ELSEVIER

Seminars in
ROENTGENOLOGY

Vascular Malformations: Classification and Terminology the Radiologist Needs to Know

Lisa H. Lowe, MD,* Tracy C. Marchant, DO,† Douglas C. Rivard, DO,* and Amanda J. Scherbel, BS‡

In recent decades, a great deal has been learned about the histopathology, etiology, and treatment of vascular anomalies, which has caused change in the classification and terminology used to describe these lesions. The International Society for the Study of Vascular Anomalies (ISSVA) classification system, which has been widely embraced by various subspecialists who care for patients with these malformations, provides an approach based on histopathology, clinical course, and treatment. However, use of older nomenclature continues to cause confusion, inaccurate diagnoses, and potential mismanagement. The overarching goal of this article is 2-fold. First, to review the ISSVA classification of vascular anomalies by discussing key pathogenesis, imaging features, and modern treatment of representative lesions from each category; and second, to discuss terminology used to describe vascular malformations with the goal of clarifying dated or confusing terms that remain in use.

International Society for the Study of Vascular Anomalies Classification

In 1982, Mulliken and Glowacki[1,2] proposed a binary classification system for vascular anomalies based on pathologic features. This system, which was adopted by the ISSVA, has since been expanded and is now widely accepted.[1,3,4] The importance of the ISSVA system is that it allows a systematic approach to vascular lesions that correlates predictably with clinical history, disease course, and treatment options, making it clinically useful.[5]

*Department of Radiology, Children's Mercy Hospitals and Clinics, University of Missouri-Kansas City, Kansas City, MO.
†Department of Medicine, University of Missouri-Kansas City, Kansas City, MO.
‡Department of Radiographic Science, Idaho State University, Pocatello, ID.
Address reprint requests to Lisa H Lowe, MD, Department of Radiology, Children's Mercy Hospitals and Clinics, University of Missouri-Kansas City, 2401 Gillham Road, Kansas City, MO 64108. E-mail: lhlowe@cmh.edu

The ISSVA classification system divides vascular anomalies into 2 (binary) primary biological categories: (1) vasoproliferative or vascular neoplasms and (2) vascular malformations (Table 1).[2] The major distinction between the 2 categories is whether there is increased endothelial cell turnover, which is ultimately determined by the identification of mitoses seen on histopathology.[1,2] Vasoproliferative neoplasms have increased endothelial cell turnover (ie, they proliferate and undergo mitosis) because they are neoplasms.[5] Vascular malformations do not have increased endothelial cell turnover. Instead, vascular malformations are structural abnormalities of the capillary, venous, lymphatic, and arterial system that grow in proportion to the child.[1,5]

Imaging Approach to Vascular Anomalies

Many vascular anomalies can be diagnosed by history and physical examination, making imaging unnecessary. However, when imaging is used, it is important to choose the modality based on the specific lesion and clinical situation, rather than using a one-size-fits-all mentality. Ultrasonography (US) and magnetic resonance imaging (MRI) are the 2 most widely used modalities of choice. US is used for initial screening because of its portability, lack of ionizing radiation, and no requirement of sedation in children. It is relatively simple, noninvasive, and yields good results for evaluating small, superficial and/or suspected, solid visceral lesions. Typically, US is able to determine the basic type of lesion, direct initial management, and plan further imaging evaluation.[6,7] For sonography to be a useful modality, it must include gray-scale, color Doppler, and spectral Doppler tracings to evaluate vascularity and determine types of vessels present.[7] MRI is helpful to further characterize sonographic findings and determine the extent of larger lesions for planning medical, interventional, and/or surgical therapy.

Radiography has limited utility in evaluating vascular anomalies, but when obtained, it may show organomegaly, soft tissue masses, and/or phleboliths. Computed tomogra-

0037-198X/12/$-see front matter
doi:10.1053/j.ro.2011.11.002

Table 1 International Society for the Study of Vascular Anomalies Classification System

Vascular (or vasoproliferative) Neoplasms	Vascular Malformations
Infantile hemangioma	Slow-flow vascular malformations
Congenital hemangiomas	Capillary malformation
RICH	Venous malformation
NICH	Lymphatic malformation
Kaposiform hemangioendothelioma and tufted angiomas (with or without Kasabach–Merritt syndrome)	Fast-flow vascular malformations
Spindle cell hemangioendothelioma	Arterial malformation
Epithelioid hemangioendotheliomas	Arteriovenous malformation
Other rare hemangioendotheliomas (ie, composite, retiform, and others)	Arteriovenous fistula
Angiosarcoma	Combined vascular malformations (various combination of the above)
Dermatologic acquired vascular tumors (ie, pyogenic granuloma)	

RICH, rapidly involuting congenital hemangioma; NICH, noninvoluting congenital hemangioma.

phy (CT) is helpful when urgent imaging is required because of its speed and less frequent need for sedation.[8]

Terminology

In the past, the suffix "oma" was used to described neoplasms and malformations. However, because malformations are not neoplasms, words such as "lymphangioma" are misnomers, and the terminology is being abandoned. The word "hemangioma" has been used to describe several lesions, which are now known to be distinct pathological entities.[9] It is the current consensus that a descriptor is needed for the term "hemangioma" to be meaningful (ie, infantile or congenital).[10]

Infantile hemangiomas present between 2 weeks to 2 months of life, undergoing a proliferative growth phase until they reach their full size, whereas congenital hemangiomas are distinguished by being fully formed at birth.[11,12] Hepatic infantile hemangiomas, which are pathologically the same as those located on the skin and other organs, have unfortunately been referred to as infantile hemangioendothelioma(s), erroneously suggesting they are distinct pathologically.[10] Further, histological studies have shown that what was commonly referred to as "hemangioma" of the adult liver, "hemangioma" of the adult vertebra, and orbital "cavernous hemangioma" are actually venous malformations rather than neoplasms.[13,14] See Table 2 for comparison of old versus new terms describing vascular anomalies.

Several studies demonstrate the utility of the current ISSVA terminology.[9] One retrospective study of children evaluated in a vascular malformations clinic highlights the confusion surrounding terminology by showing that 69% of patients were initially given a wrong diagnosis, and 53% of parents were given incorrect information regarding lesion progression and treatment.[15] Another study found that the term hemangioma was incorrectly used in 71.3% of manuscripts studied, regardless of the author's discipline.[16] The same study noted that patients with mislabeled lesions were more likely to receive improper treatment (20.6%) compared with those classified according to the ISSVA system (0%).[16]

Vascular or Vasoproliferative Neoplasms

Although a complete discussion of all permutations of vascular tumors included in the ISSVA classification system is beyond the scope of this manuscript, awareness of entities with overlapping terminology will prevent confusion. Infantile hemangiomas, congenital hemangiomas (rapidly involuting congenital hemangiomas [RICH] and noninvoluting congenital hemangiomas [NICH]), tufted angiomas (TA), kaposiform hemangioendotheliomas (KH), spindle cell and epithelioid hemangioendotheliomas, and angiosarcomas are discussed.

Recent Hypotheses and Observations Regarding the Pathogenesis of Hemangiomas

Evidence suggests that vasoproliferative tumors result from vasculogenesis (formation of primitive blood vessels from angioblasts) rather than from angiogenesis (the growth of vessels from preexisting vessels) as previously thought.[17-19] Immature stem/progenitor cells are identified within the anomaly that may originate from the placenta.[20-23] Studies have identified increased numbers of mast cells, commonly seen in involuting infantile hemangiomas undergoing apoptosis.[20,24-26] During the involution phase, mesenchymal stem cells differentiate into adipocytes, whereas capillary lu-

Table 2 Comparison of Previous Terminology and New ISSVA Terminology

Previous	ISSVA
Capillary or cavernous hemangioma of any organ(s)	Infantile hemangioma(s)
Infantile hemangioendothelioma(s) of the liver	Hepatic or infantile hemangioma(s)
Adult hepatic hemangioma	Venous malformation
Adult vertebral hemangioma	Venous malformation
Adult orbital cavernous hemangioma	Venous malformation

ISSVA, International Society for the Study of Vascular Anomalies.

