Embolization of Complex Vascular Lesions

ROBERT A. LOOKSTEIN, M.D., AND JEFFREY GULLER, M.D.

Abstract

Embolization, first described nearly a century ago, has recently emerged as a durable first-line treatment of many vascular conditions particularly in the field of endovascular surgery. As technological advancements allow easier and safer access to small and remote lesions, embolization is being utilized more frequently to treat difficult lesions. This technology has been used most extensively in the treatment of abnormal arteriovenous communications, where it has emerged as a first-line therapy. Recently, the application of these techniques to treat visceral artery aneurysms has been explored, with encouraging results. The endovascular therapy of aortic aneurysms has revealed numerous other applications for embolization therapy, including the treatment of iliac artery aneurysms and of failed aneurysm exclusion or endoleak. Embolization offers a minimally invasive treatment for lesions which have traditionally been considered inoperable, as well as those requiring extensive surgical resections and/or reconstructions that are associated with high morbidity.

Key Words: Embolization, endoleak, aneurysm, arteriovenous malformation.

Introduction

"EMBOLIZATION" means the intentional occlusion of a vessel by the introduction of some foreign material. This technique has been used extensively to occlude vessels in the last few decades as an alternative to traditional therapy or when traditional therapy has failed. Recently, embolization techniques have been employed more broadly and with greater precision and ease. As a result, this "last resort" technique has quickly evolved into first-line therapy for many complex clinical conditions. In this article, the specific role of this technology for the endovascular specialist will be reviewed, with attention to its use as an alternative to open surgery for the treatment of complex vascular lesions such as arteriovenous malformations, arteriovenous fistulae and visceral artery aneurysms, and as a perioperative adjunct to the endovascular treatment of aortic aneurysms.

History

Embolization has only recently attracted interest for the treatment of vascular lesions, but the technique was first described almost a century ago. In 1930, Brooks described injecting a fragment of muscle attached to a silver clip into the internal carotid artery (1). Lussenhop and Spence, in 1960, injected spheres of methyl methacrylate into the surgically exposed common carotid artery of a patient with an arteriovenous malformation fed by the middle cerebral artery (2).

Developments in catheter technology and embolic agents in the 1970s initiated the recent interest in embolization techniques. The availability of pre-shaped catheters and coaxial systems permitted the subselective placement of catheters. This advancement in turn made possible the selective delivery of embolic agents. In 1974, Lin et al. reported injecting silicone tubing through lumens only slightly larger than the embolization material (3). Later that year, Serbinenko described the use of detachable balloon catheters for embolization (4). Zanetti and

From the Department of Radiology, Division of Vascular Interventional Radiology, Mount Sinai School of Medicine, New York, NY.

Address all correspondence to Dr. Robert A. Lookstein, Department of Radiology, Division of Vascular Interventional Radiology, Box 1234, Mount Sinai School of Medicine, One East 100th Street, New York, NY 10029; email: robert.lookstein@mssm.edu

Sherman introduced the tissue adhesive isobutyl 2-cyanoacrylate in the United States in 1972 (5). Carey and Grace described gelfoam particles as embolic agents in 1974 (6). In 1975, Gianturco created the wool coil, which after subtle modifications is still in widespread use at present (7). Microcoils soon followed, allowing for the placement of coils through microcatheters. The Guglielmi detachable coil is a recent advancement in coil technology involving the introduction, through a microcatheter, of a coil attached to a guidewire that may be detached after the passage of an electric current through the guidewire to dissolve the attachment. This allows for the repositioning of the coil after leaving the catheter and the possibility for optimizing coil deployment (8). All of these devices have a place in embolization therapy and will be discussed as they relate to the clinical entities presented here (Fig. 1).

Since the entire spectrum of embolotherapy is fairly large, the discussion here will be limited to embolization of visceral artery aneurysms, embolization-ablation therapy of abnormal arterio-venous communications, and embolization related to the endovascular repair of abdominal aortic aneurysms.

Visceral Artery Aneurysms

A rare clinical entity, visceral artery aneurysm (VAA) remains a difficult, often catastrophic diagnostic problem. Almost 25% present already ruptured, which can be fatal in nearly 10% of these patients (9). The symptoms, natural history, and outcome of visceral artery aneurysms depend on the vessels involved. The most common sites are the splenic, hepatic, superior mesenteric, gastroduodenal, and pancreaticoduodenal arteries. Splenic artery aneurysms account for almost 60% of all splanchnic aneurysms. Causes include medial degeneration with superimposed atherosclerosis, portal hypertension, infection, fibromuscular dysplasia, trauma, and pancreatitis. It is important to mention that splenic artery aneurysms are also associated with pregnancy with a significant associated rate of rupture in the third trimester. As a result, other studies (10) have advocated aggressive treatment of these lesions in this specific population. Hepatic artery aneurysms usually are secondary to some form of trauma. Superior mesenteric artery (SMA) aneurysms are typically mycotic in origin.

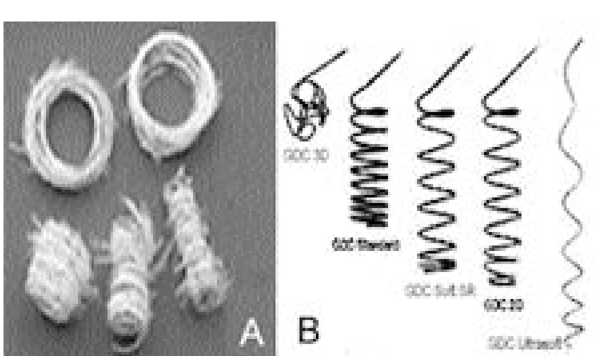

Fig. 1. (A) Embolization coils with Dacron fibers available in sizes ranging from 3 – 12 mm in diameter. Photograph reproduced with permission from Cook (Bloomington, IN). **(B)** Guglielmi detachable coils (GDC). Photograph reproduced with permission from Boston Scientific (Fremont, CA).

