Angioarchitecture and Treatment Modalities in Posttraumatic Carotid Cavernous Fistulae

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Summary

Posttraumatic carotid cavernous fistulae are abnormal direct hole communications between the intracavernous carotid artery and the cavernous sinus that can result from both blunt and penetrating trauma. They can be challenging lesions to treat and a variety of modalities and approaches have been proposed since endovascular treatment has become the standard treatment.

An analysis of the angioarchitecture of 32 consecutive patients treated in our service demonstrated that seven could be classified as small hole, eight medium and 17 large. Different size fistulae required varying endovascular tools. Small fistulae were best treated using coils and large and medium lesions with balloons. Large lesions were more likely to require multiple tools in order to achieve closure and had a lower chance of ipsilateral carotid preservation. All patients in the series were cured with a carotid preservation rate of 66%. There was no permanent morbidity associated with endovascular treatment.

Introduction

Posttraumatic carotid cavernous fistulae (CCF) are abnormal direct hole communications between the intracavernous carotid artery and the cavernous sinus that can result from both blunt and penetrating trauma. Fortunately these lesions are relatively rare and their incidence has been decreasing due to legislation making the use of protective gear and restraint devices in vehicles compulsory.

Although endovascular therapy is the standard treatment for these lesions there are quite a variety of approaches and endovascular tools used. Publications tend to emphasize the use of a particular treatment but in our experience a variety of devices may be required to close the fistula based on the time of presentation and the size of the fistula. We employ differing strategies based on the acuteness of the lesion and the angioarchitecture.

The goal of our study was to evaluate the endovascular management of posttraumatic CCF at our institution examining the tools used and outcomes in relation to angioarchitecture.

Methods

Patients

A retrospective review of patients who presented to Groote Schuur Academic and UCT Private Academic Hospitals with posttraumatic carotid cavernous fistulae and underwent endovascular treatment between January 2003 and December 2010 was performed. A total of 44 patients with carotid cavernous fistulae were identified from a database containing all patients who underwent endovascular treatment for a variety of neurovascular conditions. Six patients with spontaneous dural type fistulae were excluded. A further six patients were excluded due to incomplete medical records. A total of 32 patients were therefore included in our review.

Figure 1 A-C) Example of a small direct hole fistula occurring in a patient after a motor vehicle accident (A,B). The fistula was cured by placing a few coils trans-arterially through the fistula hole (C).

Demographic data obtained included age, sex, mechanism of injury, time from injury to presentation and time from presentation to treatment.

Clinical symptoms assessed at presentation included headache, proptosis, chemosis, orbital bruit, ophtalmoplegia, decreased visual acuity, altered facial sensation and epistaxis.

Angiographic Data

Diagnostic digital subtraction angiography was performed on all patients on admission and was reviewed for both venous and arterial char-

acteristics. All intracranial blood vessels were imaged and the size of the fistula determined. The fistula was described as small, medium or large. A small fistula had good distal ipsilateral internal carotid artery flow (Figure 1A-C), medium fistulae had decreased or no ipsilateral distal flow but no sumping of blood into the fistula from contralateral and large fistulae had no distal ipsilateral flow with sumping of blood into the fistula from the contralateral side or posterior communicating artery. In the presence of high and medium flow through the fistula, balloon occlusion of the fistula was the first choice of treatment and the largest balloon thought to

Figure 2 A-C) A large hole fistula with extensive cortical venous reflux into the deep and superficial venous systems (A,B). Post treatment with detachable balloons there is some contrast stasis within the cavernous sinus but carotid flow is re-established and there is no venous reflux.

be needed for occlusion was chosen. The balloon is navigated into the fistula using a road-map and slight inflation of the balloon just proximal to the fistula hole before catheter advancement. Occasionally the balloon microcatheter is steam shaped in order to access an opening that comes off at a difficult angle. Once the balloon is in the cavernous sinus it is incrementally inflated until the fistula is closed while the carotid remains open. In small fistulae where balloon navigation failed or was not attempted, coil placement was attempted via a trans-arterial microcatheter passed through the fistula hole.

