory short to mid-term results [2,11] as mentioned previously, long-term effects are not clear. Larger series with an adequate long-term followup are necessary to ensure result reliability.

Conclusion

Endovascular embolization using balloons, especially via the transarterial approach is preferred for the treatment of DCCFs, despite some disadvantages. Coils embolization is an effective and safe alternative treatment, particularly when balloon embolization fails or when there are additional technical obstacles. Covered-stent placement may be used as another alternative in selected cases with favorable anatomy of the carotid artery. Literature has shown successful closure rates of 55%–99% of DCCFs using one or more endovascular techniques. Nevertheless, complications accompanied by endovascular techniques such as ICA occlusion, cerebral infarction and worsening of ocular palsy have to be taken into account as well [10,13,25,27,43].

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