A carotid-cavernous sinus fistula (CCF) is an abnormal communication between the cavernous sinus and the carotid arterial system. CCFs can be classified by cause (traumatic vs spontaneous), velocity of blood flow (high vs low flow), and anatomy (direct vs dural, internal carotid vs external carotid vs both).1,2 Some fistulas are characterized by a direct connection between the cavernous segment of the internal carotid artery and the cavernous sinus. These fistulas are usually of the high-flow type. They are called direct CCFs and are most often caused by a single, traumatic tear in the arterial wall or at times by the rupture of an intracavernous aneurysm.1,2 Other CCFs are dural.2,3 Many of these lesions are actually congenital arteriovenous fistulas that develop spontaneously, often in the setting of atherosclerosis, systemic hypertension, connective tissue disease, and during or after childbirth. Dural CCFs consist of a communication between the cavernous sinus and 1 or more meningeal branches of the internal carotid artery (Fig. 1), the external carotid artery (Fig. 2), or both (Fig. 3).1 Of these, fistulas involving branches from both the internal and external carotid arteries are the most common. These fistulas usually have low rates of arterial blood flow. In this article, the author discusses the pathogenesis, causes, clinical manifestations, diagnosis, treatment, and prognosis of dural CCFs.

**PATHOGENESIS**

Dural CCFs usually become symptomatic spontaneously. The pathogenesis of these fistulas is somewhat controversial.4 One hypothesis is that spontaneous dural CCFs form after the rupture of 1 or more of the thin-walled dural arteries that normally traverse the cavernous sinus.5 According to this hypothesis, after rupture, extensive preformed dural arterial anastomoses not directly involved in the fistula dilate and contribute collateral blood supply, resulting in an angiographic appearance indistinguishable from that of a congenital vascular malformation. Indeed, sequential arteriography demonstrates that the feeder vessels of dural CCFs change with time as the vessels spontaneously open and close.6 Although this theory is favored by some investigators,7 it fails to explain why spontaneous dural CCFs are more common in elderly women than in men. A second theory for the origin of dural CCFs is that most develop in response to spontaneous venous thrombosis in the cavernous sinus and represent an attempt to provide a pathway for collateral venous outflow.7 Most investigators favor this theory because it also explains the pathogenesis of arteriovenous fistulas that develop in the sigmoid and other dural sinuses.4

Although many patients who develop a dural CCF are otherwise perfectly healthy, certain factors
seem to be predisposed to the development of this lesion. These factors include pregnancy, systemic hypertension, atherosclerotic vascular disease, connective tissue disease (eg, Ehlers-Danlos syndrome type IV), and minor trauma (Fig. 4).8–10

**CLINICAL MANIFESTATIONS**

Dural CCFs usually occur in middle-aged or elderly women, but they may produce symptoms in either gender at any age, even in childhood or infancy.11 The symptoms and signs produced by these lesions are influenced by several factors, including the size of the fistula, the location within the cavernous sinus, the rate of flow, and especially the drainage pattern.12–14

**Posteriorly Draining Fistulas**

When dural CCFs drain posteriorly into the superior and inferior petrosal sinuses, they are usually asymptomatic. In some cases, however, such fistulas produce a cranial neuropathy, such as a trigeminal neuropathy,15 facial nerve paresis,16 or an ocular motor nerve paresis.17 In most of these cases, there is no evidence of orbital congestion.2,3 In most cases of ocular motor nerve paresis caused by a posteriorly draining dural CCF, the onset of the paresis is sudden, and only one of the ocular motor nerves is affected. The oculomotor nerve is most often affected, and the resulting paresis may be complete with the involvement of the pupil, incomplete with pupil involvement, or incomplete with pupil sparing (Fig. 5). In almost all cases, the paresis is associated with ipsilateral orbital or ocular pain, a presentation that initially suggests an intracranial aneurysm.18,19 The correct diagnosis in such cases is not evident until cerebral angiography is performed. In other cases, the posteriorly draining fistula produces an abducens or trochlear nerve paresis, again usually associated with ocular or orbital pain.5,18,20,21

The cranial neuropathies that are caused by a posteriorly draining dural CCF usually are the initial sign of the fistula. In many of these cases, failure to diagnose and treat the fistula leads eventually to a change in the direction of the flow of blood in the fistula. The flow becomes anterior, and patients develop evidence of orbital congestion. In other cases, the blood flow in the fistula is initially anterior, producing orbital manifestations. With time, however, the anterior drainage ceases, and posterior flow is associated with the development of the cranial neuropathy.

