Detachable calibrated-leak balloon for superselective angiography and embolization of dural arteriovenous malformations

FERNANDO V. VIñUELA, M.D., GERARD M. DEBRUN, M.D., ALLAN J. FOX, M.D., AND SHINICHI KAN, M.D.

Department of Diagnostic Radiology, and Department of Clinical Neurological Sciences, University Hospital, London, Ontario, Canada

The authors describe a system comprising a small latex balloon attached to a Teflon catheter. The balloon has a distal calibrated leak which is used for intravascular embolization with isobutyl-2-cyanoacrylate. The balloon is easily detached after embolization. The combination of manual control of the balloon-catheter system, plus the ability of the balloon to navigate intra-arterially with the blood flow, makes this system suitable for superselective angiography and embolization of lesions supplied by the external carotid artery (ECA). This system avoids intimal dissection and concomitant arterial vasospasm when trying to negotiate steep distal curves of the ECA branches. Experimental embolization of several branches of the ECA in the dog, and clinical examples of treatment of dural arteriovenous malformations in three patients are described.

KEY WORDS • balloon embolization • angiography • arteriovenous malformation • cyanoacrylate

Dural arteriovenous malformations (AVM’s) present a well known pathological and angiographic entity that poses difficult therapeutic problems for neurosurgeons and neuroradiologists. The angiographic characteristics of these AVM’s have been described previously. They are found involving the supratentorial and/or infratentorial meninges. They may be supplied by meningeal branches of the external carotid artery (ECA), the internal carotid artery (ICA), or the vertebral artery, or they may have a mixed blood supply. It is essential to have detailed angiographic mapping of the blood supply of the dural AVM nidus, with superselective angiography of both ICA’s, both ECA’s, and both vertebral arteries. When there is a mixed blood supply to the nidus of the AVM, it may be possible to occlude it through catheterization and embolization of the ECA branches alone.

Experience with the endovascular treatment of dural AVM’s has been extensive. Different types of catheters, guide wires, and embolizing materials have been used by different investigators with a wide range of results. In an effort to spare as many normal arteries as possible, we have developed a system of intravascular balloon navigation for the embolization of small branches of the ECA. Details of this technique and some preliminary clinical examples of its use can be found in a recent paper. By this system, the balloon can be maneuvered around steep arterial curves without damaging the arterial intima, which substantially decreases the possibility of producing an intimal tear with concomitant arterial occlusion or severe vasospasm. The embolization can then be performed with the calibrated-leak balloon as close as possible to the nidus of the AVM. This distal embolization spares important proximal arteries involved in the blood supply of the skin, mucosa, and cranial nerves.

Our experience with this system in several branches of the ECA in 13 dogs and in three patients with dural AVM’s is presented here.

Experimental Series

Thirty-seven branches of the ECA in 13 dogs were selectively catheterized and embolized with isobutyl-2-cyanoacrylate (IBC). A No. 6 Cordis sheath was...
Fro. 1. **Left:** Angiogram showing a calibrated-leak balloon (straight arrow) in a branch of the lingual artery in a dog. The Teflon catheter (short curved arrow) is in the lingual artery trunk. The polyethylene catheter (long curved arrow) and introducer are in the common carotid artery.

**Right:** Superselective angiogram through the calibrated-leak balloon. The balloon (arrow) is distended with contrast medium and takes the shape of the small artery.

introduced into the dog's femoral artery and a No. 5.8 French thin-walled polyethylene catheter introducer* was positioned in the right or left common carotid artery.

A small latex balloon with a distal leak was attached to a thin-walled Teflon catheter (internal diameter 0.4 mm, external diameter 0.6 mm).† To change the balloon's direction, a second coaxial No. 4.2 French polyethylene catheter was slid up over the Teflon catheter until it was in contact with the base of the balloon.‡ The calibrated-leak balloon and Teflon and polyethylene catheter were placed in position by means of the introducer. The balloon could be advanced into specific branches of the ECA by inflation and deflation of the balloon, and by pushing and pulling the Teflon catheter.

