Pediatric Vascular Anomalies: A Clinical and Radiological Perspective

Rahul Gupta[1]   Anu Bhandari[2]   Oscar M. Navarro[3,4]

[1] Department of Paediatric Surgery, SMS Medical College, JLN Marg, Jaipur, Rajasthan, India
[2] Department of Radiodiagnosis, SMS Medical College, JLN Marg, Jaipur, Rajasthan, India
[3] Department of Diagnostic and Interventional Radiology, The Hospital for Sick Children, Toronto, ON, Canada
[4] Department of Medical Imaging, University of Toronto, Toronto, ON, Canada

Address for correspondence Rahul Gupta, MS, MCh (Paediatric Surgery), FMAS, Department of Paediatric Surgery, SMS Medical College, JLN Marg, Jaipur, Rajasthan 302004, India (e-mail: meetsurgeon007@gmail.com).

Abstract

Keywords
► congenital hemangioma
► infantile hemangioma
► pediatric
► vascular anomalies
► vascular malformations

According to the International Society for the Study of Vascular Anomalies (ISSVA) classification, vascular anomalies include a diverse range of pathologies, classified as either vascular tumors or vascular malformations. This classification, last revised in 2018, aims to explain the biological basis of vascular lesions and help clinicians to manage the anomalies. In vascular tumors, there are proliferative changes of endothelial cells, while vascular malformations primarily consist of structural vascular abnormalities. Infantile hemangioma is the most common soft-tissue vascular tumor. Vascular malformations are an extensive group of malformations of the arterial, venous, and lymphatic systems, either in isolation or in combination. Radiological evaluation plays a key part in the management of pediatric patients with these entities. The understanding of sonography and magnetic resonance imaging findings entails its correlation with clinical findings at the time of scanning.

Introduction

Congenital vascular anomalies are a diverse group of the most complex, heterogeneous congenital blood vessel disorders characterized by specific morphology, histopathologic features, pathophysiology, biological behavior, clinical appearance (presentation), and management approach.[1,2] Many of these vascular anomalies present in the pediatric age group.

Before 1982, there was inconsistency in the terminology and classification systems. A variety of terms were used including "birthmarks" and "angiomas." John B. Mulliken and Julie Glowacki were the initial researchers to subgroup the vascular anomalies into hemangiomas and vascular malformations and proposed a histology-based classification in 1982.[2–4] Subsequently, the International Society for the Study of Vascular Anomalies (ISSVA) classification divided them into vascular tumors and vascular malformations (►Table 1).[2,5–8] ISSVA is a multidisciplinary international group that was formed in 1992 to promote research in the area of vascular anomalies and to improvise a uniform nomenclature that would facilitate research and clinical practice. ISSVA created a comprehensive classification system (reference standard) based on the work of Mulliken and Glowacki. It is based on histology and the biological behavior of the disease. The updated ISSVA classifications (2018) describe the causative genes involved in various vascular pathologies.

Radiology plays a key role in the management of pediatric patients with these entities. It helps in the clinical diagnosis,

Table 1 Modified table of ISSVA classification 2018

Vascular tumors	Vascular malformations			
	Simple	Combined	Of major named vessels	Associated with other anomalies
Benign	Capillary malformations (CMs)	Capillary venous malformation (CVM = CM + VM)	Affect	Klippel–Trénaunay syndrome: CM + VM ± lymphatic malformation (LM) + limb overgrowth
Infantile hemangioma/hemangioma of infancy	Nevus simplex/salmon patch, "angel kiss," "stork bite"	Capillary lymphatic malformation (CLM = CM + LM)	lymphatics	Parkes Weber syndrome: CM + AVF + limb overgrowth
Congenital hemangioma (CH): • Rapidly involuting (RICH) • Noninvoluting (NICH) • Partially involuting (PICH)	Cutaneous and/or mucosal CM (CM with CNS and/or ocular anomalies [Sturge–Weber syndrome])	Capillary arteriovenous malformation (CAVM = CM + AVM)	Veins	Servelle–Martorell syndrome: limb VM + bone undergrowth
Tufted angioma	Reticulate CM	Lymphatic venous malformation (LVM = LM + VM)	Arteries	Sturge–Weber syndrome: facial + leptomeningeal CM + eye anomalies ± bone and/or soft-tissue overgrowth
Spindle cell hemangioma	CM of CM-AVM	Capillary lymphatic venous malformation (CLVM = CM + LM + VM)	Anomalies of	Limb CM + congenital nonprogressive limb overgrowth
Epithelioid hemangioma	Cutis marmorata telangiectatica congenita	Capillary lymphatic arteriovenous malformation (CLAVM = CM + LM + AVM)	Origin	Maffucci syndrome: VM ± spindle cell hemangioma + enchondroma
Pyogenic granuloma (also k/a lobular capillary hemangioma)	Others	Capillary venous arteriovenous malformation (CVAVM = CM + VM + AVM)	Course	Macrocephaly-CM (M-CM/MCAP)
	Telangiectasia	Capillary lymphatic venous arteriovenous malformation (CLVAVM = CM + LM + VM + AVM)	Number	Microcephaly-CM (MICCAP)
Locally aggressive or borderline vascular tumors	LMs	CVM = CM + VM	Length	CLOVES syndrome: LM + VM + CM ± AVM + lipomatous overgrowth
Kaposiform hemangioendothelioma	Common (cystic) LM: • Macrocystic LM • Microcystic LM • Mixed cystic LM		Diameter (aplasia, hypoplasia, stenosis, ectasia/aneurysm)	Proteus syndrome: CM, VM, and/or LM + asymmetrical somatic overgrowth
Retiform hemangioendothelioma	Generalized lymphatic anomaly (GLA); Kaposiform lymphangiomatosis (KLA)		Valves	Bannayan–Riley–Ruvalcaba syndrome: AVM + VM + macrocephaly, lipomatous overgrowth
Papillary intralymphatic angioendothelioma (PILA), Dabska's tumor			Communication (AVF)	CM, LM, Asymmetry, Partial Overgrowth (CLAPO) syndrome: lower lip CM + face and neck LM + asymmetry and partial/generalized overgrowth

Table 1 (*Continued*)

Vascular tumors	Vascular malformations			
	Simple	Combined	Of major named vessels	Associated with other anomalies
Composite hemangioendothelioma	LM in Gorham–Stout disease		Persistence (of the embryonal vessel)	
Pseudomyogenic hemangioendothelioma	Channel type LM			
Polymorphous hemangioendothelioma	"Acquired" progressive lymphatic anomaly (so-called acquired progressive lymphangioma)			
Hemangioendothelioma not otherwise specified	Primary lymphedema			
Kaposi's sarcoma	Others			
Malignant vascular tumors	Venous malformations (VM)			
Angiosarcoma (postradiation)	Common VM			
Epithelioid hemangioendothelioma	Familial VM cutaneomucosal (VMCM)			
Others	Blue rubber bleb nevus (Bean) syndrome VM			
	Glomuvenous malformation (GVM)			
	Cerebral cavernous malformation (CCM)			
	Familial intraosseous vascular malformation (VMOS)			
	Verrucous venous malformation (formerly verrucous hemangioma)			
	Others			
	Arteriovenous malformations (AVM)			
	Sporadic			
	In HHT			
	In CM-AVM			
	Others			
	Arteriovenous fistula (AVF) (congenital)			
	Sporadic			
	In HHT			
	In CM-AVM			
	Others			

Abbreviation: HHT, hereditary hemorrhagic telangiectasia.

Note: Combined, defined as two or more VMs found in one lesion; Of major named vessels, also known as "channel type" or "truncal" vascular malformations, abnormalities in the origin/course/number of major blood vessels that have anatomical names; Associated with other anomalies, syndromes in which VMs are complicated by symptoms other than vascular anomalies.
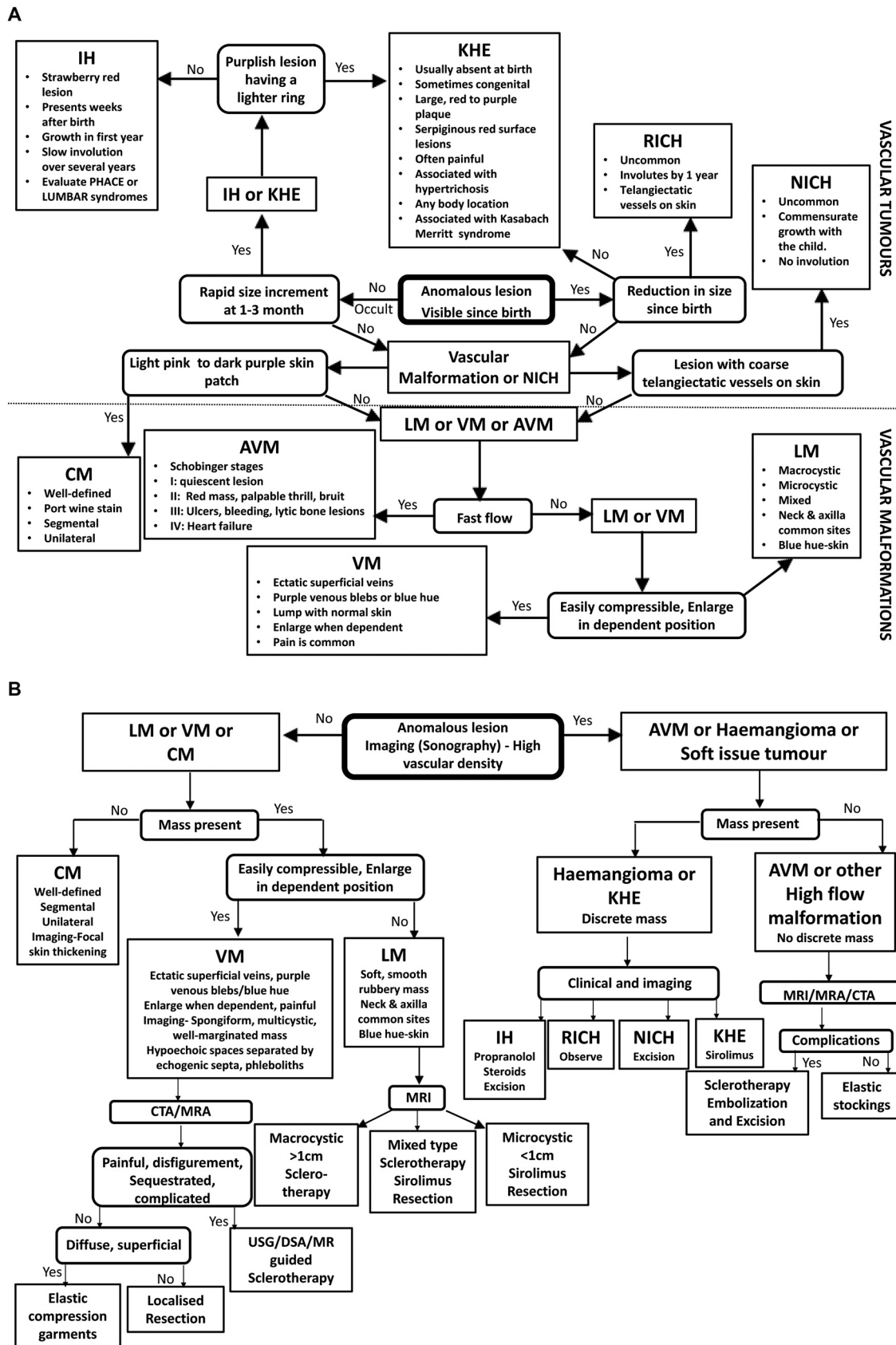
A

VASCULAR TUMOURS

IH
- Strawberry red lesion
- Presents weeks after birth
- Growth in first year
- Slow involution over several years
- Evaluate PHACE or LUMBAR syndromes

← No — **Purplish lesion having a lighter ring** — Yes →

KHE
- Usually absent at birth
- Sometimes congenital
- Large, red to purple plaque
- Serpiginous red surface lesions
- Often painful
- Associated with hypertrichosis
- Any body location
- Associated with Kasabach Merritt syndrome

RICH
- Uncommon
- Involutes by 1 year
- Telangiectatic vessels on skin

NICH
- Uncommon
- Commensurate growth with the child.
- No involution

IH or KHE

Yes

Rapid size increment at 1-3 month — No / Occult — **Anomalous lesion Visible since birth** — Yes — **Reduction in size since birth** — Yes

No → **Vascular Malformation or NICH** ← No

No → **Lesion with coarse telangiectatic vessels on skin** — Yes ↑

Light pink to dark purple skin patch ← No

VASCULAR MALFORMATIONS

LM or VM or AVM

CM
- Well-defined
- Port wine stain
- Segmental
- Unilateral

Yes

AVM
- Schobinger stages
- I: quiescent lesion
- II: Red mass, palpable thrill, bruit
- III: Ulcers, bleeding, lytic bone lesions
- IV: Heart failure

Yes — **Fast flow** — No — **LM or VM**

LM
- Macrocystic
- Microcystic
- Mixed
- Neck & axilla common sites
- Blue hue-skin

VM
- Ectatic superficial veins
- Purple venous blebs or blue hue
- Lump with normal skin
- Enlarge when dependent
- Pain is common

Yes — **Easily compressible, Enlarge in dependent position**

B

← No — **Anomalous lesion Imaging (Sonography) - High vascular density** — Yes →

LM or VM or CM

AVM or Haemangioma or Soft issue tumour

No — **Mass present** — Yes

Yes — **Mass present** — No

CM
Well-defined
Segmental
Unilateral
Imaging-Focal skin thickening

Easily compressible, Enlarge in dependent position

Yes — **VM**
Ectatic superficial veins, purple venous blebs/blue hue
Enlarge when dependent, painful
Imaging- Spongiform, multicystic, well-marginated mass
Hypoechoic spaces separated by echogenic septa, phleboliths

No — **LM**
Soft, smooth rubbery mass
Neck & axilla common sites
Blue hue-skin

Haemangioma or KHE
Discrete mass

Clinical and imaging

IH
Propranolol
Steroids
Excision

RICH
Observe

NICH
Excision

KHE
Sirolimus

AVM or other High flow malformation
No discrete mass

MRI/MRA/CTA

Complications
Yes / No

Sclerotherapy Embolization and Excision

Elastic stockings

CTA/MRA

MRI

Macrocystic >1cm Sclero-therapy

Mixed type Sclerotherapy Sirolimus Resection

Microcystic <1cm Sirolimus Resection

Painful, disfigurement, Sequestrated, complicated

No — **Diffuse, superficial**

Yes — **USG/DSA/MR guided Sclerotherapy**

Yes — **Elastic compression garments**

No — **Localised Resection**

Fig. 1 (A) An approach flowchart for the management of vascular anomalies from a clinical perspective. (B) An approach flowchart for the management of vascular anomalies from a radiological perspective. AVM, arteriovenous malformation; CM, capillary malformation; CTA, computed tomography angiography; DSA, digital subtraction angiography; KHE, Kaposiform hemangioendothelioma; LM, lymphatic malformation; MRA, magnetic resonance angiography; MRI, magnetic resonance imaging; NICH, noninvoluting congenital hemangioma; RICH, rapidly involuting congenital hemangioma; USG, ultrasonography; VM, venous malformation.

evaluating the extent and complications of the lesion, image-guided percutaneous treatment, and monitoring response to therapy in most vascular anomalies. In this study, the authors review the pertinent clinical and radiological features of pediatric vascular tumors and vascular malformations. Approach flowcharts for the management of vascular anomalies from clinical and radiological perspectives are presented in ►**Fig. 1**.[7,9,10]

Vascular Tumors

Vascular tumors are true proliferative neoplasms and generally arise de novo. They consist of clonal cellular proliferation with mitoses and lesional growth that is out of proportion to the patient. There are elevated serum markers of cellular proliferation such as vascular endothelial growth factor (VEGF) and cell nuclear antigen. ISSVA divides vascular tumors into benign, locally aggressive/borderline, and aggressive tumors (►**Table 1**). Hemangioma is the most common of the former group of tumors.[11]

Hemangiomas

Hemangiomas are classified as infantile or congenital; the former subtype is much more common. As their names

indicate, infantile hemangiomas (IHs) develop after birth, while congenital hemangiomas (CHs) are fully developed at birth.[6,12] The incidence of hemangiomas, including IHs and CHs, is between 1.1 and 2.6% in neonates,[6,12] which may exclude some IHs diagnosed in young infants after the neonatal period.