Dural fistulas that drain posteriorly sometimes cause brainstem congestion that may be associated with neurologic deficits.22 In addition,
such fistulas rarely may produce intracranial hemorrhage.23

Anteriorly Draining Fistulas

Dural CCFs that drain anteriorly usually produce visual symptoms and signs.3 In the mildest cases, there is redness of one or, rarely, both eyes caused by dilation and arterialization of both conjunctival and episcleral veins (Fig. 6). In these cases, the appearance may suggest a primary ocular disorder, such as conjunctivitis, episcleritis, or thyroid eye disease; however, a careful examination of the dilated vessels usually demonstrates a typical tortuous corkscrew appearance that is virtually pathognomonic of a dural CCF (Fig. 7).3,24,25 There also may be minimal eyelid swelling, conjunctival chemosis, proptosis, or a combination of these findings. Diplopia from abducens nerve paresis may be present (Fig. 8). The ocular fundus may seem normal, or there may be mild dilation of retinal veins.

In more advanced dural CCFs, particularly those with a high rate of flow, the symptoms and signs are identical with those in patients with a direct CCF.3,12,13,26–28 In these cases, signs of orbital congestion, including proptosis, chemosis, and the dilation of conjunctival vessels, are obvious and severe (Fig. 9).29–31 Diplopia may result from ophthalmoparesis caused by ocular motor nerve pareses, orbital congestion, or both mechanisms, and there may be significant periorbital or retro-ocular discomfort or pain, initially suggesting an inflammatory process or even the Tolosa-Hunt syndrome.32,33 Some patients develop facial pain, facial weakness, or both.34 Raised episcleral venous pressure may produce increased intraocular pressure that occasionally is quite high.24,27,35,36 Angle-closure glaucoma may develop from elevated orbital venous pressure, congestion of the iris and choroid, and forward displacement of the iris-lens diaphragm.28,37 In other cases, chronic ischemia produces neovascular glaucoma. Ophthalmoscopic abnormalities include venous stasis retinopathy with retinal hemorrhages, central retinal vein occlusion, proliferative

Fig. 3. Appearance of a dural CCF fed by extradural branches from both the internal and external carotid arteries (type D of Barrow and colleagues). (A) Selective left internal carotid arteriogram, lateral view, shows a large collection of contrast material in the cavernous sinus (arrow). The fistula drains anteriorly into the left superior ophthalmic vein, which is markedly enlarged (arrow). (B) Selective left external carotid arteriogram, lateral view, shows multiple contributions from extradural branches of the left external carotid artery (arrow). (Data from Barrow DL, Spector RH, Braun IF, et al. Classification and treatment of spontaneous carotid-cavernous sinus fistulas. J Neurosurg 1985;62:248–56.)

Fig. 4. External appearance of a 39-year-old woman with Ehlers-Danlos syndrome who developed spontaneous bilateral dural CCF. The fistulas were successfully closed using an endovascular approach, but the patient died several months later of unrelated vascular complications of the underlying disease.
retinopathy, retinal detachment, vitreous hemorrhage, choroidal folds, choroidal effusion, choroidal detachment, or optic disk swelling (Fig. 10).38–43

Visual loss, although less frequent than in patients with direct CCFs, occurs in up to 30% of patients with dural CCFs.5,30,31,44 It may be caused by ischemic optic neuropathy, chorioretinal dysfunction, or uncontrolled glaucoma.28,35,41

The ocular manifestations of unilateral dural CCFs are almost always ipsilateral to the fistula, but they may be solely contralateral or bilateral (Fig. 11).3,12,13,45 When unilateral fistulas cause bilateral manifestations, there is a high probability that the fistula is draining into cortical veins (Fig. 12).13

Although most dural fistulas are unilateral, bilateral spontaneous dural fistulas do occur. Patients with bilateral dural CCFs often have severe systemic hypertension, atherosclerosis, or some type of systemic connective tissue disease, such as Ehlers-Danlos syndrome type IV. Most patients with bilateral dural CCFs have bilateral findings; however, some patients with bilateral fistulas have only unilateral signs.3

In some instances, dural CCFs drain both anteriorly and posteriorly. In most of these cases, the only manifestations are those related to the anterior drainage; however, some patients develop manifestations from the posterior drainage, such as facial nerve paresis or acute hemiparesis associated with neuroimaging evidence of brainstem congestion.16,46

DIAGNOSIS

The diagnosis of a dural CCF should be considered in any patient who spontaneously develops a red eye, chemosis of the conjunctiva, abducens nerve paresis, or mild orbital congestion with proptosis. Auscultation of the orbit may disclose a bruit, but this is uncommon.