It was possible to catheterize arteries forming a 90° angle with the main arterial trunk (facial and lingual arteries) by changing the direction of the balloon with the coaxial polyethylene catheter (Fig. 1). Arteries as small as 1 mm in diameter could be catheterized and embolized without producing significant intimal damage with concomitant vasospasm (Fig. 2). Embolization with IBC was considered successful if the glue configuration reproduced the pre-embolization angiogram, when no reflux of the IBC proximal to the balloon was observed, and when we were able to detach the balloon and leave it in the proximal aspect of the IBC column (Fig. 3). The ability to detach the balloon after embolization and leave it in place removed the risk of intra-arterial gluing of the balloon-catheter system. Post-embolization angiography was always performed, with detailed analysis of arterial branching proximal to the balloon.

The IBC delivery system described here is unsuitable for treatment of brain AVM's. The Teflon catheter attached to the calibrated-leak balloon is too rigid to negotiate the curves of the cortical arteries of the brain. For brain pial AVM's, we glue the same balloon to a more flexible and supple Silastic tube.†

**Case Reports**

The material and methodology used in our patients was exactly the same as that described in the experimental series. Three cases represent our total clinical experience in the treatment of dural AVM's with this technique.

**Case 1**

This 69-year-old man presented with a 3-week history of progressive redness, proptosis, and decreased vision in the left eye. Selective left ICA and ECA angiograms showed a small left dural carotid-cavernous fistula supplied by cavernous branches of the left ICA and ECA (Fig. 4 upper pair). Despite the small amount of arteriovenous shunting and the relatively mild natural history of the disease, it was decided to treat the fistula because of the patient's progressive visual deterioration.

The left common carotid artery was punctured in the neck, and a No. 7 Cordis sheath was positioned in the trunk of the left ECA. The calibrated-leak balloon was successfully manipulated and positioned in the artery feeding the dural fistula (Fig. 4 lower left). The fistula was embolized with 0.15 cc of IBC. Postembolization angiography showed complete occlusion of the dural AVM nidus (Fig. 4 lower right).

**Case 2**

This 26-year-old woman was admitted to the hospital with a typical tic doloureux involving the third division of the right fifth nerve. Angiography showed a posterior fossa-cerebellopontine angle AVM fed chiefly by the right anterior inferior cerebellar artery. There was also evidence of a right dural AVM, filled through a dilated posterior branch of the right middle meningeal artery (Fig. 5 upper left). This vessel was selectively catheterized with 0.5 cc of IBC delivered through the calibrated-leak balloon and Teflon catheter system (Fig. 5 upper right), resulting in complete obliteration of the dural AVM nidus (Fig. 5 lower).
Calibrated-leak balloon embolization of dural AVM’s

Case 3

This 22-year-old woman had progressive proptosis and decreased visual acuity of the right eye. Angiography showed a right retro-orbital AVM supplied by branches arising from the right internal maxillary artery and from the middle meningeal artery (Fig. 6A). Several small feeders were also detected originating from the right ophthalmic artery and directly from the right ICA.

The calibrated-leak balloon and Teflon catheter system was used to selectively catheterize and embolize with IBC two branches arising from the internal maxillary artery and one branch from the middle meningeal artery (Fig. 6B, C, and D). Post-embolization angiography showed that most of the AVM nidus supplied by the branches of the ECA had been obliterated (Fig. 6E). The portion of the dural nidus supplied by the ICA and ophthalmic arteries remained essentially unchanged.

Discussion

Intracranial AVM’s supplied by dural meningeal arteries and drained solely by dural meningeal veins are uncommon. In the posterior fossa, however, purely dural AVM’s are encountered more often. The internal maxillary, occipital, and middle meningeal branches of the ECA, as well as the tentorial branches of the ICA, are the arteries most frequently seen supplying these malformations. Their venous drainage is most commonly via dural veins into the dural venous sinuses.