Traditional therapy consisted of surgical management with aneurysm repair and resection. Today, endovascular embolization techniques offer a safe alternative that has shown excellent short-term success. There are a limited number of published reports (11 – 14) regarding embolization of visceral artery aneurysms. Most series report on the use of coils for the procedure or a combination of coils and a liquid agent (Fig. 2).

Carr et al. reported on another single-center experience with 37 patients with VAAs (11). Seventeen patients underwent surgery, 12 had transcatheter embolization, and 8 were observed. Only poor surgical candidates were referred for embolization. All embolizations were successful, although several required repeat interventions. One patient who underwent embolization of a splenic artery aneurysm had a small post-procedure splenic infarct which resolved spontaneously. The authors went on to comment that embolization is quickly becoming the treatment of choice for these lesions in all patients. Advantages include precise localization of the aneurysms, better assessment of collateral flow, lower risk to the patients, and easier access to lesions for which surgical exposure would be difficult (11). Other authors have advocated the use of embolization rather than surgical repair as a first-line therapy for hepatic artery pseudoaneurysms, because of the decreased morbidity associated with the former procedure (12).

Gabelman et al. in 2002 reported a single-center, 10-year experience with 25 patients that demonstrated a 92% initial success rate with coil embolization. Long-term follow-up showed only one recurrence after 12 months. It is important to note that these patients must be followed with serial imaging to document success

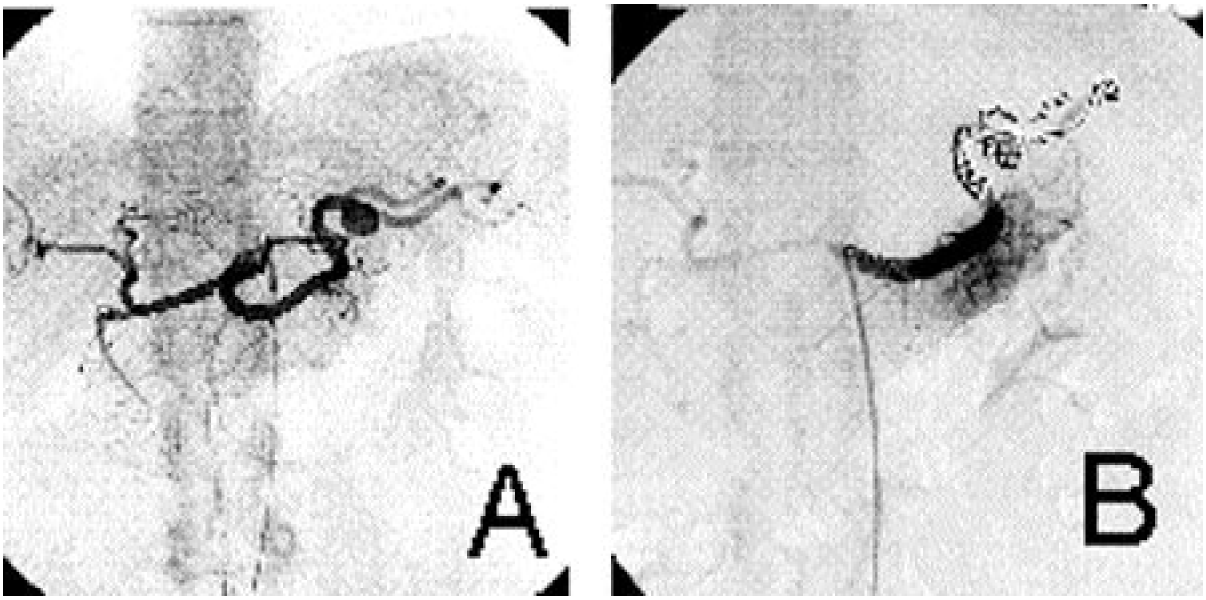

Fig. 2. (A) Cross-sectional imaging of splenic artery aneurysm in a 47-year-old female with hypertension. Selective celiac arteriogram demonstrates an aneurysm in the mid-portion of the splenic artery. **(B)** Selective splenic artery angiogram shows no flow into the aneurysm following coil embolization.

of the procedure and to monitor for future recurrence (13). Pilleul and Dugougeat showed the value of follow-up imaging in identifying incomplete embolization in 4 out of 18 patients treated in their series (14).

With the more widespread use of radiologic imaging, visceral artery aneurysms are being detected with increasing frequency. Because rupture of these lesions is associated with significant mortality and morbidity, treatment of asymptomatic patients is becoming a more prudent method of treatment. Endovascular embolization offers a low-risk alternative, especially for high-risk patients.

Abnormal Arteriovenous Communications

Vascular malformations are currently one of the most challenging conditions to diagnose properly and treat effectively. Because these lesions are relatively rare, few physicians have adequate experience with them.

The most important step in the management of patients with this condition is to properly diagnose and classify the lesion. This will in turn can give a patient realistic treatment options and expectations. Vascular malformations can currently be classified into four major categories:

- hemangioma
- arteriovenous fistula
- arteriovenous malformation
- venous malformation (15).

This classification can reliably differentiate between lesions with different treatment options and differing prognoses.

Hemangioma

A hemangioma is a benign vascular neoplasm, classically diagnosed in infancy. This lesion is characterized by a proliferative phase that is usually followed by spontaneous involution. Hemangiomas occur in infancy in almost 10% of the population. They may be present at birth or soon after and may be multiple in up to 20% of cases. These lesions are more frequent in females (15). Clinically, these lesions may begin as small, red discoloration and can rapidly proliferate to eventually show ulceration, bleeding, or infection. The lesions frequently involute in the majority of cases by the beginning of adolescence. Any residual discoloration can be readily treated by plastic surgery (16).