The intracavernous segment of the internal

carotid artery was divided into three segments in order to describe the location of the fistula within the cavernous sinus. Zone 1 extended from the entrance of the internal carotid artery into the cavernous sinus to the origin of the meningohypophyseal trunk, zone 2 from the meningohypophyseal trunk to the origin of the inferolateral trunk and zone 3 from the inferolateral trunk to the exit into the subarachnoid space. Cross compression techniques injecting both contralateral carotid and vertebral vessels were performed to identify the location of the fistula in the presence of high flow where the fistula could not be clearly visualised¹. In cases

of very high flow where fistula location was not possible even after cross compression the location of the fistula was determined from the position of the balloon following treatment. Distal internal carotid flow to the ipsilateral hemisphere was also assessed as well as flow from the contralateral side and sumping of blood into the fistula from contralateral.

Venous characteristics assessed included the presence of a subarachnoid venous pouch, venous outflow from the cavernous and angiographic venous occlusion or thrombosis. The presence of cortical venous reflux was also assessed and divided into superficial and deep reflux as well as reflux into the posterior fossa.

Treatment Data

Endovascular treatment was performed through either a transarterial, transvenous approach or combined approach. The various treatment options available were recorded, including balloon embolization, coil embolization and embolization using NBCA. The indication for using transarterial NBCA was failure of fistula closure despite filling the cavernous sinus with as many coils as possible. As far as possible NBCA use with balloons should be avoided as balloon rupture is likely to occur. Systemic heparinization was not used during any treatment. Treatment outcome was assessed in terms of closure of the fistula, patency of the internal carotid artery and status of symptoms on discharge from hospital. Complications following endovascular treatment were recorded.

Results

Demographics and Clinical Presentation

The majority of patients were male (n=28) while only four females were treated for traumatic carotid cavernous fistulae. The average patient age was 34.1 years (range 17-74). The most common mechanisms of injury are illustrated in Table 1.

Seven patients presented early (within seven days) of the injury while the majority of patients (n=25) presented more than one week following the injury. The median time from injury to presentation was two months. Ocular symptoms were the most common presenting feature. No patient presented with intracerebral haemorrhage secondary to cortical venous reflux. At presentation,

one patient was comatose with extensive subarachnoid haemorrhage on CT scan and had no ocular signs or orbital bruit. Clinical features on presentation are summarized in Table 2.

Table 1 Mechanism of injury.

Mechanism of Injury	Number
Blunt trauma	21
– MVA	10
– Blunt assault	10
– Fall	1
Penetrating trauma	11
– Transorbital stab wounds	10
– GSW Head	1

Table 2 Clinical presenting features.

Clinical Features	Number
Proptosis	31
Chemosis	31
Orbital bruit	30
Ophthalmoplegia	17
– Complete	12
– 3 rd and 6 th nerve	2
– 3 rd nerve only	1
– 6 th nerve only	2
Decreased visual acuity	15
– No light perception	8
– Light perception	2
– Hand movements	4
– Count fingers	1
Headache	8
Decreased facial sensation	3
– V1 only	1
– V1 and V2	1
– V1 to V3	1
Epistaxis	1

Angiographic Features

The arterial architecture of the fistulae evaluated in our study is summarized in Table 3.

In a single patient the fistula was also fed by branches of the external carotid artery. This patient also had traumatic closure of the ipsilateral cervical internal carotid followed by a prolonged delay to presentation (nine years). As a consequence the cavernous carotid filled via retrograde flow through the inferolateral trunk from the external carotid branches. One patient also had ipsilateral traumatic carotid dissection which was simultaneously treated by endovascular stent placement.