When a dural CCF is suspected, computed tomographic (CT) scanning, CT angiography, magnetic resonance (MR) imaging, MR angiography, orbital ultrasonography, transorbital and transcranial color Doppler imaging, or a combination of these tests may be of benefit in confirming the diagnosis (Fig. 13).2,3 The gold standard diagnostic test, however, remains a catheter angiogram. Because many dural CCFs are fed either

Fig. 5. Oculomotor nerve paresis caused by a posteriorly draining dural CCF. The patient was a 58-year-old man who developed an acute left-sided fronto-orbital headache. Four weeks later, he developed diplopia, and 7 days afterwards, he developed right ptosis and a dilated right pupil. He was thought to have an intracranial aneurysm, and an arteriogram was performed. (A) The patient has a left ptosis and exotropia consistent with a left oculomotor nerve paresis. (B) Selective left internal carotid arteriogram, lateral view, shows a left-sided posteriorly draining dural carotid-cavernous sinus fistula (arrow). The patient’s oculomotor nerve paresis resolved after the fistula was closed.

Fig. 6. Appearance of a 61-year-old man with moderate proptosis and redness of the right eye caused by a right-sided dural CCF. This appearance is often mistaken for episcleritis or dysthyroid orbitopathy.
by meningeal branches of the external carotid artery or by meningeal branches of both the internal and external carotid arteries, and others are fed by arteries from both sides or are fed by unilateral arteries but produce bilateral symptoms and signs, selective angiography of both internal and external carotid arteries on both sides should always be performed. When performed by an experienced neuroradiologist, catheter angiography has a morbidity of less than 1% and virtually no mortality, except in patients with connective tissue disorders, such as Ehlers-Danlos syndrome, in whom the risks are much greater because of the excessive fragility of the extracranial and intracranial vessels.

**NATURAL HISTORY**

Most patients with a dural CCF have no difference in mortality from that of the normal population because the lesion usually affects only the eyes. Spontaneous intracranial hemorrhage is exceptionally rare. Thus, when one considers the natural history of a dural CCF, one usually is dealing with ocular morbidity.

Regardless of whether they drain anteriorly or posteriorly and whether they are high-flow or low-flow fistulas, 20% to 50% of dural CCFs, even those associated with significant congestive orbital signs, close spontaneously (Fig. 14). In some cases, the symptoms and signs begin to resolve within days to weeks after symptoms.
develop; in others, they do not resolve until months to years after the fistula has become symptomatic. Other dural CCFs close after angiography, after air flight travel, or after incomplete treatment.\textsuperscript{48,49}

It is appropriate to follow clinically patients who have mild ocular manifestations to see if the fistula will close spontaneously. During the waiting period, patients need not alter their lifestyle. They should, however, be examined at regular intervals so that their visual function, intraocular pressure, and ophthalmoscopic appearance can be monitored. In the meantime, exposure keratopathy caused by proptosis can be treated with ocular lubrication, and persistent, bothersome diplopia can be treated with prism therapy or occlusion of one eye. Increased intraocular pressure is rarely so severe that it requires treatment.\textsuperscript{27} If it is substantially elevated, one can try to lower it with one of the many topical agents that reduce the production of aqueous humor; however, because the cause of the elevated intraocular pressure in most cases is raised episcleral venous pressure, such agents may not be helpful. In the final analysis, however, the best treatment of severely increased intraocular pressure is closure of the fistula.