Arteriovenous Fistula

An arteriovenous fistula (AVF) is a direct communication between an artery and a vein. These lesions are usually acquired as a result of trauma. It is crucial to understand the physiology of these lesions in order to plan treatment. The basic architecture is that of a low-pressure sump. The flow through the fistula depends on the size and length of the communication. This connection will classically enlarge over time, first with hypertrophy of the feeding vessel and finally with hypertrophy of the draining vessel. Whenever the resistance in the venous outflow is less than that of the distal arterial bed, as is generally the case, then arterial flow to the tissue may be insufficient to sustain tissue viability. This will manifest itself as distal ischemic changes, claudication, skin and muscle atrophy, and even gangrene. Extensive collateral networks typically accompany arteriovenous fistulae to supply the distal tissues. This is why simple interruption of the feeding artery will not close down the fistula. Other physiologic changes that can occur include venous hypertension and venous insufficiency, which can progress to changes seen in a left-to-right shunt, such as high-output heart failure.

Treatment of the condition must aim at occlusion of the fistula with preservation of distal flow. In many instances, especially, those related to trauma, the best results for treatment of these lesions still depend on surgical repair. This is certainly the case in short, side-to-side extremity fistula. At present, endovascular grafts can be used in limited settings but are not ideal for treating distal lesions or lesions located next to joints. For those lesions that are difficult to treat surgically due to complex anatomy or difficult access, embolization may be the initial treatment. The embolization procedure is directed at occluding the fistula or at isolating the artery that is feeding the fistula (Fig. 3). The choice of material will usually depend on the specific setting, but typically will consist of large permanent agents such as coils or detachable balloons (17) (Fig. 4). Particulate or liquid agents are not routinely used for large lesions, due to the risk of shunting and resultant embolization of the pulmonary circulation. After embolization, arteriovenous fistulae are considered cured and recurrences is rare. Improper embolization can turn a readily treatable lesion into a very complex one that may ultimately require surgical repair.

Arteriovenous Malformations

Arteriovenous malformations (AVMs) are congenital anomalies that result from a focal failure of vascular differentiation *in utero* between the fourth and tenth weeks of development. These are typically isolated lesions, which are not genetically transmitted. Depending on the size and location, these lesions can be asymptomatic and undetected or can be significant clinical problems. AVMs can occur anywhere in the body but have "predilections" for specific sites, including the central nervous system, the pelvis and the lower extremities. If the lesion is accessible for physical examination, it will present as a pulsatile, non-tender mass. The draining veins can be quite prominent and the presenting symptom can often be venous hypertension in an affected extremity, with skin thickening, edema and venous ulcera-

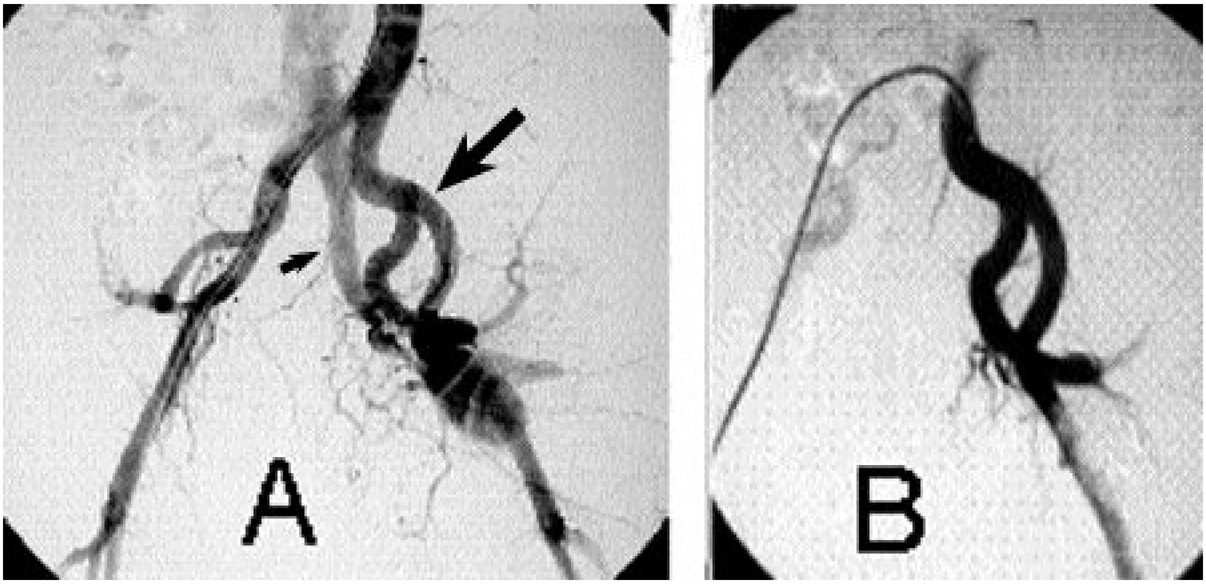

Fig. 3. (A) Pelvic angiogram demonstrates arteriovenous fistula (iliac artery: large arrow; iliac vein: small arrow) following transgluteal pelvic lymph node biopsy. **(B)** Following coil embolization of the fistula, an angiogram from the left common iliac artery demonstrates no arteriovenous shunting.

