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Original Research Article

Role of USG and Doppler Study in Evaluation of Superficial Vascular Malformations

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Abstract

Background: Superficial vascular malformations are congenital vascular anomalies that includes venous, arteriovenous, lymphatic, and mixed venolymphatic subtypes as well as vascular tumors such as hemangiomas. These lesions present with significant clinical challenges owing to their varied presentation, functional impairment, and potential for complications such as bleeding and disfigurement. Early and accurate diagnosis is crucial for appropriate management.

Aim: The purpose of this study is to evaluate the role of ultrasound (USG) and Doppler studies in evaluation of superficial vascular malformations. The objective is to highlight the strengths, limitations, and clinical relevance of these imaging modalities.

Methods: A prospective observational study was conducted on patients clinically suspected of having superficial vascular malformations. Gray-scale USG was used to assess lesion morphology, echotexture, margins, and compressibility. Color and spectral Doppler were employed to characterize flow dynamics, vascularity, and arterial/venous waveforms. Data were analyzed for lesion classification into high-flow and low-flow malformations, with correlation to clinical presentation and available MRI findings.

Results: Venous malformations constituted the largest proportion of cases, followed by lymphatic malformations and hemangiomas. USG and Doppler demonstrated high sensitivity in differentiating high-flow from low-flow lesions, with diagnostic accuracy exceeding 90% when compared with MRI and clinical correlation. The techniques were found to be non-invasive, cost-effective, and widely accessible.

Conclusion: USG and Doppler remain indispensable first-line imaging modalities in the evaluation of superficial vascular malformations. Their ability to provide real-time morphological and hemodynamic assessment makes them vital tools in guiding treatment strategies and follow-up. These modalities are recommended as the primary imaging approach, especially in resource-limited settings.

Keywords: Superficial vascular malformations, High flow and low flow lesions, hemangiomas, Arterial and venous waveforms, Hemodynamic assessment, Clinical correlation.

Introduction

Vascular anomalies represent a heterogeneous group of congenital disorders resulting from aberrant vascular development during embryogenesis. They may affect venous, arterial, capillary, or lymphatic channels, either in isolation or combination, and present across a wide clinical spectrum. Manifestations range from small cutaneous lesions to aggressive high-flow arteriovenous malformations (AVMs) that may cause pain, bleeding, tissue destruction, functional impairment, or even life-threatening complications [1,2]. The International Society for the Study of Vascular Anomalies (ISSVA) classification distinguishes vascular tumours, such as infantile haemangiomas, from vascular malformations, which are subdivided into venous, lymphatic, arteriovenous, and combined forms, including venolymphatic malformations (3). Superficial malformations are commonly seen in the head, neck, trunk, and extremities. While many are detected in childhood, others remain clinically silent until enlargement or complications necessitate evaluation. Patients may present with swelling, pain, recurrent bleeding, cosmetic concerns, or organ dysfunction depending on lesion type and anatomical location [2,4,5].

Epidemiologically, venous malformations constitute approximately 40% of all vascular malformations, followed by lymphatic malformations (20–25%) and haemangiomas (15–20%) [6,7]. AVMs are relatively uncommon but clinically significant due to their destructive growth and systemic hemodynamic consequences [11,12]. Mixed lesions, such as venolymphatic malformations, pose unique diagnostic and therapeutic challenges because of overlapping imaging and clinical characteristics [3,13,14]. Accurate classification is therefore essential for guiding treatment. Venous malformations are often managed conservatively or with image-guided sclerotherapy, while high-flow AVMs may require embolization or surgery due to risks like rapid progression and cardiac overload [4,7,15].

Ultrasound (USG) has emerged as the first-line imaging modality in superficial vascular malformations because it is non-invasive, widely accessible, radiation-free, and provides real-time assessment [5,8,10,16]. Gray-scale USG delineates morphology, echotexture, margins, extent, and compressibility. Venous malformations typically appear as lobulated, compressible hypoechoic masses with phleboliths, whereas lymphatic malformations demonstrate macrocystic, microcystic, or mixed features. AVMs often appear as ill-defined lesions with multiple anechoic channels, while venolymphatic malformations display combined cystic and venous patterns. In contrast, haemangiomas are usually solid, well-defined vascular tumours [9,17–19].

