

Classification, Diagnosis, and Interventional Radiologic Management of Vascular Malformations

Gerald M. Legiehn, MD, FRCPC^{a,*},
Manraj K.S. Heran, MD, FRCPC^{b,c}

^a*Department of Radiology, Division of Interventional Radiology, Vancouver General Hospital, University of British Columbia, 899 West Twelfth Avenue, Vancouver, British Columbia, Canada, V5Z 1M9*

^b*Department of Radiology, Division of Neuroradiology, Vancouver General Hospital, University of British Columbia, 899 West Twelfth Avenue, Vancouver, British Columbia, Canada, V5Z 1M9*

^c*Department of Radiology, Division of Pediatric Interventional Radiology, Children's and Women's Health Center of British Columbia, University of British Columbia, 4480 Oak Street, Vancouver, British Columbia, Canada, V6H 3V4*

Few areas within medical diagnosis are fraught with as many persistent misconceptions and misnomers as within the group of vascular anomalies. Historically, morphologically diverse cutaneous and visceral pigmentations, blushes, masses, and abnormal vascular spaces were named and categorized primarily by gross appearance, location, fluid content, and a frequently overlapping and unpredictable clinical course. As a result, numerous redundant, ambiguous, and even misleading terms have accumulated over the last 2 centuries describing this set of vascular defects. In all but the largest referral centers, the issue of confusing nomenclature has compounded a general lack of diagnostic and therapeutic familiarity with this group of entities and has resulted in invasive and often inappropriate therapy being founded on alarmingly high rates of misdiagnosis [1,2]. Optimal patient diagnosis and management is best achieved with the assembly of an experienced multidisciplinary team allowing effective communication and integration of the most current clinical, pathologic, and image-based diagnosis and intervention [3]. This article focuses on the diverse group of congenital *vascular malformations*, with respect to their place within the broader classification of *vascular anomalies* and their pathologic, clinical, and radiologic diagnosis and management.

Classification of vascular anomalies

In 1982, Mulliken and Glowacki [4] published a landmark article proposing characterization of vascular defects based on biologic and pathologic differences. Their work differentiated between two major categories of vascular lesions: hemangiomas and vascular malformations. *Hemangiomas* were described as lesions exhibiting a history of rapid neonatal growth and slow involution characterized by hypercellularity during the proliferating phase and fibrosis and diminished cellularity during the involuting phase. The suffix *-oma*, referring to a tumor or swelling, was thought to be reserved appropriately for the lesion given its increased cellular turnover. *Vascular malformations* were described as lesions present at birth growing commensurately or *pari passu* with the child composed of vascular channels lined with flat “mature” endothelium exhibiting normal rates of endothelial cell turnover. The term *hemangioma*, particularly in adults, is considered inaccurate and misleading in modern nomenclature and should be discarded. Vascular malformations were subdivided further into lesions consisting of capillary, venous, arterial, lymphatic, and initially fistulous networks (Table 1). Building on initial characterization of angiographic flow patterns by Burrows and colleagues [5], a complementary classification scheme was proposed by Jackson and associates [6] that considered flow rate as a variable determining appropriate investigation and treatment. Vascular anomalies were divided

* Corresponding author.

E-mail address: gerald@telus.net (G.M. Legiehn).

Table 1
Classification of vascular lesions in infants and children

Hemangiomas	Malformations
Proliferating phase	Capillary
Involuting phase	Venous
	Arterial
	Lymphatic
	Fistulae

From Mulliken JB, Glowacki J. Hemangiomas and vascular malformations in infants and children: a classification based on endothelial characteristics. *Plast Reconstr Surg* 1982;69:413.

into low-flow venous malformations (VMs) and high-flow arteriovenous malformations (AVMs) with separate categorization for lymphatic malformations (LMs) and for hemangiomas (Box 1).

Based on concepts proposed by Malan [7] and described by Degni and coworkers [8], who first categorized vascular malformations as predominantly arterial, venous, arteriovenous, lymphatic, and mixed, Belov [9,10] introduced an etiologic and pathophysiologic classification system focused on the embryologic site of origin of the defect that led to the development of each particular malformation. Each malformation type was subdivided into two basic anatomic/pathologic forms: (1) truncular and (2) extratruncular. The *truncular* form resulted from a relatively late embryologic defect or event arising within a *differentiated* vascular trunk. This form is often more severe and classified as due to a vascular aplasia, obstructive, or dilatatory phenomenon. The *extratruncular* form, often less severe, arose as a result of a relatively early embryonal dysplasia within the *primitive* undifferentiated capillary network and could

Box 1. Classification of vascular anomalies by vascular dynamics according to Jackson

- I. Hemangiomas
- II. Vascular malformations
 - a. Low-flow (VM)
 - b. High-flow (AVM)
- III. LMs

From Jackson IT, Carreno R, Potparic Z, et al. Hemangiomas, vascular malformations, and lymphovenous malformations: classification and methods of treatment. *Plast Reconstr Surg* 1993;91:1217.

present in a diffuse/infiltrating or limited/localized fashion (Table 2) [11].

Each classification scheme brought about major clarifications in clinical diagnosis and management and formed a foundation on which further research has evolved. Founded by Mulliken and Young in 1976 and convening biennially, The International Society for the Study of Vascular Anomalies (ISSVA) has been at the focal point of these developments. Discussions of the work of Malan, Degni, and Belov at the Seventh Meeting of the ISSVA in Hamburg in 1988 formed the “Hamburg classification” of congenital vascular defects [10]. A final classification of vascular anomalies based on cellular features, vascular flow characteristics, and clinical behavior was refined and updated during the 1992 meeting of ISSVA in Colorado and adopted by ISSVA in Rome in 1996 (Table 3) [12].

Histology and immunohistochemistry

As described in Mulliken’s original dissertation, traditional light microscopic staining techniques using hematoxylin and eosin among others is usually sufficient to differentiate vascular

Table 2
Anatomopathologic classification of vascular defects (Hamburg classification)

Type	Forms	
	Truncular	Extratruncular
Predominantly arterial defects	Aplasia or obstructive	Infiltrating
	Dilation	Limited
Predominantly venous defects	Aplasia or obstructive	Infiltrating
	Dilation	Limited
Predominantly lymphatic defects	Aplasia or obstructive	Infiltrating
	Dilation	Limited
Predominantly arteriovenous shunting defects	Deep	Infiltrating
	Superficial	Limited
Combined/mixed vascular defects	Arterial and venous	Infiltrating hemolymphatic
	Hemolymphatic	Limited hemolymphatic

Based on seventh Meeting of the International Workshop on Vascular Malformations. Hamburg, Germany, 1988.

Data from refs. [9–11].

Table 3
International Society for the study of Vascular Anomalies classification of vascular anomalies

Tumors	Vascular Malformations	
	Simple	Combined
Hemangioma	Capillary (C)	Arteriovenous fistula (AVF)
Others	Lymphatic (L)	AVM
	Venous (V)	CVM
		CLVM
		LVM
		CAVM
		CLAVM

Based on Scientific Committee of the Eleventh Meeting of the International Society for the Study of Vascular Anomalies. Rome, Italy, 1996.

From Enjolras O. Classification and management of the various superficial vascular anomalies: hemangioma and vascular malformation. *J Dermatol* 1997;24:701.

tumors such as infantile hemangioma from vascular malformations [4]. More recent advances in immunohistochemical techniques have allowed greater tissue diagnostic accuracy in lesions of ambiguous or mixed histology on conventional microscopy.

Hemangiomas, in proliferative phase, show increased endothelial cell activity with formation of syncytial masses with and without lumina and thickened multilaminar basement membranes on periodic acid-Schiff and electron microscopy (Fig. 1). Involuting hemangiomas reveal variable degrees of decreasing endothelial proliferation with fibrofatty infiltration [4]. North and colleagues [13] reported all infantile hemangiomas stained positive for GLUT-1 antigen, which allowed unequivocal differentiation from all other vascular tumors and malformations and established a possible relationship of this lesion to placental tissue. More recently, S-100 immunostain has been used to detect the presence of nerve tissue within vascular malformations and absence of nerve tissue in hemangiomas, allowing differentiation from clinically and angiographically similar-appearing AVMs and hemangiomas [14].

Vascular malformations consist of dilated vascular channels and spaces with variably thickened walls lined by mature endothelium (Fig. 2). VMs have normal surrounding reticulum, but often lack a distinct internal elastic lamina. Lumina reveal organizing thrombi, sometimes forming papillary fronds (Masson's endothelial hyperplasia) or dystrophic calcification in the form of phleboliths [15,16]. Collagenous tissue or fat or both

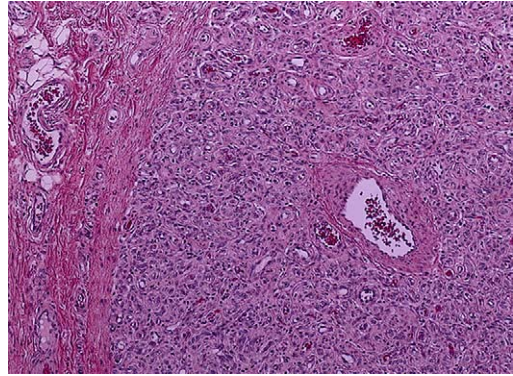


Fig. 1. Histology of proliferative phase of infantile hemangioma. Conventional hematoxylin and eosin staining reveals greatly increased endothelial cell activity with formation of syncytial masses with and without lumina [4]. (Courtesy of C. Senger, MD, Vancouver, British Columbia.)

surround the vascular channels. Alpha smooth muscle antibody stain reveals smooth muscle to be absent or in irregular clumps within vascular walls, which is likely responsible for ongoing ectasia and gross pari passu growth [17–20].

LMs have a highly variable histologic appearance comprising multicystic dilated lymphatic channels and spaces separated by fibrous septa and are unconnected to normal lymphatic vessels. The walls are lined by bland flattened endothelial cells and may be surrounded by irregularly thickened smooth muscle. The lumen may contain lymphatic fluid, proteinaceous material, or erythrocytes appearing similar to a VM (Fig. 3) [16].

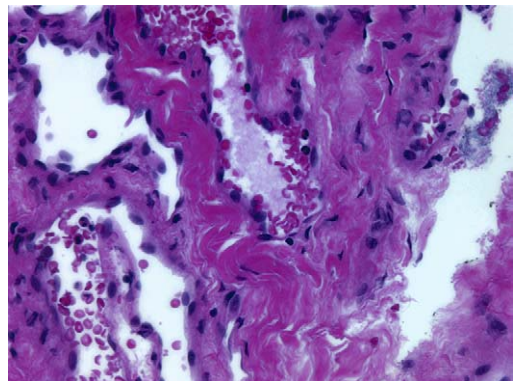


Fig. 2. Histology of VMs. Conventional hematoxylin and eosin staining shows dilated vascular channels and spaces with variably thickened walls lined by nonhypercellular flattened mature endothelial cells. (Courtesy of T. Nielsen, MD, PhD, Vancouver, British Columbia.)

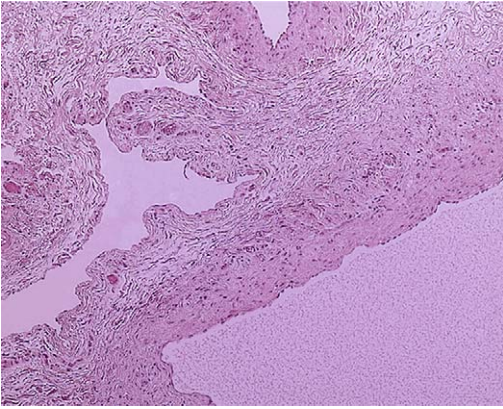


Fig. 3. Histology of LMs. Conventional hematoxylin and eosin staining shows markedly enlarged lymphatic channels lined by bland endothelial cells not contiguous with normal lymphatics. (Courtesy of C. Senger, MD, Vancouver, British Columbia.)

D2-40, a more recently developed monoclonal antibody to oncofetal antigen M2A, is highly specific for lymphatic endothelium and is negative for normal or malformed venous, arterial, or capillary endothelium [21,22].

Capillary malformations or port-wine stains usually are composed of mature ectatic capillary channels in normal numbers within the superficial dermis surrounded by disorganized collagen. With progressive dilation, these vessels can be seen in the deeper dermis and subcutaneous tissues. The density of pericapillary neurons within these lesions is reduced and is thought to lead to decreased capillary tone and progressive ectasia [23].

AVMs form a region where numerous dysplastic arteries immediately drain or shunt into arterialized veins in the form of a vascular *nidus* without an intervening normal capillary network (Fig. 4). Often, these vessels exhibit thick walls, organizing thrombus, and dystrophic calcifications [16]. As a result of local high-flow effects, these lesions can cause adjacent mass effect, soft tissue destruction, or erosion. Because of the early embryonic origin, the endothelial lining of AVMs is dysplastic and with defective growth regulation and reduced apoptosis [24]. AVMs can have an unpredictable growth pattern, lying dormant for long periods or undergoing phases of explosive growth spontaneously or secondary to trauma, surgery, or hormonal influences [25]. Combined malformations, as the name implies, show histologic features of two or more simple malformations with some variation and are encountered most often within syndromes (Table 4).

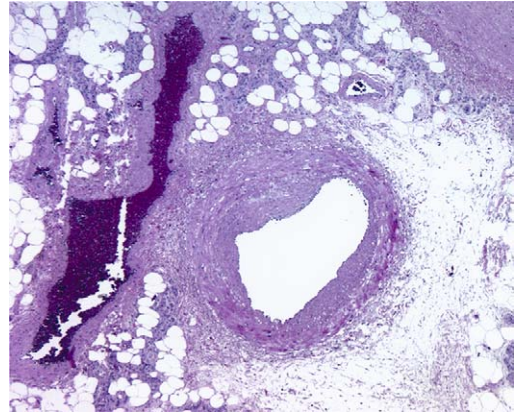


Fig. 4. Histology of AVMs. Conventional hematoxylin and eosin staining shows abnormally enlarged arterial and venous structures in close proximity with associated fatty proliferation. (Courtesy of T. Nielsen, MD, PhD, Vancouver, British Columbia.)

Embryology, vascular morphogenesis, and molecular genetics

Because of early rapid tissue growth and need for tissue oxygenation, the embryonic circulation is the first functional system to develop, with intraluminal blood circulating at 3 weeks' gestation [26]. In the first phase of vascular morphogenesis, *vasculogenesis* occurs by differentiation and organization of mesoderm into the primitive capillary network. Mesodermal angioblasts congregate to form *blood islands*, which cavitate centrally forming short tubes. Outermost cells form into primordial endothelium, and inner cells form early blood cells. These short tubes or canaliculi interconnect forming the *primitive capillary plexus*. In the second phase, *angiogenesis* occurs whereby the capillary plexus remodels by (1) addition of capillaries by *budding* or *sprouting*, (2) deletion of certain endothelial tubes by *pruning*, (3) division or coalescing of endothelial tubes through *nonsprouting*, and (4) incorporation of adjacent mesenchyme to form pericytes and smooth muscle cells [26,27]. One month after the development of the first blood vessels, two simultaneous processes are hypothesized to occur in early lymphatic system development. First, epithelial cells within embryonic veins give rise to localized lymph sacs from which lymph capillaries sprout. Second, primary lymphangioblasts within the mesenchyme differentiate into lymphatic endothelium, which forms lymphatic vessels that anastomose with the former process [28]. Overall in relation to the Hamburg classification,

Table 4
Syndromes associated with vascular malformations

Syndrome	Components				ISSVA nomenclature	Associations/comments
	C	V	L	AVM		
Sturge-Weber	X					Ophthalmic division facial port-wine stain (capillary malformation), leptomeningeal VM, and choroidal VMs of the eye
Maffucci		X				Multiple enchondromas, exostoses, and venous-type malformations (actually spindle cell hemangioendotheliomas)
Blue-rubber bleb nevus		X				Multiple VMs of skin and gastrointestinal tract associated with hemorrhage
Proteus	X	X	X			Cutaneous and subcutaneous nevi, lipomas, hyperpigmentation, and mixed VMs
Klippel-Trenaunay	X	X	X		CVM, CLVM	<i>Low-flow combined lesion</i> — port-wine stain (capillary malformation), VMs with phleboliths, soft tissue or osseous hypertrophy/limb overgrowth, with possible associated lymphedema or LM
Parkes-Weber	X	X	X	X	CAVM, CLAVM	<i>High-flow combined lesion</i> — similar to Klippel-Trenaunay with associated complex multiple AV fistulas in involved limb
Cobb	X			X		Cutaneous capillary stain versus true malformation adjacent to spinal AVM, most commonly intramedullary
Wyburn-Mason				X		Facial cutaneous AVMs, midbrain AVMs, and retinal vascular anomalies
Gorham-Stout	X	X	X			Focal areas of bone loss and replacement with fibrous tissue (disappearing bone disease) associated with VMs, usually self-limited

Abbreviations: AV, arteriovenous; AVM, arteriovenous malformation; C, capillary; L, lymphatic; LM, lymphatic malformation; V, venous; VM, venous malformation.

extratruncular malformations arise from derangements occurring in these early vasculogenic or angiogenic phases of circulatory development.