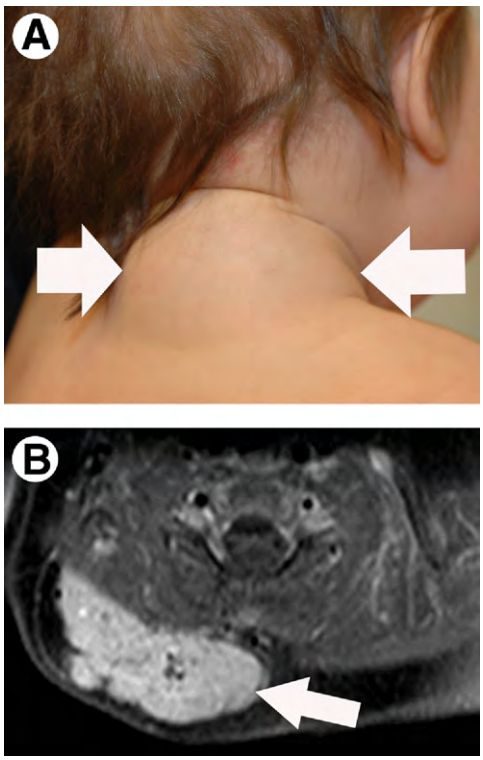

Figure 1 Infantile hemangioma in a 4-month-old female patient with a lump on her neck. (A) Photograph of the back of the neck shows a smooth focal lump (arrows). (B) Axial fat-suppressed T1-weighted postcontrast image reveals a well-defined vigorously enhancing mass with internal flow void located in the subcutaneous fat (arrow).

mens undergo apoptosis, both of which lead to lesion resolution.[12,20,27] Cellular proliferative markers, such as vascular endothelial growth factor (VEGF), are also elevated in proliferating, but not involuting, hemangiomas.[28-30]

Unique to placental endothelial cells and infantile hemangiomas is the expression of glucose transporter isoform 1 (GLUT1) protein.[12,31] GLUT1 is not expressed by any other normal tissue or vascular tumor. Placental cells and infantile hemangiomas appear to have the same life cycle, suggesting that hemangiomas may result from embolized placental cells.[20,23,31,32]

Another recent observation is that some hemangiomas occur in a nonrandom, or regional, distribution. This may be from embryologic prominences, which raises the possibility of a neuroectodermal abnormality.[33] One example of this is regional facial hemangiomas, which occur around embryologic fusion lines.[34] The mesenchyme of the fetal head and neck is mostly neuromesenchyme, which favors hemangioblast migration, and may account for the common head and neck location of hemangiomas.[20]

Cases of children with coexistent infantile and congenital (RICH or NICH) hemangiomas, as well as children with initial RICH that at some point have arrested involution, taking on the clinical appearance of a NICH, are reported. This suggests that NICH may be a later stage of RICH or possibly a transformation into RICH.[11,35] Somatic mutation with clonal expansion within a single endothelial cell may explain the fact that infantile hemangiomas are GLUT1 positive (GLUT1+) and congenital hemangiomas are not.[11,18,36] Finally, extrinsic factors, ie, milieu of the fetus and/or infant, may play an unspecified role in the development of hemangiomas, which is likely multifactorial.[34,37]

Infantile Hemangioma

Infantile hemangioma is the most common tumor of infancy and occurs in approximately 4%-10% of infants.[38-40] It is most frequent in premature Caucasian females with low birth weight, who are products of multiple gestation and have undergone chorionic villous sampling.[12] Maternal risk factors include advanced age, pre-eclampsia, and placental abnormalities.[10] The increased risk of hemangiomas in populations undergoing procedures that may cause trophoblastic

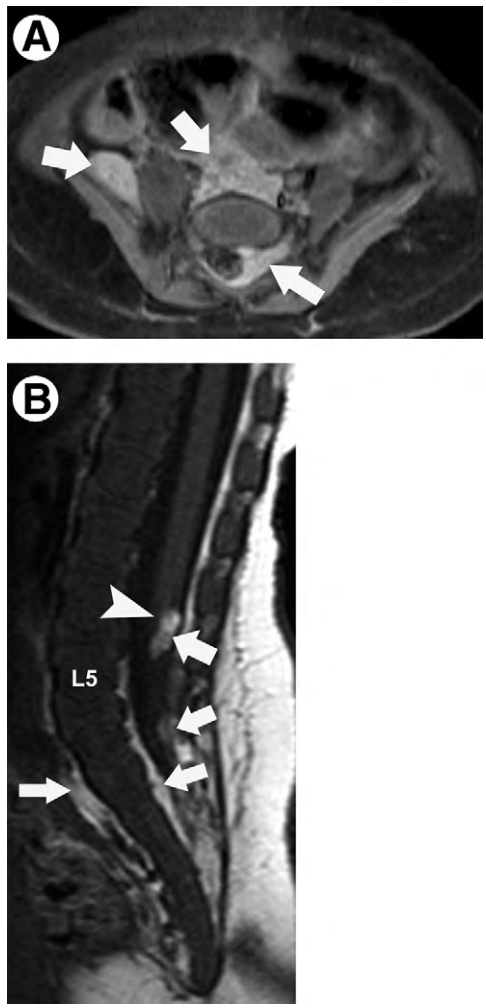

Figure 2 LUMBAR regional syndrome in a 4-week-old female patient with extensive cutaneous hemangiomas on the lower abdomen and legs, left renal agenesis, and a patent urachus. T1-weighted contrast-enhanced (A) axial and (B) sagittal fat-suppressed magnetic resonance (MR) images demonstrate multiple enhancing well-defined lobular masses consistent with hemangiomas (arrows). Abnormally low conus position (arrowhead) is also shown. L5-Fifth lumbar vertebra.

Table 3 Summary of Regional and Diffuse Associations, Including Vascular Neoplasms

PHACES association*
Posterior fossa abnormalities
Hemangiomas in 5th cranial nerve region
Arterial intracranial anomalies
Cardiac anomalies/coarctation of the aorta
Eye anomalies
Sternal defects
LUMBAR association†
Lower body hemangioma
Urogenital anomalies and ulceration
Myelopathy
Bony deformities
Anorectal and arterial malformations
Renal anomalies
Maffucci syndrome
Multiple enchondromas and spindle cell hemangioendotheliomas

*Diagnosis of PHACES requires 3 or more of the above, one of which must be hemangioma.

†Other acronyms used to describe the LUMBAR association include "SACRAL" and "PELVIS." SACRAL, spinal dysraphism, anogenital anomalies, cutaneous anomalies, renal and urological anomalies, angioma (hemangioma) of the lumbosacral region; PELVIS, perineal hemangioma, external genitalia malformations, lipomyelomeningocele, vesicorenal abnormalities, imperforate anus, skin tag.

embolization and placental disruption adds support to the theory of placental origin of hemangiomas.[21,41]

Infantile hemangiomas typically present between 2 weeks and 2 months of life.[12,40] They may be single or multiple, may involve 1 or many organ systems, and may be focal or regional (segmental). Regional hemangiomas occur along lines of embryological fusion and may be more frequent in Hispanics.[42] Examples include midline glabella (nasal bridge), low-back, and facial hemangiomas. Infants with regional or with ≥5 cutaneous hemangiomas should undergo screening US of the head and abdomen to check for additional lesions.[10,43,44]

Although classically diagnosed by their history and physical examination, biopsied infantile hemangiomas are uniquely GLUT1+ and demonstrate increased endothelial cell turnover. They have a predictable clinical course, including rapid proliferation during the first year of life (proliferative phase), followed by gradual involution over 1-7 years (involuting phase), and then complete regression after 8 years (involuted phase).[8,11,29,45] Skin is the most common location for infantile hemangiomas, especially of the head and neck (60%), trunk (25%), and extremities (15%)[12,20] (Fig. 1). Multiple cutaneous hemangiomas are seen in 10%-25% of cases, with ≥1 lesion found in 31% of cases.[46] Associated liver lesions are seen in up to 13% of children with skin lesions, making it the most common extracutaneous site.[12,47] Liver hemangiomas are subclassified as focal, multiple, or diffuse. Some authors have referred to multiple infantile hemangiomas as hemangiomatosis, and when 3 or more organ systems are involved, disseminated hemangiomas.[12,40,48] For simplicity, we will use a single term, infantile hemangioma(s).