Infantile Hemangioma

IH is a benign tumor arising from the vascular endothelium. It is the most common soft-tissue vascular tumor in the pediatric age affecting about 4 to 10% of infants. IH has a predilection for girls with a female:male ratio of 3:1 to 5:1.[1,6,10,12]

Estradiol, basic fibroblast growth factor (bFGF), and stromal cell–derived VEGF are implicated in the proliferation of IH. Risk factors associated with IH are low birth weight and prematurity. IHs are positive for GLUT-1 (glucose transport protein) on immunohistochemical staining and GLUT-1 overexpression is specific to IH.[13] The history of chorionic villous sampling in the antenatal period among patients with IH has been reported.[13,14]

More than half of IHs occur in the head and neck regions (►**Fig. 2**) and one-fourth may have multiple lesions
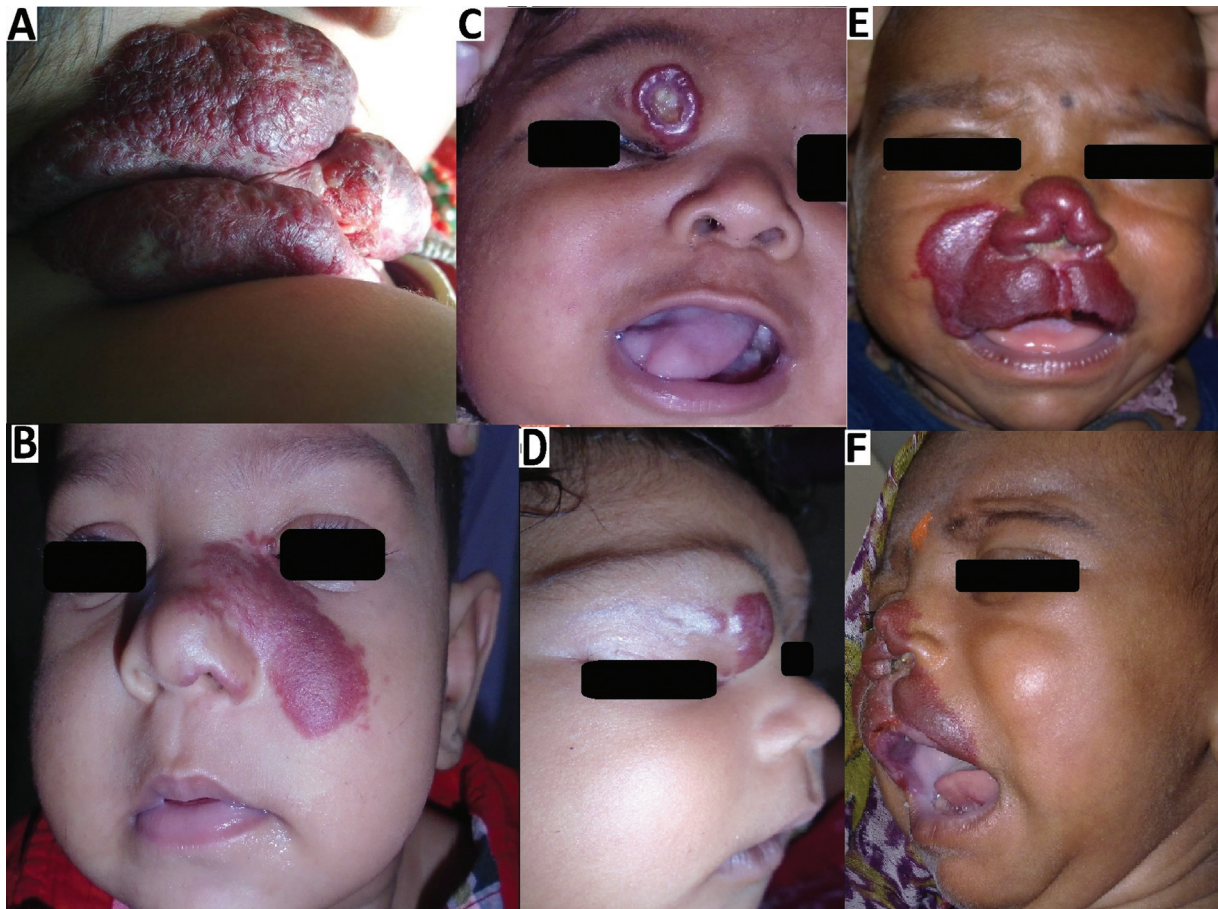
Fig. 2 Clinical photographs of infantile hemangioma (IH) in the proliferative phase show (**A**) superficial IH involving the neck region, (**B**) superficial IH causing facial disfigurement, (**C**) ulcerated ocular IH (involution phase) in a 9-month-old infant with pressure effect on the upper eyelid, and (**D**) mixed IH involving the upper eyelid. A 5-month-old infant having (**E**) a large facial proliferative IH with disfigurement and nasal septum erosion at the first outdoor visit and (**F**) partial recovery 2 months after propranolol therapy.
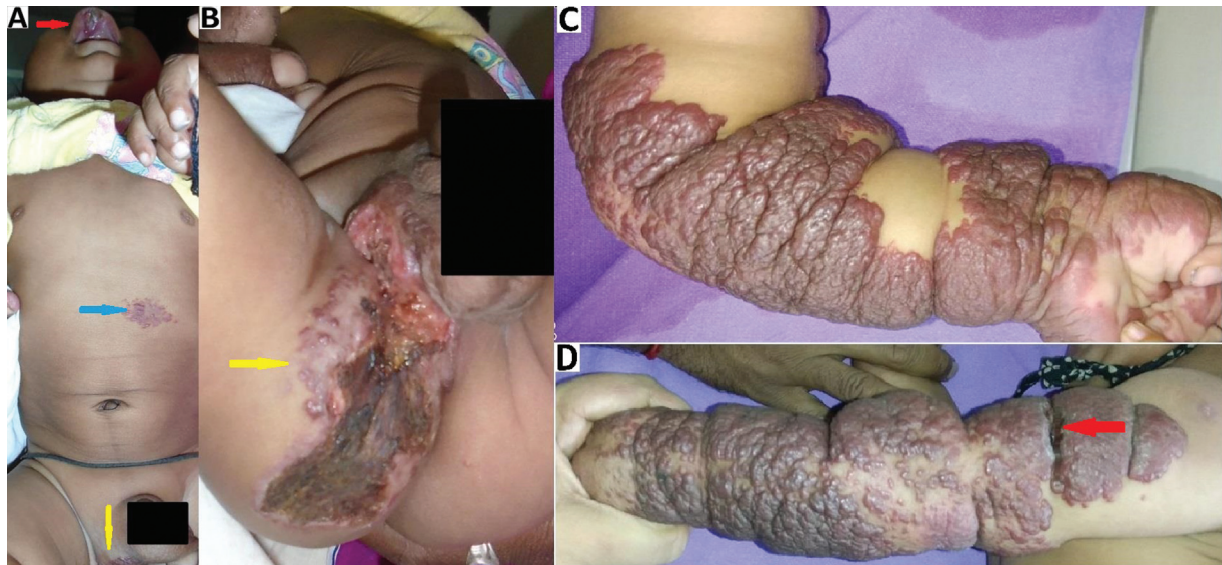
Fig. 3 Clinical photographs of a 9-month-old infant show (**A**) multiple infantile hemangiomas (IHs) in the upper lip (*red arrow*), abdominal wall (*blue arrow*), and perineal region (*yellow arrow*). (**B**) Enlarged view of large IH (involution phase) in the perineal region (*yellow arrow*) extending into the inguinoscrotal region and gluteal region with central ulceration. Large proliferative IH on (**C**) volar and (**D**) dorsal aspect (with ulceration, *red arrow*) of the arm; the patient had partial recovery after propranolol treatment.

(►**Fig. 3**).[14] The trunk and extremities are less commonly involved. IHs are categorized according to their distribution pattern into focal, multifocal, segmental, and indeterminate types, and as per the depth of involvement (►**Fig. 3**) into superficial, deep, mixed, and abortive types. The superficial type is the most common (>50%) type.[6,12]

IHs present approximately 2 weeks (age range: between 1 and 4 weeks) after birth, not later than 12 weeks of age. Sometimes a premonitory mark may be present at birth in the form of pale macule with telangiectasias, mottled vascular stain, or bruiselike area. Out of two subtypes, that is, superficial and deep type, the latter presents at 2 to 3 months of age. The growth (proliferation phase) of IH is fast in the first 3 months (maximum between 4 and 7 weeks) postnatally. The growth of IH decreases between 6 and 12 months of age. On the other hand, large and deeply penetrating lesions (e.g., parotid area) can grow until 2 years of age.[15,16]

In the proliferative phase, IH development is characterized by excessive angiogenesis. IH is brightly erythematous, that is, purplish red to bright red macule, papule, plaque (superficial type), or blue nodule (deep type), or may exhibit a combination of these features, depending on the location (►**Fig. 3**).[17]

The growth is followed by a plateau (stabilization) phase from 12 to 18 months, then a slow phase of involution (regression phase) is observed, which may continue up to 10 years.[14] The complete regression may be present at 4 years in 80% of IH cases.[16,17]

In the phase of involution, its color fades and becomes dull gray red-colored. The connective tissue, fibroblasts, and fat replace the vascular tissue with fibrofatty tissue. One-half of children after involution have residual telangiectasias, fibrofatty residuum, redundant skin, and scarring.[16,17]

Ulceration is the most common complication with IH and may be the presenting sign before the development of IH. It is

seen in 5 to 15% of cases at around 4 months of age.[14–17] Cardiac failure may complicate, especially in patients with arteriovenous shunting. Complications are relatively more common with regional/segmental variants than with focal subtypes. High-risk lesions are those located on the face measuring greater than 5 cm in the diameter, central face area, and bulky face lesions (►**Fig. 4**). These are seen both during the proliferation and involution phase, although they are more common in the latter.[16,17] Important site-specific IHs requiring early intervention are presented in ►**Table 2**.[9]

The sonographic appearance of IH depends on its phase (►**Figs. 4, 5**) as described in ►**Table 3**.[10,17,18] Sonography has proved useful in assessing response to therapy by showing a decrease in tumor volume and vascular density, especially in deep subtypes (deeper soft-tissue involvement) that are difficult to evaluate clinically (►**Table 3**).[10] Sonography of lumbosacral hemangioma is ideally done in patients under the age of 4 months, while magnetic resonance imaging (MRI) is indicated after this age. MRI characteristics of hemangiomas are briefly described in ►**Table 3**.[4] MRI of IHs provides excellent soft-tissue differentiation, and magnetic resonance angiography (MRA) is optimally done with contrast agent using a time-resolved technique.[9] Computed tomography (CT) can also accurately delineate these lesions with rapid acquisition, excellent spatial resolution, and three-dimensional (3D) reconstruction.[9]

PHACE Association and LUMBAR Syndrome

Hemangiomas may be a part of a more extensive cluster of abnormalities, for example, PHACE association and LUMBAR syndrome.

PHACE association: The PHACE association is found in the setting of segmental facial lesions. The abbreviation PHACE refers to (P) posterior fossa brain malformations, (H) hemangiomas of the face/scalp, (A) arterial anomalies, (C) cardiac
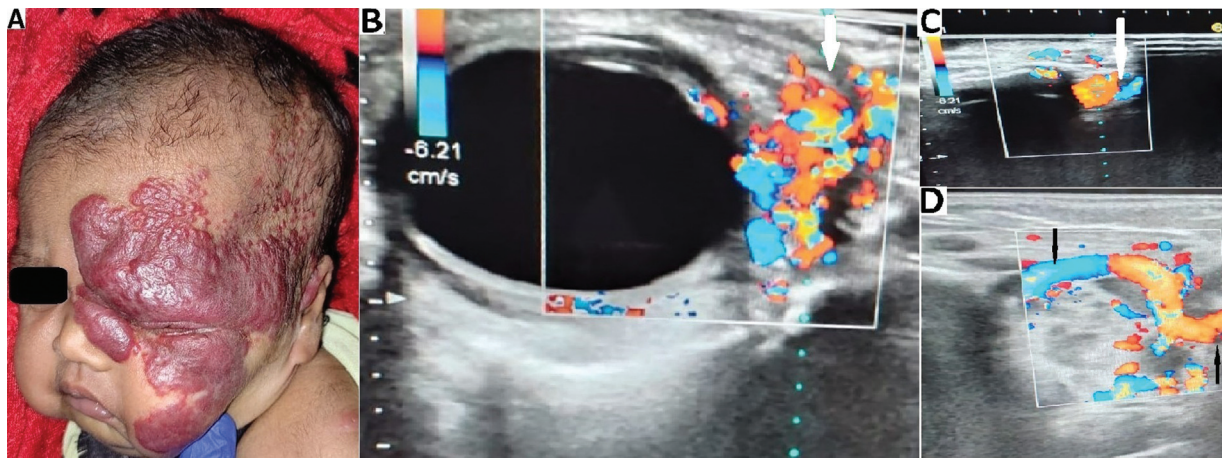
Fig. 4 Clinical photographs of (**A**) a large bulky facial lesion with scalp and ocular involvement in a 3-month-old infant suggestive of a high-risk infantile hemangioma (IH; proliferative phase). (**B,C**) Color Doppler sonography of this patient with a highly vascular high-risk facial IH (proliferative phase) shows intraorbital extension (*white arrows*) of the IH with extensive vascularity. (**D**) Large feeding vessels (*black arrows*) supply the lesion.

Table 2 Presentation and complications of site-specific infantile hemangioma (IH) requiring early intervention

Site-specific IH	Presentation	Complications
Ocular IH	Mass and pressure effect on the eyelid and cornea Interference with the extraocular muscles	Amblyopia Visual impairment
Laryngeal IH	Most frequent visceral manifestation of IH Early presentation with stridor	Subglottic stenosis Airway obstruction
Lumbosacral IH	Associated with spinal dermoid and lipomyeloschisis	Tethered cord syndrome
Head and neck	Most common site Ulceration and infection	Scarring Disfigurement Psychological effects
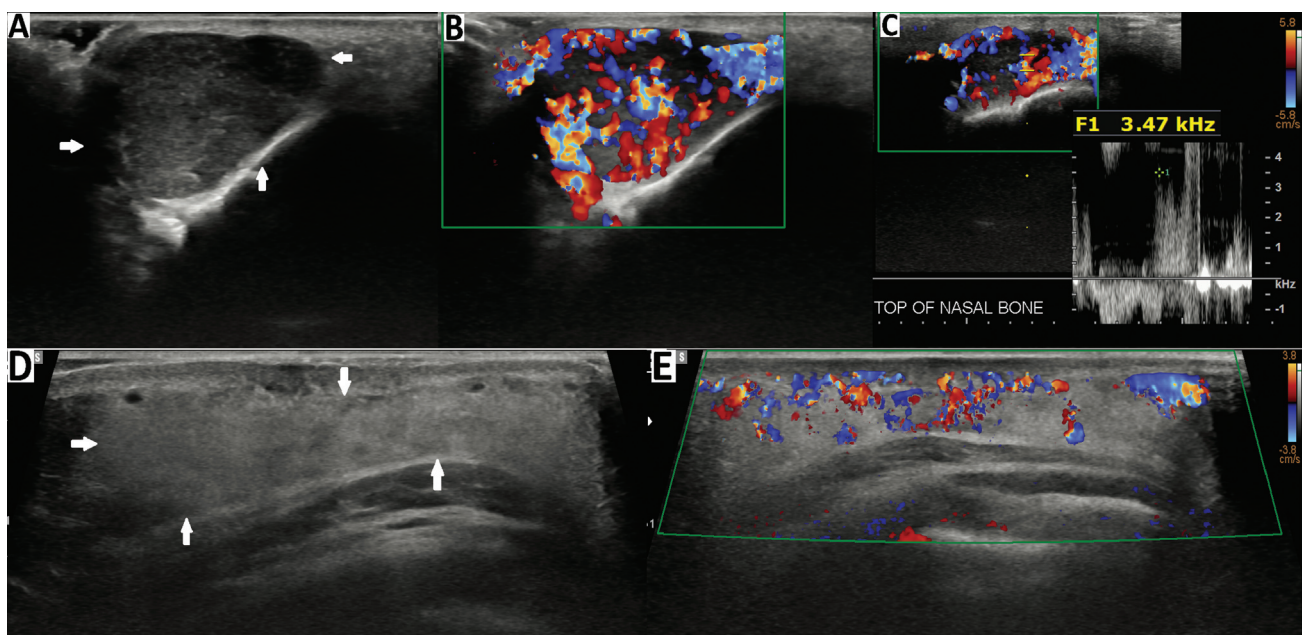
Fig. 5 Infantile hemangioma (IH) in a 10-month-old infant. (**A**) Well-defined hypoechoic nodule (*white arrows*) in the subcutaneous tissues overlying the nasal bone. (**B**) On color Doppler sonography, there is high vascular density within the lesion. (**C**) Spectral Doppler analysis shows high-velocity arteries with Doppler shift exceeding 2 kHz. IH in a 4-month-old infant. (**D**) Well-defined hyperechoic lesion (*white arrows*) in the subcutaneous tissues of the chest wall. (**E**) On color Doppler sonography, there is high vascular density within the lesion. Note the varying patterns of echogenicity of IHs in both patients.