From the pathological viewpoint, intracerebral, spinal, and dural AVM’s share the same morphological substrate: a conglomerate of vascular lumina with thickened malformed walls that are difficult to identify as either venous or arterial. The size of these abnormal vessels ranges from 5 to 60 μ. True arteriovenous shunting without an intermediate vascular network may also be observed.

Previous neurosurgical and neuroradiological experiences in the treatment of these vascular malformations show that the treatment of choice of this disease is either surgical removal or endovascular obliteration of the AVM nidus. Proximal occlusion of
FIG. 4. Case 1. **Upper Left:** Left internal maxillary arteriogram, lateral view, showing an abnormality of the superior ophthalmic vein (arrow) through a small dural carotid-cavernous fistula. The individual arterial feeders are not clearly identified. **Upper Right:** Internal carotid arteriogram, lateral view, showing abnormal early visualization of the superior ophthalmic vein (short arrow) through a branch of the inferolateral trunk (curved arrow). **Lower Left:** Angiographic “fistulogram” through the calibrated-leak balloon (straight arrow), with visualization of individual arterial feeders (open arrows) and the superior ophthalmic vein (curved arrow). The Teflon catheter (double arrows) negotiates a 360° curve of the internal maxillary artery. **Lower Right:** Post-embolization left common carotid arteriogram, lateral view, showing complete obliteration of the left dural carotid-cavernous fistula. The large branch arising from the inferolateral trunk is no longer seen. The vasospasm observed in the external carotid artery was produced by the post-embolization catheterization with a No. 5 French catheter.

...the AVM’s arterial feeders, either surgically or by the endovascular route, produces transient modifications of the dynamics of the AVM, but it does not achieve its final obliteration.\(^9\)

The technique of endovascular navigation with calibrated balloons and injection of IBC was developed from these previous experiences.\(^{11,13}\) The use of IBC challenges the therapist to position the calibrated-leak balloon as close as possible to the vascular malformation in order to avoid permanent occlusion of normal arteries. The development of the detachable calibrated-leak balloon permits very distal intravascular navigation into branches of the ECA, a task sometimes very difficult to achieve with standard
Calibrated-leak balloon embolization of dural AVM's

Fig. 5. Case 2. Upper Left: Selective internal maxillary arteriogram, lateral view, showing a large posterior branch of the middle meningeal artery (straight arrow) supplying a dural sinus fistula. There is abnormal early visualization of the sigmoid sinus (curved arrow). Upper Right: Superselective angiography of a posterior branch of the middle meningeal artery feeding the dural fistula (straight arrow). The calibrated-leak balloon (curved arrow) was introduced through the foramina spinosum. Lower: Post-embolization internal maxillary arteriogram, lateral view, showing obliteration of the dural fistula with preservation of the normal vasculature.

catheter and guide wire systems. It is possible for balloons to navigate intracranially through the basal foramina as shown in Cases 2 and 3. Superselective angiography of individual AVM arterial feeders is always performed before the embolization procedure in order to assess the proportion of the nidus that can be embolized from that feeder, and the approximate transit time to the nidus. This allows a determination of the most appropriate polymerization time for the IBC, so that it is possible to reach and obliterate the core of the AVM. The ability to maneuver the balloon distally within the artery decreases substantially the amount of the IBC needed and also the risk of occlusion of normal arterial branches.

Superselective angiography and embolization of different AVM feeders may be performed in one session or in several stages, depending on the size of the AVM and the duration of each therapeutic session.

The capability of this delivery system to catheterize distal branches of the ECA makes IBC embolization available as an alternative treatment in cases presently embolized with particles. The IBC is in liquid form when delivered into the arterial system, which enables it to reach the core of the AVM nidus, a task very difficult to accomplish with particle embolization. In some dural AVM's with multiple and bilateral feeders, a combination of particle embolization through a standard delivery system and IBC embolization via the system described here may produce a better overall result than a single method of embolization.