Doppler ultrasound adds functional information, including vascularity, flow velocity, direction, and resistance indices, which aids in differentiating low-flow lesions (venous and lymphatic) from high-flow lesions (AVMs and haemangiomas). AVMs typically show high-velocity, low-resistance arterial waveforms with early venous filling, while venous malformations may demonstrate sluggish monophasic venous flow or appear avascular. Lymphatic malformations often lack internal flow, whereas haemangiomas in the proliferative phase exhibit marked vascularity [5,7,17]. Importantly, ultrasound also helps distinguish vascular anomalies from nonvascular mimics, enhancing diagnostic accuracy [9,14]. Taken together, gray-scale and Doppler US provide a comprehensive evaluation, combining structural and hemodynamic data. This dual capability makes ultrasound an indispensable tool for classification, treatment planning, and longitudinal follow-up of superficial vascular malformations [1,7,15].

Materials and Methods

This prospective observational study was designed to evaluate the role of ultrasound (USG) and Doppler in the diagnosis and characterization of superficial vascular malformations. The study was carried out over a period of 6 months in the Department of Radiodiagnosis. All patients or their guardians provided informed consent prior to inclusion in the study.

Study Design: Prospective observational and analytical study.

Study Population: A total of 62 patients clinically suspected of having superficial vascular malformations were enrolled. Patients were recruited from both outpatient and inpatient departments of pediatrics, dermatology, and surgery. The age range of the study population was 1 month to 60 years, with a mean age of 18 years. Both male and female patients were included. The distribution of lesions was across multiple anatomical regions including head and neck, extremities, and trunk.

Study Period: 6 months (7th February, 2025 to 8thJuly, 2025).

Inclusion Criteria

- Patients with superficial soft tissue swellings suspected to be vascular in origin.
- Lesions clinically diagnosed as vascular malformations or hemangiomas.

Exclusion Criteria

- Deep visceral vascular malformations not accessible by ultrasound.
- Patients with prior surgical excision of lesions.
- Patients unwilling to undergo ultrasound examination.

Imaging Protocol: All patients underwent high-resolution gray-scale ultrasound using a linear array transducer with a frequency ranging from 7 to 15 MHz. For deeper lesions, a curvilinear probe (3–5 MHz) was used. The patients were examined in supine or prone positions depending on lesion location. Real-time scanning was performed in multiple planes. Parameters recorded included lesion size, shape, margins, echotexture, internal architecture, and compressibility.

Equipment

MINDRAY RESONA I9 ULTRASOUND machine.

Color Doppler imaging was then performed to assess vascularity, distribution of vessels, and flow characteristics. Spectral Doppler analysis was used to measure flow velocity, resistance index (RI), pulsatility index (PI), and waveform patterns. Flow was categorized as arterial, venous, or mixed.

Lesions were classified into high-flow and low-flow categories based on Doppler findings.

Data Collection: Clinical history, and examination findings were recorded for all patients. Imaging findings were documented systematically.

Lesion morphology on USG and flow characteristics on Doppler were correlated with clinical features and available MRI or histopathology reports.

Results

A total of 62 patients were included in this observational study, comprising a wide spectrum of superficial vascular malformations. The distribution of cases according to the type of malformation is summarized in the table below.

Venous malformations were the most common, followed by lymphatic malformations, hemangiomas, arteriovenous malformations, and venolymphatic malformations.

Table 1: Age Distribution of Patients (n = 62)

Age Group (years)	No. of Patients (n)	Percentage (%)
0-5	14	22.6%
6-10	12	19.4%
11-20	15	24.2%
21-30	11	17.7%
31-40	07	11.3%
41-60	03	4.8%
Total	62	100%

Table 2: Sex Distribution of Patients (n = 62)

Sex	No. of Patients (n)	Percentage (%)
Male	26	41.9%
Female	36	58.1%
Total	62	100%

Table 3 summarizes the number of cases and percentage distribution of each type of lesion. The data highlights that low-flow lesions (venous and lymphatic malformations) together constituted nearly two-thirds of all cases, whereas high-flow lesions (AVMs and hemangiomas) accounted for the remainder.