Patients with a dural CCF may experience acute worsening of ocular manifestations. The clinical deterioration results from an increase in blood flow through the fistula in some cases, but in others, it is caused by spontaneous or posttreatment thrombosis of the superior ophthalmic vein.\textsuperscript{49–51} Patients in whom spontaneous progressive thrombosis of the superior ophthalmic vein causes initial worsening of symptoms and signs usually begin to improve within several weeks,
and most eventually experience complete resolution of symptoms and signs (Fig. 15). Systemic corticosteroids given when deterioration occurs may lessen the severity of symptoms and signs and perhaps reduce the length of time until recovery occurs.50

TREATMENT

The visual manifestations of a dural CCF usually do not require local treatment. Occasionally, as previously noted, increased intraocular pressure requires treatment with topical or oral pressure-lowering agents. Although pressure-lowering ocular surgery has been advocated for patients in whom medical therapy does not reduce the intraocular pressure to an acceptable level,55,52 if intraocular pressure remains unacceptably elevated despite maximum medical therapy, the definitive treatment of the fistula should be performed instead of ocular surgery. Ocular surgery should only be considered if the treatment of the fistula cannot be performed or is unsuccessful or if the intraocular pressure remains elevated despite closure of the fistula.38 Similarly, although the proliferative retinopathy that may occasionally accompany a severe, high-flow dural CCF can be treated successfully with photocoagulation,38,53 it is best to treat the fistula producing the retinopathy whenever possible. Again, if the fistula cannot be

![Fig. 12. Cortical venous drainage from a dural CCF. Selective left internal carotid arteriogram shows a dural CCF (single arrowhead) with drainage into the superior ophthalmic vein (double arrowheads) and also into several cortical veins (triple arrowheads).](image)

![Fig. 13. Noninvasive methods of diagnosing a CCF. (A), Ultrasonography of the orbit in a patient with an ipsilateral dural CCF. Note large round void (arrow) representing cross-section of an enlarged superior ophthalmic vein. (B) CT axial image in a patient with a right-sided dural CCF. Note enlarged superior ophthalmic vein (arrow). (C) MR axial image in a patient with a left-sided dural CCF. Note enlarged left superior ophthalmic vein (arrow).](images)
treated or treatment is unsuccessful, photocoagulation may be needed to preserve vision.

Dural CCFs may be treated by direct surgery, \textsuperscript{54} conventional radiation therapy, \textsuperscript{55} stereotactic radiosurgery, \textsuperscript{49,56} intermittent manual self-compression of the affected internal carotid artery with the contralateral hand, \textsuperscript{57,58} or occlusion of the ipsilateral internal carotid artery. \textsuperscript{59} However, endovascular procedures, including transarterial embolization, transvenous embolization, or a combination of these techniques, usually are the optimum treatment of those lesions that produce progressive or unacceptable symptoms and signs, including visual loss, diplopia, an intolerable bruit, severe proptosis, and, most importantly, cortical venous drainage. \textsuperscript{60} Several synthetic and natural materials can be used for embolization. Platinum coils are most often used, but other materials include absorbable gelatin (Gelfoam, Pharmacia & Upjohn, New York, NY, USA); Silastic (Dow Corning, Midland, MI, USA); low-viscosity silicone rubber; autogenous clot, muscle, or dura; tetradecyl sulfate (a sclerosing agent); polyvinyl alcohol particles (Ivalon, Unipoint Laboratory, High Point, NC, USA); ethanol; ethylene vinyl alcohol copolymer (Onyx, ev3, Irvine, CA, USA); oxidized cellulose (Oxycel, Worcester, UK); various preparations of cyanoacrylate glue, or a combination of these. \textsuperscript{30,31,45,58,61–79}

In patients with a fistula fed only by meningeal branches of the external carotid artery, the embolization material is introduced via a microcatheter placed in the external carotid artery and passed into the specific branch or branches that feed the fistula. In this setting, successful closure of the fistula is almost always possible, resulting in rapid resolution of all symptoms and signs. When the fistula is fed by meningeal branches from both the external and internal carotid arteries, only the branches from the external carotid artery are usually emboлизed in the hopes that the flow to the fistula will be sufficiently decreased to result in its subsequent closure. The internal carotid artery is usually not embolized in this setting unless the interventionalist can successfully catheterize the meningo-hypophyseal trunk or other meningeal feeders from the artery. If the fistula does not close with this technique, the fistula often can be treated subsequently via a transvenous route. In this setting as well as in patients whose fistulae are fed only by meningeal branches from the internal carotid artery, the favored transvenous approach is usually via the femoral or internal jugular vein into the ipsilateral or rarely the contralateral inferior or superior petrosal sinus and from there into the cavernous sinus, \textsuperscript{31,62,64–66,73,77} but if this approach fails, a variety of other approaches may be used, most of which involve the cannulation of the superior or inferior ophthalmic veins (Fig. 16). \textsuperscript{3,45,61,64,65,67,70,71,73,76,78} In some cases, more than one session and more than one approach is needed, and in rare cases, the cavernous sinus can be cannulated directly via an orbital approach. \textsuperscript{70,79} Using currently available techniques, successful closure of dural CCFs can be achieved in 80% to 100% (Fig. 17). \textsuperscript{26,31,45,69,77,80}