Table 3 Sonography and magnetic resonance imaging (MRI) characteristics of vascular tumors

Vascular tumors	Sonography findings	MRI findings
Infantile hemangioma	*Proliferative phase:* Well-circumscribed mass of variable echogenicity (usually echogenic), often limited to the subcutaneous tissues (►**Fig. 5**). Intralesional vessels often not visible on grayscale imaging Calcifications are rare. High vascular density (characteristic pattern) on color Doppler (►**Figs. 5**, **6**). Spectral Doppler analysis reveals the presence of both arterial and venous flow and the arterial flow shows high velocities with a Doppler shift that exceeds 2 kHz (►**Fig. 5**). *Involution phase:* Increased echogenicity and progressive decrease of vascularity.	*Proliferative phase:* T1 Isointense to muscle, T2 hyperintense. Flow voids. Early, avid homogeneous enhancement with gadolinium.
Hepatic hemangioma	Well-defined nodule of variable echogenicity. Solitary type may be more heterogeneous and may contain calcifications. Prominent peripheral vascularity on color Doppler (►**Fig. 7**). Multiple lesions may be present.	Well-defined masses with low T1 and high T2 signal intensity relative to the hepatic parenchyma. Peripheral nodular enhancement that progresses centripetally to gradually fill in the lesion, different from soft-tissue hemangiomas.
Rapidly involuting congenital hemangioma	Mostly similar to IH. Heterogeneous echogenicity. High vascular density on color Doppler. Visible (large) veins on grayscale imaging (►**Fig. 9**). May have calcifications.	Predominantly T2 hyperintense but may be heterogeneous with intermediate to hypointense foci due to hemorrhage, fibrosis, calcification, and/or necrosis.
Noninvoluting congenital hemangioma	Well-defined hypoechoic subcutaneous nodule (►**Fig. 8**). May show arteriovenous microshunting and venous thrombi	
Pyogenic granuloma	Hypoechoic High vascular density on color Doppler	Rarely imaged
Tufted angioma	Ill-defined margins with heterogeneous echogenicity. Superficial <1 cm in thickness Low vascular density on color Doppler.	Rarely imaged
Kaposiform hemangioendothelioma	Ill-defined margins with heterogeneous Echogenicity. Focal or diffuse, involving one or multiple soft-tissue planes. May have calcifications. May have visible vessels on grayscale imaging. Moderate to high vascular density on color Doppler.	Poorly defined solid cutaneous, subcutaneous, or intramuscular mass with infiltration of surrounding tissues. Surrounding edema that is difficult to separate from tumor margins. Lobular foci of intermediate or low T2 signal intensity but may have high T2 signal intensity diffusely. Diffuse early enhancement is typical. Prominent vessels are frequently seen extending up to the lesion but are rarely identified within the lesion.

anomalies or coarctation of the aorta, and (E) eye defects.[17,19] The association is called PHACES association if there are additional (S) sternal clefting/supraumbilical raphe (ventral) anomalies (►**Fig. 6**). The ventral developmental defects are known as sternal malformation/vascular dysplasia association.[17,19] PHACE association has a greater female preponderance as compared to IH.[20] Most pediatric patients do not have all the findings as per the acronym PHACE. Definitive PHACE is facial hemangioma greater than 5 cm in diameter plus one major or two minor criteria (►**Table 4**).[21,22]

LUMBAR (SACRAL and PELVIS) syndrome: A group of structural anomalies can also be seen in association with lower body IH. The LUMBAR syndrome is seen with IHs extending over the spine and perineum.[23–25] The acronym LUMBAR refers to (L) lower body IHs, (U) urogenital anomalies and ulceration, (M) myelopathy, (B) bony deformities, (A) anorectal malformations, arterial anomalies, and (R) rectal anomalies.[6,10,23] The PELVIS syndrome is an association between segmental IHs of the perineum and congenital anomalies involving the genitalia, urinary tract, spine,
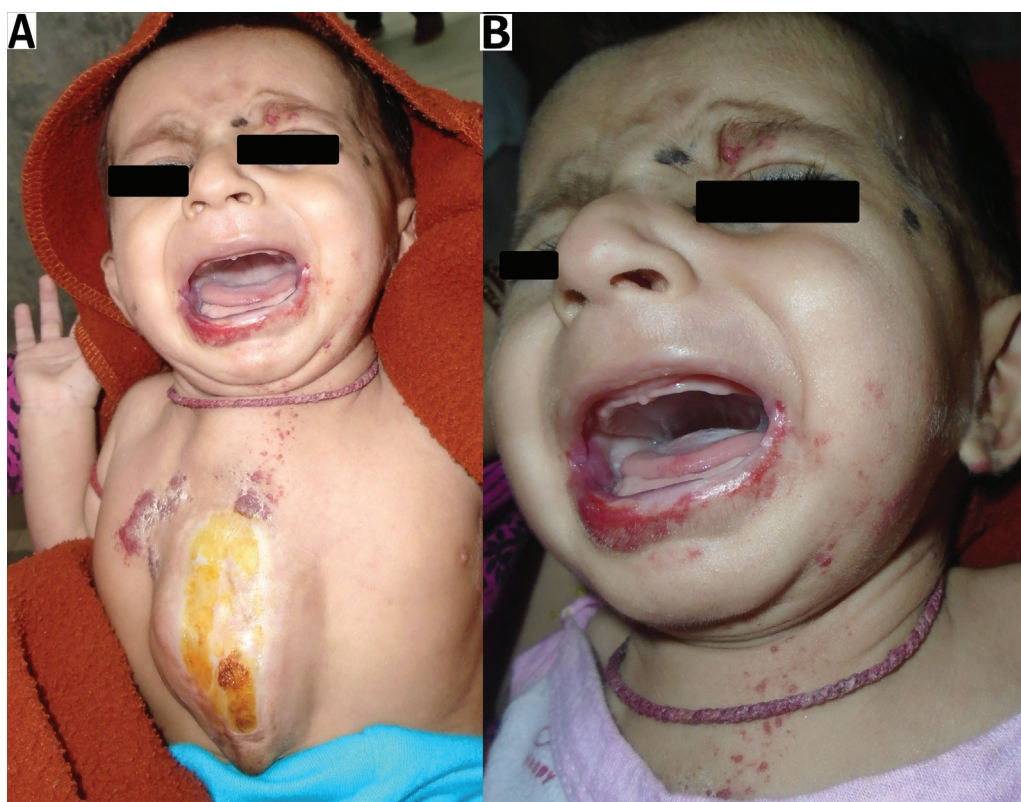
Fig. 6 (A,B) Clinical photographs of a patient with PHACES association with multiple infantile hemangiomas (IHs) on the face, neck, and chest (segmental distribution), cardiac anomalies, coarctation of the aorta, eye defects (cataract), absence of the sternum, and partial ectopia cordis covered with thin skin and soft tissues with visible cardiac impulse.
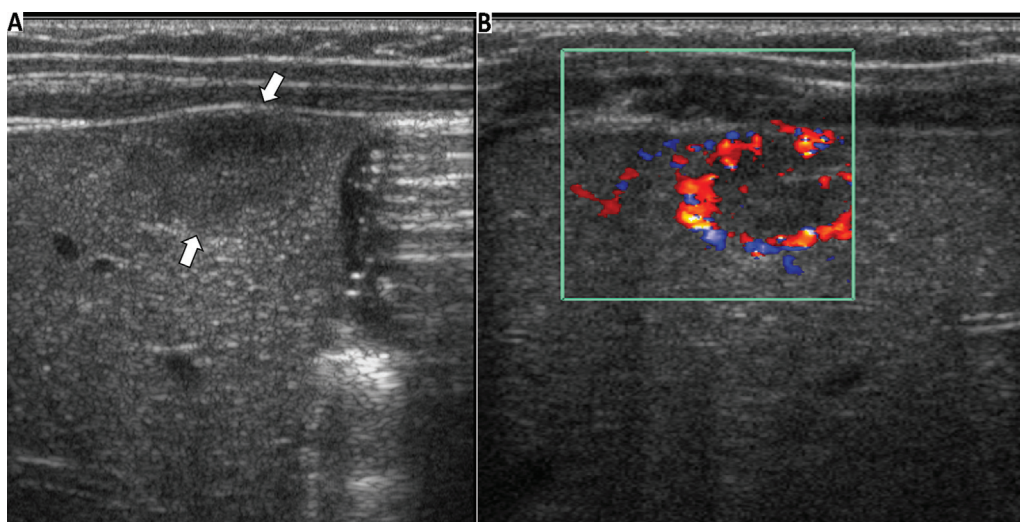

Fig. 7 Hepatic infantile hemangioma in a 3-month-old infant. (A) Longitudinal sonogram of the liver shows a slightly heterogeneous hypoechoic nodule (*white arrows*) extending to the hepatic surface. (B) On color Doppler sonography, the nodule shows prominent peripheral vascularity. There were at least three additional smaller lesions in the remainder of the liver (not shown), compatible with multiple infantile liver hemangiomas.

anus, and rectum. The acronym PELVIS stands for (P) perineal hemangioma, (E) external genitalia malformations, (L) lipomyelomeningocele, (V) vesicorenal abnormalities, (I) imperforate anus, and (S) skin tag.[24] The acronym SACRAL (syndrome) constitutes (S) spinal dysraphism, (A) anogenital anomalies, (C) cutaneous anomalies, (R) renal and urological anomalies, (L) associated with "angioma" of lumbosacral localization.[25]

Hepatic hemangioma is the most common extracutaneous site.[17] Hepatic hemangiomas have been categorized as focal, multifocal, and diffuse as per their involvement (►**Fig. 7**). Focal hemangioma is a solitary lesion, and most
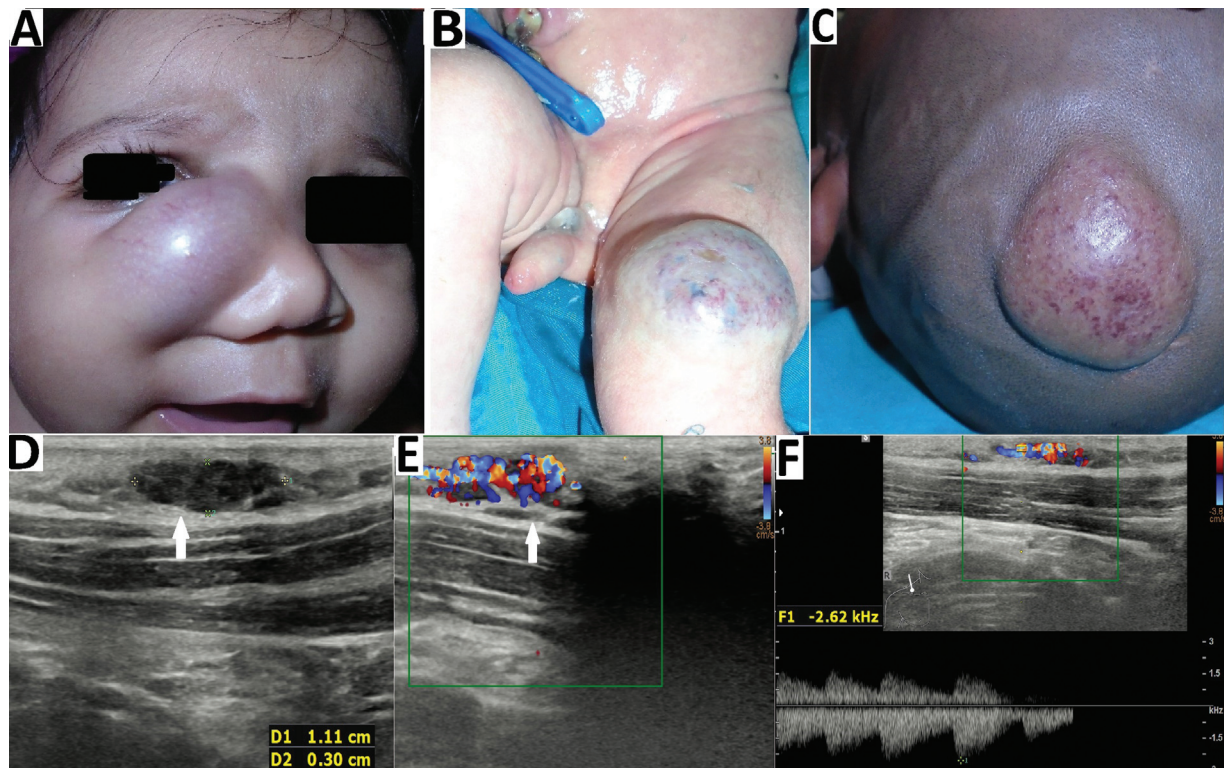
Fig. 8 Clinical photographs show (**A**) a large congenital hemangioma on the face in a 3-month-old infant causing disfigurement and vision impairment. (**B**) Congenital hemangioma (CH) on the left thigh of a 2-day-old neonate. (**C**) Noninvoluting congenital hemangioma (NICH) on the scalp of a 5-year-old boy, growing proportionally with age and without any signs of involution. Right shoulder NICH in a 9-year-old boy. (**D**) Small, well-defined hypoechoic subcutaneous nodule (*white arrow*). (**E**) On color Doppler sonography, there is high vascular density within the lesion (*white arrow*). (**F**) Spectral Doppler analysis shows high-velocity arteries with Doppler shift exceeding 2 kHz, characteristic of hemangiomas.

of them are GLUT-1 negative and show a behavior similar to rapidly involuting CH. Multifocal lesions usually behave as IHs and are seen usually with multiple skin hemangiomas. Liang and Frieden recommend abdominal sonography for screening liver IH with five or more cutaneous IHs.[17] Diffuse hepatic hemangiomas may completely replace the hepatic parenchyma and present earlier due to mass effect. Clinical manifestations include hepatomegaly, anemia, thrombocytopenia respiratory distress, hypothyroidism (due to production of type 3 iodothyronine deiodinase), and jaundice.[26] Complications like gastrointestinal (GI) bleeding, visceral hemorrhage, hemoperitoneum, liver failure, high-output congestive heart failure, and abdominal compartment syndrome have been reported with multifocal or diffuse infantile liver hemangiomas.[17,27] Most hepatic hemangiomas are small and asymptomatic and therefore do not require any treatment. Larger lesions require echocardiography and thyroxine (T4)/thyroid-stimulating hormone (TSH) monitoring to assess lesional response to therapy. MRI is imaging modality of choice (►**Table 3**).[9]

Management

Active nonintervention, that is, active observation and anticipatory guidance, is the most common therapy employed for IHs, as they can involute spontaneously. Most IHs do not necessitate treatment, except when they develop in a position that affects a vital function such as breathing, feeding, or vision, and leads to life-threatening complications and disfigurement.[16,28] Clinical evaluation is sufficient for superficial IHs.[28,29]

The therapeutic modalities for IH, used alone or in combination, are propranolol, corticosteroids (intralesional/systemic), topical 0.5% timolol maleate drops, interferon, vincristine, laser therapy, radiotherapy, and surgical excision.[9,14,27–33] Propranolol therapy (2 mg/kg/d) is effective in stopping the growth and inducing rapid involution of IH by decreasing VEGFs and proangiogenic cytokines (►**Fig. 2**).[27–33] Systemic corticosteroids (2–5 mg/kg/d for 4–12 weeks) act by halting additional IH proliferation, rather than inducing shrinkage of the tumor. Its efficacy ranges from 25 to 90%. Adverse effects have been reported in 35% of patients.[34] Based on the natural history of IH, systemic therapies are ideally initiated before the age of 3 months.[17] Hemangioma Activity Score (HAS) and hemangioma dynamic complication scale (HDCS) have been developed for the assessment of IH and the severity of its complications, respectively.[35,36] Percutaneous embolization therapy is used for hepatic hemangiomas and superficial lesions.