Because vascular malformations most commonly manifest as sporadic foci of abnormally formed vascular channels [27], it stands to reason, as alluded to by Belov [11], that the genetic cause of these entities is largely due to *localized* errors in vascular morphogenesis [27,29]. Studies of mendelian-inherited vascular malformations have helped elucidate the molecular and pathophysiologic mechanisms controlling normal vascular differentiation [30]. The source of a rare autosomal-dominant cutaneous and mucosal VM has been localized to mutation R849W on chromosome 9p21 within the tyrosine kinase or TIE-2 receptor expressed on vascular endothelial cells [31,32]. The TIE-2 receptor interacts with ligands of the angiopoietin family (Ang) located in the surrounding mesenchyme that may control the incorporation of adjacent smooth muscle cells and pericytes into the developing vessel wall during

normal angiogenesis [30,33]. Ang-1 and Ang-4 have been found to stimulate TIE-2, and Ang-2 and Ang-3 have been found to antagonize TIE-2 [34]. In mice lacking TIE-2, or in situations of underexpression of Ang-1 or overexpression of Ang-2, vasculogenesis occurs normally, but angiogenesis is grossly defective leading to nondifferentiated capillary networks that often lack perivascular cells [35–37]. Ang-2 may have a role in normal lymphatic development [38]. Other studies have found ephrinB2 and EphB2, normally expressed only in arteries, to be ectopically expressed in veins within VMs [39]. Still other studies have implicated the platelet-derived growth factor β /platelet-derived growth factor receptor β and transforming growth factor β 1/transforming growth factor β R systems [30,40]. Regardless of the exact pathway, it now seems that derangement of the endothelial cell's ability to direct and regulate the periendothelial environment during angiogenesis is the most common factor implicated in the development of most

vascular malformations. The ultimate goal is to develop novel biologic therapies directed to this end at the molecular level [19,30].

Clinical diagnosis

The diagnosis of presence and type of vascular malformation usually can be made purely on clinical history and physical examination. By definition, all vascular malformations are present at birth, and most become evident to some degree during infancy or childhood. Lesions labeled as “acquired” during adolescence are usually those of insufficient size or symptoms to have been detected during the period of *pari passu* growth in childhood, which became clinically evident as the lesion underwent continued linear growth after normal somatic growth ceased. Vascular malformations never regress or involute and may grow at a rate greater than normal somatic growth.

VMs occur anywhere in the body, but are most commonly seen in the head and neck (40%), extremities (40%), and trunk (20%) [20]. Most are solitary, but are frequently multiple. They vary between relatively small, well-circumscribed, superficial lesions to large, infiltrative lesions crossing multiple soft tissue planes involving subcutaneous fat, bone, neurovascular bundles, or even viscera. If sufficiently superficial, lesions are soft, rubbery, deformable, nonpulsatile, and without a bruit. The mass may have a light blue to deep purple hue and associated superficial venous telangiectasias, varicosities, or ecchymoses. Lesions can increase in size or intensity of hue with activity, dependent posture, or Valsalva maneuver. Patients’ complaints are often a result of localized swelling from exertional or postural venous stasis and paroxysmal localized thrombosis causing pain, and compression or dysfunction of adjacent muscle and nerves. Aside from cosmetic factors, lesion size, location, and proximity to crucial structures dictate the nature and severity of patient symptoms.

LMs are divided into *macrocytic* (previously cystic hygromas) and *microcytic* (previously cavernous lymphangiomas) and *mixed* varieties. Presentations are similar to that of VMs in that they can occur as a soft nonpulsatile mass present at birth or in childhood. Overall, LMs occur in the head and neck (48%), trunk and extremities (42%), and intrathoracic or intra-abdominal viscera (10%) [41]. Subtypes may have a different presentation and therapeutic course; mixed lesions are common, and subcategorization in larger

series in the literature are not always clearly defined. Macrocytic LMs are defined as containing cystic spaces greater than 2 cm³ most commonly occurring in the neck, axilla, mediastinum/chest, or groin, with most diagnosed before age 2 [42]. They can be solitary or multifocal, persist, slowly grow, or rarely involute and may infiltrate or maximally compress adjacent vital structures during episodes of intralesional hemorrhage or superinfection [43]. Microcytic LMs are more common; contain cavities less than 2 cm³; occur within the neck, shoulders, and proximal limbs and perineum and usually present later in childhood similar to VMs owing to *pari passu* growth. These lesions can be solitary or multifocal and well circumscribed or deeply infiltrative. Skin changes can be observed as a result of altered local lymphatic physiology and infection and range from vague discoloration to gross lymphedema and hyperkeratosis.

AVMs are a distinct entity characterized by high-flow physiology and an aggressive clinical course [44]. The lesion can be detected at birth in 40% of cases [45] and most commonly occurs in the extremities and pelvis [44]. The Schobinger clinical staging system, introduced at the 1990 meeting of the International Workshop for the Study of Vascular Anomalies in Amsterdam, outlines the inevitable clinical course of untreated AVMs from their local skin and soft tissue effects to their eventual systemic cardiovascular compromise (Table 5) [46].

Capillary malformations in isolation are not discussed further because the role of imaging in their diagnosis and management is limited. Combined lesions are discussed otherwise with respect to their individual component malformations within these syndromes (see Table 4).

Imaging diagnosis and workup of vascular malformations

Although clinical history and examination are sufficient to establish the diagnosis of a vascular malformation, imaging is an indispensable part of the full patient workup. In addition to confirming the diagnosis, defining the extent of the lesion, and detecting often occult associated pathologic findings, imaging allows feasibility assessment and planning of any potential percutaneous image-guided or surgical therapy [47].

Conventional radiography

Because of inherent low soft tissue contrast resolution, conventional radiography provides

Table 5
Schobinger clinical staging system of arteriovenous malformations

Stage I	Quiescence	Cutaneous blush, skin warmth, arteriovenous shunt on Doppler ultrasound
Stage II	Expansion	Darkening blush, lesion shows pulsation, thrill and bruit
Stage III	Destruction	Steal, distal ischemia, pain, dystrophic skin changes, ulceration, necrosis, soft tissue and bony changes
Stage IV	Decompensation	High-output cardiac failure

Based on Eighth Meeting of the International Workshop on Vascular Malformations. Amsterdam, Netherlands, 1990.

Adapted from Kohout MP, Hansen M, Pribaz JJ, et al. Arteriovenous malformations of the head and neck: natural history and management. *Plast Reconstr Surg* 1998;102:643–54.

little direct information on the lesion in question other than its mass effect and only if of sufficient size. Dystrophic calcification, either diffuse or in the form of phleboliths, can be identified within VMs [20]. Of vascular malformations, 34% cause some form of adjacent bony change [48]. In the extremities, VMs are more likely to cause bony hypoplasia and demineralization [48]; however, the authors commonly have noted local mixed sclerotic change and periosteal reaction within adjacent bone. LMs can cause hypertrophy and bony distortion, whereas AVMs are more likely to cause destructive and intraosseous change [48,49] or skeletal overgrowth (Fig. 5) [50].

Ultrasonography

Ultrasound evaluation is noninvasive, inexpensive, and readily available [51]. In addition to gray-scale characterization of the lesion morphology and defining its size and extent, Doppler evaluation is invaluable in the discrimination between high-flow and low-flow malformations.

On gray-scale imaging, VMs are compressible; show heterogeneous echotexture (98%); and appear hypoechoic (82%), isoechoic (8%), or hyperechoic (10%) relative to adjacent subcutaneous tissue [52]. Phleboliths with acoustic shadowing are highly specific for VM, but are seen in only 16%, and only a few show discernible anechoic vascular spaces [52]. LMs have a variable appearance, with macrocystic LMs showing septa separating anechoic cavities that can contain debris

[51]. Microcystic LMs have small cavities resulting in innumerable reflective interfaces and a hyperechoic appearance [50,53]. AVMs have a heterogeneous echotexture and reveal large tubular vascular structures without a well-defined soft tissue mass (Fig. 6) [50].

Color Doppler and pulsed Doppler interrogation of VMs reveals monophasic flow in 78%, biphasic flow in 6%, and no flow in 16% [52]. Biphasic flow may be characteristic of mixed lesions, and the absence of flow may represent lesion thrombosis versus flow below detectable limits [52]. LMs do not show detectable flow on Doppler; however, flow can be detected within lymphatic cyst wall and intervening tissues [51]. AVMs have high vessel density, high systolic flow, arteriovenous shunting, and arterial flow within enlarged draining veins (Fig. 7) [50].

Computed tomography

On CT, VMs often appear hypodense or heterogeneous owing to fatty infiltration when present [20,50]. CT may define alteration in bony architecture better and identify phleboliths or other dystrophic calcifications. As is classically described in hepatic lesions, contrast administration increases lesion conspicuity and gradual peripheral enhancement on serial imaging [50]. CT of LMs shows fluid-filled, low-attenuation masses occasionally with fluid-fluid levels and peripheral contrast enhancement of the wall [50]. Contrast-enhanced CT of AVMs reveals numerous enlarged feeding arteries with rapid contrast shunting into enlarged draining veins without significant intervening tissue enhancement that usually would be seen within a normal capillary network. Contrast-enhanced helical CT of AVMs is significantly more informative than in other vascular malformations because it provides a distinct three-dimensional data set for accurate mapping and measurement of arterial, nidal, and venous structures and assessment of flow patterns for interventional radiologic or surgical planning (Fig. 8) [54].

Magnetic resonance imaging

MRI has revolutionized the characterization and differentiation of vascular malformations by providing superior lesion-to-soft tissue conspicuity and allowing a semiquantitative evaluation of malformation perfusion or flow. MRI has largely replaced CT because it has the added advantage of not subjecting the patient to ionizing radiation



Fig. 5. Conventional radiographic findings in vascular malformations. (A) VM reveals multiple lamellated phleboliths (*arrowhead*) and dysplastic bony changes (*arrow*). (B) Large VM with periosteal reaction (*arrow*) and multiple dystrophic calcifications. (C) LM being targeted for sclerotherapy reveals adjacent periosteal reaction (*arrow*). (D) AVM on angiography reveals permeative osteolysis and destruction of the midfibula (*arrow*).

[55]. Serial MRI also serves as an excellent internal control in evaluating therapy in low-flow malformations, particularly after interventions such as sclerotherapy.

A typical malformation imaging protocol consists of spin echo or fast spin echo T1-weighted imaging axial to the lesion, allowing baseline evaluation of anatomy and maximal definition of tissue planes and neurovascular structures. Coronal, sagittal, or axial T2-weighted short tau inversion recovery images are performed to define maximally extent of the lesion. Gradient echo T2*-weighted imaging allows identification of hemosiderin, dystrophic calcification, or phleboliths and allows evaluation of high flow versus low flow. Axial fat-saturated fast spin echo T1-weighted imaging after and optionally before gadolinium administration is crucial in defining

low-flow vascular anatomy and perfusion and to define extent of the lesion further.

VMs typically appear isointense or hypointense [15,20,56,57]; however, lesions can appear mildly hyperintense [58], especially if containing intralesional fat [56]. They also can exhibit heterogeneous texture as a result of differential signal intensity within regions of hemorrhage and thrombosis [20,50]. Punctate areas of low intensity or signal void can be observed in the presence of phleboliths [56,57]. Associated abnormal venous structures can be identified [20]. T2-weighted or short tau inversion recovery sequences invariably show high signal intensity [15,20,50,56–59] and best demarcate the full extent of the lesion and its relation to adjacent vital structures, often within areas undetected by T1-weighted imaging. Low signal is observed in the areas containing

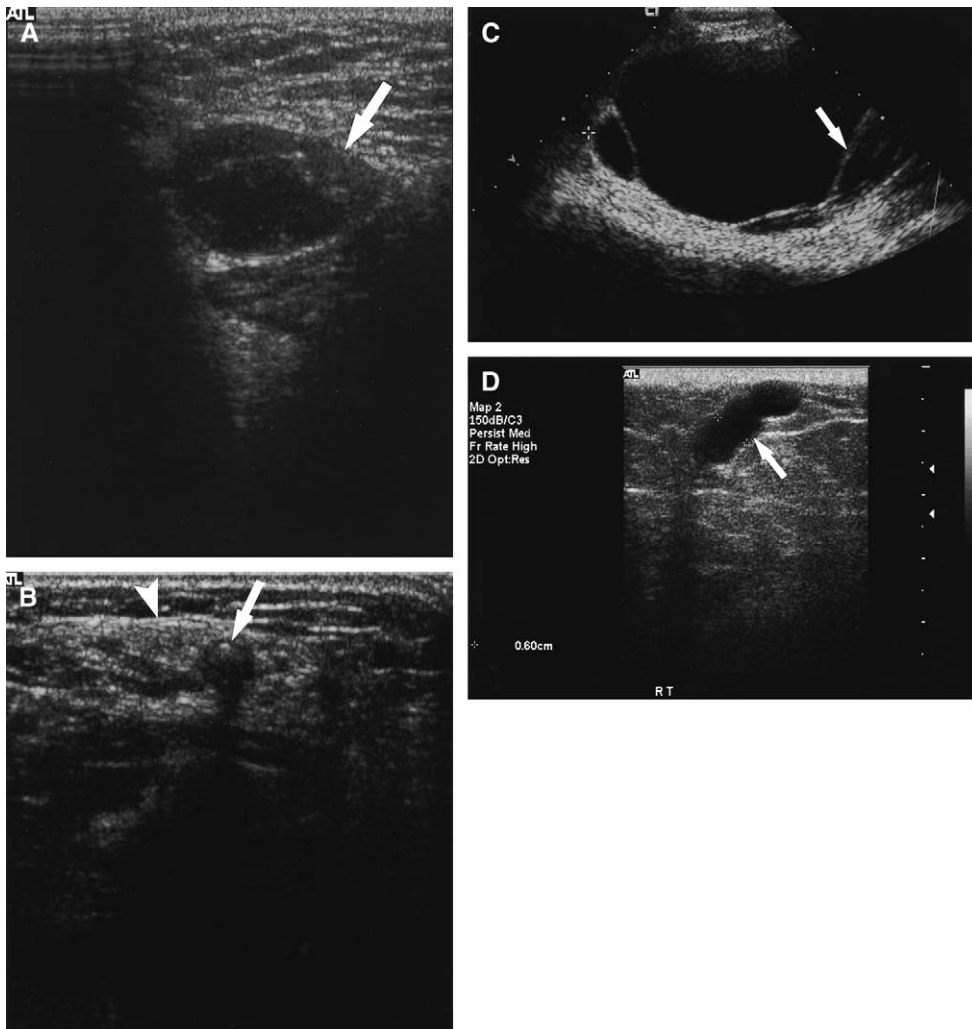


Fig. 6. Ultrasound of vascular malformations. (A) Well-defined VM reveals hypoechoic echotexture (*arrow*). (B) VM appears ill defined and mildly hyperechoic (*arrowhead*). An echogenic phlebolith with acoustic shadowing is noted (*arrow*). (C) Macrocytic LM reveals large anechoic fluid-filled spaces and internal septations (*arrow*). (D) AVM shows superficially enlarged anechoic vascular channels at site of fistulization (*arrow*).

fibrofatty septa, vascular channels, phleboliths, or thrombosis [20,56]. Gradient echo sequences reveal areas of low signal intensity corresponding to calcification or hemosiderin [20]. VMs homogeneously or heterogeneously enhance after gadolinium administration [60]. T1-weighted fat-saturated images maximally define any high signal intralésional vascularity [20] by subtracting confounding high signal caused by intralésional or adjacent fat (Figs. 9 and 10).

Categorization of MRI findings in VMs also provides information for the prediction of probability of therapeutic success from sclerotherapy.

Grade I lesions are well defined *and* less than 5 cm. Grade II lesions are either poorly defined *or* greater than 5 cm. Grade III lesions are poorly defined *and* greater than 5 cm (Fig. 11). Lower grade lesions have higher clinical response to therapy, use lower volumes of sclerosant, and have a lower number of treatment sessions [59]. MRI also can be used to monitor clinical outcomes after sclerotherapy. T1-weighted and T2-weighted imaging of treated VMs usually reveals decreased lesion size and increased heterogeneity, often with treated portions showing hypointensity on T2-weighted images and decreased enhancement [20,61].

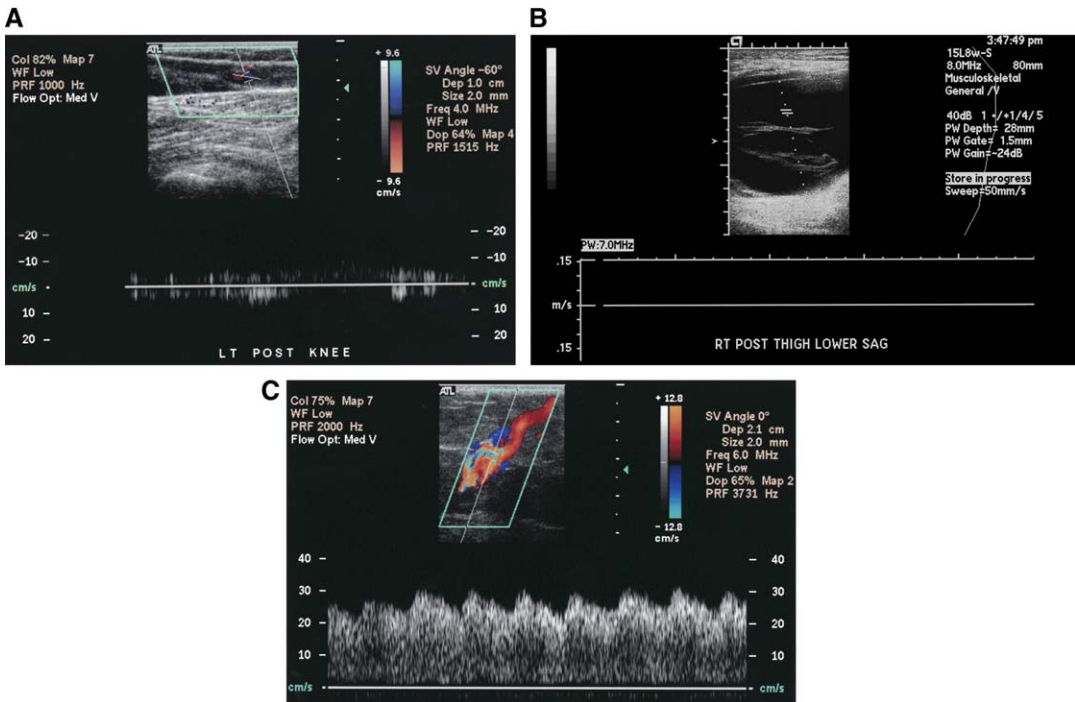


Fig. 7. Doppler ultrasound of vascular malformations. (A) VM reveals mixed venous waveform. (B) LM shows complete absence of Doppler flow. (C) AVM reveals multidirectional flow and high-amplitude arterial waveform with spectral broadening.