Complications from endovascular treatment of dural CCFs are uncommon except in patients with connective-tissue disorders, such as Ehlers-Danlos syndrome. \textsuperscript{9,81} Nevertheless, significant
complications have been reported, including hemorrhage at the catheter site, in the orbit from perforation of the superior or inferior ophthalmic vein, or even intracranially; damage to orbital structures, such as the trochlea when the superior ophthalmic vein is used for access to the cavernous sinus; local infection; sepsis; ophthalmic artery occlusion; and both transient and permanent neurologic deficits, particularly facial pain and ocular motor nerve pareses but also brainstem infarction.30,31,45,64,69,71–73,75,77,82–84 An analysis of 4 large series of patients with dural CCFs treated endovascularly revealed that of a total of 339 patients, there were complications in 35 (10.3%).30,31,45,77 Thus, because the embolization techniques used to close dural CCFs can be associated with vision-threatening and even life-threatening complications, physicians performing such procedures should explain to patients not only the benefits but also the risks of these...

Fig. 15. Spontaneous closure of a dural CCF after cerebral angiography. The patient was a 75-year-old woman who developed progressive conjunctival chemosis and injection of the right eye. (A) The patient’s right eye is swollen and chemotic. Cerebral angiography confirmed a right-sided dural CCF fed by branches of the right internal and external carotid arteries. It was elected to follow the patient without intervention. (B) Two weeks after the angiogram, the patient developed more severe swelling, injection, and conjunctival chemosis. Repeat angiography revealed that the superior ophthalmic vein had thrombosed and the fistula was closed. One week after the onset of worsening, the patient began to experience reduction in swelling and redness of the right eye. (C) Two months later, the patient has minimal swelling and redness of the right eye.
Fig. 16. Isolation (A) and cannulation (B) of the superior ophthalmic vein in a patient with an ipsilateral dural CCF.

Fig. 17. Successful endovascular closure of a dural CCF using a superior ophthalmic vein approach. (A) Before treatment, common carotid angiogram shows the fistula, which drains both anteriorly (double arrows) and posteriorly (single arrow). (B) Roadmap image shows multiple platinum coils within the fistula. (C) Postprocedure common carotid angiogram shows obliteration of the fistula with preservation of the flow through the ipsilateral internal carotid artery.
procedures and must be prepared to deal with them should they occur.\textsuperscript{83–85}

**PROGNOSIS AFTER TREATMENT**

It is not unusual for dural CCFs to recanalize or form new abnormal vessels after transarterial embolization with particles or other material.\textsuperscript{75} Recurrence of ocular symptoms and signs herald the recurrence of the fistula, and patients in whom manifestations recur require repeat angiography and consideration of further treatment. Symptoms and signs usually begin to improve within hours to days after the successful closure of a dural CCF (Fig. 18).\textsuperscript{3} Any preexisting bruit immediately disappears, and intraocular pressure immediately returns to normal. Proptosis, conjunctival chemosis, redness of the eye, and ophthalmoparesis (whether caused by orbital congestion or an ocular motor nerve paresis) usually resolve completely within weeks to months, and most patients have a normal or near-normal external appearance within 6 months. At the same time, patients with visual loss caused by choroidal effusion or detachment usually experience substantial, if not complete, recovery of visual function. Unfortunately, patients with visual loss caused by retinal damage (eg, central retinal vein occlusion) usually have persistently poor visual function.

Patients whose dural CCFs are treated with techniques other than endovascular closure, such as stereotactic radiosurgery, often take longer to improve than patients whose fistulas are closed by endovascular techniques.\textsuperscript{56,86} Nevertheless, these techniques may provide excellent results over time.

**SUMMARY**

The diagnosis and management of dural CCFs have improved substantially in recent years. The widespread availability of noninvasive imaging techniques combined with improvements in catheter angiography permit rapid and accurate diagnosis in most cases, and new endovascular and other therapeutic techniques allow most patients with these lesions to be treated successfully with little or no morbidity and mortality and with the resolution of most, if not all, clinical manifestations.
REFERENCES