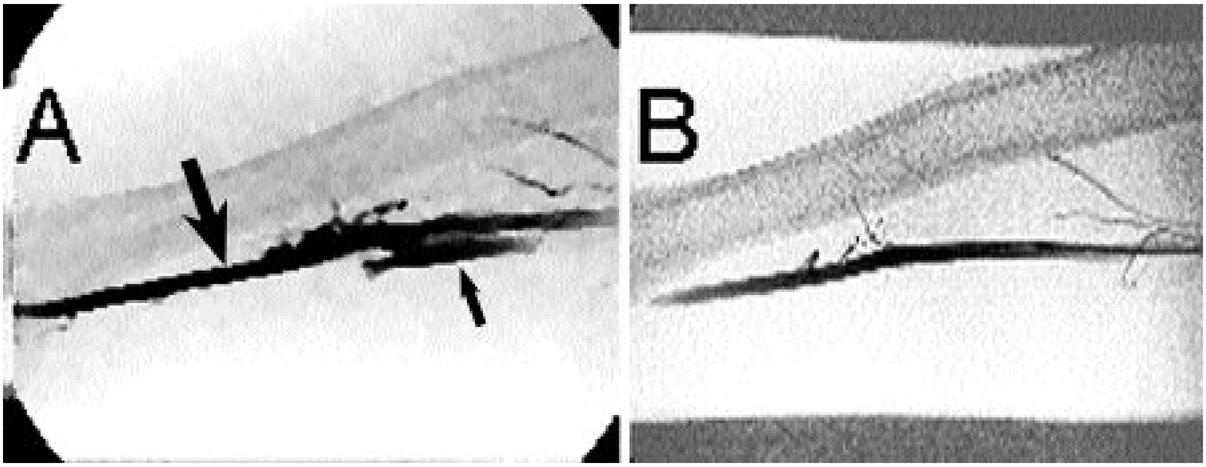

Fig. 4. **(A)** Angiogram of the brachial artery (large arrow) shows a traumatic arteriovenous fistula which occurred following placement of a peripherally inserted central catheter (PICC) line (small arrow: brachial vein). **(B)** There is no flow in the fistula after placement of a single Guglielmi (GDC) coil in the fistulous tract.

tion. When limb lesions present in childhood, limb length can be affected, usually by overgrowth. Generalized cardiovascular effects from congenital AVMs are quite rare. These lesions tend to grow slowly, but rarely some lesions can show periods of rapid enlargement. This classically occurs following a change in the hormonal environment or after unsuccessful surgical or radiological treatment. The first scenario is classically seen in female patients following menarche or pregnancy. The second scenario occurs when a stable lesion is treated resulting in recruitment of new collaterals. This will usually occur following ligation or proximal embolization of feeding arteries (16). Cross-sectional imaging has become the standard modality to properly diagnose these lesions and plan treatment. CT angiography (CTA) and magnetic resonance angiography (MRA) can demonstrate the true extent of the lesion and show the relationship of the lesion to surrounding structures. These imaging studies can also serve as a baseline, which can be repeated after treatment to monitor resolution or progression. Diagnostic angiography is not routinely performed in these cases, but can give detailed depictions of the vascular anatomy, including the demonstration of enlargement and tortuosity of feeding arteries, a dense nidus of malformation and early opacification of draining veins. Most malformations show one primary feeding artery with multiple small secondary feeders. When only the primary feeder is occluded, the secondary feeders will be recruited to supply the nidus.

AVMs are notoriously refractory to treatment. It is well known that these lesions can rarely be resected completely without tremendous blood loss and serious risk to the patient (18). Preoperative embolization can in certain instances convert an unresectable lesion into a resectable one. At present, transcatheter embolization has a primary role in the management of these lesions. Although recent technological advances in this field have made catheterization of these lesions less technically challenging, this must be tempered by the fact that improper embolization can worsen a previously symptomatic lesion. Risk and long-term results must always be presented to the patient. Complete cures are rare, and as a result, asymptomatic lesions should not be interfered with, for fear of complicating the situation. Both the treating physician and the patient must be realistic about the possibility of repeated future interventions. Each patient should be treated by a team that includes radiologists, vascular surgeons, plastic surgeons, orthopedists, and anesthesiologists.

Many embolization materials are available for the treatment of these lesions. All of these materials have been reported in the literature. With recent technological advancements, two agents have emerged as the choices for use in this setting: liquid adhesives and absolute alcohol. They have become popular because it is possible to deposit these agents solely in the nidus and minimize any damage to surrounding vessels and tissues. The liquid adhesives isobutyl cyanoacrylate (IBCA) and n-butyl cyanoacrylate (NBCA) have become the first line of therapy at many centers (16). These agents polymerize on contact with ionic material such as blood. They can be delivered through microcatheters into a vascular malformation and form a cast of the multiple small vessels near the nidus of the malformation. Although casting of the entire nidus is the goal, complete obliteration is often not achieved.

Other authors have popularized the use of absolute ethanol for the treatment of arteriovenous malformations (19). Ethanol ablation therapy can be performed either by the transcatheter technique, introduced as close to the nidus as possible or by direct puncture of the lesion. Ethanol induces thrombosis by denaturing blood proteins, dehydrating vascular endothelial cells and precipitating their protoplasm, denuding the vascular wall totally of endothelial cells, and segmentally fracturing the vascular wall to the level of the internal elastic lamina. The combination of these events causes an acute thrombosis. Advocates of this agent state that it destroys the lesion being treated by obliterating the vascular wall. This is a permanent treatment, whereas the liquid adhesives have had isolated reports of recanalization. The proponents of adhesive embolization discount alcohol therapy as being too caustic, with a relatively high incidence of skin or mucosal sloughing following treatment (16).

Pulmonary AVM. These lesions are treated even if the patient is asymptomatic. The risk of these lesions is an enhanced physiologic right-to-left shunt, which can result in hypoxia or a paradoxical embolus resulting in stroke or brain abscess. These lesions, which are classically treated with detachable balloons or coils, are not true AVMs in that they do not recruit new collateral feeders. As a result, occlusion of the pulmonary arterial feeder usually is curative. Complete embolization of the feeding vessel has been shown to be curative in almost 90% of cases, with the remainder easily treated by secondary procedures. Long-term follow-up has shown excellent durability of this procedure when either agent (coil or balloon) is used (20) (Fig. 5).