Congenital Hemangiomas

CHs are rare vascular tumors that are fully grown at the time of birth, that is, the proliferative phase in the life cycle of these lesions has finished by birth. They do not manifest the classic triphasic growth pattern.[17] Their clinical presentation
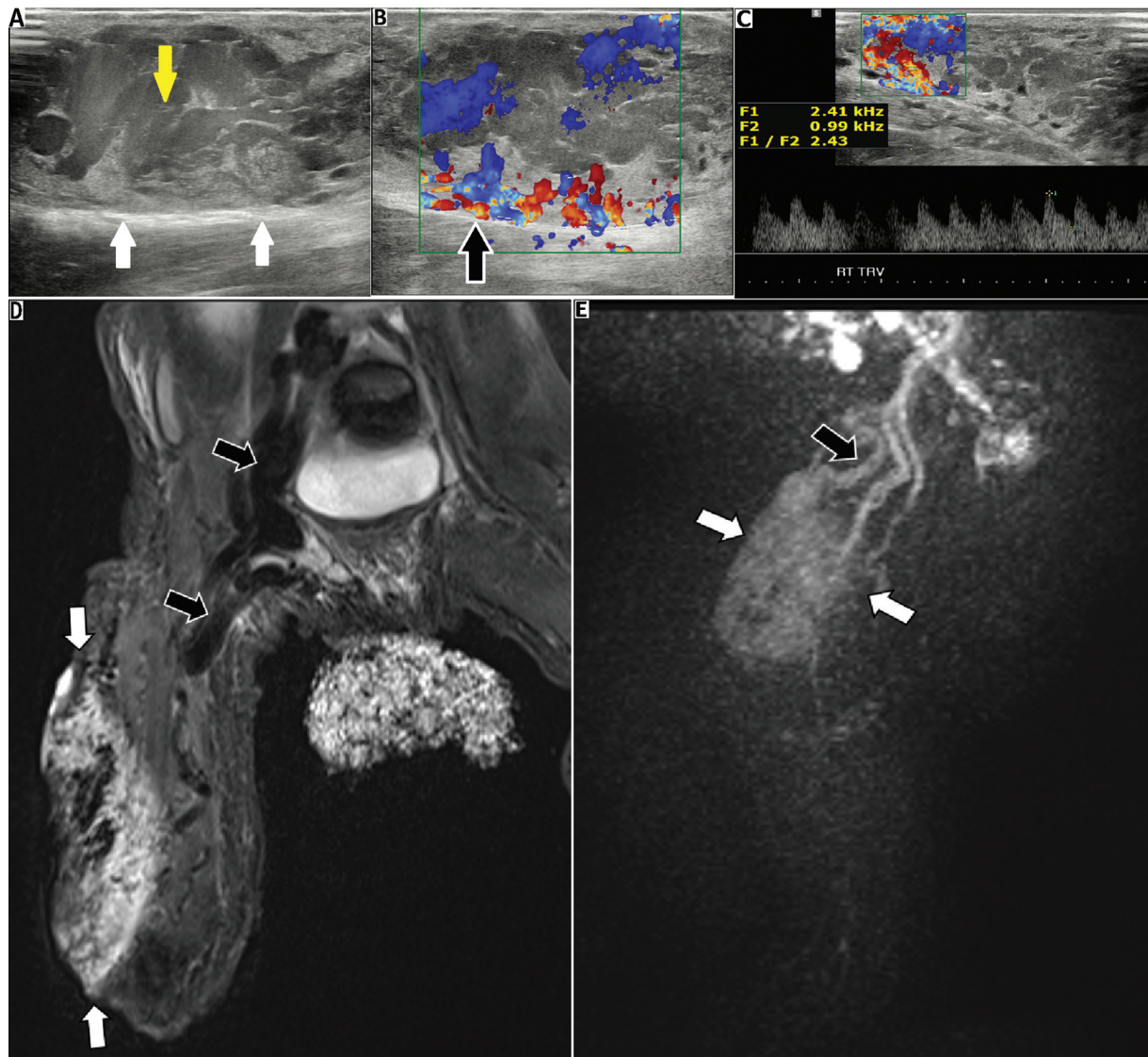
Fig. 9 Congenital hemangioma of the right thigh in a 2-day-old neonate. (**A**) Longitudinal sonogram shows a heterogeneous subcutaneous mass (*white arrows*) containing large veins (*yellow arrow*) centrally. (**B**) On color Doppler sonography, some flow is shown within the large central veins, but there are also prominent vessels (*black arrow*) in the more peripheral tissue posteriorly, which on spectral Doppler analysis (**C**) prove to be arteries with high Doppler shift exceeding 2 kHz, highly suggestive of hemangioma. (**D**) Coronal short tau inversion recovery (STIR) magnetic resonance (MR) image shows a heterogeneous subcutaneous mass (*white arrows*), predominantly hyperintense, with large central veins. There are also enlarged draining veins in the proximal thigh and in the pelvis (*black arrows*). (**E**) Sagittal MR angiogram in the early arterial phase shows prompt and diffuse enhancement of the lesion (*white arrows*) and early venous drainage (*black arrow*) indicating intralesional arteriovenous shunting.

and histology differ from IH.[17] These are located on the head, neck, and extremities as a thickened plaque or as an exophytic mass (►**Fig. 8**). CHs are GLUT-1 negative masses ranging from a few to 10 cm in size. The imaging characteristics of CHs are illustrated in ►**Figs. 8** and **9**. CHs are categorized as rapidly involuting congenital hemangioma (RICH), partially involuting congenital hemangioma (PICH), and noninvoluting congenital hemangioma (NICH).[37]

Rapidly Involuting Congenital Hemangioma
The majority of RICH involute completely by 14 months of age rather than 4 to 6 years as observed in IHs.[17] RICHs can be life-threatening in the first few weeks of life due to their ulceration followed by hemorrhage or because of their propensity to

present at birth as huge tumors with associated arteriovenous shunting, causing overwhelming cardiac failure in the neonate. Serial observation with medical support has been recommended for most infants with RICH. However, very large lesions with shunting precipitating severe cardiac failure require urgent percutaneous embolization. RICHs can be associated with thrombocytopenia owing to platelet consumption in their large vascular bed.[17,38] CHs show sonographic features that resemble those of IHs (►**Fig. 9**).

Noninvoluting Congenital Hemangioma
NICHs are much smaller and less exophytic, and present as flat, slightly indurated plaques (►**Fig. 8**). Management is case directed depending upon the size, location, and presence of

Table 4 Diagnostic criteria for PHACES association

Organ system	Major criteria		Minor criteria
Brain (structural) "P"	Posterior fossa anomaly		EA lesion compatible with IAH
		Dandy–Walker malformation	
		Cerebellum: unilateral/bilateral hypoplasia/dysplasia	
Brain (vascular) "A"	Anomalies of larger brain vessels		Persistence of the embryonic arteries
		Arterial dysplasia, stenosis, or occlusion	Proatlantal intersegmental artery
		Absence or hypoplasia	Primitive hypoglossal artery
		Aberrant origin or course	Primitive ophthalmic artery
		Persistence of the trigeminal artery	
		Saccular aneurysms	
Cardiovascular "C"	Aortic arch anomaly		Defect of the ventricular septum
		Coarctation of the aorta	Right-sided (double) aortic arch
		Aneurysm	
		Aberrant origin of the subclavian artery $\pm$ the vascular ring	
Ophthalmic "E"	Posterior segment anomalies		Anterior segment changes
		Persistence of fetal vascularization	Sclerocornea
		Vascular anomalies of the retina	Cataracts
		Optic disc anomalies, morning glory type	Coloboma
		Optic nerve hypoplasia	Microphthalmia
		Coloboma	
		Peripapillary staphyloma	
Midline "S"	Sternal deformities		Hypopituitarism
		Sternal cleft	Ectopic thyroid
		Supraumbilical raphe	
		Sternal defects	

Abbreviations: EA, extra-axial; IAH, intracranial hemangioma.

complications of CH. As the name suggests, NICH does not undergo involution and grows proportionally with age and requires eventual excision (►**Fig. 8**). Surgical intervention is also contemplated for cosmesis or complications.[17,37]

Pyogenic Granuloma (Lobular Capillary Hemangioma)
It is a quickly growing vascular skin lesion commonly involving the head, neck, and upper extremities in a patient older than 6 months. It is composed of friable lobulated red tissue that bleeds with trivial trauma. It is usually treated with cauterization or excised surgically.[10]

Tufted Angioma and Kaposiform Hemangioendothelioma
Tufted angioma is a relatively rare and benign vascular tumor of infancy with a superficial origin. It presents as violaceous, indurated, or nodular plaques with pain, focal hyperhidrosis, and hypertrichosis. Some lesions may have spontaneous regression and are understood to be the dermal counterpart of Kaposiform hemangioendothelioma (KHE).[8]

KHE is characterized by a locally aggressive/borderline malignant behavior and morphological features similar to

Kaposi's sarcoma. It may precipitate Kasabach–Merritt syndrome (profound and sustained thrombocytopenia with profound hypofibrinogenemia, consumptive coagulopathy, and elevated D-dimer).[8] There is a high frequency of the Kasabach–Merritt phenomenon in KHE (≈50%). The Kasabach–Merritt phenomenon is practically only seen in tufted angioma and KHE but not with other vascular anomalies.

Angiosarcoma
Angiosarcoma is a rare malignant vascular tumor of older adults that most often involves the scalp and skin and is associated with high rates of local recurrence and distant metastases. Pediatric presentations are rare.

Vascular Malformations
Vascular malformations are local, developmental vessel aberrations containing mature, nonproliferating cells with normal cell replication rates and demonstrate an inactive endothelium.[11] Serum markers of cellular proliferation are absent in vascular malformations. They are therefore at the other end of the spectrum when compared with vascular tumors. Vascular malformations are usually present at birth

with an incidence of approximately 1%,[39,40] but may manifest in infancy or even at a later age group. They grow commensurately with the child and do not show spontaneous regression.[3] Vascular malformations may undergo enlargement due to hormonal stimulus, trauma, bleeding, thrombosis, or infection.[9,41,42]

They are divided into four categories: (1) Simple malformations, which are composed of a single vessel type and further categorized based on the type of vessel affected, that is, lymphatic, capillary, venous, and arteriovenous malformations (AVMs). These make up the majority of vascular malformations.[42] (2) Combined malformations are those with two or more types of vascular components forming the lesion. (3) Malformations of a major vessel including anomalies of number, origin, course, length, diameter, valves, communication (arteriovenous fistula [AVF]), and persistence of an embryonic vessel. (4) Vascular malformations associated with other anomalies; they present in multiple syndromes (►Table 1).[7,42]

A vascular malformation can be slow or low flow (i.e., capillary, lymphatic, or venous) or fast or high flow (i.e., arteriovenous). Combinations of these elements are seen in lymphaticovenous malformation (LVM) or capillary lymphatic venous malformation (CLVM). The low-flow subtype presents more frequently in children than the high-flow subtype.[6]

Venous Malformations

Venous malformations (VMs) are the most common (1–2/10,000 patients) of the low-flow vascular malformations.[43] It has a prevalence of 1% in the general population.[7] VMs consist of abnormal, dysplastic ectatic superficial veins that can be localized or diffuse.[43] They are characterized by enlarged endothelial cell (mitotically inactive) lined venous channels with sparsely distributed mural smooth muscles. They lack valves and communicate with the venous system via variable-sized vessels.[43] They grow and expand proportionately with the growth of the child and do not demonstrate spontaneous involution.

Usually, VMs are sporadic in origin, although inherited VMs with germline endothelial cell tyrosine kinase receptor TIE-2 mutations have been described in the literature.[44]

VMs can either be superficial or involve deeper structures. Superficial VMs within the dermis and subcutaneous tissue present with bluish compressible soft-tissue masses and have a propensity to enlarge in a dependent position (►Fig. 10). This latter characteristic differentiates it from a deep IH.[43] The presence of purple venous blebs in the
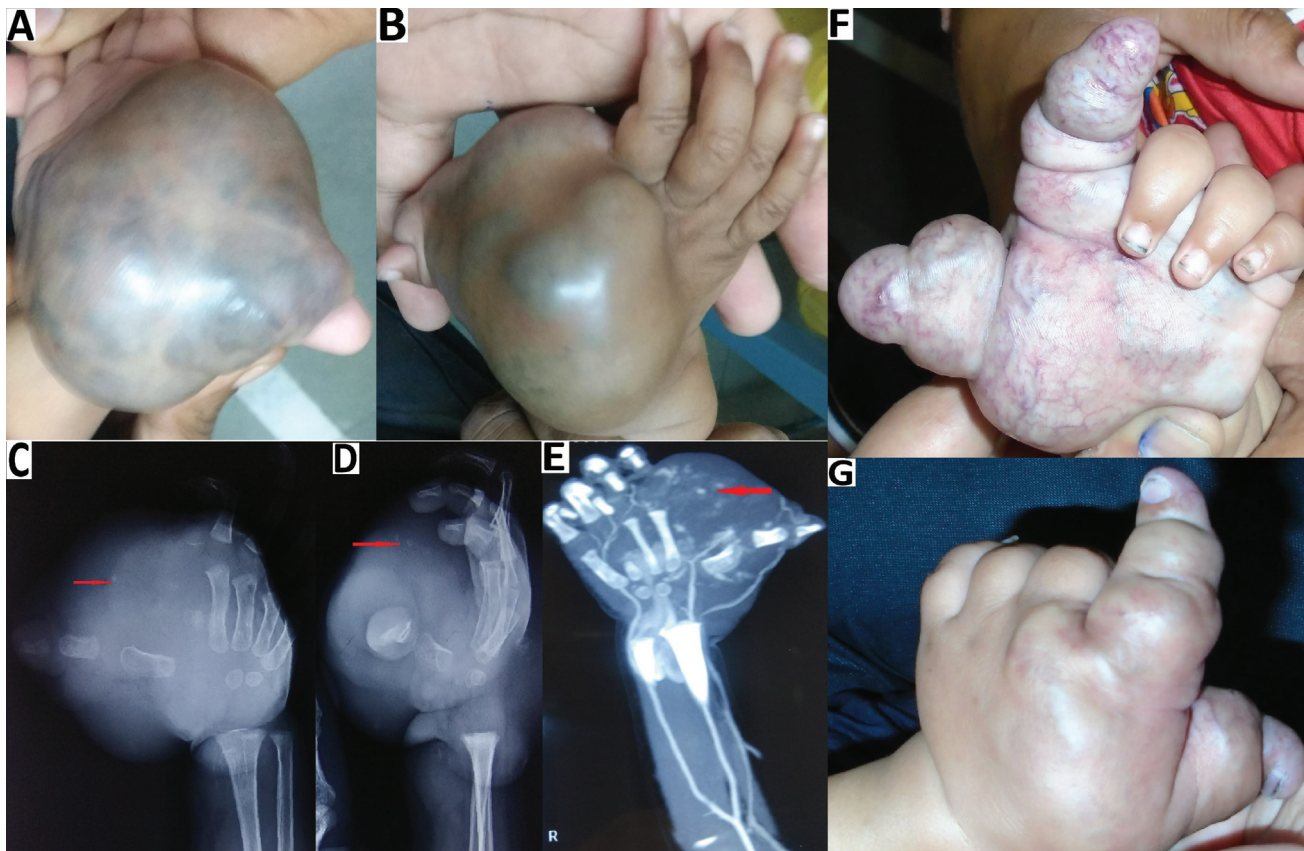

Fig. 10 Clinical photographs of a 1-year-old boy show swelling and dilated bluish venous channels involving both the palmar (**A**) and dorsal (**B**) aspects of the right hand suggestive of a venous malformation (VM). (**C**) Anteroposterior and (**D**) lateral radiographs show soft-tissue mass with few small calcific foci suggestive of phleboliths (*red arrows*). (**E**) Computed tomography (CT) angiogram of the right upper limb during the arterial phase shows soft-tissue density mass with the presence of phleboliths (*red arrows*); arterial branches are normal. (**F,G**) Clinical photographs of a 3-year-old girl show diffuse venous malformation with engorgement and bulky swelling of the radial aspect of the left hand.
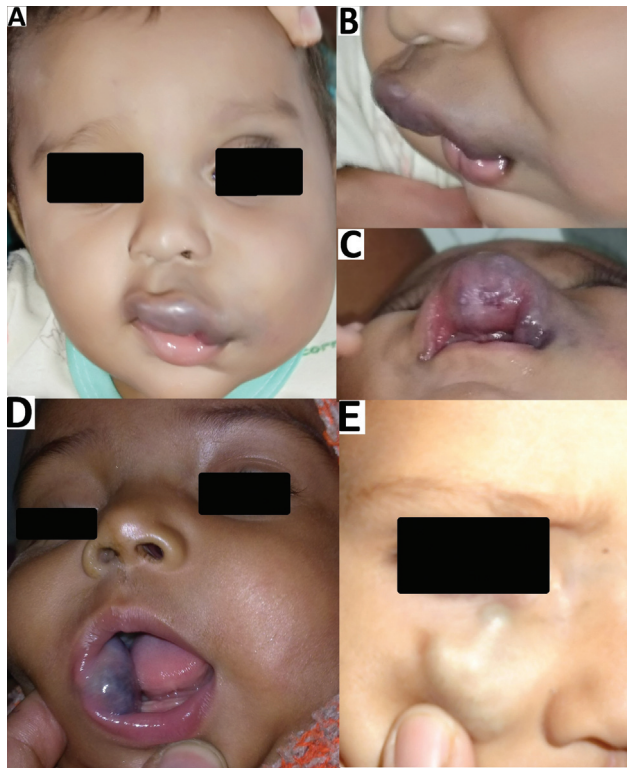
Fig. 11 (A–C) A 2-year-old boy with a venous malformation of the upper lip and left side of the face with an inability to close the lips and facial asymmetry. (D) A 1-year-old child with a venous malformation of the buccal mucosa of the right cheek. (E) Venous malformation of the right infraorbital region in a 4-year-old boy.

superficial component is suggestive of VM (►**Fig. 10**). The typical history is of fluctuating size with activity, and gravity-dependent position. In infants and younger children, they can cause a reduced range of motion in the extremities (►**Fig. 10**).