Macrocytic LMs on T1-weighted imaging most commonly show a cystic septated mass [50] that is isointense [62] or hypointense [50,57], particularly within cystic spaces [57,58,60]. T2-weighted sequences reveal marked hyperintensity [50,57,58,60,62]. Proteinaceous fluid, hemorrhage, or fluid-fluid levels can cause a more heterogeneous appearance [50,57,58]. No high-flow vascular signal voids are present. After gadolinium administration, the cystic contents of macrocytic LMs often do not enhance, allowing convincing differentiation from enhancement patterns of VMs (Fig. 12) [58,60,62]. Mild enhancement may be seen, however, within cyst walls or septa causing “rings and arcs,” and cysts may enhance after surgery or sclerotherapy [57,60] as a result of ongoing inflammation (Fig. 13).

Microcytic LMs differ significantly from macrocytic lesions in that their cystic spaces are often too small to be discernible by MRI [57]. The overall more diffuse appearance is hypointense on T1-weighted imaging and hyperintense on T2-weighted imaging and can be confused with other soft tissue masses (Fig. 14) [57]. Because of their smaller cystic spaces, microcytic LMs can mildly

enhance diffusely and homogeneously overlapping in appearance with VMs or not enhance at all [57,60]. Mixed lesions can show characteristics of macrocytic and microcytic lesions (Fig. 15).

High-flow AVMs have a dramatically different appearance from their low-flow counterparts based on two major characteristics. First, AVMs show multiple tangled hypertrophied arterial and engorged venous vascular spaces connected by linear or focal shunts that are seen as low signal on T1-weighted and T2-weighted spin echo sequences owing to flow void and turbulent flow [50] and foci of high signal on gradient echo images. Second, AVMs exhibit a characteristic lack of a soft tissue component or identifiable mass (Fig. 16) [57,58,60]. There are three exceptions to this latter point: (1) An AVM may take on a masslike appearance if compact or “confined” as within a fascial space or muscle sheath; (2) skin thickening and fatty hypertrophy associated with AVM may create the appearance of a mass in some lesions; and (3) edema or contrast enhancement in the periphery of the nidus of an AVM can give the lesion a masslike appearance (Fig. 17) [57,60].

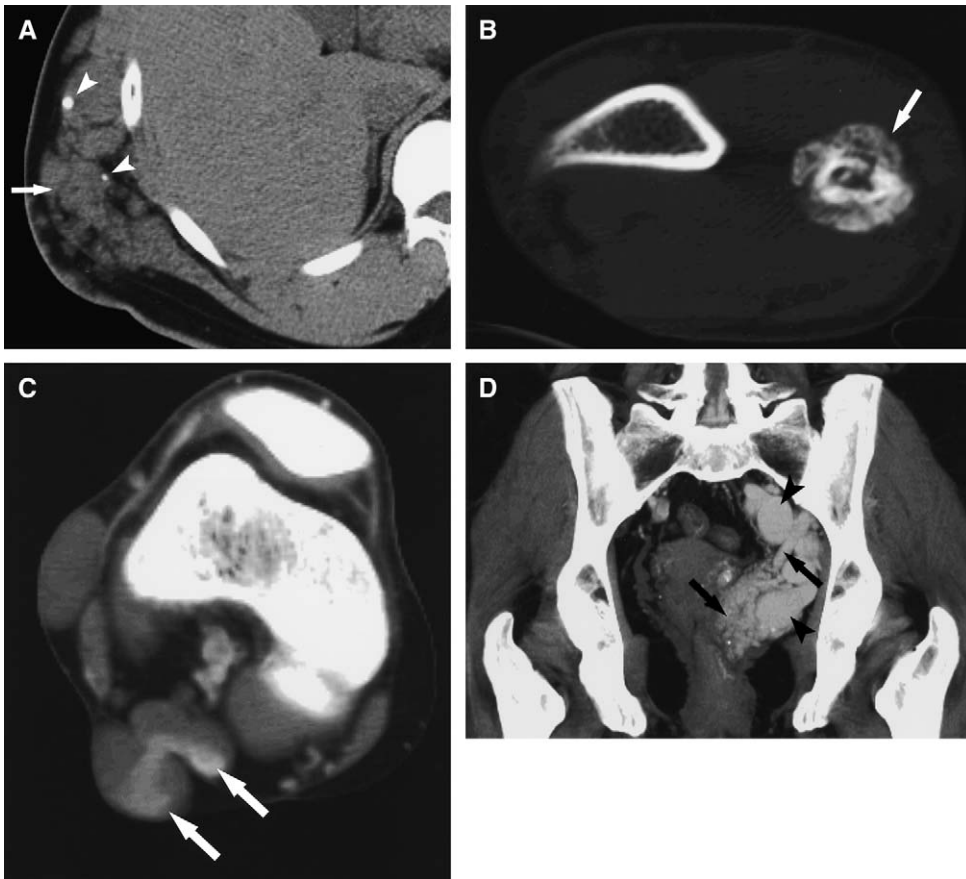


Fig. 8. CT of vascular malformations. (A) VM of the right flank (*arrow*) shows muscle and soft tissue attenuation and the presence of phleboliths (*arrowheads*). (B) VM of the forearm resulting in marked periosteal reaction and bony remodeling within the ulna (*arrow*). (C) Contrast-enhanced CT of VM with flow of contrast material through enlarged superficial venous structures (*arrows*). (D) Coronal thin maximal intensity projection of contrast-enhanced CT of the pelvis in midarterial phase. Numerous tortuous hypertrophied arterial structures (*arrows*) and enlarged draining veins are identified (*arrowheads*).

Because MRI is exquisitely sensitive, but not specific for the detection and characterization of vascular malformations, all diagnoses have to be made in the context of clinical history and findings. If MRI findings are atypical or suspicious, one should consider proceeding to diagnostic phlebography or angiography or biopsy [20].

Nuclear medicine

In contrast to MRI, inherent low spatial resolution and emission of ionizing radiation have limited the role of nuclear imaging in vascular malformations to specific indications. Technetium-99m-tagged red blood cell whole-body pool scintigraphy can show increased uptake and pooling of radiotracer within VMs and AVMs, which can be

relatively quantified before and after intervention to evaluate efficacy of therapy [3,63] and can be used to differentiate LMs from other vascular malformations [63]. Transarterial lung perfusion scintigraphy requires an intra-arterial injection of technetium-99m macroaggregated albumin upstream of an AVM. Measuring the level of activity of radiotracer reaching the lungs that has passed unfiltered through the AVM shunt allows an exact quantification of shunt percentage. This imaging can be used at the initiation and end of treatment and can quantify efficacy of therapy objectively [3,25,63].

Diagnostic phlebography

Diagnostic direct percutaneous phlebography (DPP) can be used for the diagnostic confirmation

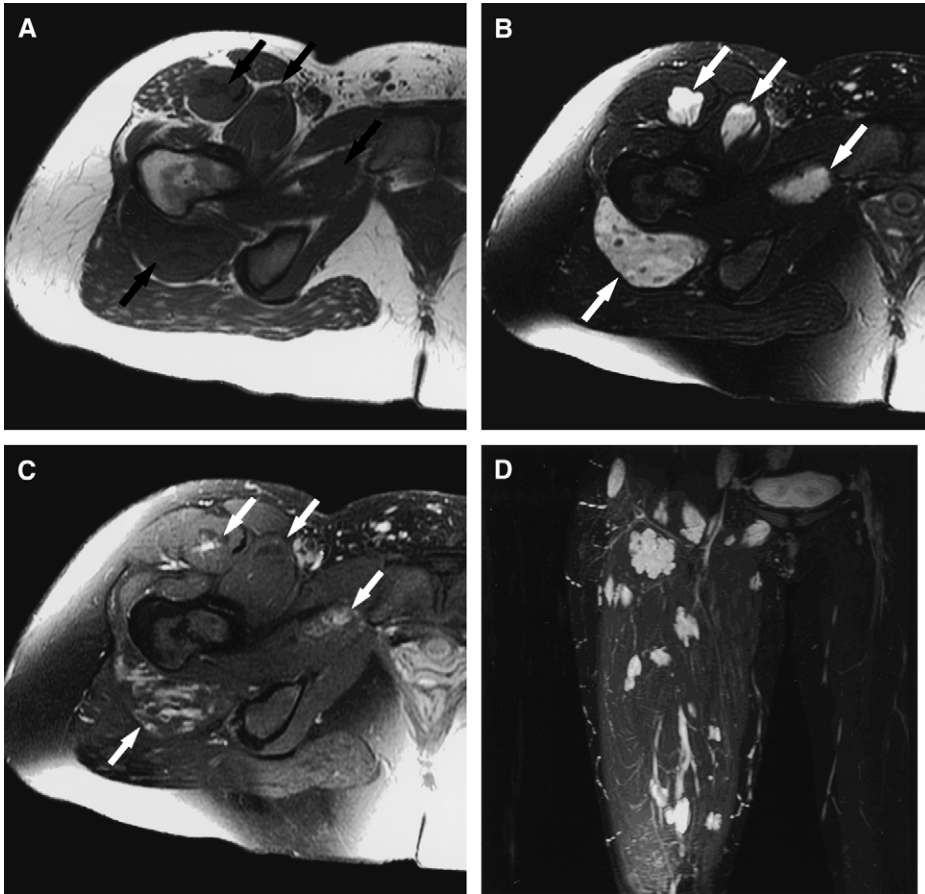


Fig. 9. MRI of VMs. (A) T1-weighted image reveals isointense to hypointense lesions relative to muscle (*arrows*). (B) T2-weighted fast spin echo imaging shows marked signal increase and lesion conspicuity (*arrows*) relative to adjacent soft tissues. (C) Gadolinium-enhanced T1-weighted fat-saturated image shows variable heterogeneous contrast enhancement of lesions (*arrows*). (D) Thin maximal intensity projection coronal reconstruction of the thigh using fast short tau inversion recovery sequence shows similar lesion characteristics to T2-weighted imaging.

and differentiation of suspected low-flow or combined malformations that are equivocal on other imaging modalities, for treatment planning of a known malformation, or for exclusion of the possibility of a neoplasm in cases under consideration for biopsy because of suspicious or nonspecific findings of a soft tissue mass on MRI. VMs show one or more characteristic patterns on DPP—cavitary, spongy, and dysmorphic (Fig. 18) [20]. Phlebography also can be performed to characterize LMs (Fig. 19). Therapeutic DPP is performed as a part of a percutaneous sclerotherapy procedure. The phlebographic technique and subcategorization of phlebographic findings are discussed in the section on sclerotherapy of venous malformations.

Diagnostic angiography

With the development of MRI, the historically ubiquitous use of arteriography in the *diagnostic* imaging workup of vascular malformations has been relegated to a few specific clinical indications. Arteriography is invasive, involves ionizing radiation, and is an intimidating examination for patients of all ages. Angiography is *not* indicated in the workup of VMs or LMs that have been confidently diagnosed by clinical findings and noninvasive imaging [64]. Diagnostic arteriograms of VMs still are done at major centers through referrals, however, and reveal either completely negative findings or evidence of venous stasis, pooling, or puddling (Fig. 20) [57].

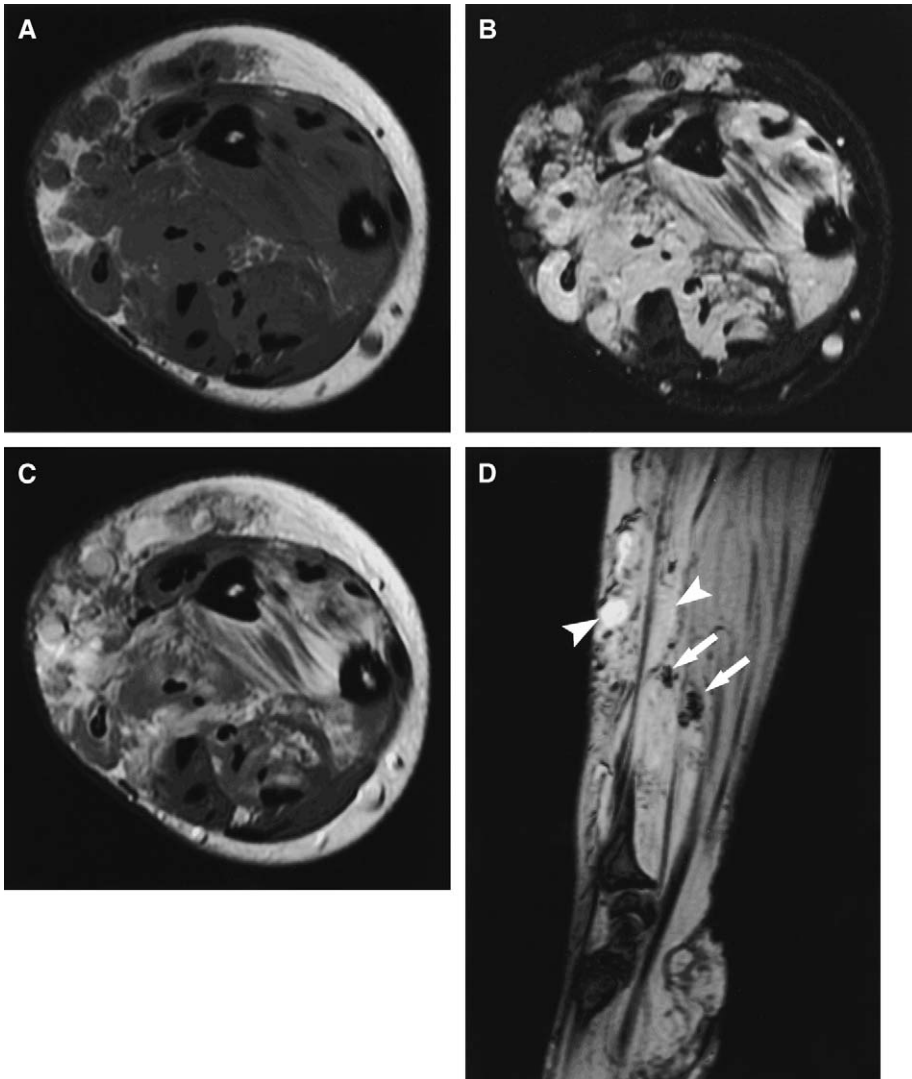


Fig. 10. MRI of VM of the arm. (A) T1-weighted image of an ill-defined VM of the arm. (B) Fast short tau inversion recovery image better defines the infiltrative intramuscular nature of the lesion. (C) Gadolinium-enhanced T1-weighted image shows similar infiltrative pattern to fast short tau inversion recovery sequences. (D) Sagittal T2-weighted multiplanar gradient recalled sequence shows foci of low signal corresponding to phleboliths (arrows). With T2-weighted technique, the malformation showed hyperintense signal (arrowheads).