Although the majority of infantile hemangiomas are self-limited, treatment may be required if complications arise. Ulceration is the most common complication occurring in up to 13% of lesions.[10] As the size and number (>5) of infantile hemangiomas increase, so does the risk of complications.[49] Infantile hemangiomas located on the face, those that are regional, and those near vital structures are more likely to have complications requiring treatment.[49]

In certain locations, infantile hemangiomas may pose important risks or herald possible underlying anomalies. Orbital hemangiomas may cause visual compromise; hemagiomas adjacent to the nose and mouth are at risk for airway obstruction; hemangiomas involving breast bud may impair breast development; and midline lesions on the forehead, nose, and back raise concern for brain and spinal anomalies. The association of hemangiomas with regional/segmental anomalies has been described, the most common of which include posterior fossa anomalies, hemangiomas, arterial anomalies, cardiac anomalies, eye anomalies, sternal anomalies (PHACES) and lower body hemangioma, urogenital anomalies and ulceration, myelopathy, bony deformities, anorectal and arterial malformations, renal anomalies (LUMBAR) associations (Fig. 2) as listed in Table 3.[50] Liver hemangiomas are associated with high-output congestive heart failure (shunting of blood through the vascular

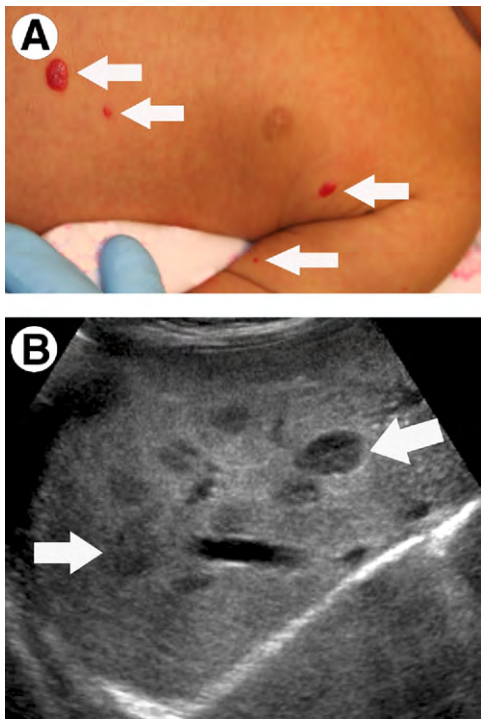

Figure 3 Infantile hemangiomas in a 5-week-old female patient with multiple skin lesions. (A) Clinical photograph of the chest shows multiple well-defined red plaques and papules (arrows) typical for hemangiomas. (B) Axial sonogram through the liver demonstrates multiple well-defined hypoechoic hepatic lesions of varied echogenicity and size (arrows).

Table 4 Key Imaging Features of the Most Common Pediatric Vascular Anomalies

	Gray Scale US	Doppler US	MRI
Vasoproliferative neoplasms			
Infantile hemangioma	Well-defined Solid Homogenous Variable echogenicity	Hypervascular Arterial and venous waveforms High vessel density (>5 vessels/cm^2) High Doppler shift (>2 kHz)	Iso-to-intermediate signal on T1W Bright signal on T2W High-intensity flow enhancement on gradient echo Internal flow voids Vigorous enhancement after contrast administration
Slow-flow vascular malformations			
Venous	Solid echogenic mass with phleboliths; often multispacial and compressible	Monophasic (venous) or no flow pattern	T1W heterogenous intermediate signal, no flow voids, T2 FSE fat-saturated or short T1 inversion recovery high signal intensity, T1W SE post gadolinium: enhancement
Lymphatic	Variable multicystic, multispacial masses, with or without fluid and/or debris levels	Multispacial, macrocystic mass with no flow except in septa	T1W low-intermediate signal intensity; T2W high signal intensity; T1W post gadolinium: no enhancement, except within septa
Venolymphatic	Combined venous and lymphatic components above		
Fast-flow vascular malformations			
Arteriovenous malformations and fistulas	Cluster of vessels with no intervening well-defined mass	Arterial and venous signals from vessels in the lesions with arterialization of venous structures	T1W and T2W sequences show serpiginous signal voids without a focal mass

FSE, fast spin echo; MRI, magnetic resonance imaging; SE, spin echo; T1W, T1-weighted; T2W, T2-weighted; US, ultrasonography.

mass), hepatomegaly (which can lead to lung compression and respiratory distress), thrombocytopenia, and hypothyroidism (increased type 3 iodothyronine deiodinase activity)[47,51-53] (Fig. 3).

If the history, physical examination, and imaging findings are atypical, raising concern for a lesion more aggressive than an infantile hemangioma, tissue biopsy is occasionally required.[12] Neuroblastoma, the main differential diagnosis for multiple hepatic hemangiomas, and the most common metastatic infantile hepatic lesion, can overlap in appearance on cross-sectional imaging.[54] Fortunately, neuroblastoma is usually distinguished by urine catecholamine screening and abdominal US with identification of a primary retroperitoneal neoplasm.[54] Imaging with CT and/or MRI is not able to definitively distinguish hepatic neuroblastoma metastases and infantile hemangiomas. Thus, urine screening and/or abdominal US should precede CT and MRI to avoid unnecessary risk and waste of resources.[12,54]

Characteristic US and MRI findings of infantile hemangiomas are summarized in Table 4.[7] Follow-up sonography is useful to confirm lesion regression.[7,47] Smaller lesions are more likely to be homogenous in signal and enhancement, whereas larger lesions tend to be more heterogeneous and more likely to show centripetal enhancement. Enhancement patterns are nonspecific in infantile hemangiomas, and as involution occurs, gradual replacement by fibrofatty tissue causes MRI features to vary accordingly[47] (Fig. 4).

Treatment options for hemangiomas vary depending on the type and severity of complications ranging from laser therapy of skin lesions and medical management with antiangiogenic drugs, to embolization, surgery, and, rarely, organ transplant.[8,55] Propanolol has recently been used to treat infantile hemangiomas. Other drugs include steroids followed by chemotherapeutic agents, such as vincristine.[56,57] In patients with cardiac shunts, aggressive therapy is more likely. Although clinical parameters can predict which patients will require pharmacotherapy, imaging findings predict nonpharmacologic treatment (ie, embolization).[12,47]

Congenital Hemangiomas (RICH and NICH)

Congenital hemangiomas differ from infantile hemangiomas in that they are fully developed at birth and test negative for the immunohistochemical marker GLUT1.[12,58] Two main types of congenital hemangiomas have been described: (1) NICH, which present at birth and demonstrate proportional growth without regression and (2) RICH, which present at birth and regress completely within 2 years.[11] Congenital hemangiomas are much less common than infantile hemangiomas and have no gender predisposition.[11,59] Because these

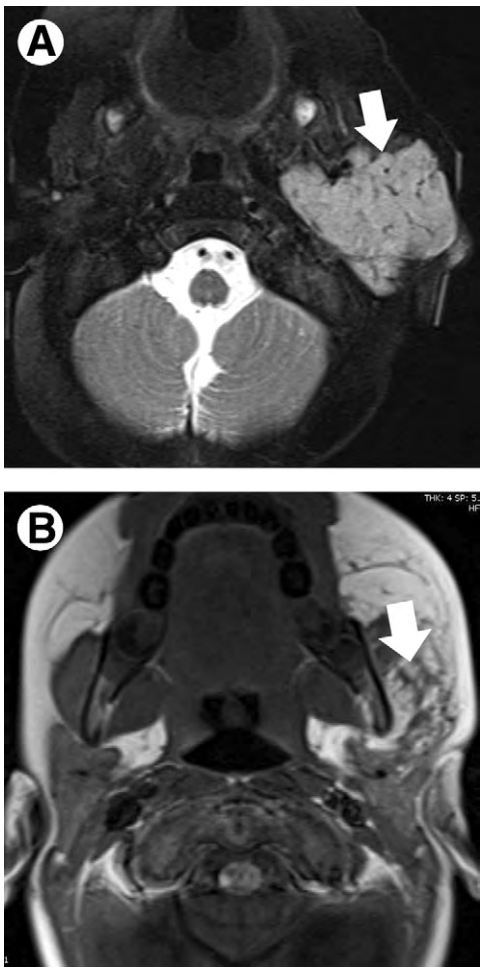

Figure 4 Involuting parotid space infantile hemangioma in a 2-month-old female patient. (A) Axial T2-weighted MR image shows a well defined hyperintense parotid mass with internal flow voids (arrow). (B) Axial T1-weighted MR image 18 months later shows a poorly defined mass partially replaced by adipose tissue consistent with an involuting infantile hemangioma (arrow).

tumors undergo their proliferative phase in utero, they may be seen on prenatal imaging.[58,60,61] Histologically, variable-sized lobular capillaries with prominent endothelial cells are seen. They have involuting centers characterized by fibrous tissue, large abnormal draining channel, and loss of lobulations.[58,61]

Congenital hemangiomas are usually solitary and present on the head and limbs near a joint, unlike infantile hemangiomas, which may occur anywhere in the body[11] (Fig. 5). Dermatologists may distinguish these lesions by physical examination, where they will observe a pink-to-violaceous color with multiple tiny or coarse telangiectasias and a surrounding pale halo.[11] Involution starts just after birth with RICH, beginning centrally and progressing to atrophy.[58] Most regress within 1-2 years, if not within the first months of life.[11,39] Interestingly, RICH leave behind a region of thin atrophied skin with little subcutaneous fat, which is in contrast to infantile hemangiomas, which are gradually replaced by fibrofatty tissue.[11] NICH may partially involute and soften, but complete resolution is not seen.