Renal AVM. These lesions can be asymptomatic for long periods of time and then present with significant hematuria. Classically, they are found in the right kidney of adult females. Embolization is now considered first-line therapy for them, as it produces excellent results (21). The procedure can be performed with either coils or a liquid agent. We prefer the use of liquid adhesives and have found them to be extremely safe and durable (Fig. 6).

Extremity AVM. These lesions are among the most difficult to treat. Because they often interfere with function of the limb, it is difficult to predict preoperatively how the embolization of the lesion will affect the extremity involved. These lesions are rarely treated completely, and more often than not they will require repeat procedures and ultimately surgery. It is imperative not to attempt proximal ligation or embolization of these lesions, because this can make future procedures all but impossible. Long-term follow-up of embolization of extremity AVMs suggests that better results are obtained from the treatment of upper extremity

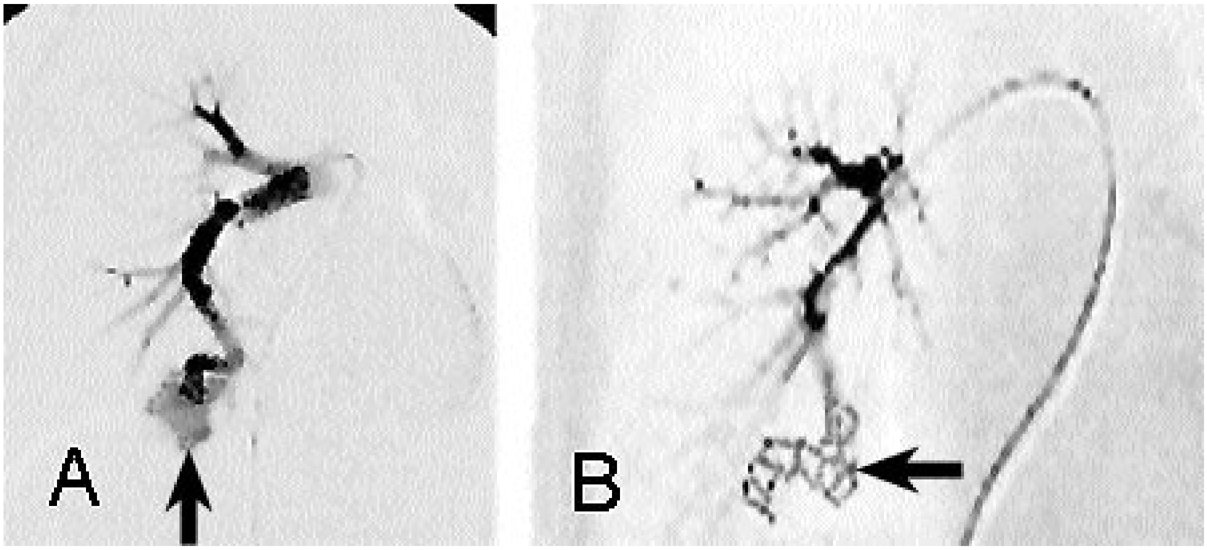

Fig. 5 (A) Right pulmonary angiogram shows a pulmonary AVM (arrow) arising off the right posterior basal artery. **(B)** Following coil (arrow) embolization, there is no flow in the AVM.

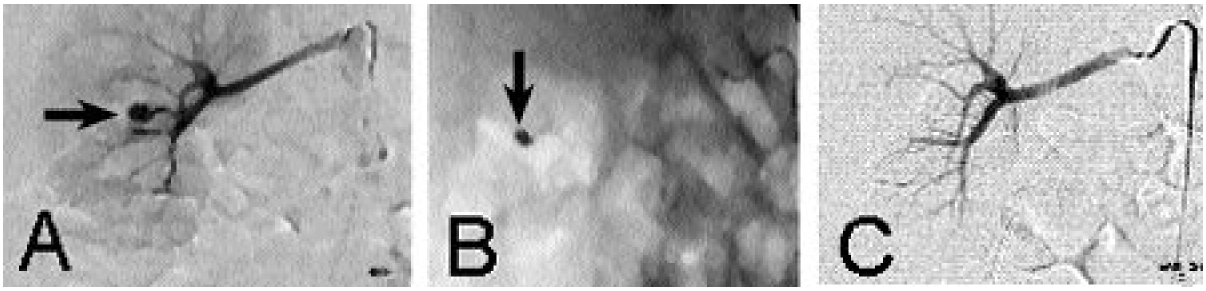

Fig. 6. (A) Right renal artery AVM (arrow) in a 27-year-old pregnant female with gross hematuria. **(B)** Following embolization with glue, there is a cast (arrow) of the AVM. **(C)** Post-embolization angiogram shows no flow in the AVM.

lesions than from treatment of lower extremity lesions (22). The lower extremity lesions appear to ultimately lead to limb loss in a majority of patients. Embolization may be able to palliate the symptoms of these patients for a period of time, but ultimately a majority of AVMs recur. This is yet another reason to use caution and realistic expectations in the treatment of these lesions (Fig. 7).

Pelvic AVM. These lesions are also quite difficult to treat. They present classically with vague symptoms including pain, mass effect and hemorrhage. Embolization of these lesions offers a minimally invasive option that has little or no morbidity and has been shown to have excellent long-term results (23).

Venous Malformations

Venous malformations, ranging from anomalies of venous anatomy to focal cavernous lesions, are relatively common. As with other vascular malformations, these are not neoplastic lesions and generally show growth commensurate with growth of the individual. Cavernous malformations can occur anywhere in the body and are composed of irregular venous spaces with slow flow under low pressure. When they are close to the skin surface, they are characteristically bluish in appearance and demonstrate a soft, nonpulsatile consistency. They can be actively emptied by manual compression or passively by elevation of the affected part. Conversely, they can become engorged when they are in a dependant position and can be quite disfiguring in appearance. These lesions are not tender unless there is superimposed acute thrombosis. Very superficial lesions can demonstrate skin thinning or even breakdown with resultant bleeding (16).