Head and neck lesions can be disfiguring and even cause mass effect on the airway. Involvement of the oral cavity may be present (►**Fig. 11**). VM of the tongue may present with bluish or purple-colored blebs and pain (►**Fig. 12**). VMs may become more symptomatic during puberty and pregnancy secondary to increased intralesional clotting.[7]

Deep VMs within muscles and joints are usually asymptomatic at birth, but later they are often symptomatic, especially during growth spurts. The most common complaint is pain from mass effect, congestion, thrombosis, bleeding into the surrounding tissues and joints, or neural compression.[45] Swelling (►**Fig. 10**), cosmetic disfigurement (►**Fig. 11**), and functional impairment later in life are other common symptoms.

Large lesions lead to blood stagnation and activate low-grade coagulation cascade and continuous depletion of clotting factors. This precipitates coagulopathy with elevated D-dimer levels and may result in pulmonary embolism.[43]

The initial step in the imaging assessment is sonography (►**Figs. 12**, **13**).[7,46,47] The sonographic appearance is described in ►**Table 6**. Phleboliths are small intralesional calcific thrombi that are seen as small round or oval-shaped opacities on radiographs (►**Fig. 14**). These calcified lesions may be present in up to 30% of radiographs in adult patients with VMs (►**Table 6**).[43]

MRI is the best investigation for VM (►**Fig. 13**).[9] It characterizes the type, extent of VMs, and involvement of adjacent structures. It is performed before interventional treatment for the assessment of its extent and relationship with deeper structures (►**Table 6**).[48] The protocol should include T1, T2 (with fat saturation), or inversion recovery, as well as dynamic contrast-enhanced MRA images (►**Fig. 14**).

The treatment of a patient with VMs is through a multi-disciplinary approach and personalized as per the region and
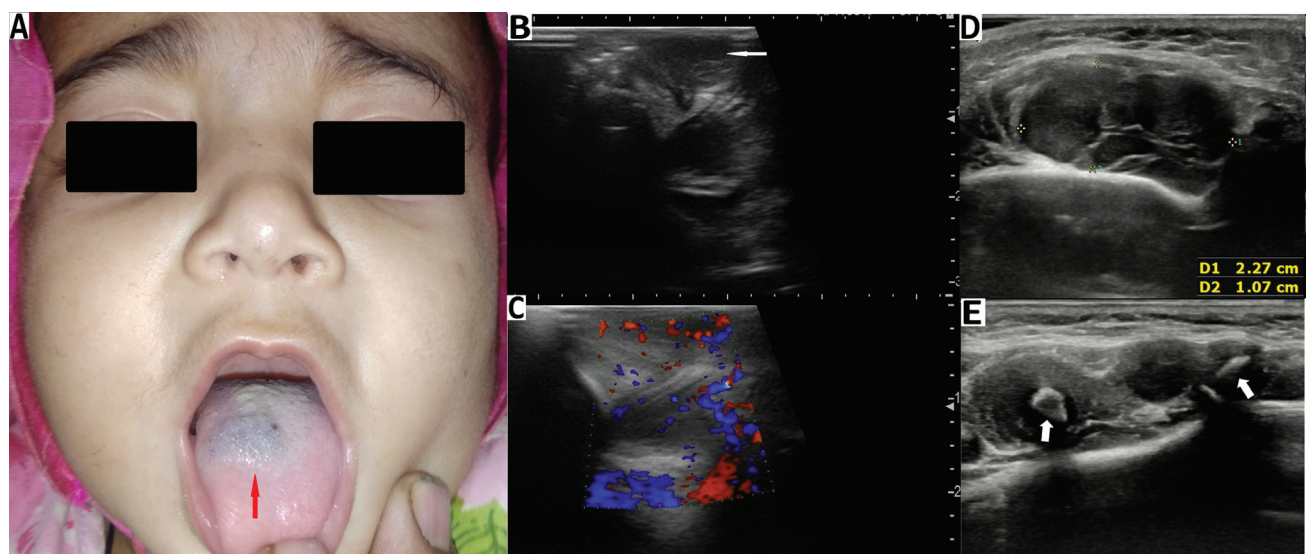

Fig. 12 (A) Clinical photograph of a 10-month-old infant presenting with a bluish-colored bleb on the dorsal surface of the tongue (*red arrow*). (B) Sonography shows a hypoechoic area (*arrow*) inside the tongue tissue. (C) Color Doppler sonography shows a low vascular density lesion suggestive of venous malformation. A 3-year-old boy with a lump in the face: (D) Transverse sonogram shows a hypoechoic lesion with thin internal hyperechoic septa within the masseter muscle. (E) Longitudinal sonogram shows hyperechoic foci (*white arrows*) with posterior shadowing in keeping with calcifications. Findings are in keeping with an intramuscular venous malformation with phleboliths.
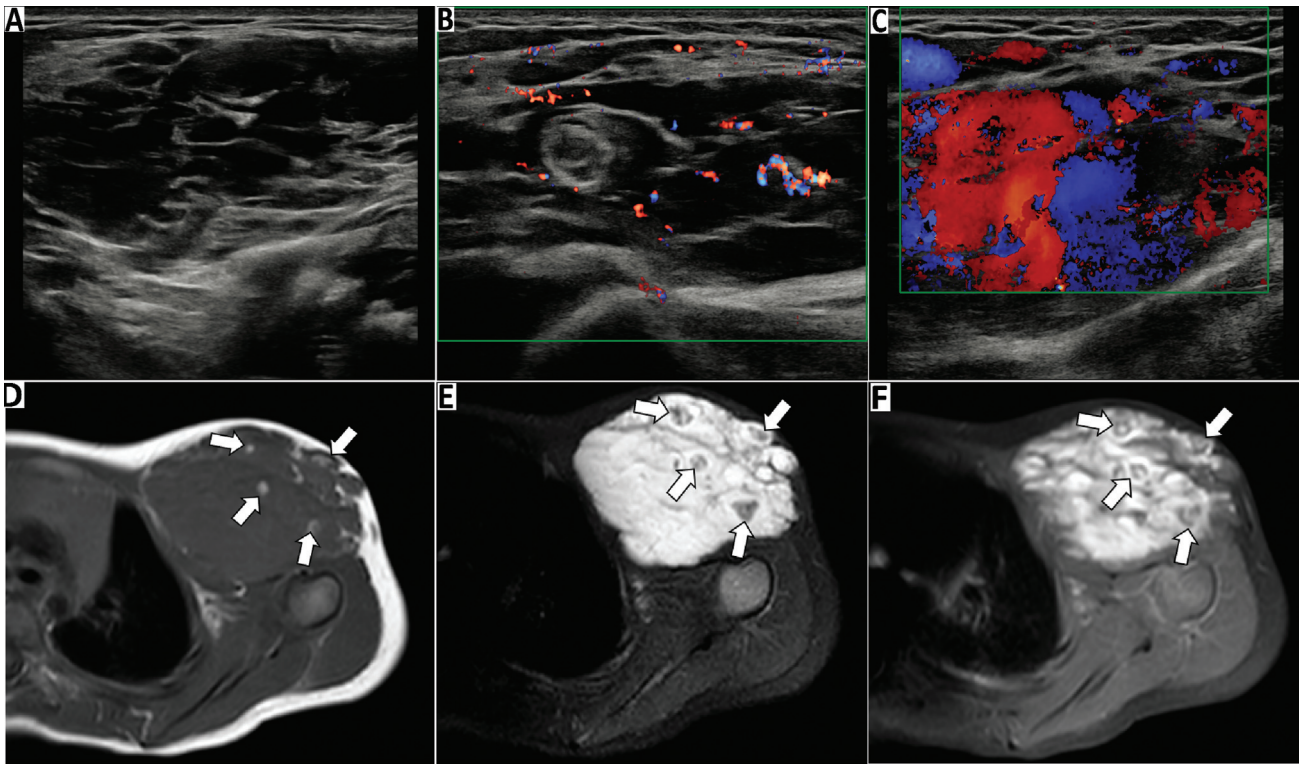
Fig. 13 Venous malformation of the left shoulder region. (**A**) Transverse sonogram shows a well-defined subcutaneous lesion comprised of numerous hypoechoic spaces separated by hyperechoic septa resulting in a multilocular appearance. (**B**) On color Doppler sonography, the lesion shows low vascular density. (**C**) After compression with the transducer and subsequent release, there is increased flow within the venous spaces as they fill back with blood. This appearance should not be confused with a high-flow lesion. Axial T1, fat-suppressed T2, and contrast-enhanced fat-suppressed T1-weighted magnetic resonance (MR) images show a well-defined multiseptated lesion that is (**D**) isointense to muscle on T1, (**E**) hyperintense on T2, and (**F**) with heterogeneous contrast enhancement. There are scattered intralesional foci (*arrows*) that are (**D**) hyperintense on T1, (**E**) hypointense on T2, and (**F**) that do not enhance with gadolinium, in keeping with thrombi.

extent of affliction. The primary goal is to treat the symptoms (pain) and prevent venous stasis and its complications. Warm compresses, compression garments, and anti-inflammatory medicines are prescribed for superficial malformations. Interventional treatment approaches are sclerotherapy (sodium tetradecyl sulfate [STS]/ethanol/bleomycin) under sonographic guidance, laser ablation, cryoablation, and surgical resection.[6] Long-term follow-up is vital throughout childhood into adulthood.

Capillary Malformations

Capillary malformations (CMs) are commonly called "port-wine" stains (►**Table 5**). CMs are usually sporadic, unifocal, red, flat, localized, or spread lesions most often localized on the head and neck, usually with a segmental distribution due to the presence of ectatic capillary channels in the dermis (►**Table 6**).[7,49,50] They are seen in 0.3% of newborns (►**Fig. 15**).[7] It is usually a cosmetic issue, except for Sturge–Weber syndrome. The port-wine stain can be treated with pulsed-dye laser photocoagulation, which results in irreversible damage to the blood vessels.[51]

Lymphatic Malformations

Lymphatic malformations (LMs) are benign vascular lesions that arise from the failure of embryonic lymphatics to connect and drain into the venous system.[52] They were previously termed lymphangioma. LMs are common in lymphatic-rich areas, such as the head and neck (45–52%), axilla, mediastinum, groin, and retroperitoneum.[52] Morphologically LMs are classified into three subtypes, macrocystic, microcystic, and mixed (macrocystic and microcystic). In head and neck LMs, the macrocystic type is commonly located below, while microcystic variety is located above the level of the mylohyoid muscle.[52,53] Seventy-five percent are cervical in location (►**Fig. 15**). The mixed type is common below the head and neck region.[52]

Table 5 Terminology for common vascular anomalies

New terminology (ISSVA)	Old terminology
Hemangioma	Capillary hemangioma
Capillary malformation	Port-wine stain Capillary hemangioma Strawberry hemangioma
Venous malformation	Cavernous hemangioma Ossifying hemangioma
Lymphatic malformation	Lymphangioma Cystic hygroma

Abbreviations: ISSVA, International Society for the Study of Vascular Anomalies.

Table 6 Sonography and MRI characteristics of vascular malformations

Vascular malformations	Sonography findings	MRI findings
Venous	Variable appearance (spongiform, multicystic, usually heterogeneous), more commonly a compressible, well-marginated mass with hypoechoic spaces separated by echogenic septa (►**Figs. 12** and **13**). Intralesional phleboliths (calcifications) only present in approximately 9% of pediatric patients (►**Fig. 12**). May involve multiple soft-tissue planes Low vascular density on color Doppler with flow present within the cystic spaces with enhanced detection by performing Valsalva maneuver or compression (►**Fig. 13**). Venous flow sometimes not detected on color Doppler	Localized or trans-spatial T2 hyperintense vascular spaces separated by thin septa containing hypointense foci (representing thrombi and phleboliths; ►**Fig. 13**). Patchy enhancement with gadolinium that progresses on delayed imaging
Capillary	Often not visible Thin superficial hypoechoic lesions Focal thickening of skin and subcutaneous soft tissues Low to moderate dermal vascular density on color Doppler	Rarely imaged
Macrocystic lymphatic	Multicystic (anechoic cystic spaces) with thin septa (►**Fig. 16**). Variable echogenicity of cystic contents, sometimes with fluid–fluid levels, especially if complicated with intralesional hemorrhage No flow or low vascular density on color Doppler, confined to the septa (►**Fig. 16**). May involve multiple planes.	Multicystic lesions with cysts >1–2 cm that follow fluid signal on all sequences. Fluid levels common. Sometimes, T1 hyperintense intracystic content due to hemorrhage or proteinaceous material. Contrast enhancement confined to the septa without enhancement of cystic spaces.
Microcystic lymphatic	Ill-defined and hyperechoic due to the multiple interfaces caused by tiny cysts Contain scattered cysts <1–2 cm Sometimes no visible cysts. No flow or low vascular density on color Doppler. Mixed LMs show features of both types of lesions (►**Fig. 17**).	Irregular, reticulate appearance with variable identification of tiny cysts May show faint contrast enhancement (►**Fig. 18**).
Arteriovenous	Conglomerate of tortuous vessels typically without a discrete soft-tissue mass that can involve multiple soft-tissue planes. High vascular density (typical high flow of the lesions) on color Doppler (►**Fig. 19**). High-velocity, turbulent low-resistance flow on the arterial side on spectral Doppler Arterialization of the venous side (pulsatile venous flow) on spectral Doppler.	Signal voids on the spin echo or less reliably bright signal on gradient-echo imaging. Usually no distinct mass MRA shows early arterial enhancement with early venous drainage (►**Fig. 19**).

Abbreviations: LM, lymphatic malformation; MRA, magnetic resonance angiography; MRI, magnetic resonance imaging.

The criteria for a cyst to be labeled as microcystic type is either the contained cysts are less than 1 or 2 cm or the lesion cannot be effectively reduced in size with aspiration or sclerosis in contrast to the macrocystic lesions.[52] Macrocystic LMs contain multiple cystic spaces that are separated from one another by thin septa (►**Fig. 16**). Compression does not collapse the cyst, as opposed to the VMs.

LMs are commonly noted at birth (►**Fig. 16**), persist throughout life, grow proportionately with age, and do not involute, as does IH.[52] LMs have a propensity to swell during concurrent viral illnesses or repeated intralesional hemorrhage due to bruising.[6] Pain, mass effect, and oozing from the lesions affect the quality of life. Indications for treatment include cosmetic deformity, mass effects, recurrent infections, lymphatic leak, or functional issues.