Imaging features of congenital and infantile hemangiomas overlap. Thus, the radiologist must be aware of the physical examination and clinical history (age at presentation, lesion course) to suggest a possible congenital hemangioma. A study detailing the imaging tendencies of congenital vs infantile hemangiomas, including heterogeneity (72% of NICH, 62.5% of RICH vs 42.3% of infantile hemangiomas), visible vessels (72% NICH, 62.5% RICH vs 15.4% infantile hemangiomas), and calcifications (17% NICH, 37.5% RICH vs none in infantile hemangiomas), has been performed.[62] Although conventional angiography is no longer indicated in the evaluation of hemangiomas, earlier studies of RICH have demonstrated larger flow voids on MRI and arterial aneurysms on angiography[39] (Fig. 6). In addition, angiography of RICH demonstrates a well-circumscribed mass with intense persistent tissue staining in a lobular pattern with enlarged surrounding systemic artery branches.[55] If occasionally needed, magnetic resonance angiography of hemangiomas is sufficient.

Treatment for RICH is similar to infantile hemangiomas.[39,59] Rarely, antiangiogenic drugs, embolization, and/or surgery may be necessary.[4] Surgery is the treatment of choice for NICH because of lack of regression.[63]

Tufted Angioma and Kaposiform Hemangioendothelioma

TA and KH are rare vasoproliferative tumors that present at or shortly after birth. On histology, TA shows vascular tufts of tightly packed capillaries in a cannonball pattern.[64,65] KH has both vascular and lymphatic components, consisting of irregular infiltrating nodules of compressed vessels.[66] Recent studies have shown differences in the immunostaining patterns of monoclonal antibody D2-40 that may help distin-

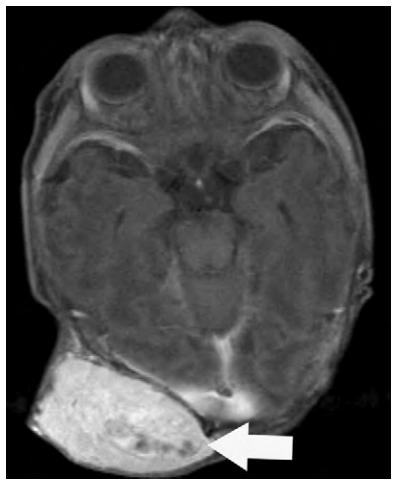

Figure 5 Rapidly involuting congenital hemangioma in a newborn female with a scalp mass. Axial contrast-enhanced fat-suppressed T1-weighted image shows a vigorously enhancing well-defined right occipital subcutaneous mass (arrow) causing mild calvarial deformity.

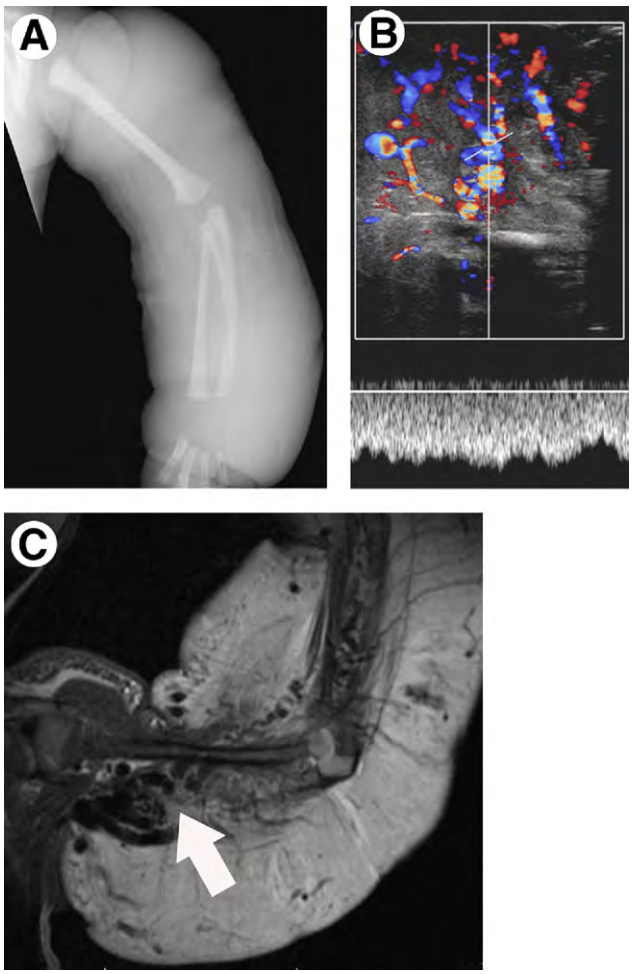

Figure 6 Rapidly involuting congenital hemangioma in a newborn female with severe swelling, high-output cardiac failure and thrombocytopenia. (A) Plain radiograph of the arm shows soft tissue swelling without boney deformity or soft tissue calcification. (B) Color Doppler sonogram reveals a poorly defined hypervascular mass with venous waveforms. Large internal flow voids and arterial waveforms were also present (not shown). (C) Sagittal contrast-enhanced T1-weighted fat-suppressed image reveals extensive enhancement throughout the thickened soft tissues of the arm with innumerable large flow voids (arrow).

guish TA from KH.[67] Both lesions may occur on the trunk, extremities, head, neck, retroperitoneum, and, rarely, other locations.[66,68] Expansion into regional nodes and soft tissues is common in KH, but no distant metastases are seen.[66] TA and KH may be associated with Kasabach–Merritt syndrome—thrombocytopenia caused by platelet sequestration.[69] Kasabach–Merritt phenomenon is a generic term referring to thrombocytopenia resulting from a consumptive coagulopathy.[70]

The imaging characteristics of TA and KH are similar to other vasoproliferative neoplasms, although KH tends to be larger, more ill-defined and infiltrative and is more often associated with impressive flow voids because of numerous feeding and draining vessels (Fig. 7). KH are also more likely associated with secondary destructive osseous changes.[12]

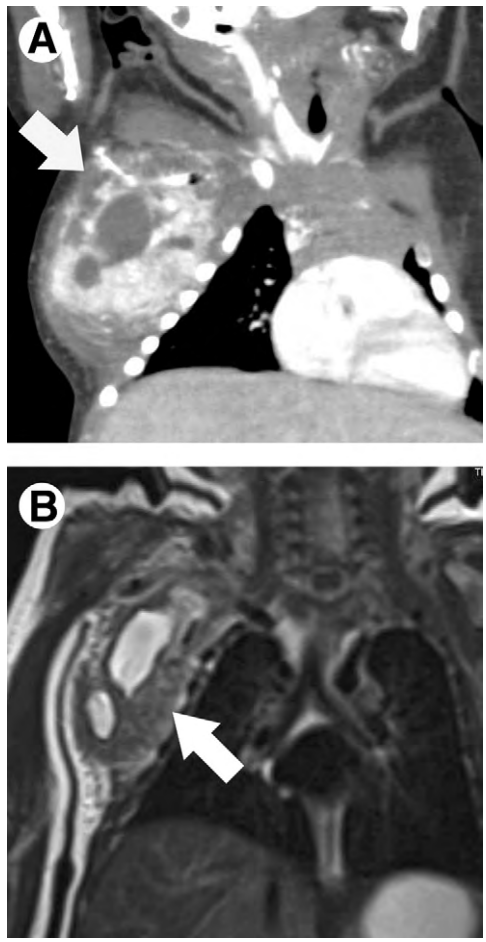

Figure 7 Kaposiform hemangioendothelioma in a 1-day-old female patient with a right chest mass. (A) Coronal reconstructed contrast-enhanced CT image reveals a lobulated enhancing mass with central necrosis in the chest wall (arrow). (B) Coronal T1-weighted MR image confirms a right chest wall mass (arrow) with intrinsic high signal centrally, suggesting internal hemorrhage.

Treatment options for TA and KH are similar to those for infantile hemangiomas.[71,72] The presence of Kasabach–Merritt syndrome portends a poor prognosis with a mortality rate of 30% in KH, and is thus an indication for aggressive treatment.[51,70] KH demonstrates aggressive local behavior, and a

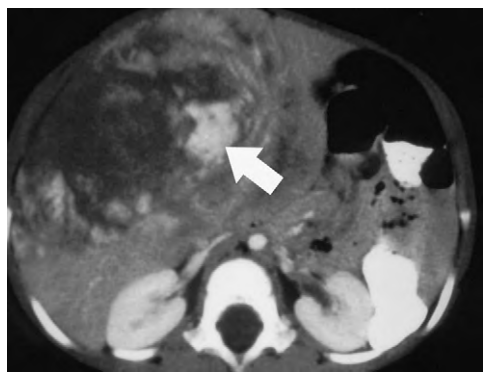

Figure 8 Angiosarcoma in a 2-year-old female patient with an abdominal mass. Axial contrast-enhanced CT image shows a heterogeneously enhancing right hepatic mass. Note focal pooling of contrast (arrow).