Arteriography most commonly is reserved for the confirmation and treatment planning for suspected or known AVMs. The classic angiographic appearance of AVMs shows innumerable hypertrophied feeding arteries rapidly shunting into engorged dilated draining veins across a *nidus*, defined as the point at which arterial structures first opacify the venous drainage (Fig. 21) [50,65]. Less frequently, diagnostic arteriography

may be helpful in the evaluation of high-flow masses or lesions exhibiting ambiguous high-flow or intermediate-flow patterns on ultrasound and MRI in which the clinical and imaging differential diagnosis includes a combined malformation or neoplasm in addition to AVM. Arteriography may be helpful in the diagnosis of capillary VMs. This lesion shows contrast opacification across normal or slightly enlarged arteries leading

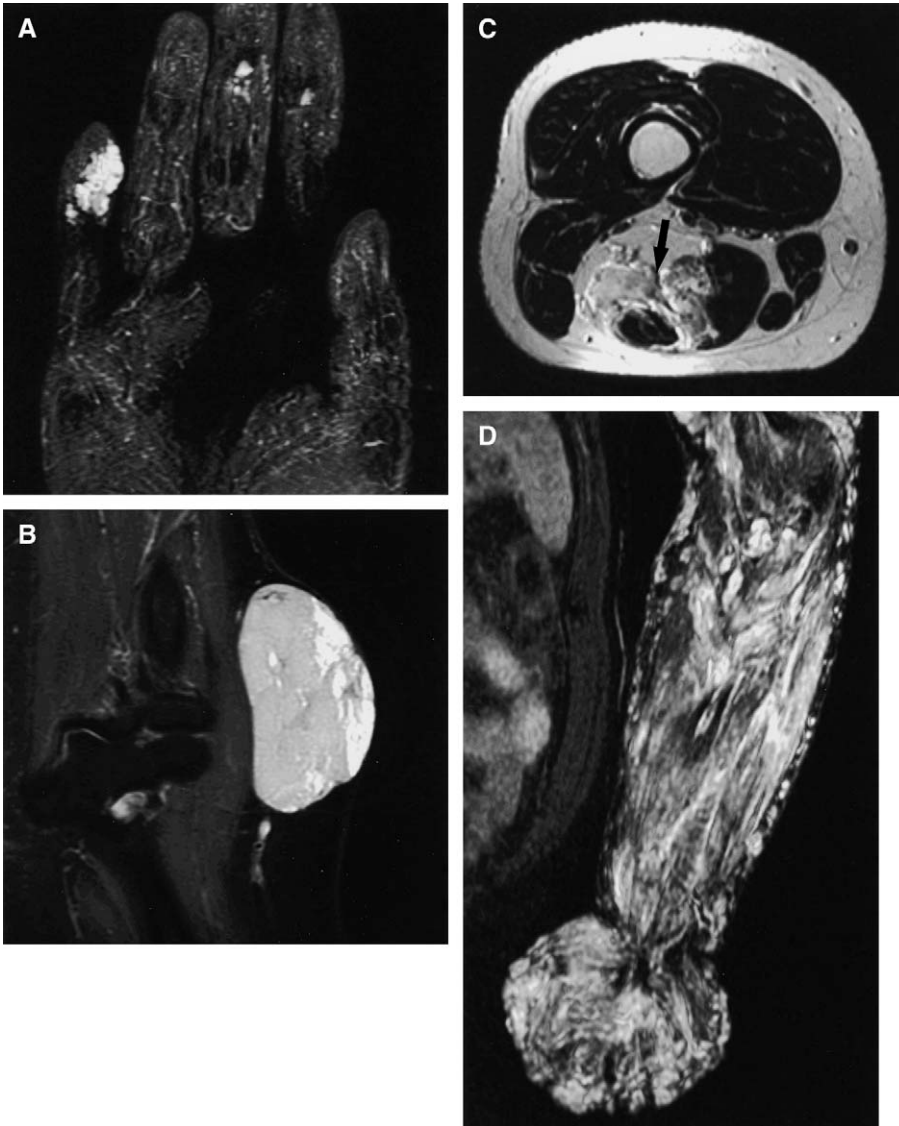


Fig. 11. MRI grading classification of VMs [59]. (A) Grade I lesion of the fifth digit measuring less than 5 cm shows clear definition on fast short tau inversion recovery sequence. (B) Grade II lesion of the antecubital fossa shows clearly defined borders measuring greater than 5 cm diameter on fast short tau inversion recovery sequence. (C) Grade II lesion of the posterior thigh measuring less than 5 cm shows poor definition on fast spin echo T2-weighted sequence. (D) Large grade III lesion shows diffuse infiltration of the entire forearm and hand on fast short tau inversion recovery sequence.

to prolonged pooling within ectatic dilated venous spaces, presumably across dilated capillaries or venules [5].

Therapeutic options for vascular malformations

Essential to the optimal care of patients with vascular malformations is the assembly of an experienced multidisciplinary team that is well

versed in the latest diagnostic and therapeutic techniques and controversies within the field of study of vascular anomalies. This level of familiarity and expertise usually can be achieved only through frequent exposure to vascular anomalies facilitated through streamlined interdisciplinary communication and usually is found at larger referral institutions in the form of a vascular anomalies center. Based on the specific patient

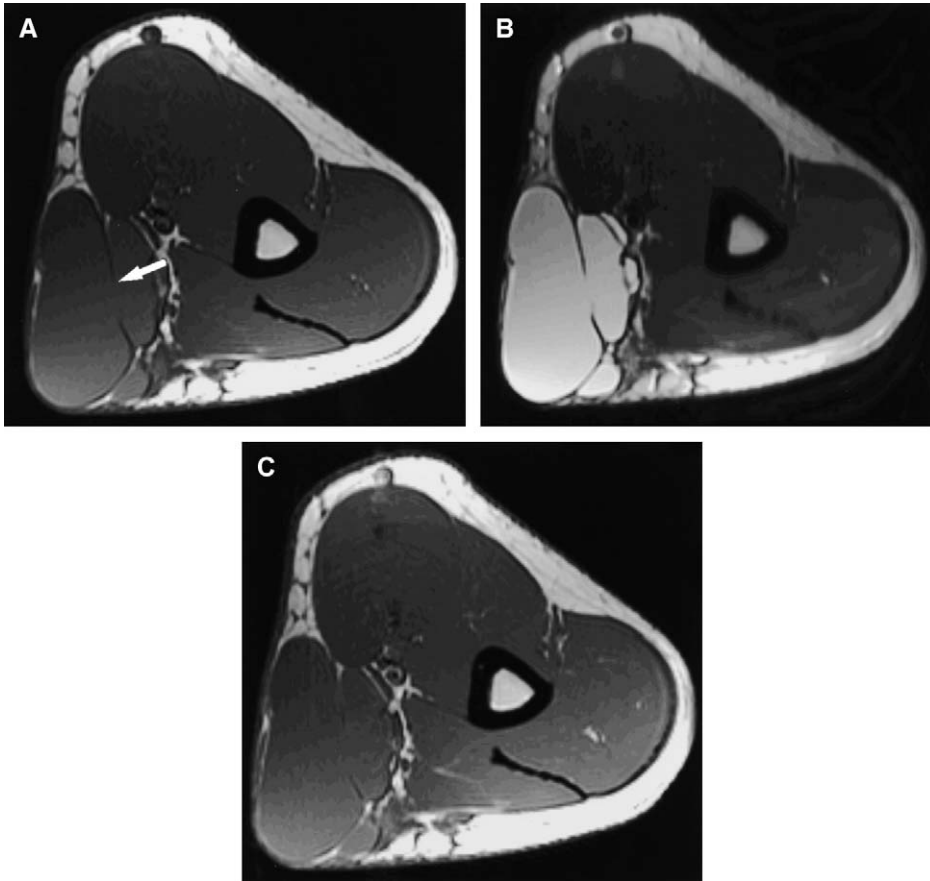


Fig. 12. MRI of macrocystic LMs. (A) T1-weighted imaging of a malformation of the medial upper arm shows multiple isointense cystic spaces with internal septations (*arrow*). (B) Fast spin echo T2-weighted imaging reveals marked hyperintensity within cystic spaces. (C) Gadolinium-enhanced T1-weighted imaging reveals no contrast enhancement of the malformation.

population, such a team comprises many specialties, including dermatology, vascular or plastic and reconstructive surgery, otolaryngology, orthopedic oncology, anesthesiology, pediatrics, radiology, and rehabilitation medicine supported by physiotherapy or occupational therapy [3,15].

Indications for therapy

One should arrive at the decision to treat a vascular malformation by consensus between referring specialties [3], with careful consideration of the potential procedure's associated morbidity relative to the present and often uncertain future morbidity if left untreated [66]. Lee [63] devised a "decision to treat" formula in which therapy is initiated based on the patient possessing at least one absolute or two relative indications. Absolute

indications include hemorrhage; progressive high output failure; complications secondary to venous hypertension; and lesion location within a life-threatening area, such as the airway, or lesion location threatening vital functions. Abbreviated relative indications include progressive disabling pain or discomfort, functional disability or impairment affecting daily life and quality of life, cosmetically severe deformity, vascular-bone syndrome causing growth discrepancy, lesion location at high risk for complication, and recurrent infection or sepsis.

In the case of flow malformations, where appropriate, invasive management should be reserved for patients who meet the above-mentioned criteria after failing more minimal therapies. VMs often can be treated at least initially successfully with elevation, compression garments,

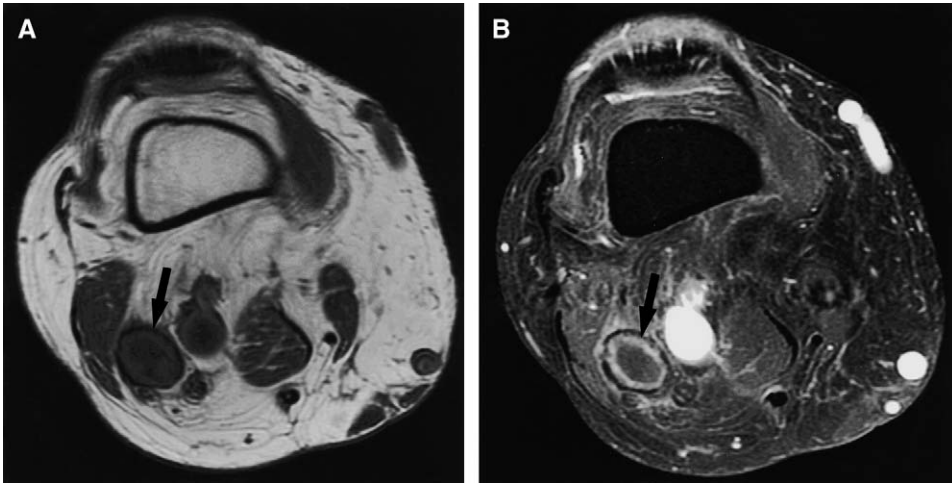


Fig. 13. Atypical enhancement patterns of macrocystic LMs. (A) Contracted thick-walled cyst within a macrocystic LM on T1-weighted imaging that had undergone sclerotherapy previously (*arrow*). (B) Pronounced cyst wall enhancement with gadolinium (*arrow*) on fat-saturated T1-weighted imaging.

and aspirin, whereas medical management of LMs requires antibiotics and steroids during infectious or hemorrhagic episodes [15,44].

Surgery versus interventional radiology

The decision of whether to treat vascular malformations via surgery or interventional radiologic techniques is complex and often dictated by factors specific to the lesion in question, patient preference, and availability of expertise or patterns of practice within a given institution. Several

attempts have been made to define more clearly treatment modality algorithms between surgery and interventional radiology based on lesion type, size, location, and morphology [3,6,63,67–71]. Overall, the Hamburg classification of vascular malformations provides a framework through which general trends in current therapy can be observed [63]. Truncular VMs, often more extensive and requiring correction of hemodynamic factors, are treated primarily surgically with or without adjunctive radiologic embolosclectherapy. There is little role for radiologic management of other truncular lesions. Conversely, extratruncular

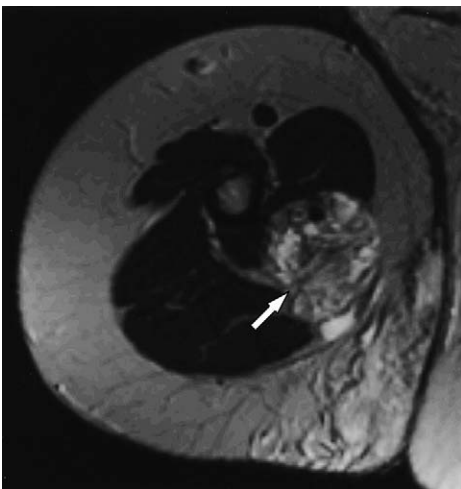


Fig. 14. MRI of microcystic LMs. Fast spin echo T2-weighted imaging of a microcystic lesion in the upper arm (*arrow*) lacking clear definition of cysts and having an appearance indiscernible from a VM.

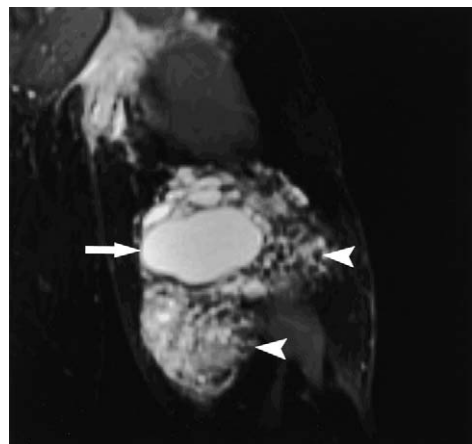


Fig. 15. MRI of mixed LMs. Lesion combining macrocystic (*arrow*) and microcystic (*arrowheads*) elements on fast short tau inversion recovery imaging.

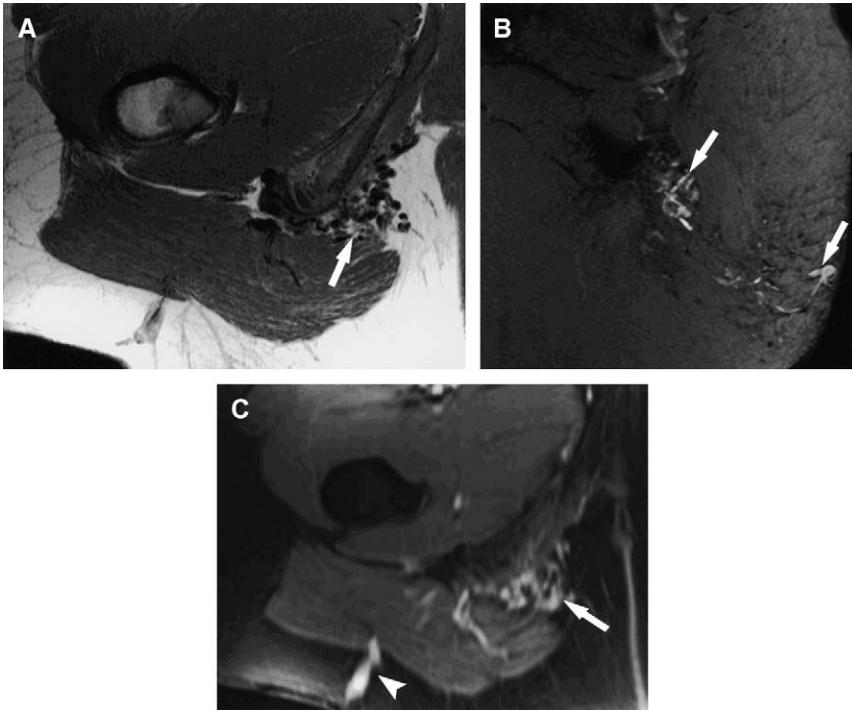


Fig. 16. MRI of AVMs. (A) Thin minimum intensity projection T1-weighted sequence shows numerous tortuous vascular spaces with flow voids (*arrow*) within an AVM of the ischial and buttock region with a characteristic lack of discernible “mass.” Findings are commonly similar on T2-weighted imaging. (B) Thin maximal intensity projection sagittal multiplanar gradient recalled sequence reveals mixture of focal high signal intensity owing to turbulent or abnormal flow (*arrows*). Note lack of discernible mass. (C) Gadolinium-enhanced fat-saturated image reveals hyperintensity with the arteriovenous nidus (*arrow*) and within venous drainage (*arrowhead*).

forms of VMs and LMs incorporate interventional radiologic therapy to a much greater degree. AVMs are largely treated via percutaneous means with or without adjunctive surgical resection.

Percutaneous image-guided embolization and sclerotherapy

Rationale

Whether percutaneous or surgical, the ultimate goal of any therapy for vascular malformations is to correct or remove the focal structural vascular derangement or mass responsible for the patient’s symptoms. Because vascular malformations are the result of continued disordered growth, or more precisely enlargement of structures originating and controlled at the endothelial level, only therapy directed to this end is effective. Endothelial cells not only direct continued vascular growth and angiogenesis, but also are thought to initiate vascular clearance and recanalization [65]. A

direct-contact *endothelial-cidal* approach using endovascular administration of a sclerosant is the only predictably effective and durable form of therapy short of surgical resection [65,72]. In sclerotherapy, the degree of endothelial damage incited and therapeutic effect is a factor of the type of agent, its *in vivo* concentration, and its contact or “dwell time” with endothelium [64,73]. These latter two factors depend on volume and *in vitro* concentration of agent, total vascular volume being treated, rate of injection, and local vascular flow rate. To optimize these variables and effect maximal endothelial damage while limiting effects on normal adjacent tissue, a series of sclerotherapy and embolization techniques have been developed using different agents, viscosities, routes of administration, and flow-occlusion techniques.

Major sclerosing agents

Numerous sclerosing agents are available to the interventional radiologist to treat vascular

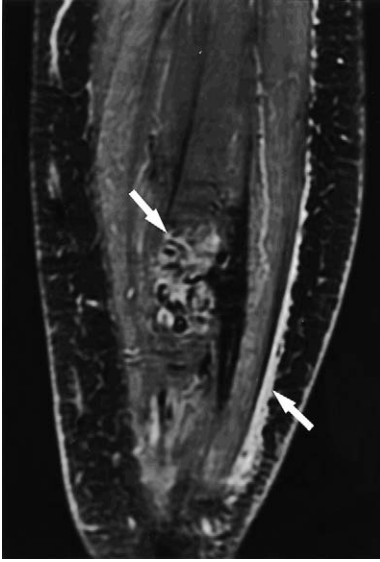


Fig. 17. Atypical MRI findings in AVMs. Interosseous AVM of the calf has a “masslike” appearance that can be caused by perilesional edema (arrows), fatty hypertrophy, or adjacent flow phenomena.

malformations. The choice of agent is based on its relative toxicity, viscosity, and, in the case of solid embolic agents, size; durability of occlusion; and safety of delivery. Conventional intravascular contrast agents or oil-based contrast agents, such as ethiodized oil (Lipiodol Ultra Fluid; Guerbet Group, Roissy CdG Cedex, France) can be mixed with sclerosant to improve visibility during administration to avoid local extravasation or nontarget embolization. Personal preference and experience are important in the choice of sclerosing agent because there are no known clinical trials comparing the efficacy of these agents in vascular malformations [74].