The venous architecture is summarized in Table 4. Venous drainage through the superior orbital vein was present in almost all patients (n=29). The most common drainage pathway involved the superior orbital vein, pterygoid plexus and petrosal sinuses in combination. Two patients had no filling of the ipsilateral cavernous sinus due to occlusion, while occlusion of the superior orbital vein was present in another two patients. Cortical venous reflux was present in 20 patients and two of these had both ipsi- and contralateral cortical venous reflux (Figure 2A-C).

Table 3 Arterial architecture.

Arterial Architecture	Number
Location of fistula	
– Zone I	15
– Zone II	11
– Zone III	6
Size of fistula	
– Small	7
– Medium	8
– Large	17
Hemispheric blood supply on CCF side	
– Ipsilateral	16
– Contralateral	16
Sumping into fistula from contralateral	13

Table 4 Venous architecture.

Venous Architecture	Number
Subarachnoid venous pouch	11
Venous exits from cavernous sinus	
– SOV, pterygoid plexus, petrosal sinuses	17
– SOV only	5
– SOV, petrosal sinuses	6
– Petrosal sinuses only	2
– SOV, pterygoid plexus	1
– Pterygoid plexus, petrosal sinuses	1
– Contralateral cavernous sinus	14
Cortical venous reflux	20
– Superficial and deep	14
– Superficial only	5
– Posterior fossa	8

Treatment Results

The average time from presentation to treatment was 14 days. A total number of 40 procedures were performed on the 32 study patients. Multiple procedures were required in seven patients. One patient required three procedures and six patients required two procedures be-

fore fistula closure was achieved. The majority of the procedures (n=39) were performed through the transfemoral arterial route. A combined transarterial and transvenous approach (through the transverse sinus) was performed in one patient. Only one procedure was performed solely transvenously through the superior ophthalmic vein after unsuccessful attempt to place balloon or coils using a standard transarterial approach. A summary of the treatment modalities used to achieve closure of the different size fistulae is given in Table 5.

Transvenous coils were placed in one patient, retrograde arterial coils in four patients, anterograde arterial coils in three patients and retrograde transarterial NBCA injections in two patients.

Table 5 Fistula size and treatment modalities.

Fistula Size	Patient #	Coils	Balloon	Combined
Small	7	6	1	0
Medium	8	2	6	0
Large	17	1	10	6

Outcome Data

Complete occlusion of the fistula was eventually achieved in all patients. Successful treatment after the first procedure was achieved in 29 patients. Three patients underwent further procedures at a later stage before successful closure of the fistula. Five patients experienced recurrence of the fistula after initial closure and required additional intervention. Preservation of the carotid was possible in 21 (65.6%) patients. Proptosis and chemosis had improved in all patients at the time of discharge from hospital. Orbital bruit had also resolved in all patients. In patients with ophthalmoplegia, all except two had experienced improvement in the ophthalmoplegia at the time of discharge from hospital. At the time of discharge two patients with initial decreased visual acuity had experienced improvement. One patient had died due to associated injuries sustained during his initial injury.

Complications

A single patient experienced vasospasm following attempted balloon placement which was successfully reversed with intravenous nitrates.

Unintended distal embolization of glue cast occurred in two patients, balloon displacement in three patients and coil loops protruding into the internal carotid artery lumen in two patients. Occlusion of the fistula was also hampered by balloon rupture or deflation in eight patients. No patient suffered temporary or permanent neurological sequelae as a result of above complications.

Discussion

The majority of patients included in our study were male and of young age, which is to be expected in our clinical environment. Young male individuals are more likely to be associated with risk-taking behaviour, substance abuse and interpersonal violence². Direct carotid cavernous fistulae can occur following both blunt and penetrating craniomaxillofacial injuries and in our study most patients presented following blunt trauma (66%)³⁻⁷. Patients can present acutely or in a delayed fashion^{2,7}. Seventy-eight percent of patients had a delayed presentation following initial injury. A possible explanation for this is that periorbital swelling is often attributed to the head trauma and patients are often managed expectantly waiting for periorbital swelling to resolve^{8,9}. Only if periorbital swelling persists patients are referred for investigation of proptosis, which also delays the time to treatment. Our recommendation in this regard is that any patient with orbital penetrating trauma and all patients with proptosis following blunt head trauma be assessed for the presence of an orbital bruit and then undergo further investigation as appropriate⁸. Earlier diagnosis and intervention could significantly reduce the morbidity of deteriorating visual acuity for these patients in view of the fact that decreased visual acuity may become irreversible if treatment is delayed.

