Embolization of High-Flow Arteriovenous Malformation

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Semin Intervent Radiol 2016;33:157–160

Vascular malformations are a complex group of lesions which are typically present at birth but may not be recognized until adolescence or later. When treatment is necessary, embolization is usually the therapy of choice and may be either palliative or curative. From a treatment perspective, the most important distinguishing factor between different vascular malformations is the presence or absence of arterial shunting. The presence of arteries and shunting defines "high-flow lesions" (arteriovenous malformations), whereas "low-flow lesions" (venous or lymphatic malformations) consist of dilated veins or lymphatics.

Clinical Case

A 21-year-old college student presented to her primary physician with a painful lump on the sole of her right foot which had been present for several years. Two years earlier, she had bunion surgery for the same pain which failed to alleviate her symptoms. In the past several months, it had become increasingly painful and she now walked with a slight limp. She underwent a magnetic resonance imaging (MRI) and ultrasound exam of her foot (►**Fig. 1**) which revealed a 2 × 3 cm focal vascular lesion. On T1-weighted images of her MRI exam, flow voids were identified within the lesion indicating rapid flow, and on the corresponding ultrasound exam, arterial flow was confirmed by Doppler ultrasound. She was referred to the University of Chicago for further evaluation and management.

She was seen in the Interventional Radiology clinic. On physical exam, the abnormality appeared slightly elevated (►**Fig. 2**) and was barely palpable. She characterized her pain as 6 out of 10 resting, increasing to 9 out of 10 with prolonged walking or exercise. She walked with a slight limp. A diagnostic angiogram was performed to plan treatment (►**Fig. 3**). The angiogram revealed a highly vascular lesion on the sole of her foot with arterial perfusion from numerous branches of both the anterior and posterior tibial arteries accompanied by rapid shunting within the lesion and outflow via enlarged posterior tibial veins.

A treatment plan was formulated and discussed in detail with the patient and her mother. She returned to our hospital 1 month later for the embolization. The left common femoral artery was catheterized and a 5F diagnostic catheter was positioned over the aortic bifurcation into the right popliteal artery. This catheter was used to help guide the planned venous embolization. Using ultrasound guidance, one of the enlarged outflow veins in the ankle was catheterized and a 4F dilator of a Micropuncture set (Cook, Bloomington, IN) was advanced under fluoroscopic guidance into the nidus of the lesion. A venogram was performed with a blood pressure cuff inflated to 100 mm Hg over the calf (►**Fig. 4**). This demonstrated contrast stasis and enabled determination of the volume of the nidus. The cuff was released and a 3-mL preparation of n-butyl cyanoacrylate (Trufill) was prepared in a 3:1 ratio with lipiodol. The dilator was flushed with dextrose solution and the blood pressure cuff reinflated. The embolic was then slowly injected to fill the nidus of the lesion and reflux a small amount of glue into the outflow veins (►**Fig. 5**). The blood pressure cuff was left inflated for approximately 1 minute and then slowly released under fluoroscopic observation. There was no evidence of migration of the embolic agent. A postembolization angiogram was then performed revealing complete occlusion of the lesion (►**Fig. 6**) and excellent perfusion to the remainder of the foot. The patient made an uneventful recovery with complete resolution of symptoms. Within 1 month, she was ambulating without any pain.

Discussion

In normal tissue, oxygenated blood from the heart flows from arteries which divide into smaller arterioles and then into capillaries (which perfuse tissue) and subsequently drain into veins which bring blood back to the heart. High-flow arteriovenous malformations are abnormal communications between arteries and veins that lack an intervening capillary (and tissue) bed. The absence of capillaries in the circuit

Issue Theme Inferior Vena Cava Filters; Guest Editors, Kush R. Desai, MD and Robert J. Lewandowski, MD

DOI http://dx.doi.org/10.1055/s-0036-1582125.
ISSN 0739-9529.