Involvement in LMs of the tongue is either purely mucosal, resulting in increased sensitivity of the tongue surface, which is prone to bleeding and infections, or it may involve the deeper tissues of the tongue, resulting in macroglossia.[6] The presence of lymphatic vesicles on the skin and mucosal surfaces of the oral cavity is helpful for the diagnosis of microcystic LMs (►**Fig. 15**). Ecchymosis is observed in macrocystic LMs with intralesional hemorrhage (►**Fig. 16**). On sonography (►**Table 6**), subcutaneous LMs may involve
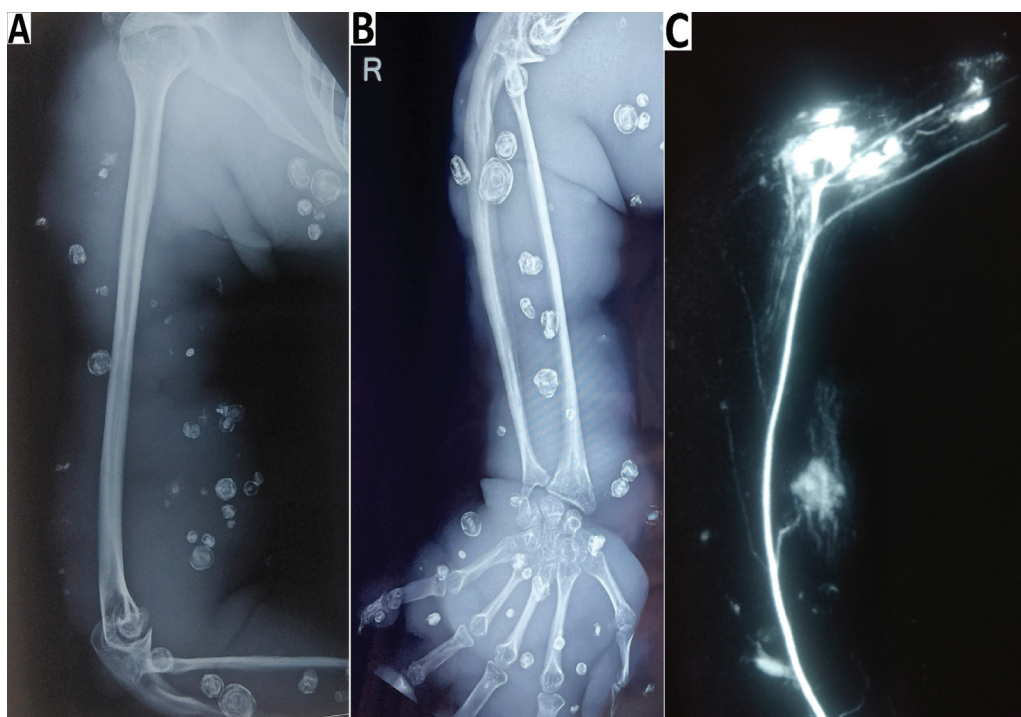
Fig. 14 (**A,B**) Radiographs of the right upper limb in a 13-year-old adolescent girl with combined vascular malformation (venolymphatic) show several round and oval phleboliths due to localized intravascular coagulopathy secondary to the flow alteration confirming a venous component to the mass. (**C**) Magnetic resonance angiography (MRA) of the patient with a venous component of the combined vascular malformation shows a puddling of the contrast in the dilated venous channels consistent with findings in venous malformation.

Fig. 15 Capillary malformation (port-wine stain) of the (**A**) left side of the face in a neonate and (**B**) right side of the face in an infant. Lesions are dark, well-demarcated, located laterally on the face or body, and respect the midline. (**C**) Clinical photographs show microcystic lymphatic malformation involving the right side of the face and neck since birth, along with the presence of tiny lymphatic vesicles on the skin (*red arrow*) and (**D**) microcystic lymphatic malformation of the abdominal wall with the presence of lymphatic vesicles (*red arrows*).

multiple planes (►**Fig. 16**).[7] MRI is the imaging modality of choice for LMs (►**Figs. 17**, **18**).

Macrocystic disease is relatively easily treated with percutaneous image-guided sclerotherapy.[6] It is less invasive and has an acceptable complication rate, with a short recovery time. Among the sclerosants for macrocystic subtype, doxycycline (100–200 mg in infants) is usually the first-line agent, because of its ease of availability and high safety profile.[54] Other agents are bleomycin, STS, Picibanil (OK-432), Ethibloc, and ethanol.

Intralesional bleomycin under sonographic guidance is generally believed to be the best agent to achieve a bulk reduction in microcystic type. Its instillation into the stroma or solid component of the lesion leads to effective results.[55] Rapamycin (mammalian target of rapamycin [mTOR]) inhibitors such as sirolimus have been reported to be effective for microcystic LMs.[56] Surgical resection is usually reserved as second-line therapy.

Arteriovenous Malformations

AVMs are high-flow lesions and comprise up to 4.7% of all vascular anomalies. They are disorganized tangles of vessels with direct communications between an artery (or arteries) and a vein (or veins) bypassing the capillary bed (►**Fig. 19**). There may be a partial or complete absence of normal intervening capillaries.[9,57] AVMs have an identifiable nidus with feeders. These lesions can occur in any area of the body, but they have an affinity for the head and neck region (≈50%) followed by the extremities. They have a gradual onset and
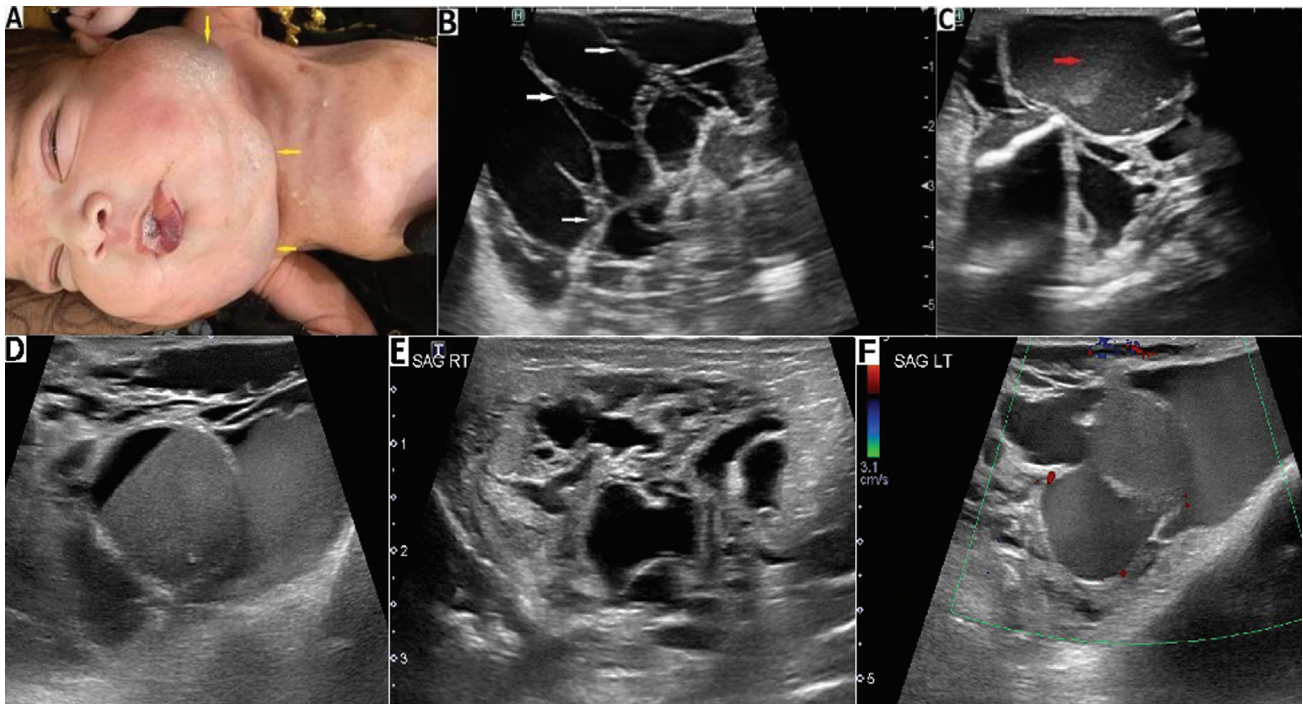
Fig. 16 (**A**) Clinical photograph of a neonate with a large cystic swelling in the neck (*yellow arrows*). (**B,C**) Sonogram shows a large cystic lesion with septations (*white arrows*). Few of the cystic spaces show echoes (*red arrow*). Findings are suggestive of a lymphatic malformation. Large mixed lymphatic malformation of the neck in a newborn baby boy. (**D**) Sonogram of the left side of the neck shows the macrocystic component with cystic spaces mostly filled with echogenic material creating a fluid-debris level, likely reflecting intralesional hemorrhage. (**E**) In the right side of the neck, there are smaller and more irregular cystic spaces with adjacent and intervening hyperechoic tissue representing the microcystic component. (**F**) Color Doppler sonography shows minimal flow confined to the walls of the cysts.
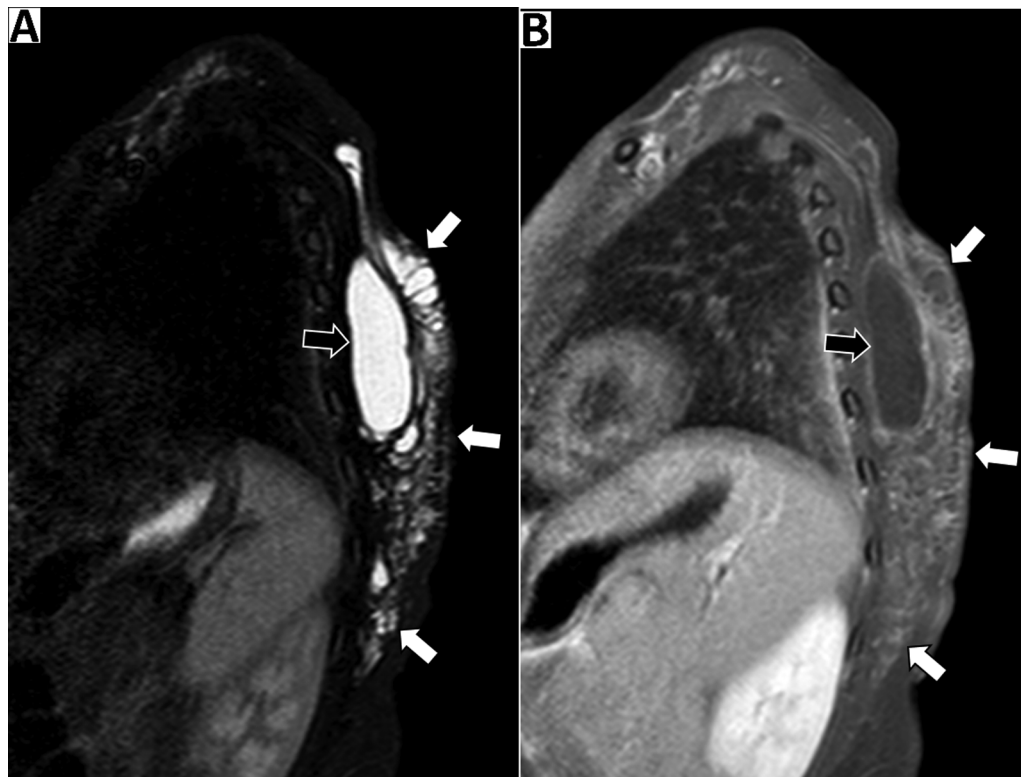
Fig. 17 Mixed lymphatic malformation of the posterior chest wall in a 4-year-old girl. (**A**) Sagittal short tau inversion recovery (STIR) magnetic resonance (MR) image shows a large hyperintense cyst (*black arrow*) representing the macrocystic component and a larger heterogeneous area comprising smaller cysts and reticulate high signal that involves the subcutaneous fat plane and skin (*white arrows*) representing the microcystic component. (**B**) Sagittal contrast-enhanced fat-suppressed T1-weighted MR image shows enhancement of the walls of the macrocyst (*black arrow*) and of the walls of the microcysts and patchy areas within the microcystic component (*white arrows*).
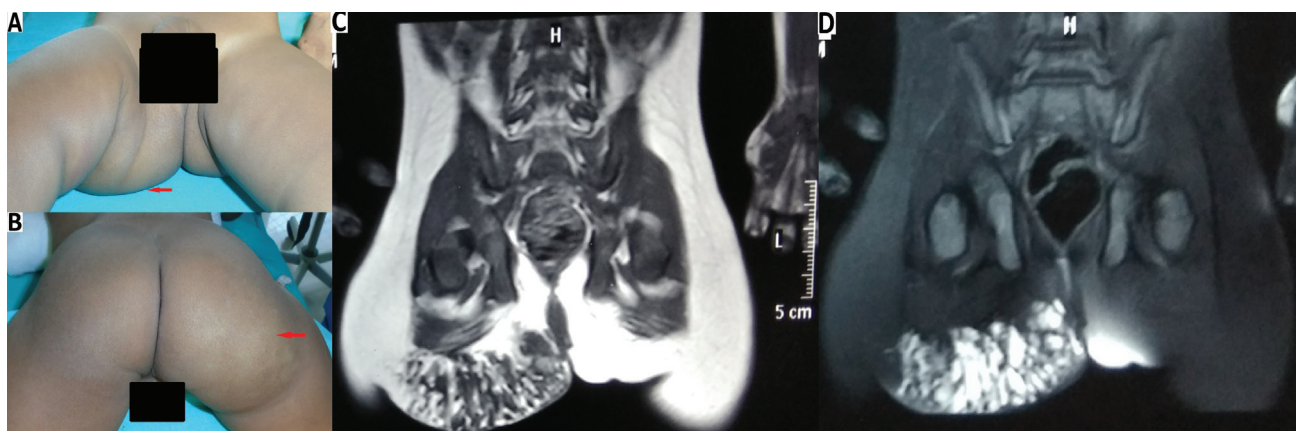
Fig. 18 (A,B) A 2-year-old male child patient presented with a soft lump over the right gluteal region extending to the right thigh (*red arrows*). (C) Coronal T1-weighted magnetic resonance (MR) image shows ill-defined lobulated heterogeneous signal intensity soft-tissue mass in the right gluteal region with serpiginous hypointense signal intensity. (D) coronal short tau inversion recovery (STIR) MR image shows hyperintense signal intensity in keeping with microcystic lymphatic malformation.

grow proportionately with age. They are potentially the more aggressive type of vascular malformations.[7,42]

AVMs have bimodal distribution with one-half presenting at birth and the rest after the first decade of life.[7,9] Clinical presentation depends on the localization, size, and degree of AV shunting through the lesion. One of the typical presenta-tions is growth and pain in a long-standing lesion, most commonly present at the time of puberty or pregnancy (secondary to hormonal influences).