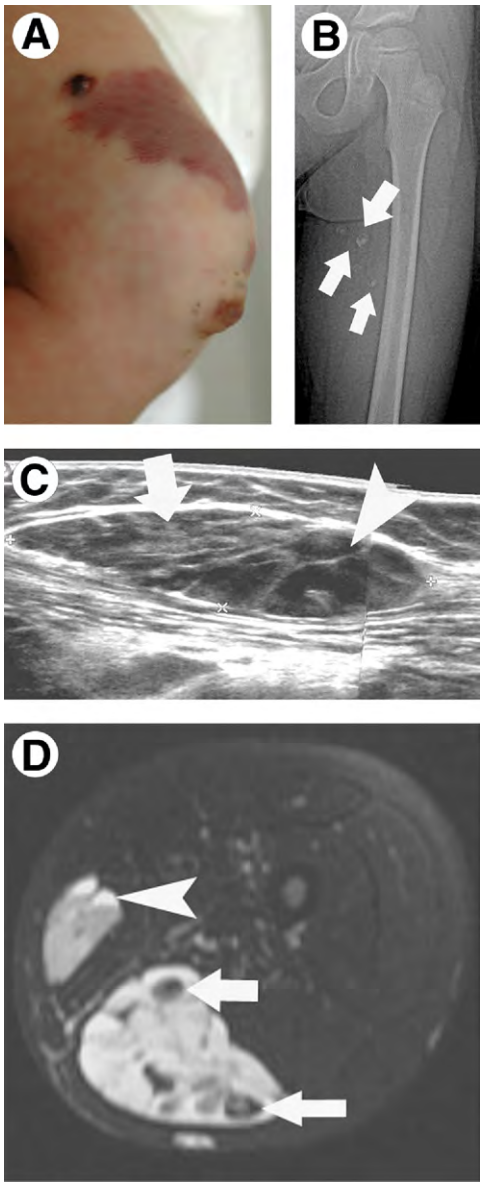

Figure 9 Venolymphatic malformation in a 6-year-old female with leg swelling for 2 months. (A) Photograph of the lower extremity shows an ill-defined purple plaque with nodules. (B) Plain radiograph demonstrates several focal phleboliths (arrows). (C) Sonogram of the leg shows mixed echogenic, partially cystic (arrow head), and partially solid mass (arrow). (D) Axial T2-weighted fat-suppressed image reveals a multispacial multicystic mass with fluid levels (arrow head) and phleboliths (arrows).

lack of distant metastases makes wide local excision and supportive treatment the mainstay of therapy.[68,72]

Hemangioendotheliomas (Spindle Cell, Epithelioid, and Other Variants)

First described in 1986, spindle cell hemangioendothelioma is a rare vascular neoplasm originally thought to be a low-grade angiosarcoma.[73,74] Today it is believed to be a benign reactive vasoproliferation that may present at any age throughout the body.[75,76] Histologically, lesions are composed of gaping thin-walled vessels containing thrombi, solid areas of spindle cells, and plump endothelial cells.[74] Immunohistochemistry is positive for CD31 and factor VIII antigen and negative for CD34.[77,78] Interestingly, an association between spindle cell hemangioendothelioma and Maffucci syndrome has been described (refer to Table 3).[79]

Epithelioid hemangioendothelioma is a rare, slowly progressive, distinct pathological vascular tumor that can occur at any age anywhere in the body. It is most common in the skeleton, a location not primary to vascular neoplasms.[1,80,81] Because of the rarity of this lesion, its nonspecific imaging appearance, and its varied locations and ages of presentation, the pathologist is usually the first to diagnose this tumor, and it is not typically part of the radiology differential diagnosis.[81,82]

Other rare subtypes of hemangioendotheliomas have been described, including composite, retiform, polymorphous, Dabska tumor, and lymphangioendotheliomatosis.[76,83] A complete discussion of these subtypes is beyond the scope of this review article.[69]

Angiosarcoma

Angiosarcoma is a rare aggressive neoplasm with a dismal prognosis. By 1999, there were 30 published cases of angiosarcoma. By 2006, 8 cases had been reported in association with multiple infantile hemangiomas.[46] Angiosarcoma has a female preponderance, and the average age of onset is 3.7 years.[46] Cross-sectional imaging tends to show an aggressive heterogeneous mass with pooling of contrast and multiple synchronous or metastatic lesions in the liver (Fig. 8).

Vascular Malformations

Vascular malformations are congenital morphogenic anomalies of various vessels that can present at any age.[84] They are subdivided into 2 categories: (1) slow- or low-flow and (2) fast- or high-flow malformations. Low-flow malformations contain combinations of capillary, venous, and lymphatic components.

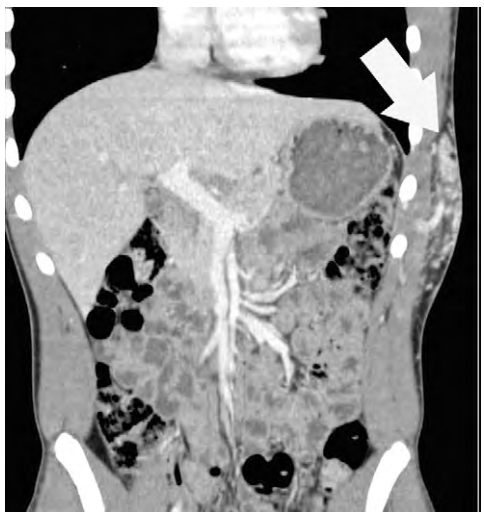

Figure 10 Arteriovenous malformation in a 16-year-old male patient with a left chest wall mass. Contrast-enhanced coronal reconstructed CT image demonstrates a cluster of enhancing vessels in the chest wall (arrow).

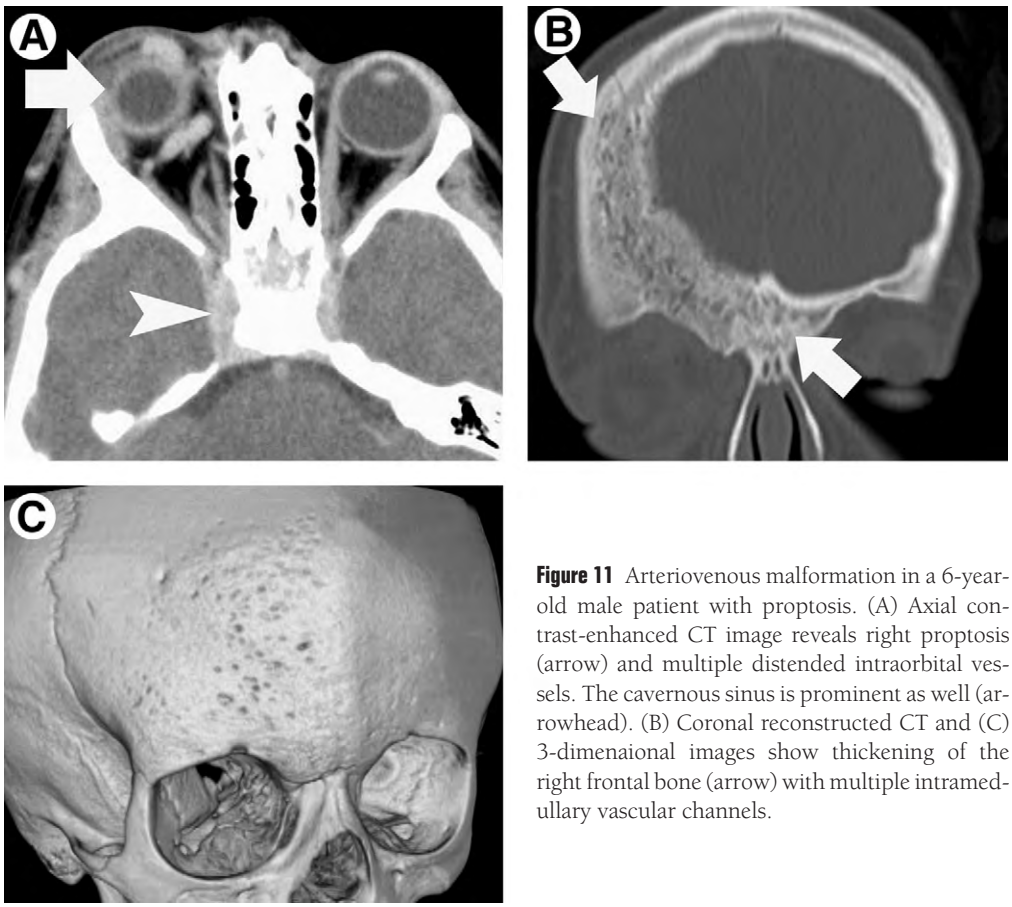

Figure 11 Arteriovenous malformation in a 6-year-old male patient with proptosis. (A) Axial contrast-enhanced CT image reveals right proptosis (arrow) and multiple distended intraorbital vessels. The cavernous sinus is prominent as well (arrowhead). (B) Coronal reconstructed CT and (C) 3-dimenaional images show thickening of the right frontal bone (arrow) with multiple intramedullary vascular channels.