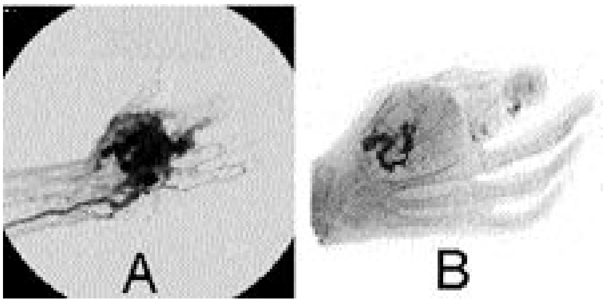

Fig. 7. (A) AVM at the left wrist in a 22-year-old female who had undergone radial artery ligation at another institution. **(B)** Following embolization with glue, a second digit had to be amputated.

Again, MRI/MRA is extremely valuable in delineating the true extent of the lesion, which may involve a much larger territory than is evident clinically. Arteriography is usually non-revealing. Standard venography often fails to show any filling of the lesion from normal venous structures. Direct puncture or closed space venography is a more effective technique for outlining these lesions. When the capacity of the lesion is reached, opacification of the small draining veins is usually observed, with eventual drainage into the normal venous system. This direct puncture technique is also used for treatment. Direct puncture embolization is a simple technique that has proven effective in treating venous lesions. After closed space venography, usually performed through a sheathed needle, the lesion is allowed to empty passively. The lesion is then partially refilled with a solution of contrast and absolute ethanol. The alcohol is left in place causing clotting of the blood and damage to the vascular endothelium lining the venous spaces. Signs of thrombosis will persist for 2–3 weeks and shrinkage will be seen 6–8 weeks following treatment. Depending on the anatomy and size of the lesion, multiple puncture sites may be needed as well as multiple treatments over time (Fig. 8).

Sclerotherapy alone or in combination with surgical resection has shown excellent pallia-

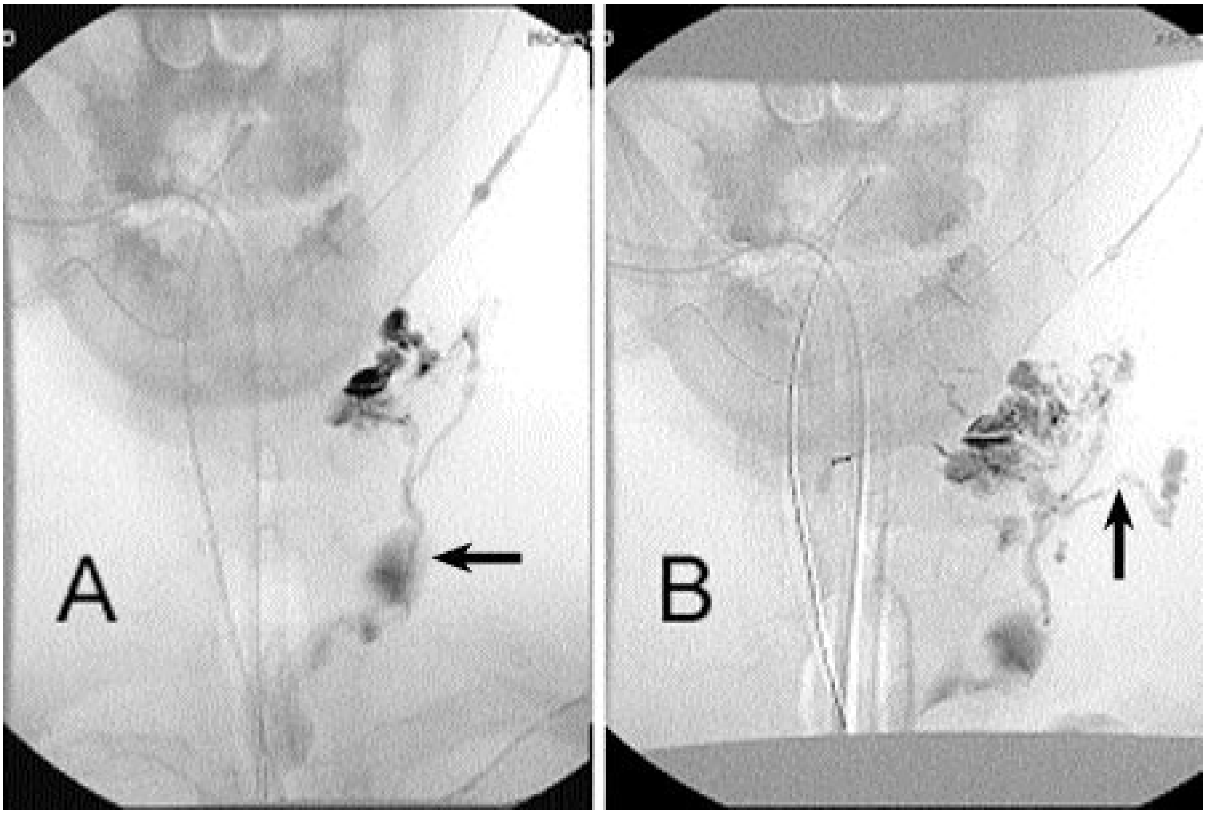

Fig. 8. (A) Direct puncture venogram of a venous malformation in a 23-year-old male reveals a large vein (arrow) draining centrally into the chest. **(B)** Following alcohol ablation, the capacity of the malformation is decreased. A new draining vein (arrow) is now apparent This will be sclerosed later.

tive results and is widely regarded as the preferred mode of therapy (24).