The majority of patients in our review presented with orbital symptoms as described in other series^{2,10-12}. Two patients presented with proptosis but had no filling of the SOV on angiography. Orbital congestion related to SOV thrombus was the cause of proptosis in these cases and symptoms are unlikely to improve in these patients even after fistula occlusion. Venous thrombosis is paradoxical in a high flow situation but is likely related to turbulent flow¹³. The majority of patients with ophthalmople-

gia experienced complete ophthalmoplegia (70.5%). This could possibly be explained by prolonged ischemia or stretching of cranial nerves following delayed presentation¹⁴⁻¹⁶. An interesting finding was that despite a very high rate of cortical venous reflux (62.5%) no patient initially presented with intracerebral haemorrhage^{3,11,13,17,18}. This is in contrast to spontaneous dural carotid cavernous fistulae where intracerebral haematomas occur more commonly. Postulated reasons for this are that traumatic direct CCF's present more acutely than the more slowly progressive orbital symptoms of dural CCF's and that traumatic fistulae occur in younger population with a more resilient venous system. We were also unable to demonstrate a clear relationship between cortical venous reflux and headache as the presenting symptom. The majority of patients with cortical venous reflux (70%) also had reflux involving both the superficial and deep venous systems of the brain. Careful evaluation of angiographic studies for the presence of filling of the deep venous system can therefore provide a way to confirm cortical venous reflux in situations where it is difficult to distinguish superficial cerebral veins from cerebral arteries. Although 40% of patients with cortical venous reflux experienced venous drainage to the posterior fossa, brain stem oedema and its associated complications remain an uncommon finding. Epistaxis has been described previously as an indication for urgent treatment¹³. In our review only a single patient presented with epistaxis and was successfully treated.

The fistula was most commonly located on the proximal and middle portions of the intracavernous carotid artery which appears to be a more vulnerable to injury. The explanation for this is that arterial injury is more likely to occur where the carotid artery is more fixed, for example at the proximal dural ring^{4,19}. Transorbital penetrating injuries are also directed towards the middle segment of the intracavernous carotid artery by the lateral orbital wall through the superior orbital fissure⁶. The majority of fistulae evaluated were large (53%). This appeared especially true for penetrating trauma where 82% of fistulae were large. Penetrating cranial injuries are therefore more likely to produce large CCF's while blunt trauma leads to smaller and more limited carotid perforations. We were unable to demonstrate any pattern between the direction of ve-

nous drainage and either fistula size or location of the fistula within the cavernous sinus²⁰. The most common venous drainage involved all the venous exits of the cavernous sinus. Although venous occlusion was fairly uncommon in our group of patients (n=4) it still remains the most likely cause of a focal venous drainage pattern. The presence of a subarachnoid venous pouch has been described as an indicator of high risk of bleeding and a need for urgent intervention¹³. A venous pouch was present in 34% of our patients, but none of them presented with haemorrhage. We therefore summarize that the presence of a subarachnoid venous pouch is not clearly associated with an increased risk of haemorrhage.

The majority of carotid cavernous fistulae can be successfully treated via the transfemoral arterial route which allows for both antero-grade and retrograde embolization of the fistula^{10,21}. Transvenous approaches have also been described in the management of especially indirect CCF²²⁻²⁸. The need for transvenous approaches is uncommon in the setting of traumatic CCF and often only required in the presence of proximal arterial occlusion where arterial access is hampered. A transvenous approach was only needed in two cases in our series, in one of which the patient had an ipsilateral dissection of the carotid artery. In the other patient the fistula was still filling after transarterial embolization of the fistula was performed but further cannulation of the fistula was not possible via the arterial route.