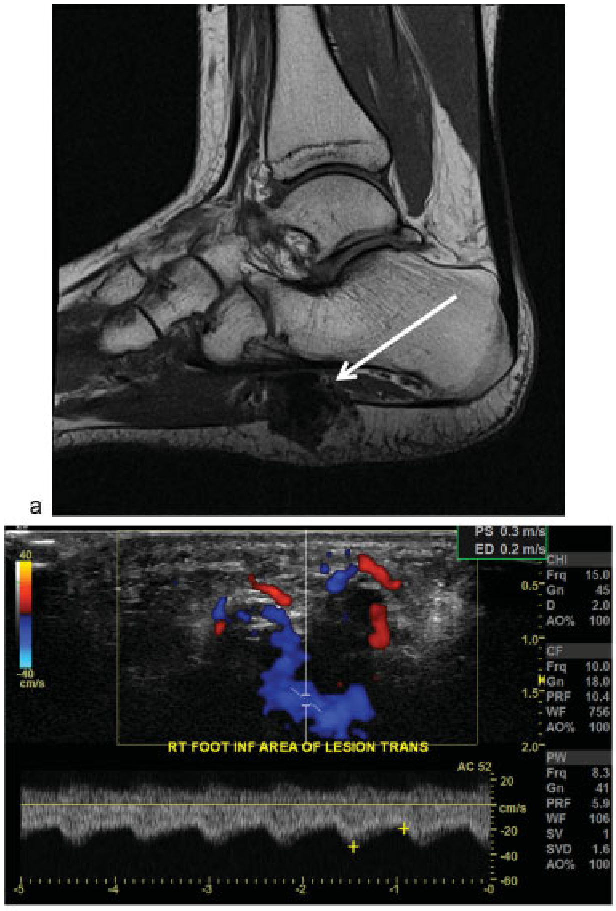

Fig. 1 Noninvasive imaging of the right foot abnormality. (**a**) Sagittal T1-weighted MRI image shows round lesion with flow voids on the sole of the foot (white arrow). (**b**) Doppler ultrasound of the lesion shows arterial waveforms.

creates several undesirable hemodynamic consequences. Blood flows preferentially through this abnormal communication because it is the path of least resistance; as it enlarges, it compresses and erodes adjacent tissue. Additionally, the shunt may deprive adjacent normal tissue of blood and, if the

Fig. 2 Photograph of foot shows slightly raised smooth lump on the sole of the foot (circle).

Fig. 3 Diagnostic angiogram of the right foot. (**a**) Selective angiogram of the anterior tibial artery shows shunting and rapid egress of contrast from the arteriovenous malformation. (**b**) Selective angiogram of the posterior tibial artery similarly demonstrates rapid shunting and egress of contrast from the lesion.

Fig. 4 Diagnostic venogram of the right foot with blood pressure cuff inflated over the calf (not shown) shows stasis of contrast within the arteriovenous malformation.

Fig. 5 Therapeutic embolization. Static fluoroscopic image shows n-cyanoacrylate filling the lesion.

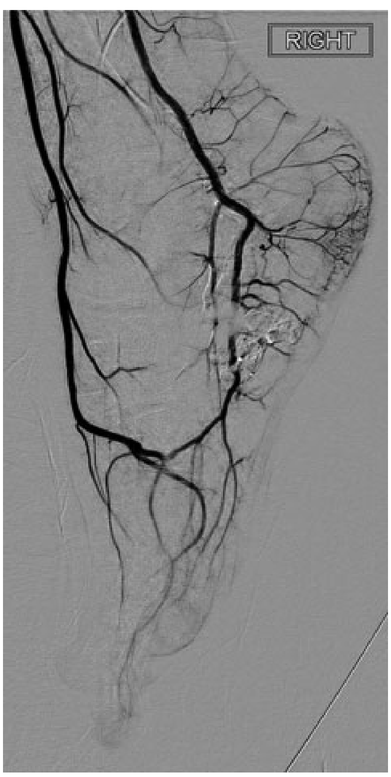

Fig. 6 Postembolization digital subtraction angiogram shows complete occlusion of the AVM with normal perfusion to the foot.

shunt becomes large enough, it can put an abnormal strain on the heart and eventually lead to high output heart failure. High-flow arteriovenous malformations (AVMs) are thought to be congenital anomalies that manifest in adolescence when they enlarge. These are among the most difficult vascular anomalies to treat. Surgical resection may be impossible or very debilitating.