High-flow malformations contain arterial components in combination with other vascular structures.[1] In general, pure malformations in either category are rare. Additionally, because capillary malformations and capillary components of malformations typically involve superficial layers of skin (for example, facial malformations of Sturge–Weber syndrome) that are obvious on physical examination but not well seen with imaging, they will not be discussed further here.

Slow Flow

Venous, lymphatic, and venolymphatic malformations are the most common types of vascular malformations with an overall prevalence of up to 1% in the general population.[85] At histology, purely venous and purely lymphatic malformations are rare. The venous portions of malformations contain abnormally formed and dilated superficial or deep veins, the walls of which are thin because they lack smooth muscle. The lymphatic portions of these malformations are formed from collections of lymph vessels filled with serous fluid. Research suggests that altered cell signals may be involved in the formation of lymphatic malformations, such as vascular endothelial growth factor C, which causes lymphatic hyperplasia.[86]

The clinical presentation of low-flow vascular malformations varies because of the many combinations of venous and lymphatic components, as well as variation in size and location. Predominantly venous lesions may present at birth, but they are also seen in later years.[4] Predominantly lymphatic malformations are often apparent at birth and nearly all are present by 2 years of age.[12] The natural history of venolymphatic malformations consists of slow steady enlargement. Venolymphatic malformations present with soft, easily compressible, blue masses that may swell in dependent positions or when venous pressures increase (ie, crying or valsalva).[8] They may be small and localized or extensive with infiltration throughout an anatomical region. Although venous malformations most often involve the face, limbs, and/or trunk, they may be found within the internal viscera, bones, and skeletal muscle.[14,87] Venous malformations are commonly confused with hemangiomas in adults, especially in the liver. Further, the intraosseous location of venous malformations is notable in comparison with hemangiomas, which do not occur within osseous structures, as was previously thought.[13] Lesions previously described as "intraosseous hemangiomas" are now pathologically known by their lack of GLUT1 to be venous malformations.[13,14]

Imaging of low-flow vascular malformations involves US for general characterization of cystic (mostly lymphatic) versus solid (mostly venous) components. MRI is often performed to determine lesion extent and plan for treatment. Phleboliths, a specific feature of venous components of vascular malformations, may be seen on plain radiographs when calcified and on MRI before or after calcification (Fig. 9). Both US and MRI are able to demonstrate the typical multispacial, multicystic, and/or partially solid nature of slow-flow

Table 5 Summary of Regional and Diffuse Syndromes Associated With Vascular Malformations

Regional syndromes with associated vascular malformations
Sturge–Weber: facial capillary malformation with intracranial capillary malformation, venous malformation, or AVM.
Klippel–Trenaunay: limb/trunk capillary venous lymphatic malformations with overgrowth.
Parkes Weber: CAVM with overgrowth; lymphatic malformation.
Diffuse syndromes associated slow-flow malformations
Proteus syndrome: vascular malformations (capillary or venous), hamartomatous syndrome with overgrowth (hemihypertrophy and macrodactyly), lipomas, pigmented nevi.
Blue rubber bleb nevus (Bean) syndrome: multiple cutaneous, musculoskeletal, and gastrointestinal tract venous malformations.
Epidermal nevus syndrome (Solomon syndrome): vascular malformations (intracranial AVM), epidermal nevi, various developmental abnormalities of the skin, eyes, nervous, skeletal, cardiovascular, and urogenital systems.
Bannayan–Riley–Ruvalcaba syndrome: vascular malformations (cutaneous, intracranial), macrocephaly, ectodermal dysplasia, lipomatous masses, and intestinal hamartomatous polyps, PTEN suppressor gene mutation association.
Diffuse syndromes associated fast flow malformations
Hereditary hemorrhagic telangiectasia (Osler–Weber–Rendu): telangiectasias (skin, mucous membranes, gastrointestinal mucosa) and AVMs (lungs, liver, brain, spinal cord).

AVM, arteriovenous malformation; CAVM, capillary arterial venous malformation; PTEN, phosphatase and tensin homolog.

venolymphatic malformations, allowing a diagnosis.[7] Imaging findings are summarized in Table 4.

Treatment of predominantly venous malformations is determined by the extent and location of the lesion. Although many are managed expectantly, some require treatment because they are painful, are in a location where they can cause significant morbidity, or are threatening vital organs (ie, airway compromise). Therapeutic options range from observation and compression garments for palliation of pain and swelling, to sclerotherapy of mostly cystic mass and, finally, surgical excision.[88-90] However, because of their frequent infiltrative and widespread nature, therapy is often challenging and incomplete.

High-Flow Vascular Malformations

Arteriovenous malformations (AVMs) and arteriovenous fistulas (AVFs) are typically congenital and acquired malformations, respectively. They are characterized by a cluster of arterial and venous channels without a significant solid identifiable mass. AVFs lack the nidus that AVMs contain, and usually occur within the brain.[8] Histologically, AVMs and AVFs consist of dysplastic arteries that drain into arterialized veins forming a vascular nidus in AVMs bypassing capillary beds. The prevalence of AVMs is unknown, but estimates range from 5 to 613 per 100,000 persons.[91] AVMs and AVFs may present with pain, ulceration, ischemic changes, bleeding, and congestive heart failure. On physical examination, they may be warm pink patches on the skin with an underlying vascular murmur or thrill.[8] Common locations include intracranial, intraosseous, muscle, and subcutaneous fat (Fig. 10). AVMs may be single, multiple, or part of a genetic disorder, such as hereditary hemorrhagic telangiectasia syndrome (Osler–Weber–Rendu) (refer to Table 4).

Imaging characteristics are summarized in Table 4. Lesions are often multispacial and hypervascular on color Doppler US.[8] Lesion extent is best determined with MRI, which shows numerous flow voids (because of turbulence) and hyperintense signal on gradient echo as well as angiographic sequences. Intraosseous lesions may benefit from contrast-enhanced CT (Fig. 11).

Therapy for high-flow malformations is preceded by angiography for complete mapping of vessels.[8,12] The first-line therapy for AVMs and AVFs is embolization.[8,12] Surgery, or a combination of therapies, may be needed in some children.

Regional Associations and Diffuse Syndromes

Vascular malformations can occur as primary lesions or as a part of a regional or diffuse syndrome[1] (Table 5). Treatment of regional and/or diffuse syndromes varies according to the type of anomalies and symptoms[8,63,88,92,93] (Fig. 12).

Conclusions

Much has been learned about the histopathology malformations in recent decades, causing change in classification and terminology. The ISSVA classification divides vascular anom-

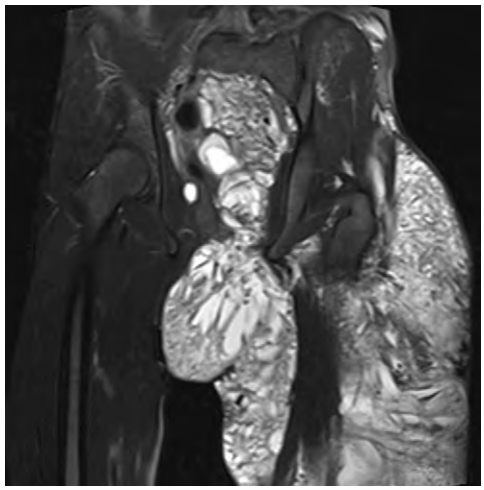

Figure 12 Klippel–Trenaunay syndrome in an 18-year-old male patient with painful leg swelling. Extensive infiltrative, multispacial T2 bright vascular malformation of the pelvis, lower extremity, and scrotum. Abnormal signal extends to the ankle (not shown).

alies into neoplasms and malformations, and it corresponds with consistent diagnosis and treatment, making it clinically useful. Radiologists can best use the ISSVA classification system by correlating imaging findings with patient history and physical findings. Consistent use of this system will help patients receive the correct diagnosis and treatment.