Various endovascular techniques have been described in the management of traumatic carotid cavernous fistulae, including balloon embolization^{29-31,42}, coil occlusion³²⁻³⁶, stent grafts³⁷⁻⁴⁰, NBCA embolization⁴¹ and a combination of these techniques. Balloon embolization, however, remains the most simple, effective and inexpensive treatment for this condition⁴². Although closure of the fistula by balloon embolization remains our first line of treatment, a large number of our patients required the use of additional agents to achieve successful closure. There are however certain situations in which treatment is more difficult. Firstly, in the very acute setting the fistula is fragile and a tract or dural laceration may only be covered with blood clot and attempted embolization of the fistula could lead to catastrophic haemorrhage. Our approach in this situation is to sacrifice the ipsilateral internal carotid artery during trapping distal and proximal to the fistula

hole. In very large fistulae with high flow and cavernous sinus enlargement, multiple balloons may be required and treatment may be complicated by balloon displacement after it has been detached. The presence of a subarachnoid venous pouch on angiography can be helpful in anticipating these problems. In very small fistulae, successful balloon occlusion is also unlikely and other treatment options should be considered.

With the use of NBCA injections to close the fistula, controlled injection is very important as distal embolization of the glue cast with resultant cerebral ischemia is a risk when the fistula is closed and distal flow in the internal carotid artery is restored. The moment the fistula closes and flow redirects into the carotid glue can be sumped into the carotid and distal vessels. Assessment for the presence of sumping of blood supply into the fistula from contralateral is very important, especially in cases where proximal occlusion of the internal carotid artery is considered. In these cases the absence of filling of the fistula on ipsilateral angiography is no guarantee of successful fistula closure and a high risk situation for bilateral cerebral ischemia also exists. Additional intervention via a retrograde transarterial or transvenous route may be required to close the fistula and remove the risk of cerebral ischemia. Sumping of contralateral blood supply into the fistula was present in 41% of our study patients and this situation therefore poses a significant risk of morbidity to the patient.

Successful treatment is usually defined as closure of the fistula with preservation of the patency of the internal carotid artery and resolution of symptoms^{11,12,42}. In our study the fistula was successfully closed with endovascular techniques alone in all patients and the patency of the internal carotid artery was preserved in 66% of cases. This is lower than the preservation rate quoted by Higashida/Halbach. The majority of our cases in whom the carotid was sacrificed (ten out of 11) were large fistulae and the other patient was treated acutely and had a large amount of subarachnoid blood on CT scan of the brain. Two of these patients also suffered recurrent balloon rupture after detachment and one patient also had coil prolapse into the ICA through a large fistula. In these patients a decision was made to sacrifice the carotid to obtain closure of the fistula. All patients experienced resolution of the orbital bruit on discharge from hospital with improve-

ment of proptosis and chemosis. Although the majority of patients with ophthalmoplegia experienced some improvement in symptoms, the long-term outcome and success of treatment is not available because of lack of follow-up. Improved follow-up is suggested both for patients with ophthalmoplegia and decreased visual acuity. It would be interesting to see whether treatment results in an improvement of visual acuity even though most patients present very late. In our study recurrence of symptoms usually occurred early and therefore early follow-up is suggested in these patients.

Conclusion

Classification of post-traumatic CCF into small, medium and large fistulae based on angioarchitecture is helpful in selecting treatment tools. Small fistulae are unlikely to accept detachable balloons but offer an inexpensive and safe option for medium and large fistulae. Large fistulae are challenging to treat and carotid preservation may be hard to achieve in this group. Cortical venous reflux is a common observation but did not result in haemorrhagic presentation in any of our cases.

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