We limit the use of this delivery system to the ECA territory. The thin Teflon catheter holding the calibrated-leak balloon is too rigid to safely negotiate the sharp curves of cortical arteries of the brain. For IBC embolization of AVM's in the brain we use a latex calibrated-leak balloon attached to a more flexible Silastic tubing, as described by Debrun, et al.

Conclusions

1. The detachable calibrated-leak balloon system is a safe technique for embolization of dural AVM's with IBC.

2. This system allows superselective catheterization of distal branches of the ECA with a substantial decrease in arterial spasm and dissection.
FIG. 6. Case 3. A: Internal maxillary arteriogram, lateral view. Dural carotid-cavernous and retro-orbital arteriovenous malformations (AVM's) are visualized, supplied by feeders arising from the internal maxillary artery and anterior branch of the middle meningeal artery. The accessory meningeal artery (straight arrow) participates to a smaller degree. The abnormally enlarged superior ophthalmic vein (curved arrow) can be seen. B, C, and D: Pre-embolization superselective angiograms of individual arterial feeders, lateral view, showing the distal location of the calibrated-leak balloon (straight arrow) and peripheral curves negotiated by the Teflon catheter (curved arrow). There is a sudden deflection of the middle meningeal artery when it traverses the foramen spinosum (open arrow). E: Post-embolization external carotid arteriogram, lateral view, showing obliteration of most of the dural AVM supplied by external carotid artery branches. There is concomitant occlusion of the distal internal maxillary artery (thin arrow) and middle meningeal artery (thick arrow), with preservation of the accessory meningeal artery (open arrow) and normal arterial branches to the face.

3. Superselective distal catheterization of dural feeders provides good control of embolization with IBC. The distal position of the balloon and the smaller amounts of polymerizing substance required decrease the possibility of occlusion of proximal normal arterial branches.

4. This method of IBC embolization of dural AVM's may be used instead of particle embolization or as a complementary therapeutic tool in specific cases.

References
Calibrated-leak balloon embolization of dural AVM's

11. Kendall B, Moseley I: Therapeutic embolisation of the
eexternal carotid arterial tree. J Neurol Neurosurg Psychia-
try 40:937–950, 1977
therapy for arteriovenous malformations. Invest Radiol
10:536–537, 1975 (Letter)
13. Kerber C: Use of balloon catheters in the treatment of
of inoperable dura and sinus angiomia in an infant.
Neuropaediatric 8:451–458, 1977
15. Laine E, Galibert P: Anévrysmes artério-veineux et
cirsoïdes de la fosse postérieure. À propos de quarante
16. Latchaw RE, Gold LHA: Polyvinyl foam embolization
of vascular and neoplastic lesions of the head, neck,
17. Manaka S, Izawa M, Nawata H: Dural arteriovenous
malformation treated by artificial embolization with
18. McCormick WF: The pathology of vascular ("arterio-
19. McCormick WF, Boulter TR: Vascular malformations
("angiomas") of the dura mater. Report of two cases. J
21. Newton TH, Cronqvist S: Involvement of dural arteries
in intracranial arteriovenous malformations. Radiology
93:1071–1078, 1969
22. Newton TH, Troost BT: Arteriovenous malformations
and fistulae, in Newton TH, Potts DG (eds): Radiology
of the Skull and Brain, Vol II. St Louis: CV Mosby,
1974, Book 2, pp 2490–2565
malformation in the posterior fossa. Radiology 90:
27–35, 1968
24. Nicola GC, Nizzoli V: Dural arteriovenous malforma-
tions of the posterior fossa. J Neurol Neurosurg Psy-
dural AVM—embolization using aron alpha.] Neurol
Med Chir 20:845–851, 1980 (Jpn)
carotid arteriovenous fistula with detachable balloon.
Neuroradiology 17:265–267, 1979
27. Seeger JF, Gabrielsen TO, Giannotta SI, et al: Carotid-
cavernous sinus fistulas and venous thrombosis. AJNR
1:141–148, 1980
ogy of arteriovenous malformations embozided with
isobutyl-2-cyanoacrylate (bucrylate). Report of two