Embolization to Facilitate Endovascular Repair of Abdominal Aortic Aneurysms

Hypogastric Artery Embolization

Endovascular repair of abdominal aortic aneurysms has rapidly gained acceptance as an alternate form of treatment for patients at high risk with traditional open repair. Originally, one limitation to the procedure was the co-existence of common iliac artery aneurysms. Parodi described a technique to circumvent this obstacle, in order to offer more patients the option of endovascular repair (25). This technique involved extension of the iliac limb of the device down to the external iliac artery after the origin of the internal iliac artery had been coil embolized. This would prevent a future endoleak from reversal of flow in the hypogastric artery and back-up into the aneurysm sac. For common iliac aneurysms, the origin of the hypogastric artery would be embolized, whereas for true hypogastric artery aneurysms the entire vessel would be embolized, including anterior and posterior divisions, as previously described (26) (Fig. 9).

Numerous studies have shown not only the safety of this procedure but also its durability. Yano et al. (27) reviewed their experience with 103 internal iliac artery embolizations and showed an incidence of pelvic ischemia of approximately 20%, including 12 patients with buttock claudication, 9 patients with new-onset impotence, and 1 patient with fulminant visceral ischemia. Criado et al. (28) reviewed a series of 39 patients who underwent embolization of one or both hypogastric arteries. The post-procedure complication incidence was 1 patient with impotence and 5 patients with buttock claudication. No patients had severe ischemic complications. Recent studies have looked at the risks associated with bilateral hypogastric artery embolization. Engelke et al. (29) reviewed their experience comparing the results of simultaneous bilateral embolization with sequential bilateral embolization. Their study reviewed 16 patients and showed early complica-

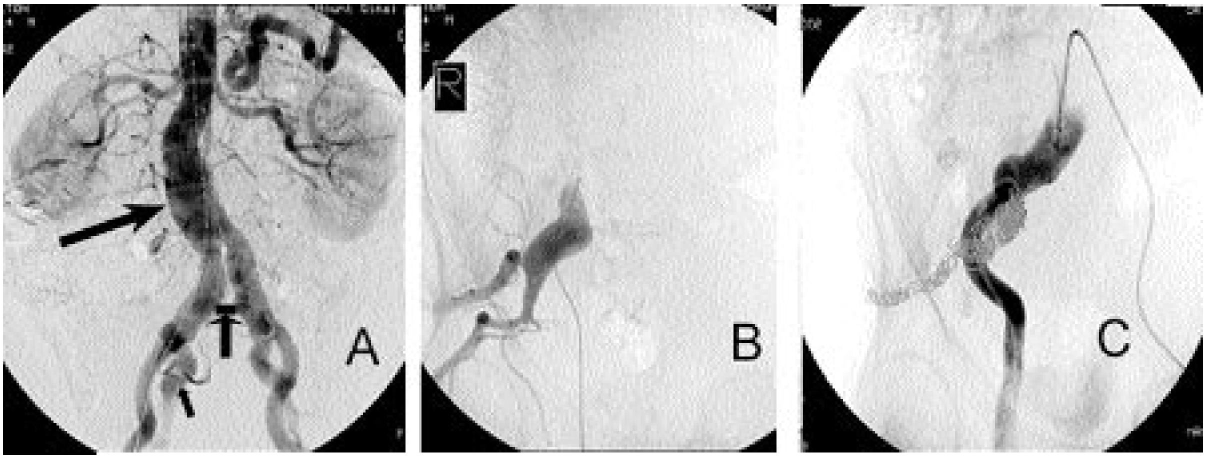

Fig. 9. (A) Flush aortagram shows an infrarenal abdominal aortic aneurysm (large arrow), bilateral common iliac aneurysms (medium-sized arrow), and a right hypogastric artery aneurysm (small arrow). **(B)** Selective right internal iliac angiogram shows the extent of the hypogastric aneurysm. **(C)** Following coil embolization, there is no flow in the right hypogastric artery.

tions, including an 18% incidence of buttock claudication and 6% incidence of impotence. It also showed a reduced complication rate in the simultaneous group (12.5%) as compared to the sequential group (50%). Razavi et al. reported a 57% incidence of symptoms including claudication and impotence following bilateral hypogastric artery embolization (30).

Endoleak Embolization

One of the most common complications of endovascular aneurysm repair is incomplete exclusion of flow in the aneurysm sac, which has been given the descriptive term “endoleak.” This describes the presence of blood leaking into the aneurysm sac around an endovascular graft. Endoleaks have been classified according to their origin and their direction of flow. Type 1 leaks are the result of an incomplete seal at the proximal or distal attachment sites. Leaks through occluder devices related to aorto-monoiliac devices are also considered type 1 leaks. Type 2 leaks are the result of retrograde flow in aortic side branch vessels back into the aneurysm sac after stent graft implantation. The most common sites for type 2 endoleaks are the inferior mesenteric artery and the lumbar arteries. Endoleaks are regarded as a failure of the endovascular aneurysm repair procedure and should be occluded to prevent pressurization of the sac, resulting in aneurysm enlargement and possibly rupture (31). Many authors have agreed that type 1 leaks are probably more dangerous than type 2 leaks and should be treated on an urgent basis. Type 2 leaks are considered more benign and have often been shown to close spontaneously. As a result, type 2 leaks are treated only if they remain patent and are associated with aneurysm enlargement (32) (Fig. 10).