References

1. Mulliken JB, Glowacki J: Hemangiomas and vascular malformations in infants and children: A classification based on endothelial characteristics. Plast Reconstr Surg 69:412-422, 1982
2. Mulliken JB, Glowacki J: Classification of pediatric vascular lesions. Plast Reconstr Surg 70:120-121, 1982
3. Enjolras O: Classification and management of the various superficial vascular anomalies: Hemangiomas and vascular malformations. J Dermatol 24:701-710, 1997
4. Legiehn GM, Heran MK: Venous malformations: Classification, development, diagnosis, and interventional radiologic management. Radiol Clin North Am 46:545-597, vi, 2008
5. Van Aalst JA, Bhuller A, Sadove AM: Pediatric vascular lesions. J Craniofac Surg 14:566-583, 2003
6. Dubois J, Garel L: Imaging and therapeutic approach of hemangiomas and vascular malformations in the pediatric age group. Pediatr Radiol 29:879-893, 1999
7. Dubois J, Patriquin HB, Garel L, et al: Soft-tissue hemangiomas in infants and children: Diagnosis using Doppler sonography. AJR Am J Roentgenol 171:247-252, 1998
8. Legiehn GM, Heran MK: Classification, diagnosis, and interventional radiologic management of vascular malformations. Orthop Clin North Am 37:435-474, vii-viii, 2006
9. Hand JL, Frieden IJ: Vascular birthmarks of infancy: Resolving nosologic confusion. Am J Med Genet 108:257-264, 2002
10. Frieden IJ, Haggstrom AN, Drolet BA, et al: Infantile hemangiomas: current knowledge, future directions. Proceedings of a research workshop on infantile hemangiomas, April 7-9, 2005, Bethesda, Maryland, USA. Pediatr Dermatol 22:383-406, 2005
11. Mulliken JB, Enjolras O: Congenital hemangiomas and infantile hemangioma: Missing links. J Am Acad Dermatol 50:875-882, 2004
12. Moore CW, Lowe LH: Hepatic tumors and tumor-like conditions, in Slovis TL (ed): Caffey's Pediatric Diagnostic Imaging. Philadelphia, PA, Mosby Elsevier, 2008, pp 1929-1948
13. Greene AK, Rogers GF, Mulliken JB: Intraosseous "hemangiomas" are malformations and not tumors. Plast Reconstr Surg 119:1949-1950, 2007; author reply 1950
14. Bruder E, Perez-Atayde AR, Jundt G, et al: Vascular lesions of bone in children, adolescents, and young adults. A clinicopathologic reappraisal and application of the ISSVA classification. Virchows Arch 454:161-179, 2009
15. MacFie CC, Jeffery SL: Diagnosis of vascular skin lesions in children: An audit and review. Pediatr Dermatol 25:7-12, 2008
16. Hassanein AH, Mulliken JB, Fishman SJ, et al: Evaluation of terminology for vascular anomalies in current literature. Plast Reconstr Surg 127:347-351, 2011
17. Cohen MM Jr: Vasculogenesis, angiogenesis, hemangiomas, and vascular malformations. Am J Med Genet 108:265-274, 2002
18. Boye E, Yu Y, Paranya G, et al: Clonality and altered behavior of endothelial cells from hemangiomas. J Clin Invest 107:745-752, 2001
19. Nguyen VA, Fürhapter C, Romani N, et al: Infantile hemangioma is a proliferation of beta 4-negative endothelial cells adjacent to HLA-DR-positive cells with dendritic cell morphology. Hum Pathol 35:739-744, 2004
20. Lo K, Mihm M, Fay A: Current theories on the pathogenesis of infantile hemangioma. Semin Ophthalmol 24:172-177, 2009
21. Kaplan P, Normandin J Jr, Wilson GN, et al: Malformations and minor anomalies in children whose mothers had prenatal diagnosis: Comparison between CVS and amniocentesis. Am J Med Genet 37:366-370, 1990
22. Khan ZA, Boscolo E, Picard A, et al: Multipotential stem cells recapitulate human infantile hemangioma in immunodeficient mice. J Clin Invest 118:2592-2599, 2008
23. North PE, Waner M, Mizeracki A, et al: A unique microvascular phenotype shared by juvenile hemangiomas and human placenta. Arch Dermatol 137:559-570, 2001
24. Glowacki J, Mulliken JB: Mast cells in hemangiomas and vascular malformations. Pediatrics 70:48-51, 1982
25. Bischoff J: Progenitor cells in infantile hemangioma. J Craniofac Surg 20suppl 1:695-697, 2009
26. Boscolo E, Bischoff J: Vasculogenesis in infantile hemangioma. Angiogenesis 12:197-207, 2009
27. Yu Y, Fuhr J, Boye E, et al: Mesenchymal stem cells and adipogenesis in hemangioma involution. Stem Cells 24:1605-1612, 2006
28. Zhang L, Lin X, Wang W, et al: Circulating level of vascular endothelial growth factor in differentiating hemangioma from vascular malformation patients. Plast Reconstr Surg 116:200-204, 2005
29. Takahashi K, Mulliken JB, Kozakewich HP, et al: Cellular markers that distinguish the phases of hemangioma during infancy and childhood. J Clin Invest 93:2357-2364, 1994
30. Ritter MR, Dorrell MI, Edmonds J, et al: Insulin-like growth factor 2 and potential regulators of hemangioma growth and involution identified by large-scale expression analysis. Proc Natl Acad Sci U S A 99: 7455-7460, 2002
31. North PE, Waner M, Mizeracki A, et al: GLUT1: A newly discovered immunohistochemical marker for juvenile hemangiomas. Hum Pathol 31:11-22, 2000
32. Friedlander SF, Ritter MR, Friedlander M: Recent progress in our understanding of the pathogenesis of infantile hemangiomas. Lymphat Res Biol 3:219-225, 2005
33. Haggstrom AN, Lammer EJ, Schneider RA, et al: Patterns of infantile hemangiomas: New clues to hemangioma pathogenesis and embryonic facial development. Pediatrics 117:698-703, 2006
34. Waner M, North PE, Scherer KA, et al: The nonrandom distribution of facial hemangiomas. Arch Dermatol 139:869-875, 2003
35. Chiavérini C, Kurzenne JY, Rogopoulos A, et al: Noninvoluting congenital hemangioma: 2 cases. Ann Dermatol Venereol 129:735-737, 2002
36. Walter JW, North PE, Waner M, et al: Somatic mutation of vascular endothelial growth factor receptors in juvenile hemangioma. Genes Chromosomes Cancer 33:295-303, 2002
37. Chang EI, Thangarajah H, Hamou C, et al: Hypoxia, hormones, and endothelial progenitor cells in hemangioma. Lymphat Res Biol 5:237-243, 2007
38. Holmdahl K: Cutaneous hemangiomas in premature and mature infants. Acta Paediatr 44:370-379, 1955
39. Berenguer B, Mulliken JB, Enjolras O, et al: Rapidly involuting congenital hemangioma: Clinical and histopathologic features. Pediatr Dev Pathol 6:495-510, 2003
40. Bruckner AL, Frieden IJ: Hemangiomas of infancy. J Am Acad Dermatol 48:477-493; quiz: 494-476, 2003
41. Campbell S, Park JH, Rowe J, et al: Chorionic villus sampling as a source of trophoblasts. Placenta 28:1118-1122, 2007
42. Chiller KG, Passaro D, Frieden IJ: Hemangiomas of infancy: Clinical characteristics, morphologic subtypes, and their relationship to race, ethnicity, and sex. Arch Dermatol 138:1567-1576, 2002
43. Lopriore E, Markhorst DG: Diffuse neonatal haemangiomatosis: New views on diagnostic criteria and prognosis. Acta Paediatr 88:93-97, 1999
44. Drolet BA, Esterly NB, Frieden IJ: Hemangiomas in children. N Engl J Med 341:173-181, 1999
45. Donnelly LF, Adams DM, Bisset GS, 3rd: Vascular malformations and hemangiomas: A practical approach in a multidisciplinary clinic. AJR Am J Roentgenol 174:597-608, 2000
46. Nord KM, Kandel J, Lefkowitch JH, et al: Multiple cutaneous infantile hemangiomas associated with hepatic angiosarcoma: Case report and review of the literature. Pediatrics 118:e907-e913, 2006
47. Kassarjian A, Zurakowski D, Dubois J, et al: Infantile hepatic hemangiomas: Clinical and imaging findings and their correlation with therapy. AJR Am J Roentgenol 182:785-795, 2004