Ethanol (Dehydrated Alcohol, injection USP, 100% v/v; Sandoz Canada, Inc, Boucherville, QC) is the most widely used and accepted percutaneous sclerosing agent for the treatment of all vascular malformations, being readily available, inexpensive, easy to use, and with a long shelf life [75,76]. Ethanol sclerotherapy is painful and requires general anesthesia for most cases. Ethanol achieves vascular closure by denaturing blood proteins, dehydrating endothelial cells, precipitating their cytoplasm, denuding and fracturing intima to the level of the internal elastic lamina, and eliminating the possibility of recanalization and revascularization [65,77]. Ethanol must be used with extreme caution. It has low viscosity

and must be administered in small aliquots during superselective positioning. Nontarget embolization rapidly penetrates the capillary wall and devitalizes normal tissue [77]. In treatment of vascular malformations, the most common complications associated with ethanol are juxtaleisional skin necrosis, nerve impairment or palsy, and hemoglobinuria [72–74,78,79]. Skin necrosis may occur as a result of reflux from superficial venous channels to the skin surface during or after the embolization procedure [71]. Intravascular ethanol administration can cause precapillary pulmonary arterial vasospasm [77] leading to sustained pulmonary hypertension in nearly a third of patients without lasting effect on pulmonary artery pressure [76], bronchospasm [80], cardiopulmonary collapse [81], pulmonary embolus [72], hyperthermia [82], death [83], and intoxication [78]. As a guideline, ethanol administration should not exceed 1 mL/kg at any one visit [65].

Sodium tetradecyl sulfate (Thromboject 1% and 3%, Omega, Montreal, QC) is an anionic surfactant that has been widely used in the past for sclerosis of esophageal varices and varicose veins and has been increasingly used in the treatment of vascular malformations [64]. The material has a soapy consistency, contains 2% benzyl alcohol [65], and causes erythrocyte sludging and permanent obliteration of vascular structure by organized thrombosis, necrosis, and adventitial thrombosis [84]. The agent has not been found to be as effective as ethanol in the treatment of higher flow AVMs [65]. In lower flow lesions, it has been found to be effective in closure of capillaries and smaller channels of VMs, but occasionally venous lakes have been found to recanalize on follow-up [15,64]. Although larger doses of sodium tetradecyl sulfate can cause urticaria, anaphylaxis, hemolysis, and hematuria [74], this agent is likely less toxic than ethanol because there are lower reported rates of skin necrosis and nerve impairment and systemic complications [64,84]. As a result, this agent is used predominantly in VMs; some authors advocate that the potential lesser effectiveness outweighs the higher risks associated with ethanol [64].

Ethanolamine oleate (Ethamolin 5%; Questcor Pharmaceuticals, Union City, CA) is a salt of unsaturated fatty acid originally used in gastroesophageal varices as a result of its ability to induce thrombosis by damage to the vascular wall [85]. It has been used to treat high-flow and low-flow malformations [73,86–88]. Compared with

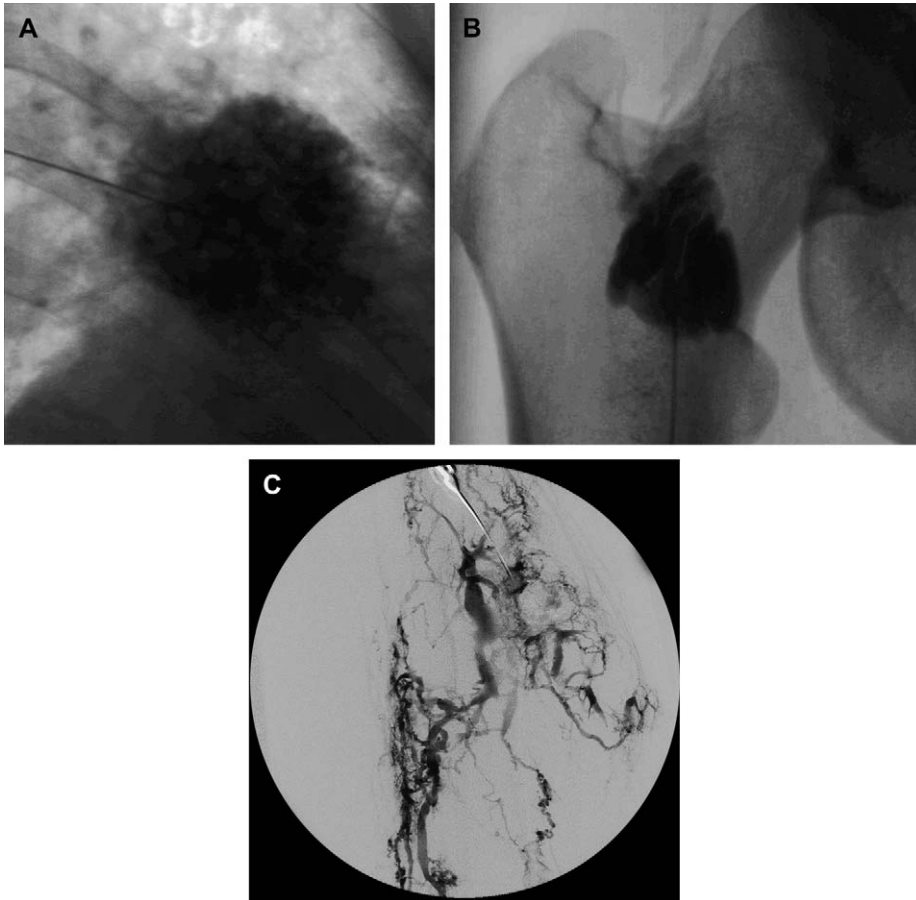


Fig. 18. Diagnostic phlebography of VMs. (A) Spongy appearance. (B) Cavitory appearance. (C) Dysmorphic appearance.

ethanol, ethanolamine oleate has less effect on deeper layers of the vascular wall and has no penetrative effect and is safer to use in situations where vascular structures are in proximity to nerves [87]. This material can cause renal insufficiency, intravascular hemolysis, and hepatotoxicity in higher doses; prophylactic haptoglobin may be necessary during and after the injection [55,73,86].

Polidocanol (Aethoxysclerol, Kreussler, Wiesbaden, Germany) is a widely used nonionic surfactant sclerosant that was first developed as an anesthetic [89] and acts through endothelial overhydration, vascular injury, and closure [90]. The agent's attractive anesthetic properties make it a nearly painless alternative in the treatment of VMs; however, it does not induce the same degree of endothelial damage as ethanol, sodium

tetradecyl sulfate, or ethanolamine oleate [91]. A case of reversible cardiac arrest has been reported with use of this agent [92].

Alcoholic solution of zein (Ethibloc; Ethicon, Norderstedt, Germany) consists of a solution of zein, sodium amidotrizoate, oleum papaveris, and propylene glycol. Zein is a water-insoluble prolamine from corn gluten that forms hard clear shells used in coatings of foods and pharmaceutical products. The resulting solution is 20 times more viscous than conventional aqueous solutions allowing it to remain relatively static in the lesion to effect intravascular thrombosis, necrosis, and fibrosis without premature passage into the venous outflow [93,94]. This agent is particularly attractive for the treatment of VMs [93,95–97]; it has been used with good success in LMs [98,99] and occasionally has been used in AVMs [97].

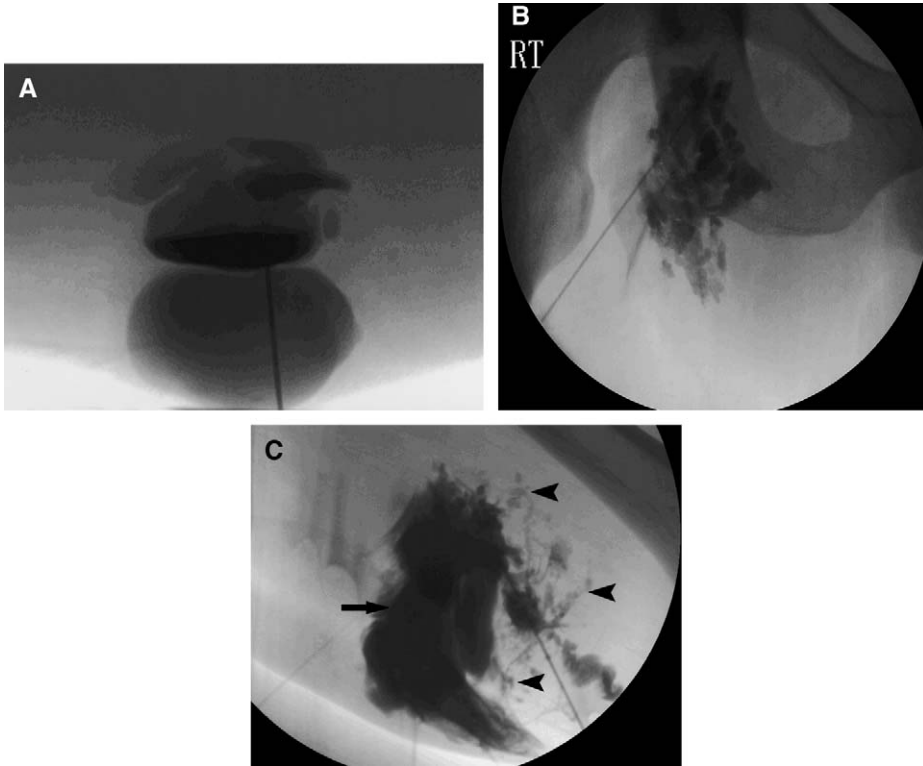


Fig. 19. Diagnostic phlebography of LMs. (A) Macroscopic lesion reveals large multiloculated cavities. (B) Predominantly microcystic lesion on phlebography. (C) Mixed LM on phlebography reveals macrocystic (arrow) and microcystic (arrowheads) spaces.

Ethibloc requires approximately 10 to 15 minutes to solidify and is degraded by approximately 11 days into amino and glutamic acids.

Sodium morrhuate (Scleromate 5%; Palisades, Glenwood Inc., Englewood, NJ) is a sodium salt of the fatty acids in cod liver oil. This agent is an irritant and sclerosing agent that originally was used to treat varicose veins and arthritic joints. The agent has been used in the treatment of VMs [74], but has been found to be 1.5 to 4 times less effective than sodium tetradecyl sulfate [100]. Historically, other agents have been used, such as hypertonic 50% dextrose, acetic acid, methyl methacrylate, triamcinolone, and bleomycin [101]. Other agents specific to the treatment of LMs have been developed and are discussed later.

Embolic agents

To ensure adequate dose and dwell time of sclerosant within the critical regions of a vascular malformation, various techniques of flow occlusion or redirection may be necessary, particularly

in the case of AVMs, in which high flow and collateral flow continuously conspire to dilute and redirect sclerosant from the nidus. Combinations of metallic coils, occlusion balloons, and intra-vascular “glues” may be employed to this end.

The cyanoacrylates are adhesive glues that polymerize when exposed to anions such as hydroxyl groups in water or blood causing an acute fibrotic inflammatory foreign body granulomatous reaction progressing over approximately 1 month [102]. These agents alone may be sufficient for closure of an AVM; however, they can be plagued by recanalization [103] and often require additional sclerotherapy for durable result. In addition to embolization of glue into the lungs via the shunt and inadvertent gluing of the catheter to the vessel, masses of cyanoacrylate within AVMs can cause muscular dysfunction, become superinfected, and erode or extrude into adjacent tissue [72]. Originally, isobutyl-2-cyanoacrylate was used; however, concerns regarding the development of sarcomas in laboratory animals prompted a transition to *N*-butyl-2-cyanoacrylate



Fig. 20. Angiography of VMs. (A) Conventional arteriogram reveals pooling and puddling of contrast material in portions of multiple VMs within the hindfoot. (B) Maximal intensity projection contrast-enhanced volume interpolated gradient echo image reveals similar foci of increased signal intensity within multiple VMs (arrows).

(Histoacryl; B. Braun, Melsungen, Germany) in the late 1980s [102]. In 2000, *N*-butyl cyanoacrylate (Trufill n-BCA Liquid Embolic System, Cordis Neurovascular Inc., Johnson and Johnson, Miami Lakes, Florida) received approval from the FDA for use in the presurgical devascularization of cerebral AVMs. The cyanoacrylates alone are not radiopaque and require the addition of

a contrast agent, most commonly ethiodized oil for radiopacity. Increasing ratios of ethiodized oil to cyanoacrylate result in longer “set times” for polymerization and can be used as a method of finely tailoring the degree of penetration into the lesion based on each vessel’s unique flow characteristics.

Ethylene vinyl alcohol copolymer (Onyx Liquid Embolic System; Micro Therapeutics, Inc,



Fig. 21. Angiography of AVMs. (A) Early arterial phase pelvic arteriogram in a Schobinger stage 4 patient reveals a markedly enlarged internal iliac arterial distribution leading to a hypervascular nidus (arrow). (B) Mid-to-late arterial phase image shows the full extent of the nidus with grossly enlarged internal iliac draining veins (arrow).

Irvine, CA) is a nonadhesive liquid embolic dissolved in dimethyl sulfoxide with suspended micronized tantalum powder for radiographic visualization. Originally used as an embolic agent in brain AVMs and hypervascular tumors, ethylene vinyl alcohol has more predictable fixation, can contour to the vessel in question, is very radiopaque, and is much less likely to fixate the delivery catheter to the vessel wall [104]. Additionally, the agent leaves a more “spongy” mass than cyanoacrylates that can be resected more easily if necessary [105]. The material has been used predominantly in peripheral high-flow AVMs [104] and in some VMs [106] with mixed results.

Patient preparation

After multidisciplinary consultation, treatment should be preceded by an in-person office consultation by the radiologist performing the procedure. A directed medical history and directed physical examination should be performed incorporating tape measurements and medical photography of the lesion if applicable for baseline assessment and future objective evaluation of therapy. This visit should occur outside the angiography area and preferably on a day well in advance of the intervention. This visit allows adequate undistracted time to discuss the procedure in depth with the patient addressing issues of inherent acute complications, expected level of postprocedure pain and swelling, and the likely need for more than one therapy session. The advance patient visit also allows time to obtain written consent, collect laboratory specimens, and arrange outpatient anesthetic consultation.

All procedures are performed in the angiography suite, which is equipped with fluoroscopy and digital subtraction angiographic capabilities, real-time ultrasound with Doppler, and “in-room” ability to review and correlate with prior imaging studies such as MRI and previous interventions. Conscious sedation, local or regional block, or most commonly general anesthesia is administered, and the appropriate bodily region and all relevant sites of potential remote arterial or venous access are sterilely prepared and draped.

Sclerotherapy of venous malformations

Percutaneous sclerotherapy of VMs begins with a real-time ultrasound-directed [107,108] or MRI-correlated fluoroscopic puncture of the malformation for diagnostic phlebography. A 21G to 27G needle or butterfly needle is advanced during gentle saline aspiration, observing for a flash of blood confirming intraluminal position (Fig. 22). Occasionally, tourniquets or pneumatic cuffs inflated to subsystolic pressures are placed proximally to distend the intraluminal component of the lesion to improve access stability. When a flash is observed, contrast material is injected under digital subtraction technique to show distribution, flow rate, and internal architecture of the VM and intravascular volume of the region injected and type and rate of venous drainage. Overly rapid efflux of contrast material via normal venous structures may require additional tourniquets or cuffs or direct application of instrument compression at the site of venous outflow to opacify better the internal structure of the lesion [64]. Demonstration of typical VM anatomy allows the

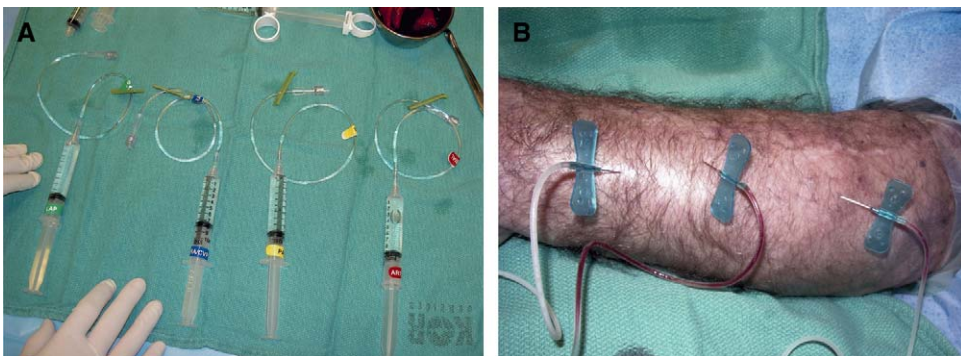


Fig. 22. Technique of phlebography and sclerotherapy. (A) Setup for percutaneous sclerotherapy including saline for initial puncture and aspiration, contrast for malformation opacification, and various sclerosants including sodium tetradecyl sulfate and ethanol. (B) 23G butterfly needle access over three sites for sclerotherapy of a large diffusely infiltrating VM of the forearm.

exclusion of soft tissue neoplasms from the differential diagnosis [20].

As described earlier, three basic VM patterns of the VM proper observed on phlebography: cavitory, spongy, and dysmorphic [20]. Given technical implications and differential response and complication rates from sclerotherapy, the pattern of venous drainage from the malformation has been subdivided further into three or four types by Dubois and colleagues [93] and Puig and associates [69,71]. Type I lesions represent isolated malformations without discernible venous drainage. Type II lesions drain into normal veins. Type III lesions drain into dysplastic veins. Type IV lesions consist primarily or solely of venous ectasia (Figs. 23 and 24). Type I and to a lesser extent type II lesions respond best to sclerotherapy with higher cure rates and lower number of sessions of therapy to achieve cure [93]. Higher complication rates related to systemic

venous embolization and sclerosant are attributed to type III and type IV anatomy [71]. This information, along with the MRI grade of the lesion, should be factored into the decision to proceed to sclerotherapy [59,71].