Table 3: Distribution of superficial vascular malformations in the study population

Type of Malformation	Number of Cases	Percentage
Venous Malformation	25	40%
Lymphatic Malformation	15	24%
Hemangioma	12	19%
Arteriovenous Malformation	6	10%
Venolymphatic Malformation	4	7%

The bar chart (Figure 6) and pie chart (Figure 7) provide a visual representation of the distribution. Venous malformations, being the largest group, accounted for 40% of cases. Lymphatic malformations made up 24%, while hemangiomas constituted 19%. AVMs and venolymphatic malformations together comprised less than 20% of cases.

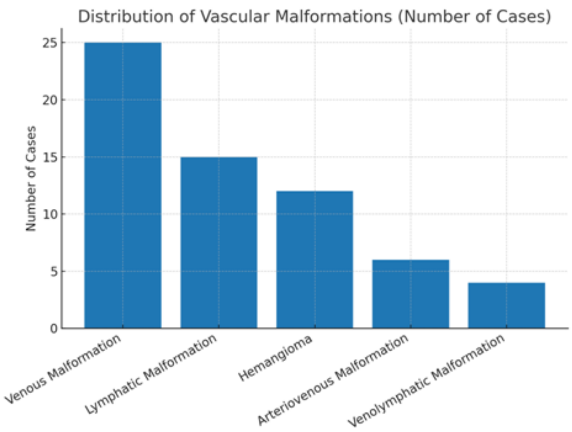

Figure 1: Bar chart showing distribution of vascular malformations by number of cases

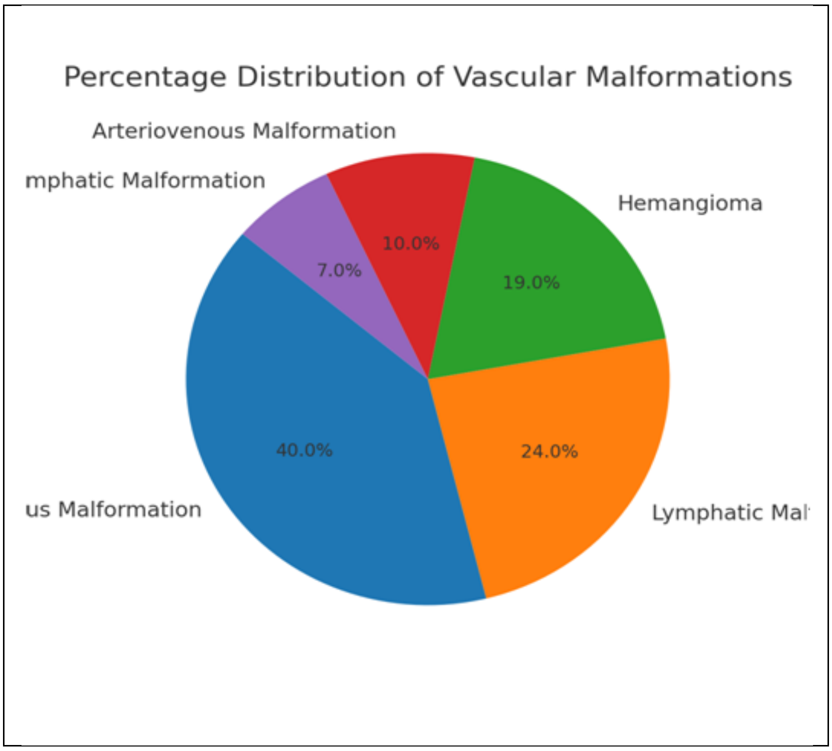

Figure 2: Pie chart showing percentage distribution of vascular malformations

Interpretation of Results

The findings demonstrate that venous malformations were the most frequently encountered type, highlighting the prevalence of low-flow vascular anomalies in clinical practice. Their compressibility and phleboliths made them distinct on USG. Lymphatic malformations were the second most common and were easily identified as cystic, avascular lesions. Hemangiomas, although less frequent, presented diagnostic challenges in distinguishing them from AVMs during the proliferative phase due to their hypervascularity.

AVMs, though only 10% of cases, represented the most clinically significant group due to their potential for rapid progression and complications such as bleeding and high-output cardiac failure. Venolymphatic malformations, though rare, illustrated the diagnostic importance of USG and Doppler in recognizing mixed lesions.