Therapeutic embolization, the intentional occlusion of an artery or vein, has many applications in a variety of diseases. Most often, this procedure is performed by percutaneously accessing an artery or vein and advancing a catheter under fluoroscopic guidance to a target vessel. For example, in a patient with life-threatening hemoptysis, a catheter is usually advanced from the common femoral artery into a bronchial artery and small particles are delivered through a microcatheter to completely block it, thereby stopping hemorrhage. Another application of embolization is the treatment of malignancies such as hepatocellular carcinoma where chemotherapeutic agents attached to small particles or radioactive beads are directly infused into the tumor to slow down growth or eradicate it altogether. There are a variety of embolic agents used by Interventional Radiologists including coils (small metal springs), particles, and liquids such as alcohol and n-cyanoacrylates (glue). Historically, initial treatment of high-flow arteriovenous malformations with arterial embolization using large embolic agents such as coils was limited by a very high rate of recurrence because the nidus (i.e., the central portion of the lesion where arteries and veins directly communicate) tends to function as a sump and recruits additional arteries when larger ones are blocked. Today, it is generally accepted that, when feasible, the best treatment strategy is to completely occlude the nidus by filling it with a liquid embolic agent such as ethanol or cyanoacrylate (glue). This can be done from an arterial approach but increasingly, a venous approach is utilized and at least anecdotally and in the authors' own experience, appears to be safer with equal or greater success compared with an arterial approach. The authors' preference is to use a combined approach and initiate embolization from the venous side of the lesion whenever possible.

Noninvasive imaging with ultrasound and MRI is very helpful for diagnosis and classification of vascular malformations. On MRI, flow voids on T1-weighted images usually indicate rapid flow within the lesion establishing the diagnosis of a high-flow arteriovenous malformation. An arterial waveform on Doppler ultrasound provides similar information. A detailed planning angiogram is important to fully visualize the vascular architecture of the lesion, define all feeding arteries and veins, and formulate a "plan of attack." A wide variety of approaches and embolic agents continue to be used in the treatment of high-flow lesions and overall, every malformation is slightly different and requires a tailored approach. As mentioned earlier, the authors prefer to initiate treatment from the venous side of the lesion, either by directly puncturing the nidus or by accessing a draining vein such as in this patient. The rationale for this approach is that by obliterating the nidus and outflow, the sump effect will be eradicated, and arterial flow will be redistributed into the normal arteries and veins in adjacent tissue. Often, further embolization from the arterial side becomes unnecessary when a venous approach successfully eliminates the venous outflow. Clearly, there are a variety of different types of AVMs and not all lesions can be treated from this approach.

Liquid embolics are integral to the treatment of vascular anomalies and are among the difficult and unforgiving tools in the interventional radiology armamentarium. They should always be used with extreme caution and only after proper training. Unlike a coil which could be retrieved if it migrates to an unintended vessel, once liquid embolics are administered, they become "toothpaste outside the tube." Absolute ethanol is probably the most effective and potent liquid embolic agent available but also the least forgiving. Nontarget embolization may be catastrophic; ethanol may produce pulmonary vasospasm, cardiovascular collapse, and death even when treating peripheral arteriovenous malformations. The authors generally favor other liquid embolic agents such as n-cyanoacrylate which is similar to "super-glue" (used in this patient) or ethyl vinyl copolymer which may also result in serious complications but have a slightly more favorable risk profile.

Two challenges in the embolization of a high-flow lesion are delivering the embolic agent to the nidus of the lesion and keeping it there in the presence of rapid shunting. In this patient, a blood pressure cuff was inflated to temporarily arrest shunting in the lesion by blocking venous return. At this point, the liquid embolic agent was delivered. In some lesions, this type of maneuver is impossible. Other techniques can sometimes be used to limit shunting such as deploying coils in the venous outflow to slow down flow. Often, a combination of embolic agents and approaches may be required.

At the University of Chicago, a dedicated team of surgeons, geneticists, dermatologists, and diagnostic and interventional radiologists all contribute to the care of patients with vascular malformations. It is the authors' belief that these patients are best served by the combined expertise of this type of multidisciplinary collaboration.