When characterized and isolated, VM sclerotherapy begins with the injection of most commonly ethanol [3,15,20,44,50,63,66,69–71,74,79,109–119] or tetradecyl sulfate [15,20,64,69,71,74,84,100,116,119], Ethibloc [20,50,69,71,93,96,119], ethanolamine oleate [15,51,73,74,88,120,121], polidocanol [44,69,90,108,122–124], sodium morrhuate [74], or Onyx [106]. A volume is administered to replace that which opacified the malformation on the preceding diagnostic phlebogram within the recommended dose limitations of each particular agent (Fig. 25). The agents can be mixed with non-ionic contrast material or Lipiodol; the latter increases viscosity and “dwell time” within the lesion allowing for better control and monitoring

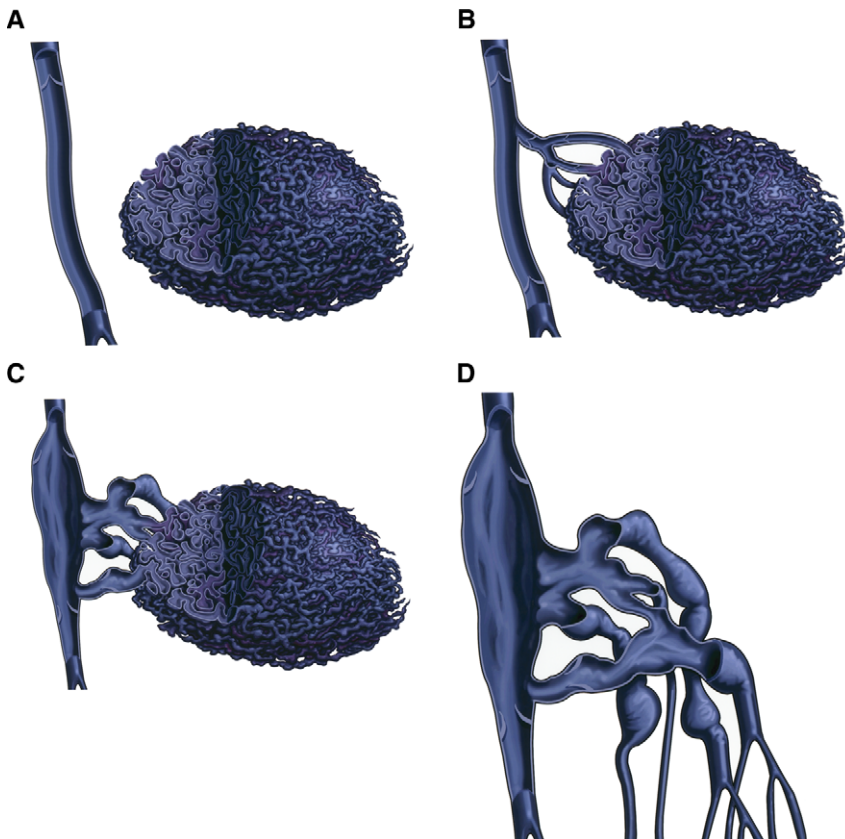


Fig. 23. VM types [69,71,93]. (A) Type 1 VM shows negligible venous outflow to normal venous circulation. (B) Type 2 anatomy reveals normal venous outflow to the general circulation from the malformation. (C) Type 3 anatomy with abnormally dilated and tortuous venous outflow from the malformation. (D) Type 4 VM anatomy with dilated tortuous, abnormally functioning venous structures without a discrete focal mass lesion.

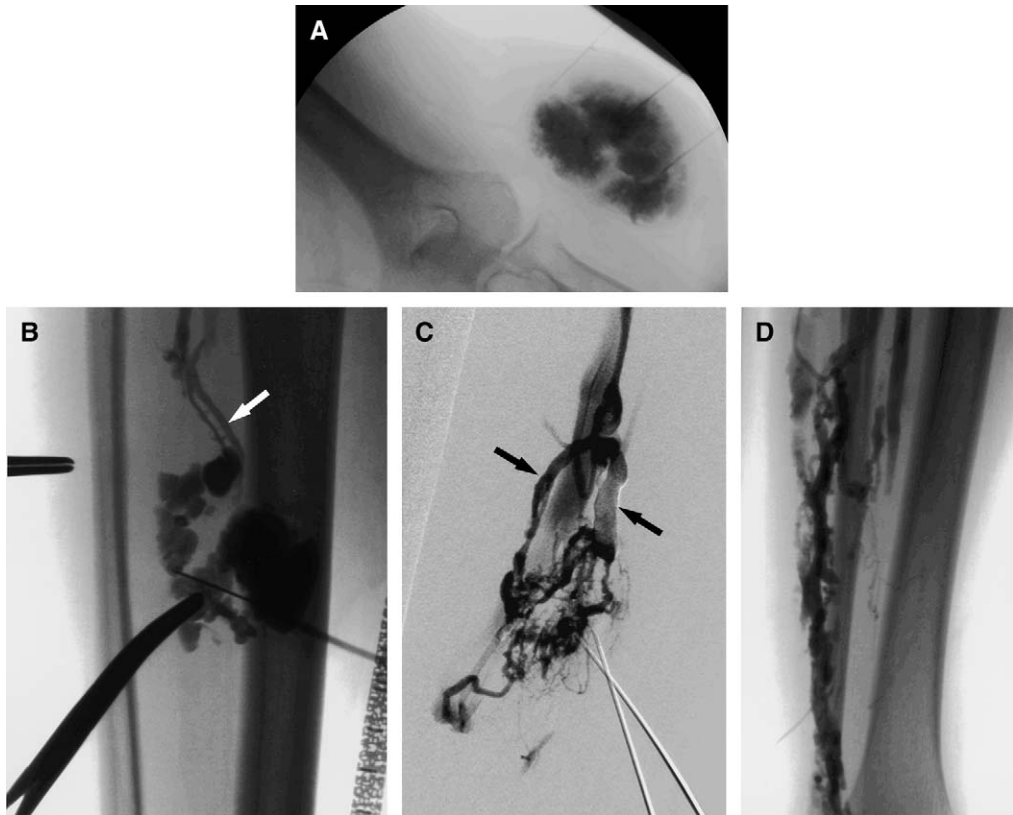


Fig. 24. VM types on phlebography. (A) Phlebography shows type 1 anatomy with a spongy pattern. (B) Type 2 VM on phlebography with a mixed pattern and normal outflow veins (*arrow*). (C) Type 3 outflow shows abnormal dilated venous structures (*arrows*) draining from a VM. (D) Type 4 VM composed almost entirely of dilated large venous channels.

of movement within the lesion and ready identification of untoward movement into a nontargeted region [59,112]. Various techniques have been described to increase viscosity or visibility by the creation of a foam by mixing and agitation of several components through a three-way tap between two syringes. First described by Tessari [125], the technique is now used to mix any combination of sclerosant with air, carbon dioxide, contrast material, or Lipiodol [122,123]. Compression with tourniquets, pneumatic cuffs, or an instrument may be required if there is significant efflux of contrast agent or sclerosant from the lesion (Fig. 26) [20]. A double-needle technique may be employed, whereby sclerosant is administered at one site and allowed to exit via a path of least resistance at an additional needle site to lower the risk of local extravasation [126]. Repeat contrast injections are performed to confirm closure of the targeted structures. Further injections at the same or additional percutaneous puncture sites are made for

additional sclerotherapy. The overlying skin is observed for areas of untoward development of erythema or blanching that may indicate skin embolization is occurring.

Elegant techniques of real-time MRI-directed sclerotherapy have been described. Using fast imaging steady-state procession (FISP) MRI-fluoroscopy, mixtures of ethanolamine or sodium tetradecyl sulfate and gadolinium have been used in the treatment of VMs [61,121]. Another technique involves injection of dilute gadolinium under FISP MRI-fluoroscopy into an isointense malformation, rendering it hyperintense followed by injection of a sclerosant/gadolinium mixture under reversed FISP MRI-fluoroscopy that gradually renders the lesion hypointense [120].

The procedure is terminated when an adequate area or volume of the VM is treated, maximal sclerosant dose is used [69,126] (1 mL/kg in the case of ethanol), or a high level of local resistance is noted during injection [115]. Depending on the

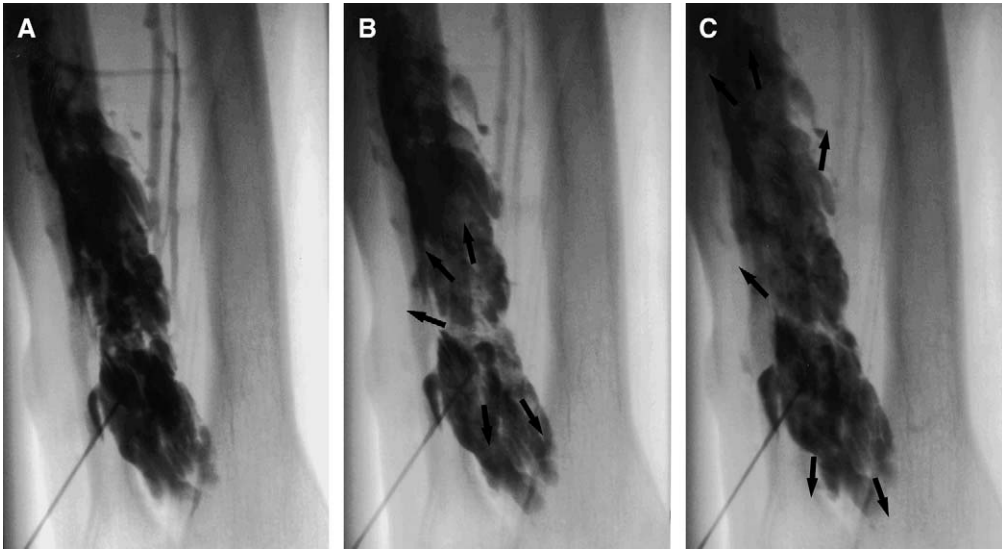


Fig. 25. Administration of sclerosant in VMs. (A) Near-complete contrast opacification of a mixed spongy-cavitory type 1 VM of the forearm. (B) Administration of radiolucent sclerotherapy material that is shown as displacement of clearance of radiopaque contrast material within its path (arrows). (C) Continued administration of sclerosant “deopacifying” the malformation (arrows) and leading to some expansion of the lesion.

site of the lesion, a local compression dressing may be applied for 5 to 10 minutes after injection to oppose the walls of treated vasculature better and decrease the overall lesion volume [64,74,124]. When the patient is awake, a neurovascular and skin examination is performed and documented. The patient usually is admitted for overnight observation for all but the most routine focal lesions. Barring complications, the patient is discharged on 1 week of anti-inflammatory medications and instructed to limit use of the involved region. Patients should be counseled on the expected levels of pain and inflammation. Because of localized scar formation and retraction [119], physiotherapy may need to be incorporated into the postprocedure management plan.

Aside from the grade and type of VM, therapeutic effect can be predicted by the degree of swelling postprocedure, with higher levels of swelling predicting a prolonged recovery period and greater clinical effect [115]. The degree of “success” of sclerotherapy for VMs can be evaluated by clinical criteria based on reduction of physical lesion size, clinical symptoms, improvement in quality-of-life variables, and imaging criteria of decreasing size and T2 signal intensity within the lesion on follow-up MRI (Fig. 27).

Success rates for sclerotherapy alone in VMs range from 31% to 100% with most reporting fair

to good response in 72% to 95% of cases with no particular agent clearly identified as superior [15, 64,71,73,90,93,96,100,109,112–114,122–124]. In the largest series by Lee and coworkers [113], ethanol sclerotherapy performed in 87 patients over 399 sessions with minimum and mean follow-up of 18.2 and 24.7 months resulted in 95% technical success rate and 95.4% clinical success rate based on concordant clinical and imaging findings with no evidence of recurrence.

With all agents, the most common complications observed were skin erythema, blistering, and necrosis with much lower rates of thrombophlebitis, thromboembolism, and other cardiovascular complications. There is a difference in complication rates between sclerotherapy agents. In the largest series using ethanol, minor or major complications occurred in 12.4% of sessions and 27.9% of patients [113]; 8.8% of sessions resulted in skin injury requiring conservative management with 1.5% of sessions requiring surgical intervention. Deep venous thrombosis and pulmonary embolism occurred in 1.2% and 0.3%. Transient and permanent nerve injury occurred in 0.8% and 0.5% of sessions. These data are consistent with other studies using exclusively ethanol as a sclerosant [109,112,114]. Total complication rates of 0 to 9.6% with sodium tetradecyl sulfate are significantly lower and only minor compared with

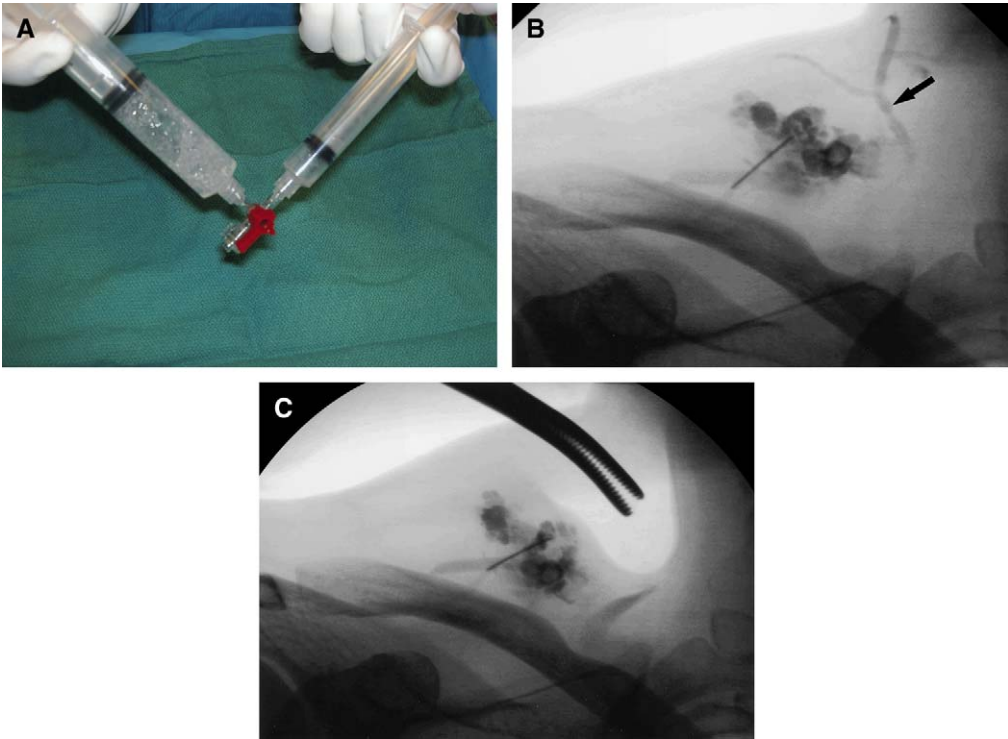


Fig. 26. Ancillary techniques for sclerosant administration. (A) Tessari technique [125] used for creation of a sclerofoam through a three-way stopcock between two syringes containing air and sclerosant. (B) Opacification of a small symptomatic supraclavicular VM limited by relatively rapid costocervical venous outflow (arrow). (C) Cervical outflow reduced by local compression allowing for greater “dwell-time” of the administered sclerosing agent within the lesion proper.

ethanol [64,100]. Negligible complication rates are reported with Ethibloc [93,96] and ethanolamine oleate [73]. Polidocanol has a low complication rate except for several reports of blistering, thrombophlebitis, bradyarrhythmias, hypotension, and reversible cardiac arrest [90,92,122–124].

Sclerotherapy of lymphatic malformations

Sclerotherapy technique of LMs is similar to that of VMs except for the introduction of two novel agents particular to the treatment of LMs that have met with high rates of clinical success and minimal side effects. OK-432 (Picibanil; Chugai Pharmaceuticals, Tokyo, Japan) is a biologic preparation of lyophilized powder made of *Streptococcus pyogenes* (group A, type 3, Su strain) inoculated with benzylpenicillin. Ogita and colleagues [127] first described its use in LMs in 1987. It is hypothesized that the agent works by inducing apoptosis of lymphatic endothelium or stimulating the production of soluble cytokines inducing a local cellular inflammatory reaction [128].

Bleomycin was first used by Yura and co-workers in 1977 [129,130] and later put into a fat emulsion for the intralesional sclerotherapy of LMs [131,132]. The agent scleroses lymphatic endothelium via a nonspecific inflammatory reaction [129,130]. Bleomycin is absorbed systemically at very low levels, even if administered locally [133]. Although systemic bleomycin administration may be suspected in the development of fatal pulmonary fibrosis even in low doses [134], no definitive cases of this complication have been identified during local administration for LM [135–137].

Sclerotherapy of LMs begins with ultrasound-directed insertion of a 21G to 25G needle into the anechoic cystic portion of the lesion. When lymphatic or serosanguineous fluid is produced, the lesion is aspirated as much as possible [98,118,138,139]. A small pigtail-type catheter can be placed for greater access stability if the morphology and cyst size permits [140]. Contrast material is injected to assess size and distribution of the lesion and show any communications with other cysts or other draining channels [98,141,142].