48. North PE, Waner M, Buckmiller L, et al: Vascular tumors of infancy and childhood: Beyond capillary hemangioma. Cardiovasc Pathol 15:303-317, 2006
49. Haggstrom AN, Drolet BA, Baselga E, et al: Prospective study of infantile hemangiomas: Clinical characteristics predicting complications and treatment. Pediatrics 118:882-887, 2006
50. Iacobas I, Burrows PE, Frieden IJ, et al: LUMBAR: Association between cutaneous infantile hemangiomas of the lower body and regional congenital anomalies. J Pediatr 157:795-801, e1-e7, 2010
51. Sarkar M, Mulliken JB, Kozakewich HP, et al: Thrombocytopenic coagulopathy (Kasabach-Merritt phenomenon) is associated with Kaposiform hemangioendothelioma and not with common infantile hemangioma. Plast Reconstr Surg 100:1377-1386, 1997
52. Ruppe MD, Huang SA, de Beur J: Consumptive hypothyroidism caused by paraneoplastic production of type 3 iodothyronine deiodinase. Thyroid 15:1369-1372, 2005
53. Kalpatthi R, Germak J, Mizelle K, et al: Thyroid abnormalities in infantile hepatic hemangioendothelioma. Pediatr Blood Cancer 49:1021-1024, 2007
54. Rivard DC, Lowe LH: Radiological reasoning: Multiple hepatic masses in an infant. AJR Am J Roentgenol 190:S46-S52, 2008
55. Konez O, Burrows PE, Mulliken JB, et al: Angiographic features of rapidly involuting congenital hemangioma (RICH). Pediatr Radiol 33: 15-19, 2003
56. Denoyelle F, Leboulanger N, Enjolras O, et al: Role of propranolol in the therapeutic strategy of infantile laryngotracheal hemangioma. Int J Pediatr Otorhinolaryngol 73:1168-1172, 2009
57. Léauté-Labrèze C, Dumas de la Roque E, Hubiche T, et al: Propranolol for severe hemangiomas of infancy. N Engl J Med 358:2649-2651, 2008
58. Krol A, MacArthur CJ: Congenital hemangiomas: Rapidly involuting and noninvoluting congenital hemangiomas. Arch Facial Plast Surg 7:307-311, 2005
59. Boon LM, Enjolras O, Mulliken JB: Congenital hemangioma: Evidence of accelerated involution. J Pediatr 128:329-335, 1996
60. Marler JJ, Fishman SJ, Upton J, et al: Prenatal diagnosis of vascular anomalies. J Pediatr Surg 37:318-326, 2002
61. Gorincour G, Kokta V, Rypens F, et al: Imaging characteristics of two subtypes of congenital hemangiomas: Rapidly involuting congenital hemangiomas and non-involuting congenital hemangiomas. Pediatr Radiol 35:1178-1185, 2005
62. Rogers M, Lam A, Fischer G: Sonographic findings in a series of rapidly involuting congenital hemangiomas (RICH). Pediatr Dermatol 19:5-11, 2002
63. Lopez-Gutierrez JC, Diaz M, Ros Z: Giant rapidly involuting congenital hemangioma of the face: 15-year follow-up. Arch Facial Plast Surg 7:316-318, 2005
64. Herron MD, Coffin CM, Vanderhooft SL: Tufted angiomas: Variability of the clinical morphology. Pediatr Dermatol 19:394-401, 2002
65. Jones EW, Orkin M: Tufted angioma (angioblastoma). A benign progressive angioma, not to be confused with Kaposi's sarcoma or low-grade angiosarcoma. J Am Acad Dermatol 20:214-225, 1989
66. Lyons LL, North PE, Mac-Moune Lai F, et al: Kaposiform hemangioendothelioma: A study of 33 cases emphasizing its pathologic, immunophenotypic, and biologic uniqueness from juvenile hemangioma. Am J Surg Pathol 28:559-568, 2004
67. Arai E, Kuramochi A, Tsuchida T, et al: Usefulness of D2-40 immunohistochemistry for differentiation between kaposiform hemangioendothelioma and tufted angioma. J Cutan Pathol 33:492-497, 2006
68. Zukerberg LR, Nickoloff BJ, Weiss SW: Kaposiform hemangioendothelioma of infancy and childhood. An aggressive neoplasm associated with Kasabach-Merritt syndrome and lymphangiomatosis. Am J Surg Pathol 17:321-328, 1993
69. Enjolras O: Color Atlas of Vascular Tumors and Vascular Malformations. West Nyack, NY, Cambridge University Press, 2007
70. Mukerji SS, Osborn AJ, Roberts J, et al: Kaposiform hemangioendothelioma (with Kasabach Merritt syndrome) of the head and neck: Case report and review of the literature. Int J Pediatr Otorhinolaryngol 73: 1474-1476, 2009
71. Ishikawa K, Hatano Y, Ichikawa H, et al: The spontaneous regression of tufted angioma. A case of regression after two recurrences and a review of 27 cases reported in the literature. Dermatology 210:346-348, 2005
72. Vin-Christian K, McCalmont TH, Frieden IJ: Kaposiform hemangioendothelioma. An aggressive, locally invasive vascular tumor that can mimic hemangioma of infancy. Arch Dermatol 133:1573-1578, 1997
73. Weiss SW, Enzinger FM: Spindle cell hemangioendothelioma. A low-grade angiosarcoma resembling a cavernous hemangioma and Kaposi's sarcoma. Am J Surg Pathol 10:521-530, 1986
74. Eltorky M, McC Chesney T, Sebes J, et al: Spindle cell hemangioendothelioma. Report of three cases and review of the literature. J Dermatol Surg Oncol 20:196-202, 1994
75. Hisaoka M, Kouho H, Aoki T, et al: DNA flow cytometric and immunohistochemical analysis of proliferative activity in spindle cell haemangioendothelioma. Histopathology 27:451-456, 1995
76. Dhawan SS, Raza M: Spindle cell hemangioendothelioma. Cutis 79: 125-128, 2007
77. Fukunaga M, Ushigome S, Nikaido T, et al: Spindle cell hemangioendothelioma: An immunohistochemical and flow cytometric study of six cases. Pathol Int 45:589-595, 1995
78. DeYoung BR, Swanson PE, Argenyi ZB, et al: CD31 immunoreactivity in mesenchymal neoplasms of the skin and subcutis: Report of 145 cases and review of putative immunohistologic markers of endothelial differentiation. J Cutan Pathol 22:215-222, 1995
79. Hisaoka M, Aoki T, Kouho H, et al: Maffucci's syndrome associated with spindle cell hemangioendothelioma. Skeletal Radiol 26:191-194, 1997
80. Weiss SW, Enzinger FM: Epithelioid hemangioendothelioma: A vascular tumor often mistaken for a carcinoma. Cancer 50:970-981, 1982
81. Larochelle O, Périgny M, Lagacé R, et al: Best cases from the AFIP: Epithelioid hemangioendothelioma of bone. Radiographics 26:265-270, 2006
82. Kopniczky Z, Tsimpas A, Lawson DD, et al: Epithelioid hemangioendothelioma of the spine: Report of two cases and review of the literature. Br J Neurosurg 22:793-797, 2008
83. Fukunaga M, Suzuki K, Saegusa N, et al: Composite hemangioendothelioma: Report of 5 cases including one with associated Maffucci syndrome. Am J Surg Pathol 31:1567-1572, 2007
84. Burrows PE, Mulliken JB, Fellows KE, et al: Childhood hemangiomas and vascular malformations: Angiographic differentiation. AJR Am J Roentgenol 141:483-488, 1983
85. Eifert S, Villavicencio JL, Kao TC, et al: Prevalence of deep venous anomalies in congenital vascular malformations of venous predominance. J Vasc Surg 31:462-471, 2000
86. Filston HC: Hemangiomas, cystic hygromas, and teratomas of the head and neck. Semin Pediatr Surg 3:147-159, 1994
87. Hein KD, Mulliken JB, Kozakewich HP, et al: Venous malformations of skeletal muscle. Plast Reconstr Surg 110:1625-1635, 2002
88. Pappas DC Jr, Persky MS, Berenstein A: Evaluation and treatment of head and neck venous vascular malformations. Ear Nose Throat J 77: 918-922, 1998
89. Pascarella L, Bergan JJ, Yamada C, et al: Venous angiomata: Treatment with sclerosant foam. Ann Vasc Surg 19:457-464, 2005
90. Rebeiz E, April MM, Bohigian RK, et al: Nd-YAG laser treatment of venous malformations of the head and neck: An update. Otolaryngol Head Neck Surg 105:655-661, 1991
91. Stapf C, Mohr JP, Pile-Spellman J, et al: Epidemiology and natural history of arteriovenous malformations. Neurosurg Focus 11:e1, 2001
92. Alomari AI: Comments on imaging and management of hepatic hemangiomas. Pediatr Radiol 39:637-638, 2009
93. Christison-Lagay ER, Fishman SJ: Vascular anomalies. Surg Clin North Am 86:393-425, x, 2006