Superficial lesions on the head and neck and also extremi-ties can present with cosmetic deformity, pain, swelling, weakness, nerve palsy, skin pigmentation, dilated superficial,
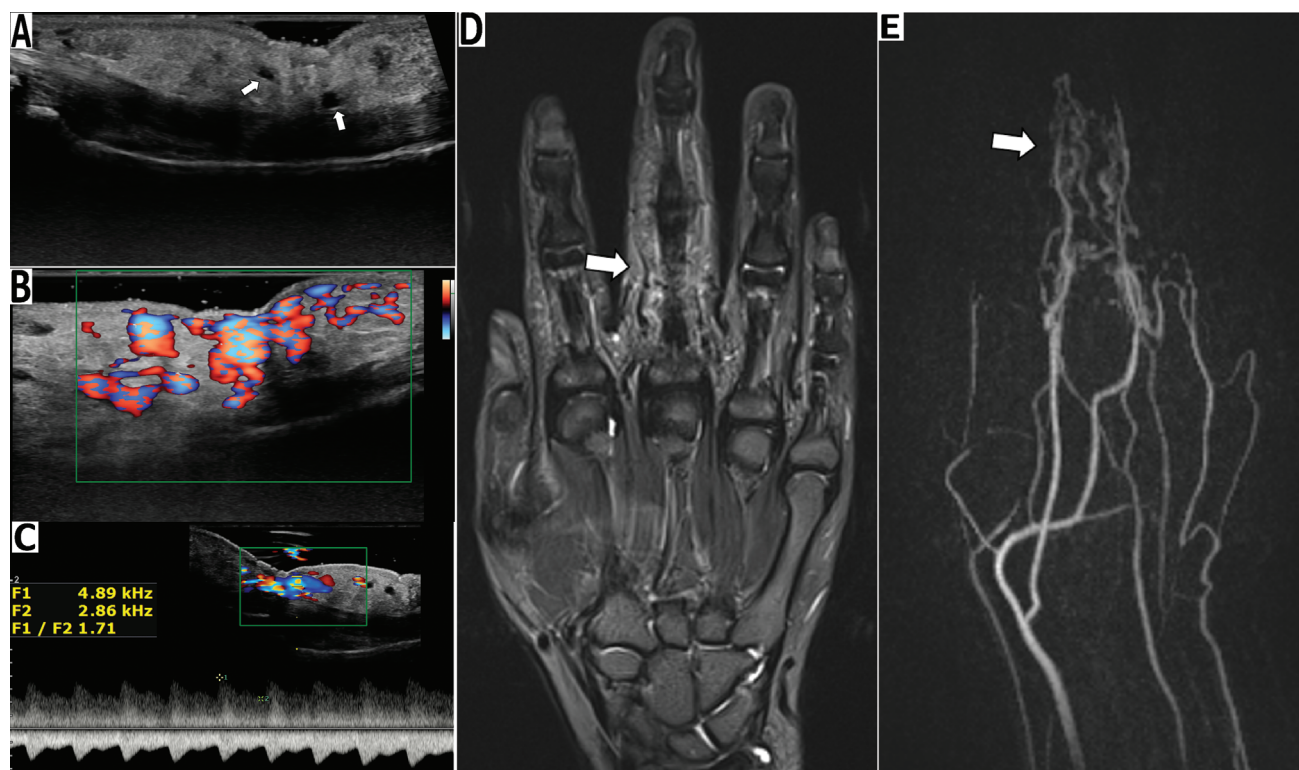

Fig. 19 Arteriovenous malformation in a 14-year-old adolescent girl with swelling and pain in the right third finger. (A) Longitudinal sonogram shows thickening and increased echogenicity of the subcutaneous soft tissues in the palmar aspect of the third digit. A few prominent vessels (*arrows*) are seen coursing through the lesion. (B) On color Doppler sonography, there are numerous prominent vessels, more than suspected on (A). (C) On spectral Doppler analysis, there is high Doppler shift exceeding 2 kHz and also low resistance with high diastolic flow denoting arteriovenous shunting. (D) Coronal short tau inversion recovery (STIR) magnetic resonance (MR) image shows soft-tissue thickening around the proximal and middle phalanges of the third digit (*arrow*) with the presence of punctate and linear signal void foci in keeping with high-flow vessels. There is no discrete mass. (E) Coronal MR angiogram shows a tangle of vessels in the third digit (*arrow*) associated with early venous opacification, in keeping with arteriovenous malformation.

bony overgrowth, vascular bruits, and ulceration. Deeper lesions may present with local mass effect, organ-specific dysfunction, and ischemic symptoms (steal phenomenon) from arteriovenous shunting, bleeding, and ulceration, especially in the head.

In the oral cavity, these can present at any site, but most commonly occur on the anterior two-thirds of the tongue, palate, and gingival and buccal mucosa. They present with multiple swellings on the face and inside the mouth.[58]

The clinical severity of AVMs is graded using the Schobinger classification: stage I represents a clinical inactive AVM presenting with local skin hyperthermia; stage II is a lesion with an increase of arteriovenous shunting, expanded and with the presence of pulsation and bruit; stage III shows signs of tissue destruction with adjacent ulcers, hemorrhage, bone lytic lesions, and pain; and stage IV reflects decompensated AVM with development of cardiac failure (<2%) in a patient with stage III lesion.[7,42] This classification may be extrapolated to describe the outcomes of management.

Sonography of AVM grossly estimates the size of the lesion and determines its complexity (►**Fig. 19**), involvement of soft-tissue planes, and its association with adjacent structures (e.g., bone).[7] CT angiography with reconstructions has been used in differentiating AVMs from hemangiomas.[9] MRI is also the best imaging modality for evaluating the involvement of adjacent soft tissues and visceral organs (►**Fig. 19**) as shown in ►**Table 6**.[9] Percutaneous embolization is the reference standard treatment for AVMs. Surgical resection of AVMs is feasible in early-stage or localized lesions.[59]

Arteriovenous Fistula

Fistulas are direct communications that most commonly occur secondary to trauma, particularly iatrogenic such as biopsy or vascular cannulation. They are usually acquired, but may rarely be congenital, with two typical such lesions being the vein of Galen malformation and a hepatic arterio-portal fistula. The typical imaging manifestations consist of enlargement of a feeding artery(s) and associated draining veins without an intervening nidus.

Combined Malformations

Combined malformations are composed of two or more types of vascular malformations (CM, LM, VM, AVM) found within one lesion. A venolymphatic malformation (also called LVM, LM + VM) is a combined malformation. In addition, cutaneous CMs may be present overlying one or more deeper simple vascular malformations (►**Table 1**) as seen in ►**Fig. 20**. Combined lesions are frequently extensive throughout a limb and portions of the trunk and head/neck. These patients present with long-term pain and functional problems.

Vascular Malformations of Major Named Vessels

Vascular malformations of major named vessels include anomalies affecting the origin, course, number, length, or diameter of larger lymphatic, venous, arterial vessels, or persistent embryonal vessels. Examples are the following: (1) PHACE-associated carotid anomalies, which are carotid artery anomalies associated with PHACE syndrome; (2)

Fig. 20 A neonate with combined capillary, venous, and lymphatic malformation of the face and neck with respiratory distress due to airway involvement.

persistent stapedial artery, which is present in the temporal bone; (iii) Abernethy malformation (with partial or complete congenital absence of the portal vein); (iv) sciatic vein persistence; and (v) vein of Galen malformation.

Vascular Malformations Associated with Other Anomalies

Vascular malformations can occur as part of a much wider abnormal growth pattern. Almost all of these clusters of malformations are related to underlying somatic mutations in growth genes.[60]

PIK3CA-Related Overgrowth Syndromes

The most common gene identified among mixed vascular lesions is phosphatidylinositol-4,5-bisphosphate 3-kinase, catalytic subunit alpha (*PIK3CA*), giving rise to anomalous PIK3-AKT-mTOR pathway activations, with cell signaling dysregulation and angiogenesis.[61] Mosaic somatic mutations in the PIK3CA gene cause many complex overgrowth syndromes.[61] An umbrella term "PIK3CA-related overgrowth syndrome" (PROS) is useful in the management approach of these mixed lesions. Klippel-Trénaunay syndrome, CLOVES syndrome, and fibroadipose vascular anomaly (FAVA) are relatively common overgrowth syndromes. These overgrowth syndromes require a multidisciplinary approach.

Klippel–Trénaunay syndrome presents with CM, VM/varicosities, and LMs causing limb overgrowth involving the bone and soft tissues. High-flow lesions are absent. It usually affects one lower extremity, although bilateral lower limbs, an upper limb, or an extension into the trunk may be present (►Fig. 21).[43,62] The marginal vein of Servelle, a dilated vein in the lateral aspect of the thigh and lower leg, is the characteristic feature present in about 55%

of these patients (►Fig. 21).[43] Sonography with color Doppler is helpful in the initial evaluation of both lymphatic and venous component malformation. However, MRI is better at demonstrating the overall involvement by the vascular malformations as well as the associated bone or soft-tissue overgrowth (►Fig. 21).

Congenital lipomatous overgrowth with vascular malformations, epidermal nevi, and skeletal anomalies (CLOVES) syndrome typically presents with a congenital truncal lipomatous mass that sometimes contains an LM. Cutaneous and musculoskeletal anomalies such as epidermal nevus, hand and feet overgrowth, macrodactyly, and sandal gap toe deformity are present. VMs (phlebectasia) and rarely AVMs may be appreciated.[63]

FAVA is a complex mesenchymal malformation included in the category of provisionally unclassified vascular anomalies in the ISSVA classification. It is characterized by focal or diffuse intramuscular (calf or forearm) fibrofatty replacement associated with low-flow vascular malformations—predominantly phlebectasia and less commonly LMs with adjacent subcutaneous tissues involvement.[40] MRI is the investigation of choice, which, in addition to showing the vascular anomalies, will reveal fatty signal within the lesion (►Fig. 22). The patients characteristically present with pain on the site of the malformation. Sirolimus is now being used as first-line treatment for the management of FAVA.[64]

Parkes–Weber Syndrome: *RASA1* Gene Mutation

CM-AVMs are inherited, small, multifocal lesions commonly surrounded by a pale halo. Parkes–Weber syndrome is an explicit type of CM-AVM with limb overgrowth, usually affecting one of the lower extremities. A large cutaneous capillary

Fig. 21 Klippel–Trénaunay syndrome (KTS) in a 9-year-old boy shows (**A**) a dilated vein in the lateral aspect of the thigh (marginal vein of Servelle, *red arrows*). (**B–D**) Another patient with KTS showing capillary malformation (*blue arrows*), varicosities, and lymphatic malformation (*black arrows*) with limb overgrowth. (**E**) Coronal short tau inversion recovery (STIR) magnetic resonance (MR) image (an 8-year-old boy) shows mild soft-tissue hypertrophy of the left lower extremity with numerous dysplastic veins involving the muscle, subcutaneous, and dermal planes. At the lateral aspect of the thigh, there is a large dilated subcutaneous vein, corresponding to the marginal vein of Servelle (*arrow*).
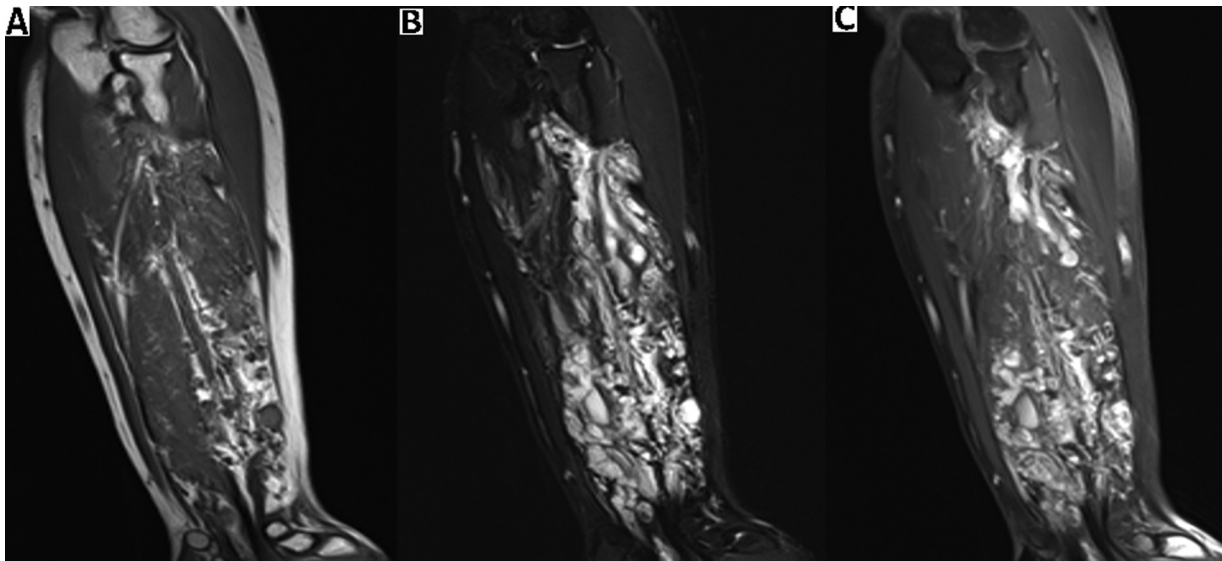
Fig. 22 Fibroadipose vascular anomaly in the forearm of a 14-year-old adolescent boy. (**A**) Coronal T1-weighted magnetic resonance (MR) image shows heterogeneous appearance of the muscles in the volar compartment of the forearm with reticulate areas of high signal intensity in keeping with fatty tissue. (**B**) Coronal short tau inversion recovery (STIR) MR image shows that most of the intramuscular lesion is comprised of tubular and irregular areas of high signal intensity, suggestive of ectatic veins. (**C**) Coronal contrast-enhanced fat-suppressed T1-weighted MR image shows partial enhancement of the dilated veins denoting slow flow.

blush is associated with underlying multiple micro-AVFs leading to overgrowth of the affected body part. The underlying cause is the *RASA1* gene mutation. On clinical examination, the affected limb is very warm, and there is absence of typical pulsatility of the involved extremity. There is exercise intolerance and arterial claudication from AV shunting and relative hypoxemia and finally manifesting as nonhealing ulcers of the involved limb.[65]

Provisionally Unclassified Vascular Anomalies

A distinct category named "provisionally unclassified vascular anomalies" has been created for lesions in which the histology and behavior generally have overlapping features of both neoplasm and congenital malformation. Lesions in this category include poorly understood focal or multifocal masses with or without other tissue/organ anomalies. They are intramuscular hemangioma, angiokeratoma, sinusoidal hemangioma, acral arteriovenous "tumor," multifocal lymphangioendotheliomatosis with thrombocytopenia/cutaneovisceral angiomatosis with thrombocytopenia (MLT/CAT), *PTEN* (phosphatase and tensin homolog protein type) hamartoma of soft tissue/"angiomatosis" of soft tissue (PHOST) *PTEN*, and FAVA.

PTEN Hamartoma of Soft Tissue

Mutations in the *PTEN* tumor suppressor gene are now known to be a common underlying factor in both Bannayan–Riley–Ruvalcaba syndrome and Cowden's syndrome. Both are now better referred to as *PTEN* hamartoma tumor syndromes. They are listed in the category of provisionally unclassified vascular anomalies in the ISSVA classification. These are high-flow vascular anomalies with an overgrowth of an admixture of adipose tissue, fibrous tissue, and abnormal blood vessels of various types.[66]

AKT1 Somatic Gene Mutation-Related Proteus Syndrome

Proteus syndrome is a rare entity characterized by progressive, segmental, and disproportionate overgrowth that affects the dermis, fat, bones, and central nervous system. These patients have low-flow vascular malformations (CM, VM, LM) without high-flow vascular malformations. A cerebriform nevus is the most characteristic skin lesion in these children.[7]

Blue Rubber Bleb Nevus Syndrome *TEK* or *TIE2* Mutation

Blue rubber bleb nevus syndrome (BRBNS) is a genetic disorder linked to *TEK* or *TIE2* mutations. It is characterized by multifocal discrete VMs that occur on the skin and GI tract (visceral involvement). Complications are GI bleeding and transfusion dependence. Sirolimus has a role in the management of symptomatic GI lesions.[6]

Sturge–Weber Syndrome

It is also called encephalotrigeminal angiomatosis, with ocular and intracranial vascular abnormalities. It is a neurocutaneous syndrome with leptomeningeal CMs, CMs of the skin, choroid, and face, typically in the ophthalmic (V1) and maxillary (V2) distributions of the trigeminal nerve. The hallmark of Sturge–Weber syndrome is facial cutaneous CM, also referred to as a nevus flammeus or port-wine stain. Sturge–Weber syndrome presents with neurologic manifestations including atonic, tonic, or myoclonic seizures.[51]

Visceral Vascular Malformations

Vascular malformations can afflict any region of the body. The presentation and management depend on the organ involved, its type, and its extent.[67]
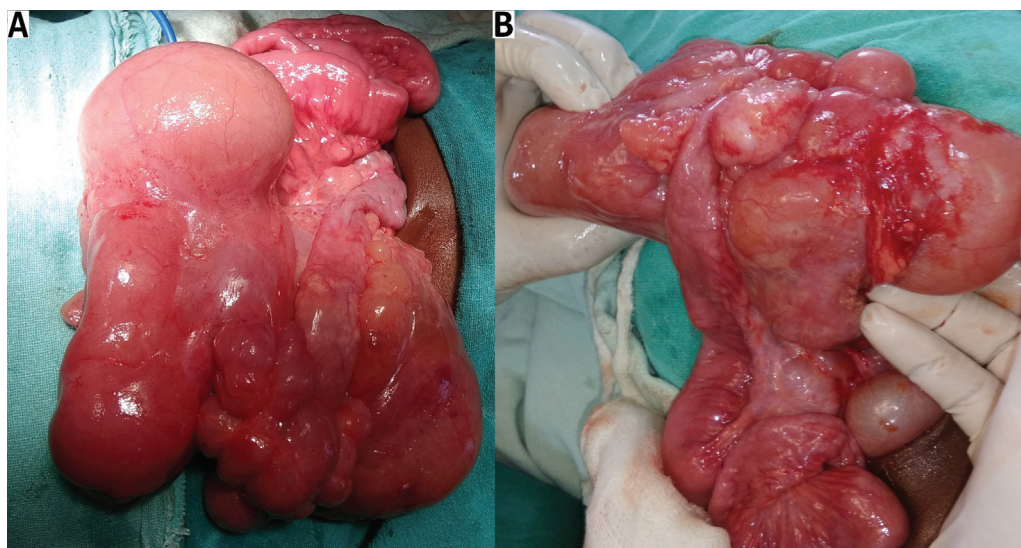
Fig. 23 (A,B) Patient with abdominal lymphatic malformation with involvement of the small bowel and its mesentery along with extension into the retroperitoneum. Excision of the malformation with resection and anastomosis of the distal ileum resulted in a favorable outcome.