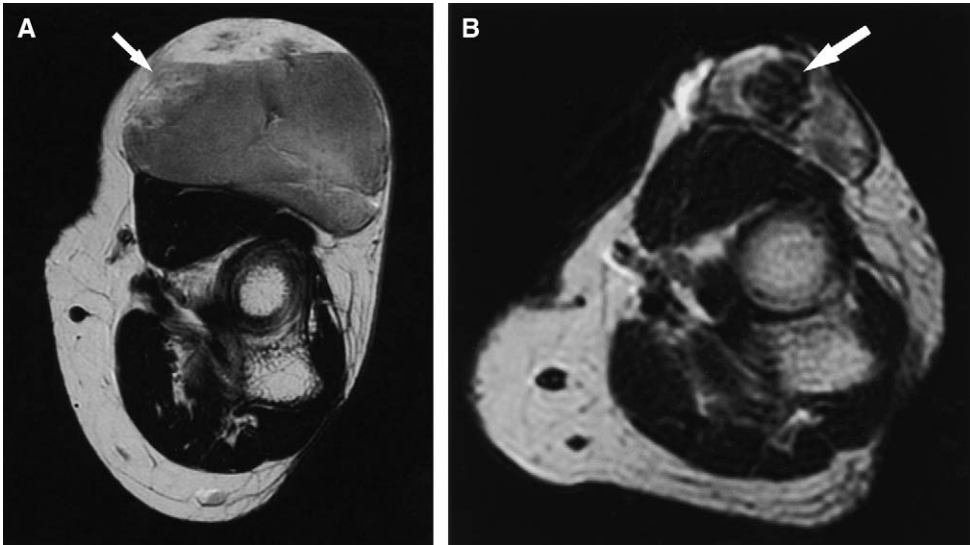


Fig. 27. MRI for monitoring outcome of sclerotherapy in VMs. (A) Presclerotherapy T2-weighted imaging of a large VM of the anterior arm shows heterogeneously hyperintense signal (*arrow*). (B) T2-weighted image 6 months after one session of sclerotherapy reveals marked decrease in size and decreased signal intensity within treated portions of lesion (*arrow*) relative to untreated portions.

After further aspiration, a combination of contrast agent and sclerosant or sclerosant alone is administered with further delayed aspiration based on the agent used (Fig. 28). Sclerosant options include OK-432 [63,70,127,128,138,139,141,143–149], bleomycin [101,131,135,150–152], Ethibloc [98], ethanol [63,70,149,153], tetradecyl sulfate [154], doxycycline [142], hypertonic saline [155], and acetic acid [153].

Overall, clinical success in lesion reduction with OK-432, bleomycin, ethanol, and Ethibloc ranges from 67% to 100% with minor complications of tenderness and swelling in nearly all cases, accompanied by low-grade fever in the case of OK-432 and leakage of agent to the skin surface in the case of Ethibloc [98,127,128,135,136,138,139,141,143,144,148–152]. A significant difference in outcome is apparent when lesions are divided into

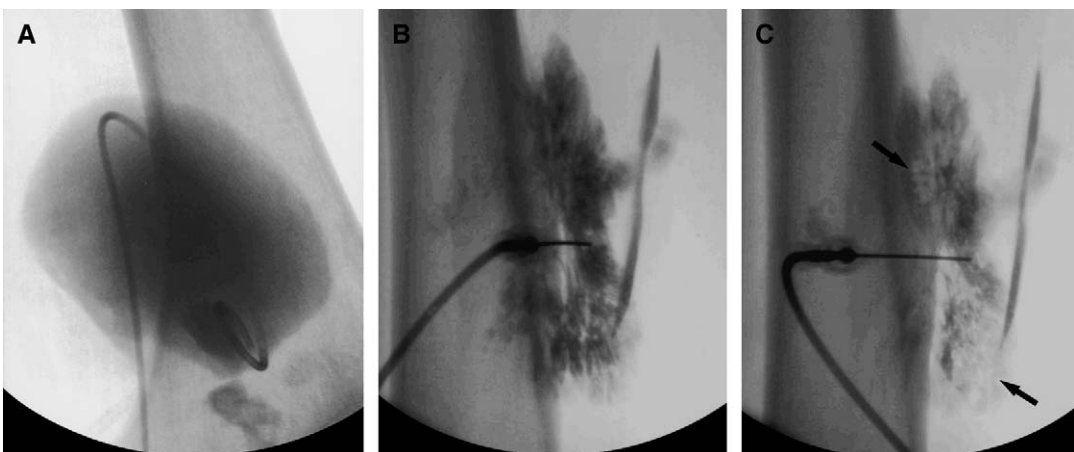


Fig. 28. Administration of sclerosant in LMs. (A) Pigtail catheter within a contrast-opacified macrocystic LM allows more durable access for sclerotherapy. (B) Contrast opacification of a low-volume deep microcystic LM of the thigh. (C) Radiolucent sclerosant is shown as it displaces intraluminal radiopaque contrast material (*arrows*).

macrocystic and microcystic subtypes. In a prospective multi-institutional randomized trial using OK-432, 95% of complete or substantial treatment successes were macrocystic, and 80% of intermediate success or no response patients were microcystic or mixed lesions [138]. Other authors have described a similar differential success rate between the two malformation subtypes ranging from 77% to 100% success in macrocystic/cystic subtypes and 0 to 80% success in microcystic/cavernous subtypes (Fig. 29) [136,143,144,148,149].

Embolosclerotherapy of arteriovenous malformations

The decision to treat any AVM should be based on Schobinger's criteria and the criteria outlined by Lee [63] through referral by a multidisciplinary team [25,65,156,157]. In addition to the usual imaging workup, noninvasive shunt calculations including whole-body pool scintigraphy [25,72] or initial angiographic transarterial lung perfusion scintigraphy may be invaluable for monitoring ongoing therapy [25]. Given AVMs' high variability and complexity, purely diagnostic arteriography often is performed for the first patient encounter to interventional radiology. This diagnostic procedure allows time for the radiologist to interrogate fully the lesion's supply, distribution, and drainage and carefully plan the

method of embolosclerotherapy for subsequent visits. Before the procedure, the patient is given intravenous steroid as a prophylactic anti-inflammatory. When the patient is under general anesthesia, a Swan-Ganz catheter is placed for monitoring pulmonary arterial pressure [65].

To understand concepts of therapy, AVMs are best thought of as congenital defects occurring at a nidus, the site or region marked by an absence of normally differentiated intervening capillary network between arterioles and venules [27,75]. The nidus is the causative factor that leads to high-flow shunting and is fed by and recruits adjacent arteries to hypertrophy causing adjacent venous engorgement and high flow [46,75]. Only the complete eradication of the nidus offers the potential for cure [25]. Proximal arterial embolic occlusion or surgical ligation of arterial feeding vessels alone can have disastrous consequences. AVMs not only can be stimulated to grow more rapidly, but also the most attractive transarterial routes for further therapy are lost, leaving behind tortuous, often inaccessible collateral routes to the nidus for the radiologist to negotiate (Fig. 30) [25,72,158]. Particles and glues cause variable degrees of occlusion, but it is difficult to control the level of occlusion; particles and glues can shunt across into systemic circulation and have been found to recanalize spontaneously (Fig. 31) [25,65,72,103,157,159].

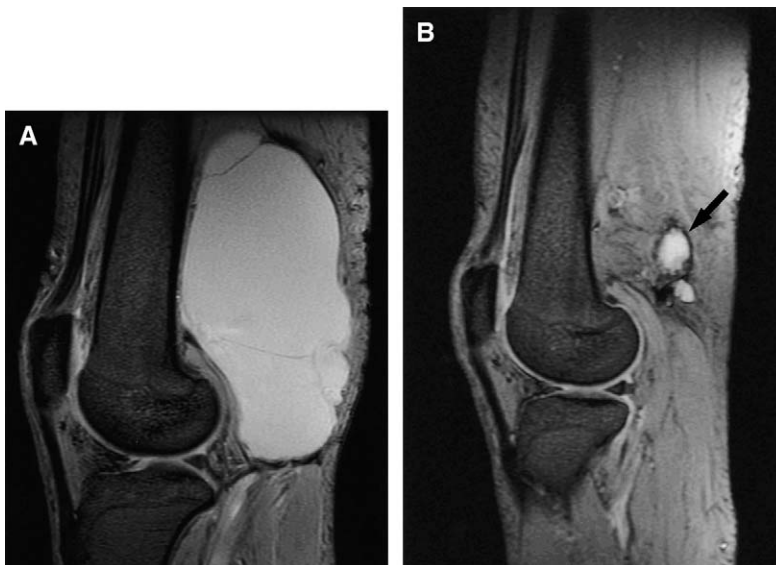


Fig. 29. MRI for monitoring outcome of sclerotherapy in LMs. (A) Presclerotherapy sagittal multiplanar gradient recalled image of a large popliteal fossa macrocystic LM. (B) Sagittal multiplanar gradient recalled image 8 months after two sessions of sclerotherapy reveals marked reduction in the volume of the malformation (arrow).

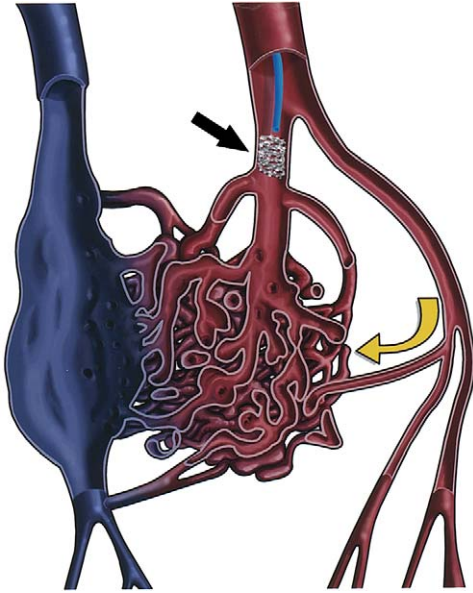


Fig. 30. Ineffective AVM embolization techniques. Diagrammatic representation of an AVM shows an ill-advised proximal coil embolization (*black arrow*). Aside from not destroying the nidus that is essential for cure, acute and chronic collateral circulation to the nidus can develop (*yellow arrow*), which can prove difficult to negotiate if and when the patient presents again.

Similar to other malformations, appropriate sclerosant concentration and dwell time are required to effect endothelial damage within the target vessels (ie, the nidus). AVMs provide unique challenges to achieve this end, however. First, by definition, AVMs are high-flow lesions, so any amount of agent delivered through an arterial catheter at a particular site is significantly diluted and has shortened transit through the target vessel owing to high inflow [75]. Second, as is often the case, more than one arterial and venous system leads to and drains the nidus. Any sclerosant administered within a segment of the lesion is subject to further dilution and misdirection by parallel or adjacent arterial inflow by the time it reaches the nidus, resulting in a lesser and more unpredictable effect (Fig. 32). Finally, owing to the strong sump effect of the nidus, normal arteries leading to vital structures arising from hypertrophied arteries adjacent to the nidus may be angiographically occult, which may lead to nontarget sclerosant embolization and significant morbidity after treatment [72].

To overcome these challenges, two categories of techniques can be employed that first allow

a more selective *nidal-specific access* site and second involve some form of *flow reduction or cessation* for sclerosant delivery. These techniques, often used in concert, leave the nidus maximally “vulnerable” to the effects of the chosen agent with minimization of local and systemic complications of nontarget arterial embolization and systemic embolization into the venous circulation.

To achieve more nidal-specific access, three routes are employed. First, the sclerosant can be delivered transarterially in as close proximity to the nidus as possible by way of superselective microcatheter techniques that often can enter into the nidus proper [65,72,156,158]; this allows for maximal dose to be administered to the nidus with minimal dilution and maximal protection against nontarget embolization (Fig. 33) [65,75]. Second, direct percutaneous puncture can be made into the nidus where feasible for direct sclerotherapy into the target (Fig. 34) [65,72,86,116,159,160]. Third, sclerosant can be delivered retrograde via a transvenous approach, often with the assistance of a balloon occlusion device [87,158]. Because the nidus often shows a greater number of feeding arteries compared with draining veins, this latter option allows the most direct and comprehensive access to the nidus at the level of the abnormal arteriolar-venular interface (Fig. 35).

Flow reduction techniques increase concentration and dwell time and allow greater control of distribution of sclerosant within the nidus. Temporary flow arrest or reduction can be achieved by the use of balloon occlusion catheters at the arterial inflow [25,65,72] or venous outflow during sclerosant delivery [25,65]. Similarly, tourniquets or pneumatic cuffs can be inflated upstream or downstream of the lesion if in an extremity (Fig. 36) [65,72,116,157,158]. Permanent occlusion can be performed using coils or cyanoacrylate adhesives to collateral arterial pathways in an effort to reduce arterial inflow and reduce the amount of sclerosant necessary (Fig. 37) [72]. Large coils also can be placed within the collateral or main venous drainage to assist flow reduction or often to provide the crucial definitive curative maneuver (Fig. 38) [72].

Whatever the technique used, injection of sclerosant always is preceded immediately by contrast agent injection into the vascular distribution to be embolized, noting volume and flow rate [72,157]. The sclerosant, most commonly ethanol, is administered with or without contrast opacification to duplicate these findings, often in

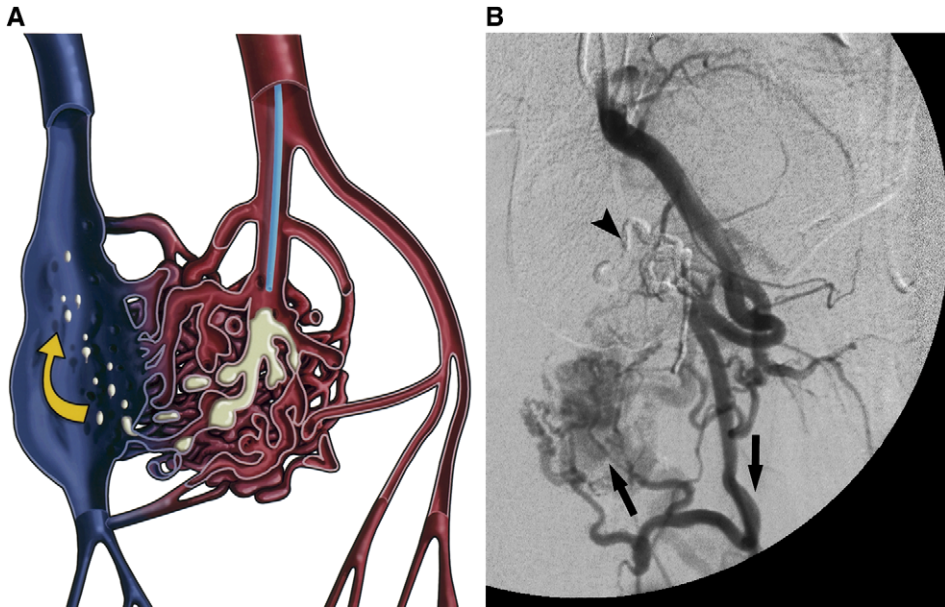


Fig. 31. The use of glues in AVM embolization. (A) The results of administration of cyanoacrylates within an AVM can be unpredictable. Based on the unique anatomy of each lesion, the agent can deposit too proximally relative to the nidus or pass distally through arteriovenous fistulas into systemic venous circulation (*yellow arrow*). (B) Persistent filling of an AVM nidus via increased collateral circulation (*arrows*) resulting from overly proximal deposition of cyanoacrylate (*arrowhead*).

small 0.5- to 1-mL aliquots. Allowing time for endothelial damage to become evident, repeat angiography is performed 5 to 10 minutes after ethanol administration [72]. If still patent, the procedure is repeated, until closure in the chosen area is achieved. Pulmonary arterial pressure is monitored during ethanol administration, and vasodilator therapy is administered if pulmonary arterial pressures increase to greater than 25 mm Hg [72]. The procedure is terminated based on time, contrast, sclerosant volume limits, or other lesion-specific factors.

When alert, the patient should be examined for any signs of abnormal cutaneous or neurovascular sequelae. Patients are admitted overnight and begun on an analgesic, anti-inflammatory, and antiemetic regimen. The next day, Doppler evaluation of the region can be performed to assess changes in flow patterns within the AVM and to assess for deep venous thrombosis if relevant [65]. Barring complications, the patient can be discharged the day after therapy on oral analgesic and anti-inflammatory medication with instructions to limit activity and expect swelling and inflammation to persist for several days. Any subsequent staged procedures should occur after

several weeks to allow maturation of microscopic shunts that were not initially apparent on the prior procedure [159].

In the largest series of AVMs treated percutaneously [72], 175 sessions of embolosclectherapy performed in 40 patients resulted in total cure (40% of patients), partial remission (28%), no change (18%), and aggravation of symptoms (2%). Complications occurred in 52% of patients and 18% of procedures. Minor complications occurred in 45% of patients and 15% of procedures. Skin blistering or necrosis occurred in 14.3% of procedures, and all were treated successfully with conservative management. Transient nerve injury was observed in 1.1% of procedures. Major complications occurred in 12% of patients and 3% of procedures, including infection requiring amputation, acute renal failure, permanent median nerve injury, and focal bladder necrosis. In a similar study [25] involving 32 patients over 171 sessions, excellent results were achieved in 78%, and good-to-fair results were achieved in the remaining 22% on 19-month mean follow-up. Complications were observed in 18% of sessions and were almost all minor; 2% of sessions resulted in major complications of deep venous

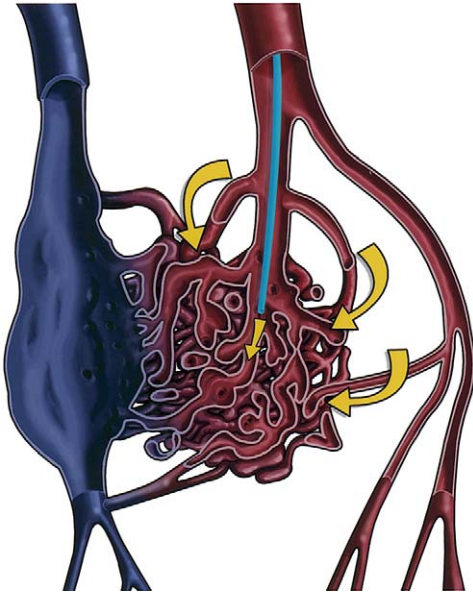


Fig. 32. Complex flow patterns in AVMs. Even when the catheter is positioned close to the nidus of an AVM, the embolization is subject to high rates of competitive inflow (yellow arrows) that dilutes, possibly misdirects, and shortens the “dwell time” of the chosen sclerosant-embolic agent.

thrombosis, pulmonary embolism, and permanent nerve impairment or cartilage necrosis. Other potential complications include hemoglobinuria [72], fever and tachycardia [82], and bronchospasm [80].