Many techniques have been described to treat endoleaks, including embolization, the endovascular placement of extender cuffs for type 1 leaks, laparoscopic clipping of side branches for type 2 leaks, and conversion to open repair (33–38). The most commonly used method of endoleak treatment is embolization. This has been extensively reported for the treatment of type 2 leaks. It was first described in 1997 with a technique involving microcatheters tracked through the feeding vessels back to the aneurysm sac (33). Many authors have reported on single-center experiences with both transarterial and translumbar approaches to cannulate the endoleak channel and embolize the feeding vessels (34). Many different materials have been used, including coils, glue, particles, and thrombin, with variable results. Most authors report that type 2 endoleaks classically have inflow and outflow vessels and behave physiologically like an arteriovenous malformation. As a result, the embolization of a single feeding vessel can be ineffective and can make future interventions more difficult (35, 36). We currently advocate the embolization of all feeding vessels visualized during angiography as well as the endoleak itself. This effectively obliterates the “nidus” of the endoleak as well as the feeding vessels treating it as an AVM.

The embolization of type 1 endoleaks is a more controversial subject. The ideal treatment

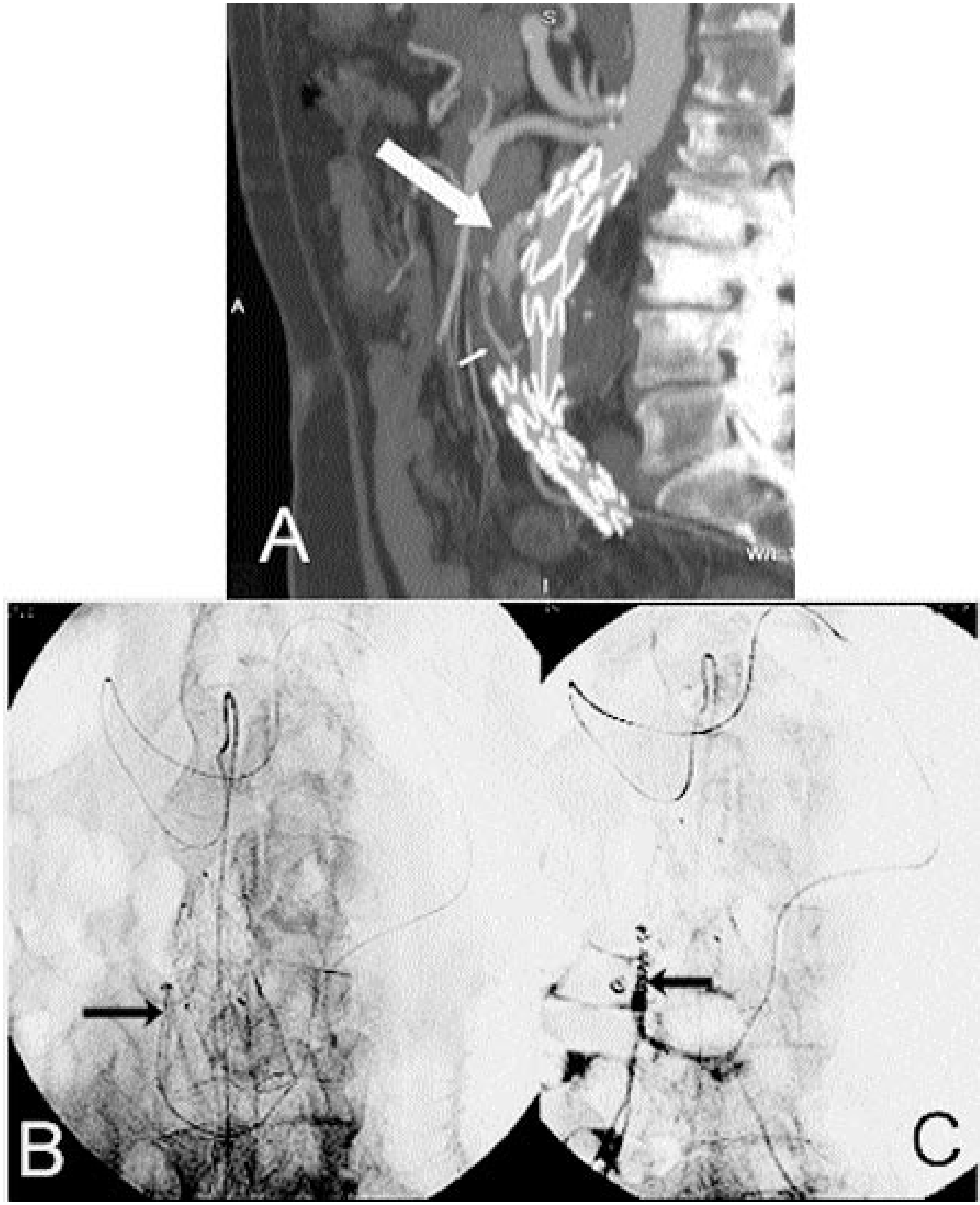

Fig. 10. (A) Sagital reformat of a mutidetector CTA of a patient who has undergone endovascular repair of an infrarenal abdominal aortic aneurysm. There is an endoleak (large arrow) anterior to the stent-graft. The leak is in continuity with the inferior mesenteric artery (small arrow), suggestive of a type 2 leak. **(B)** Angiography after selective catheterization of the inferior mesenteric artery (arrow) from the superior mesenteric artery via the arc of Riolan. **(C)** Following embolization of the inferior mesenteric artery at its origin (arrow) off the aneurysm, there is no inflow to the endoleak.

for type 1 endoleaks is usually the placement of proximal or distal extender cuffs to tighten the seal and obliterate the endoleak channel. With the recent development of transrenal devices, this option has been replaced for the treatment of proximal type 1 leaks. Our center has had extensive experience with embolization of type 1 leaks and has found it to be an effective treatment option (39).

Summary

Embolization has recently emerged as a first-line treatment for many vascular lesions that are considered at high risk with surgical repair. The technological advances in microcatheters and new, safer embolic agents have permitted a wider range of applications of this form of treatment. As more experience is gained with these procedures and long-term results are reviewed, this procedure will increasingly gain acceptance as first-line treatment for many more vascular lesions. Endovascular specialists will surely rely more and more on these procedures to assist in the management of all aspects of vascular disease.

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