In the thoracic cavity, most of the vascular malformations are LMs; lesions may be either macrocystic, microcystic, or mixed subtype. The most common site is the mediastinum or retropleural space. The macrocystic type can be managed by image-guided intralesional sclerotherapy, while the large microcystic variety requires surgical resection.[67] Endothoracic AVMs and VMs are rare entities. Intrapulmonary AVMs may result in hemoptysis and high-output cardiac failure.[67]

In the abdominal cavity, LMs are the most common vascular malformations. The macrocystic type is common and it is seen as a uniseptate or multiseptate cystic mass on imaging. The presentation may be acute with pain, distension, vomiting, and constipation, and may sometimes be with internal hemorrhage.[67] The treatment LMs in the abdominal cavity is variable. Surgical resection is the treatment of choice if the malformation is amenable for resection (►**Fig. 23**). Image-guided intralesional sclerotherapy with doxycycline is another alternative.[68] Internal bleeding may act as a sclerosing agent and the lesion may diminish in size on its own.

VMs in the abdominal cavity present with GI bleeding. VMs can be focal, multifocal, or diffuse. In CLOVES syndrome and Klippel–Trénaunay syndrome, vascular malformations may encompass the pelvic organs. Management of VMs is surgical resection and is individualized as per the system involved.[67,69]

Conclusion

The vascular anomalies encompass a very diverse group of diseases ranging from benign to malignant, simple to complex, isolated to syndromic, and unifocal to multifocal to diffuse. The currently used ISSVA classification categorizes these anomalies based on their biological basis into vascular tumors and vascular malformations. The ISSVA classification and its terminology provide an accurate diagnosis, risk stratification, and treatment as well as study potential therapies that would improve the standard of care. Sonography is a useful tool for diagnosis, assessing the extent of pediatric vascular anomalies, evaluating complications, and monitoring response to treatment. MRI is the imaging modality of choice for vascular malformations. It characterizes the type, extent of the lesion (s), and involvement of adjacent soft tissues and visceral organs. Multiple therapeutic approaches are required for the management of vascular anomalies.

Author Contributions
R.G. conceived and designed the study. All the authors contributed in the drafting of the article. All the authors collected, organized, analyzed, and interpreted the data. O.N. and A.B. provided critical revision and wrote the final draft of the article. All the authors critically reviewed and approved the final draft and are responsible for the content and similarity index of the manuscript.

References

1 Sadick M, Müller-Wille R, Wildgruber M, Wohlgemuth WA. Vascular anomalies (Part I): classification and diagnostics of vascular anomalies. Röfo Fortschr Geb Röntgenstr Neuen Bildgeb Verfahr 2018;190(09):825–835

2 Wassef M, Borsik M, Cerceau P, et al. Classification of vascular tumours and vascular malformations. Contribution of the ISSVA 2014/2018 classification. Ann Pathol 2021;41(01):58–70

3 Mulliken JB, Glowacki J. Hemangiomas and vascular malformations in infants and children: a classification based on endothelial characteristics. Plast Reconstr Surg 1982;69(03):412–422

4 Shatzkes DR. Vascular anomalies: description, classification and nomenclature. Appl Radiol 2018;47(09):8–13

5 International Society for the Study of Vascular Anomalies ISSVA Classification of Vascular Anomalies. 2018. Accessed March 15, 2022 at: issva.org/classification

6 Gibson CR, Barnacle AM. Vascular anomalies: special considerations in children. CVIR Endovasc 2020;3(01):60

7 Johnson CM, Navarro OM. Clinical and sonographic features of pediatric soft-tissue vascular anomalies part 2: vascular malformations. Pediatr Radiol 2017;47(09):1196–1208

8 Kunimoto K, Yamamoto Y, Jinnin M. ISSVA classification of vascular anomalies and molecular biology. Int J Mol Sci 2022; 23(04):2358

9 Vaidya S, Cooke D, Kogut M, Stratil PG, Bittles MA, Sidhu M. Imaging and percutaneous treatment of vascular anomalies. Semin Intervent Radiol 2008;25(03):216–233

10 Johnson CM, Navarro OM. Clinical and sonographic features of pediatric soft-tissue vascular anomalies part 1: classification, sonographic approach and vascular tumors. Pediatr Radiol 2017;47(09):1184–1195

11 Merrow AC, Gupta A, Patel MN, Adams DM. Revised classification of vascular lesions from the International Society for the Study of Vascular Anomalies: radiologic–pathologic update. Radiographics 2016;36(05):1494–1516

12 Krol A, MacArthur CJ. Congenital hemangiomas: rapidly involuting and noninvoluting congenital hemangiomas. Arch Facial Plast Surg 2005;7(05):307–311

13 Smith CJF, Friedlander SF, Guma M, Kavanaugh A, Chambers CD. Infantile hemangiomas: an updated review on risk factors, pathogenesis, and treatment. Birth Defects Res 2017;109(11):809–815

14 Padhiyar JK, Patel NH, Gajjar TP, Buch MD, Shah YB, Solanki R. Efficacy and safety of propranolol on the proliferative phase of infantile hemangioma: a hospital-based prospective study. Indian J Dermatol 2018;19:224–229

15 Brandling-Bennett HA, Metry DW, Baselga E, et al. Infantile hemangiomas with unusually prolonged growth phase: a case series. Arch Dermatol 2008;144(12):1632–1637

16 Léauté-Labrèze C, Harper JI, Hoeger PH. Infantile haemangioma. Lancet 2017;390(10089):85–94

17 Liang MG, Frieden IJ. Infantile and congenital hemangiomas. Semin Pediatr Surg 2014;23(04):162–167

18 Dubois J, Patriquin HB, Garel L, et al. Soft-tissue hemangiomas in infants and children: diagnosis using Doppler sonography. Am J Roentgenol 1998;171(01):247–252

19 Metry DW, Haggstrom AN, Drolet BA, et al. A prospective study of PHACE syndrome in infantile hemangiomas: demographic features, clinical findings, and complications. Am J Med Genet A 2006;140(09):975–986

20 Haggstrom AN, Garzon MC, Baselga E, et al. Risk for PHACE syndrome in infants with large facial hemangiomas. Pediatrics 2010;126(02):e418–e426

21 Metry D, Heyer G, Hess C, et al; PHACE Syndrome Research Conference. Consensus statement on diagnostic criteria for PHACE syndrome. Pediatrics 2009;124(05):1447–1456

22 Rotter A, Samorano LP, Rivitti-Machado MC, Oliveira ZNP, Gontijo B. PHACE syndrome: clinical manifestations, diagnostic criteria, and management. An Bras Dermatol 2018;93(03):405–411

23 Iacobas I, Burrows PE, Frieden IJ, et al. LUMBAR: association between cutaneous infantile hemangiomas of the lower body and regional congenital anomalies. J Pediatr 2010;157(05):795–801.e1, 7

24 Girard C, Bigorre M, Guillot B, Bessis D. Pelvis syndrome. Arch Dermatol 2006;142(07):884–888

25 Stockman A, Boralevi F, Taïeb A, Léauté-Labrèze C. SACRAL syndrome: spinal dysraphism, anogenital, cutaneous, renal and urologic anomalies, associated with an angioma of lumbosacral localization. Dermatology 2007;214(01):40–45

26 Hsi Dickie B, Fishman SJ, Azizkhan RG. Hepatic vascular tumors. Semin Pediatr Surg 2014;23(04):168–172

27 Ji Y, Chen S, Wang Q, et al. Intolerable side effects during propranolol therapy for infantile hemangioma: frequency, risk factors and management. Sci Rep 2018;8(01):4264

28 Martin K, Blei F, Chamlin SL, et al. Propranolol treatment of infantile hemangiomas: anticipatory guidance for parents and caretakers. Pediatr Dermatol 2013;30(01):155–159

29 Frieden IJ, Eichenfield LF, Esterly NB, Geronemus R, Mallory SBAmerican Academy of Dermatology Guidelines/Outcomes Committee. Guidelines of care for hemangiomas of infancy. J Am Acad Dermatol 1997;37(04):631–637

30 Kono T, Sakurai H, Groff WF, et al. Comparison study of a traditional pulsed dye laser versus a long-pulsed dye laser in the treatment of early childhood hemangiomas. Lasers Surg Med 2006;38(02):112–115

31 Léauté-Labrèze C, Dumas de la Roque E, Hubiche T, Boralevi F, Thambo JB, Taïeb A. Propranolol for severe hemangiomas of infancy. N Engl J Med 2008;358(24):2649–2651

32 Oranje AP, Janmohamed SR, Madern GC, de Laat PC. Treatment of small superficial haemangioma with timolol 0.5% ophthalmic solution: a series of 20 cases. Dermatology 2011;223(04): 330–334

33 Wu HW, Wang X, Zhang L, Zheng JW, Liu C, Wang YA. Topical timolol vs. oral propranolol for the treatment of superficial infantile hemangiomas. Front Oncol 2018;8:605

34 Bennett ML, Fleischer AB Jr, Chamlin SL, Frieden IJ. Oral corticosteroid use is effective for cutaneous hemangiomas: an evidence-based evaluation. Arch Dermatol 2001;137(09):1208–1213

35 Haggstrom AN, Beaumont JL, Lai JS, et al. Measuring the severity of infantile hemangiomas: instrument development and reliability. Arch Dermatol 2012;148(02):197–202

36 Janmohamed SR, de Waard-van der Spek FB, Madern GC, de Laat PC, Hop WC, Oranje AP. Scoring the proliferative activity of haemangioma of infancy: the Haemangioma Activity Score (HAS). Clin Exp Dermatol 2011;36(07):715–723

37 Weitz NA, Lauren CT, Starc TJ, et al. Congenital cutaneous hemangioma causing cardiac failure: a case report and review of the literature. Pediatr Dermatol 2013;30(06):e180–e190

38 Berenguer B, Mulliken JB, Enjolras O, et al. Rapidly involuting congenital hemangioma: clinical and histopathologic features. Pediatr Dev Pathol 2003;6(06):495–510

39 Martines F, Immordino V. Arteriovenous malformation of the base of tongue in pregnancy: case report. Acta Otorhinolaryngol Ital 2009;29(05):274–278

40 Khera PS, Garg PK, Babu S, Elhence P, Tiwari S, Nk S. Fibro adipose vascular anomaly: a rare and often misdiagnosed entity. Indian J Radiol Imaging 2021;31(03):776–781

41 Ji Y, Li K, Xiao X, Zheng S, Xu T, Chen S. Effects of propranolol on the proliferation and apoptosis of hemangioma-derived endothelial cells. J Pediatr Surg 2012;47(12):2216–2223

42 Abreu MC, Pinto J, Rocha G, et al. Arteriovenous malformations in the neonatal period: case report and literature review. J Pediatr Neonat Individual Med 2020;9(01):e090126

43 Dasgupta R, Patel M. Venous malformations. Semin Pediatr Surg 2014;23(04):198–202

44 Soblet J, Limaye N, Uebelhoer M, Boon LM, Vikkula M. Variable somatic TIE2 mutations in half of sporadic venous malformations. Mol Syndromol 2013;4(04):179–183

45 Legiehn GM, Heran MK. A step-by-step practical approach to imaging diagnosis and interventional radiologic therapy in vascular malformations. Semin Intervent Radiol 2010;27(02):209–231

46 Trop I, Dubois J, Guibaud L, et al. Soft-tissue venous malformations in pediatric and young adult patients: diagnosis with Doppler US. Radiology 1999;212(03):841–845

47 Paltiel HJ, Burrows PE, Kozakewich HP, Zurakowski D, Mulliken JB. Soft-tissue vascular anomalies: utility of US for diagnosis. Radiology 2000;214(03):747–754

48 Lowe LH, Marchant TC, Rivard DC, Scherbel AJ. Vascular malformations: classification and terminology the radiologist needs to know. Semin Roentgenol 2012;47(02):106–117

49 Legiehn GM, Heran MK. Classification, diagnosis, and interventional radiologic management of vascular malformations. Orthop Clin North Am 2006;37(03):435–474, vii–viii

50 Nguyen HL, Boon LM, Vikkula M. Genetics of vascular malformations. Semin Pediatr Surg 2014;23(04):221–226

51 Comi AM. Sturge-Weber syndrome. Handb Clin Neurol 2015; 132:157–168

52 Elluru RG, Balakrishnan K, Padua HM. Lymphatic malformations: diagnosis and management. Semin Pediatr Surg 2014;23(04): 178–185

53 de Serres LM, Sie KC, Richardson MA. Lymphatic malformations of the head and neck. A proposal for staging. Arch Otolaryngol Head Neck Surg 1995;121(05):577–582

54 Hawkins CM, Chewning RH. Diagnosis and management of extracranial vascular malformations in children: arteriovenous malformations, venous malformations and lymphatic malformations. Semin Roentgenol 2019;54(04):337–348

55 Chaudry G, Guevara CJ, Rialon KL, et al. Safety and efficacy of bleomycin sclerotherapy for microcystic lymphatic malformation. Cardiovasc Intervent Radiol 2014;37(06):1476–1481

56 Wu C, Song D, Guo L, Wang L. Refractory head and neck lymphatic malformation in infants treated with sirolimus: a case series. Front Oncol 2021;11:616702

57 Uller W, Alomari AI, Richter GT. Arteriovenous malformations. Semin Pediatr Surg 2014;23(04):203–207

58 Garzon MC, Huang JT, Enjolras O, Frieden IJ. Vascular malformations: part I. J Am Acad Dermatol 2007;56(03):353–370, quiz 371–374

59 Lam K, Pillai A, Reddick M. Peripheral arteriovenous malformations: classification and endovascular treatment. Appl Radiol 2017;46(05):15–21

60 Uller W, Fishman SJ, Alomari AI. Overgrowth syndromes with complex vascular anomalies. Semin Pediatr Surg 2014;23(04): 208–215

61 Kang H-C, Baek ST, Song S, Gleeson JG. Clinical and genetic aspects of the segmental overgrowth spectrum due to somatic mutations in PIK3CA. J Pediatr 2015;167(05):957–962

62 John PR. Klippel-Trenaunay syndrome. Tech Vasc Interv Radiol 2019;22(04):100634

63 Martinez-Lopez A, Blasco-Morente G, Perez-Lopez I, et al. CLOVES syndrome: review of a PIK3CA-related overgrowth spectrum (PROS). Clin Genet 2017;91(01):14–21

64 Al-Huniti A, Fantauzzi M, Willis L, Sadlier M, Amaral JG, Carcao MD. Sirolimus leads to rapid improvement in fibroadipose vascular anomalies: experience in 11 children. J Vasc Anomalies (Phila) 2021;2(04):e030

65 Revencu N, Boon LM, Mendola A, et al. RASA1 mutations and associated phenotypes in 68 families with capillary malformation-arteriovenous malformation. Hum Mutat 2013;34(12): 1632–1641

66 Kurek KC, Howard E, Tennant LB, et al. PTEN hamartoma of soft tissue: a distinctive lesion in PTEN syndromes. Am J Surg Pathol 2012;36(05):671–687

67 Dasgupta R, Fishman SJ. Management of visceral vascular anomalies. Semin Pediatr Surg 2014;23(04):216–220

68 Chaudry G, Burrows PE, Padua HM, Dillon BJ, Fishman SJ, Alomari AI. Sclerotherapy of abdominal lymphatic malformations with doxycycline. J Vasc Interv Radiol 2011;22(10):1431–1435

69 Wassef M, Blei F, Adams D, et al; ISSVA Board and Scientific Committee. Vascular anomalies classification: recommendations from the International Society for the Study of Vascular Anomalies. Pediatrics 2015;136(01):e203–e214