Patient follow-up

Follow-up of vascular malformation patients after discharge requires a combination of clinical and image-based monitoring, underscoring the need for multidisciplinary management. Documentation of patient symptoms referable to the lesion and physical lesion size and appearance in the weeks to months after sclerotherapy requires on-site patient visits. Noninvasive imaging should be performed after each intervention or planned multisession therapy [63]. In low-flow malformations, ultrasound or MRI or whole-body pool scintigraphy can provide information on degree of flow involution, which can be correlated with patient symptoms and physical findings for planning the type and timing of additional interventions. MRI should not be performed before several months post-therapy to allow sclerotherapy-related high T2 signal inflammation to subside adequately before evaluation [20]. In VMs, treated regions appear lower signal on

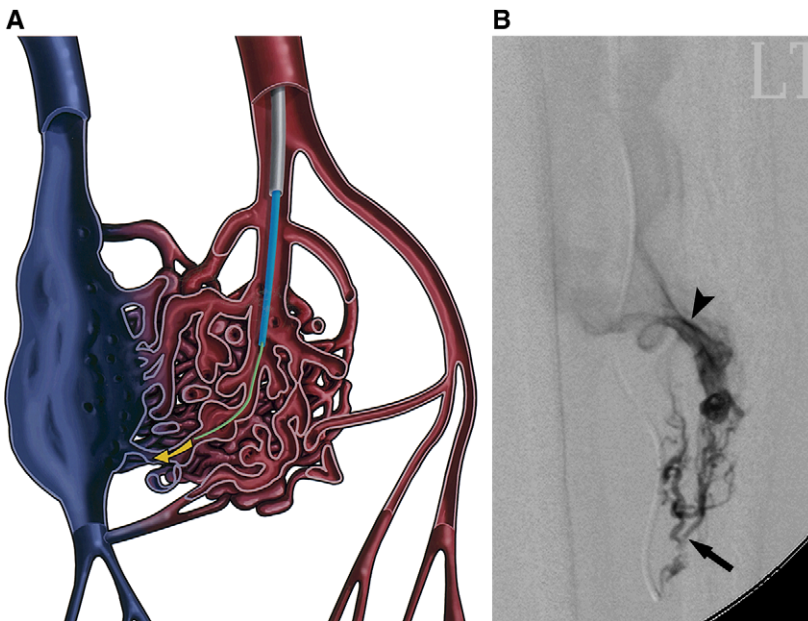


Fig. 33. Transarterial routes to AVM nidus. (A) A superselective catheter site close the anomalous arteriovenous communication of an AVM should be chosen for embolosclectherapy to be maximally effective (yellow arrow). (B) Superselective microcatheter angiogram performed within a small arterial tributary (arrow) in close proximity to an AVM nidus (arrowhead) before embolization with sclerosant.

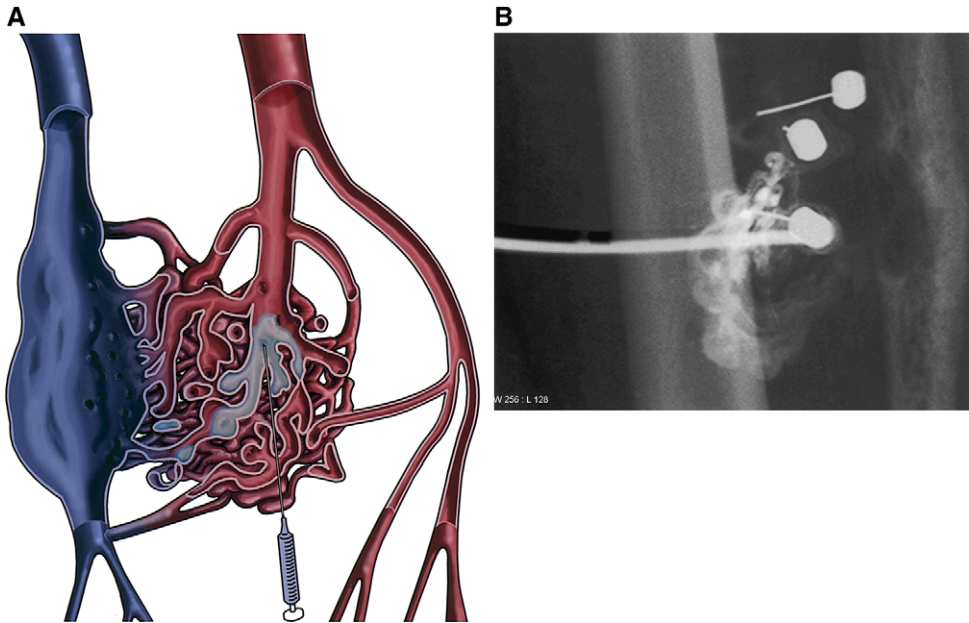


Fig. 34. Direct puncture route to AVM nidus. (A) Direct percutaneous needle puncture into the nidus for administration of sclerosant that allows for maximal endothelial-cidal effect of the agent and protection against nontarget embolization. (B) Contrast administration via percutaneous needle puncture directly into an AVM nidus before administration of sclerosant.

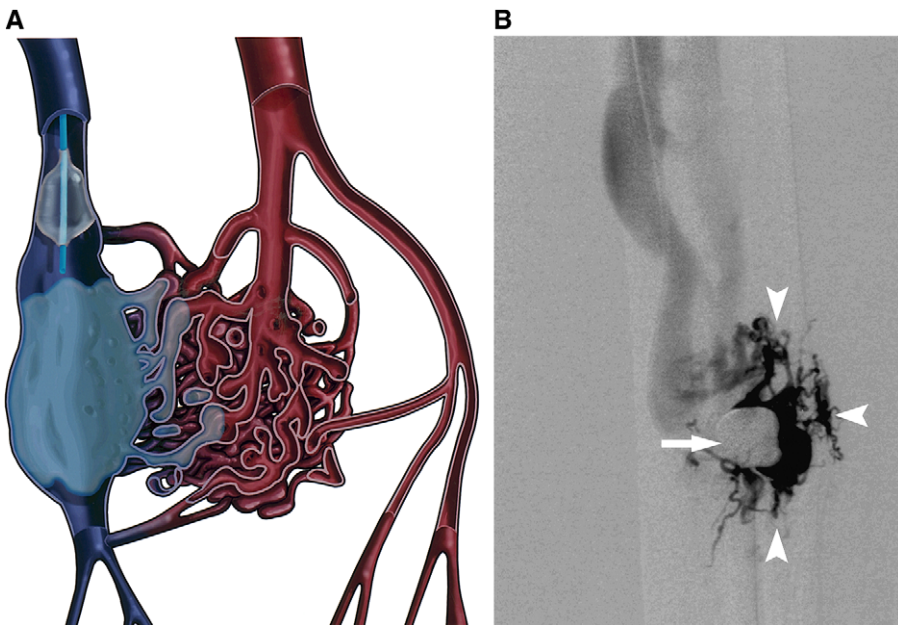


Fig. 35. Retrograde venous route to AVM nidus. (A) Retrograde venous approach to an AVM nidus for the administration of an embolic agent, such as cyanoacrylate, or a sclerosant, such as ethanol. (B) A transvenous retrograde balloon occlusion catheter appearing as a filling defect (arrow) is inflated within the main draining channel immediately downstream of an AVM nidus. Retrograde contrast injection before sclerotherapy reveals opacification of the true arteriovenous microarchitecture of an AVM that must be destroyed for cure (arrowheads).

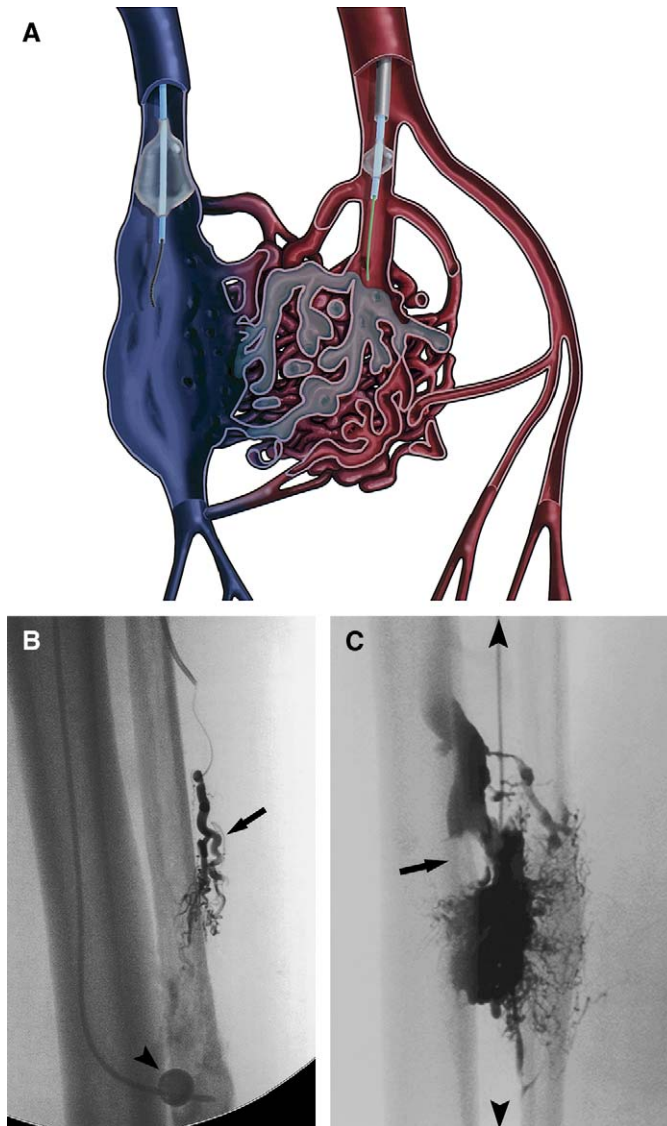


Fig. 36. Temporary arterial inflow or venous outflow occlusion during embolosclectomy of AVMs. (A) Balloon occlusion catheters (tourniquets) can be inflated to slow arterial inflow or venous outflow allowing greater concentration and “dwell time” of the chosen sclerosant within the nidus. (B) Transarterial antegrade contrast injection (*arrow*) to gauge volume and flow during simultaneous retrograde balloon occlusion of venous outflow (*arrowhead*). (C) Retrograde transvenous balloon (*arrow*) occlusion contrast injection shows a larger portion of the AVM nidus with the assistance of subsystolic pneumatic cuffs inflated above and below the lesion (*arrowheads, off image*).

T2-weighted imaging, with untreated regions remaining high signal. In AVMs, follow-up intervention can be based on the presence of persistent symptoms and concordant findings on combinations of Doppler, MRI, whole-body pool scintigraphy, and the gold standard of angiography and transarterial lung perfusion scintigraphy [25].

Summary

Confusion still exists as to the classification and nomenclature of vascular anomalies, which has an impact on the clinical diagnosis and management. The term *hemangioma* should be reserved for lesions histologically exhibiting rapid hypercellular endothelial growth, most commonly

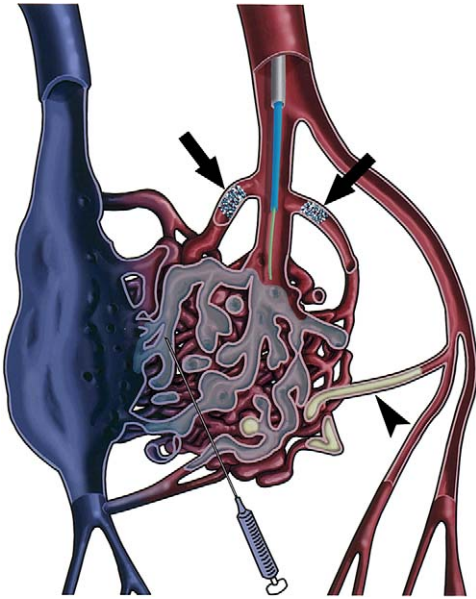


Fig. 37. Permanent arterial inflow occlusion. The judicious use of coils (*arrows*) and cyanoacrylate (*arrowhead*) can decrease total arterial inflow to an AVM allowing greater concentrations and “dwell time” of sclerosant to be delivered to the nidus.

seen in the form of infantile hemangioma in pediatric patients. Essentially all other vascular anomalies are termed *vascular malformations* and are described as being present at birth and growing commensurately or *pari passu* with the child. Vascular malformations are characterized by a normal rate of endothelial cell turnover comprising vascular channels lined with flat “mature” endothelium. Vascular malformations can be divided into *venous*, *lymphatic*, *arteriovenous*, or *mixed* varieties. These can be divided further into *truncular* lesions, which result from a relatively late embryologic defect or event arising within a differentiated vascular trunk, or *extratruncular* lesions, which result from a relatively early embryonal dysplasia within the primitive undifferentiated capillary network during *vasculogenesis* and *angiogenesis*. These latter two processes occur by interaction between primitive endothelial cells and the adjacent embryonic mesenchyme to produce ordered vascular channels containing smooth muscle and adventitia. A molecular defect in this process is hypothesized as the cause of many vascular malformations.

VMs and LMs constitute the low-flow category and can have a varied appearance, may be solitary or multiple, may be localized or infiltrating, and

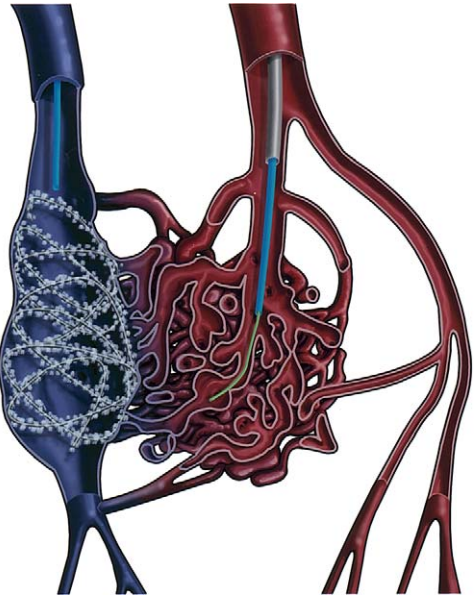


Fig. 38. Permanent venous outflow occlusion. Coil embolization of the venous portion of the AVM nidus can reduce total flow within the lesion allowing greater effectiveness of transarterial sclerosant. This technique also may serve as the most definitive AVM closure technique during multitechnique therapy.

can occur anywhere in the body. Patients present with functional disability and compression of vital structures or pain secondary to mass effect and in the case of VMs pain owing to stasis and thrombosis. LMs are divided further into *macrocytic*, *microcystic*, and *mixed* varieties. AVMs constitute the high-flow category and consist of a nidus of abnormally developed arteriolar venular interface without a normal intervening capillary network. They can occur anywhere and follow a predictable clinical course according to the Schobinger classification, with locally aggressive symptoms of pain, congestion, and erythema progressing to high output failure.

The mainstay of imaging diagnosis and differentiation comprises ultrasound and MRI, with VMs and LMs exhibiting a variable nonspecific echotexture on gray-scale imaging. Macrocytic lesions show large anechoic spaces with septa allowing differentiation from VMs and microcystic lesions. Doppler assessment allows detection of slow flow in most VMs, whereas flow is not usually seen in LMs. MRI of slow-flow malformations usually reveals high signal intensity on T2-weighted imaging, with visualization of cystic spaces in the case of LMs. VMs diffusely enhance

with gadolinium, in contrast to macrocystic LMs, in which enhancement may occur only along septa. Microcystic LMs can overlap in appearance with VMs on ultrasound and MRI. AVMs show high flow on Doppler ultrasound and have conspicuously absent mass detected by MRI. Enlarged arterial and engorged venous structures are seen on both modalities with high and turbulent flow findings seen on gradient echo images.

Sclerotherapy of low-flow malformations involves the percutaneous injection of a sclerosing agent into the vascular spaces, which results in endothelial damage, thrombosis, and closure of the vascular spaces. Ethanol is probably the most commonly used agent in VMs; others include sodium tetradecyl sulfate, ethanolamine oleate and polidocanol. Sclerotherapy of LMs most commonly involves OK-432, ethanol, and bleomycin. Each agent has different benefits and risks. Response rates to sclerotherapy for VMs are 72% to 95%, with moderate risk of complications. Success rates for macrocystic malformations are 77% to 100% with lower rates of success for microcystic malformations. Emboloscclerotherapy of AVMs can effect cure only through endothelial damage to the nidus itself. Numerous superselective techniques via arterial, retrograde venous, and direct percutaneous puncture, along with flow reduction techniques, allow maximal damage to be inflicted on the nidus with minimal risk to adjacent normal tissue. Success rates in experienced hands are 68% to 100% with complication rates higher given the complexity of these lesions. With current trends, percutaneous management of vascular malformations has become the mainstay of therapy; however, the clinical evaluation, decision to treat, surgical or radiologic management, and patient follow-up all must occur within the framework of an experienced multidisciplinary team.

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