Overall, the results validated the accuracy of USG and Doppler in differentiating high-flow from low-flow lesions. In more than 90% of cases, the imaging findings were consistent with clinical and MRI correlation. Thus, USG with Doppler was shown to be a reliable, first-line imaging modality in the evaluation of superficial vascular malformations.

Discussion

The present study highlights the critical role of ultrasound (USG) and Doppler in the evaluation of superficial vascular malformations. These imaging modalities provide a unique combination of morphological and hemodynamic assessment that is not easily achievable with other techniques (1–3). The discussion below compares our findings with existing literature, explores clinical implications, addresses limitations, and suggests directions for future research.

Comparison with Literature

Arteriovenous Malformations (AVM): AVMs were detected in 6 cases (10%). On grey-scale USG, they appeared as ill-defined, heterogeneous lesions with multiple tubular anechoic channels representing abnormal vessels, often extending across tissue planes and involving both subcutaneous and muscular layers. Recognition on Gray-scale invariably prompted Doppler evaluation. Colour Doppler demonstrated a tangled vascular network with aliasing due to turbulent flow [4,5].

Spectral Doppler confirmed high-velocity, low-resistance arterial signals with early venous filling, reflecting direct arteriovenous shunting. Arterialized venous waveforms were considered diagnostic [6,7]. In several patients, feeding arteries and draining veins could be delineated, aiding pre-procedural assessment and planning for embolization or surgical interventionas described in illustration 1& 2.

Case 1: Arteriovenous Malformation (AVM) in Left Arm region:

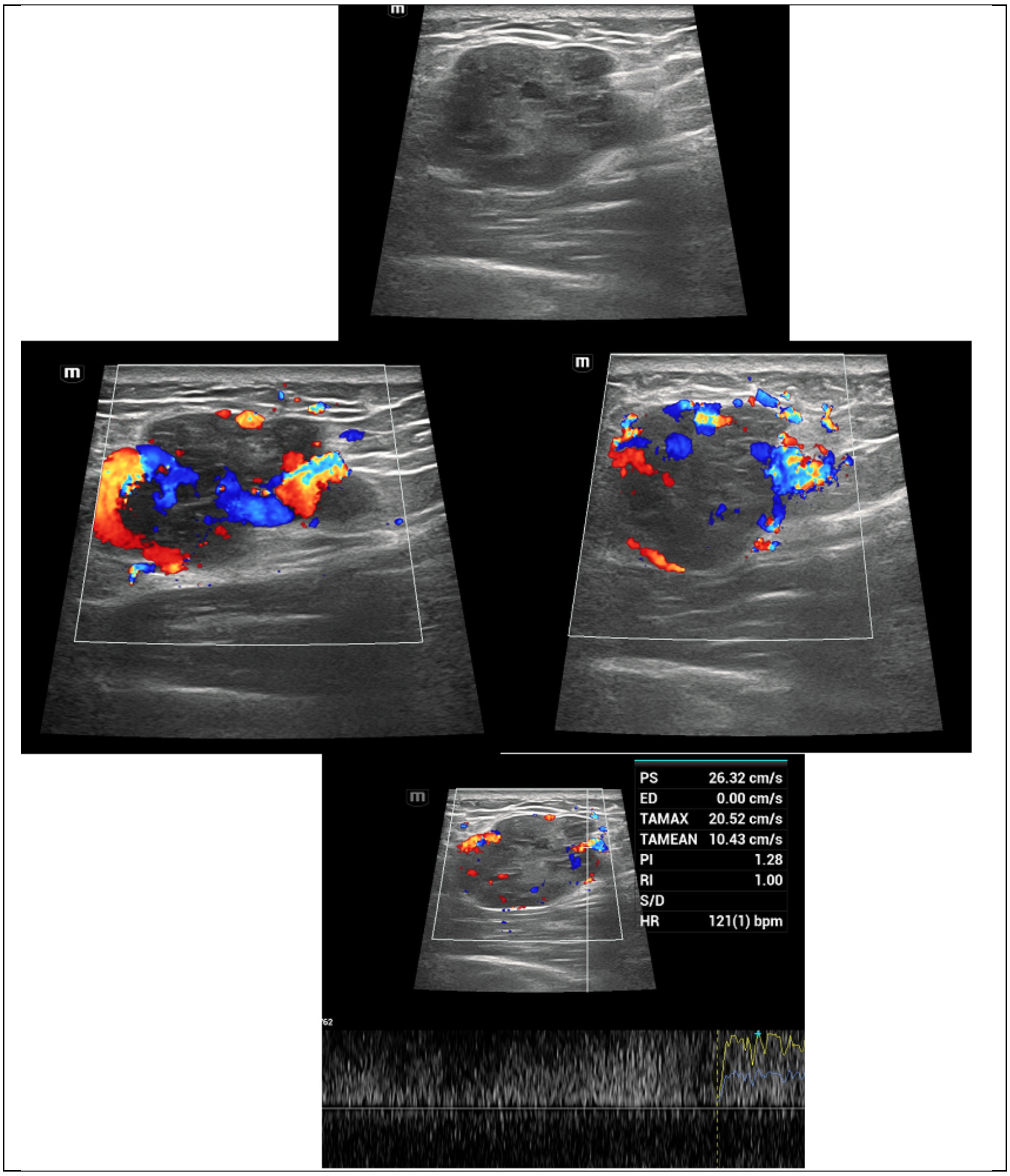

Figure 3:

Illustration 1: Multiple tubular tortuous vessels with aliasing: high velocity low resistance arterial flow with adjacent soft tissue changes.

Case 2 : Arteriovenous Malformation (AVM) in Left Scapular region:

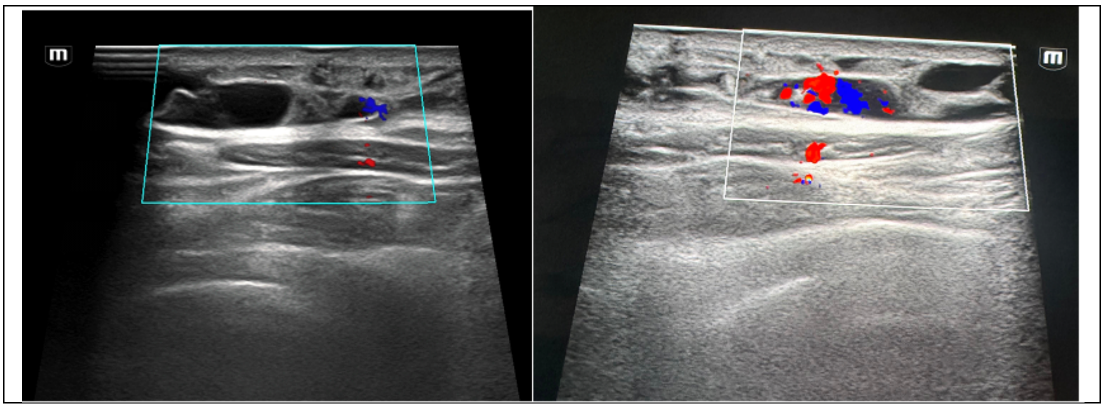

Figure 4:

Illustration 2 : Multiple tubular tortuous vessels with aliasing: high velocity low resistance arterial flow with adjacent soft tissue changes.

Venous Malformations (VM): In our study, venous malformations were the most common subtype, comprising 25 cases (40%), which aligns with previous reports noting VMs as 40–50% of all vascular anomalies. On USG, they appeared as lobulated, hypoechoic or heterogeneous lesions, often compressible with reduction in size on manual pressure, a distinguishing feature from solid masses.

Phleboliths, seen as echogenic foci with posterior acoustic shadowing, were identified in several patients and are considered virtually pathognomonic [8,9].

In children, lesions tended to be more cystic, whereas in adults they appeared fibrotic and heterogeneous. Doppler typically demonstrated sluggish, monophasic venous flow, with many lesions appearing avascular on colour Doppler but detectable with power Doppler.

Spectral Doppler confirmed their low-flow nature, with absence of arterial signals. Thrombosed channels were occasionally avascular, requiring correlation with clinical findingsas described in illustration 3.

Case 3 : Venous malformation in left lower leg:

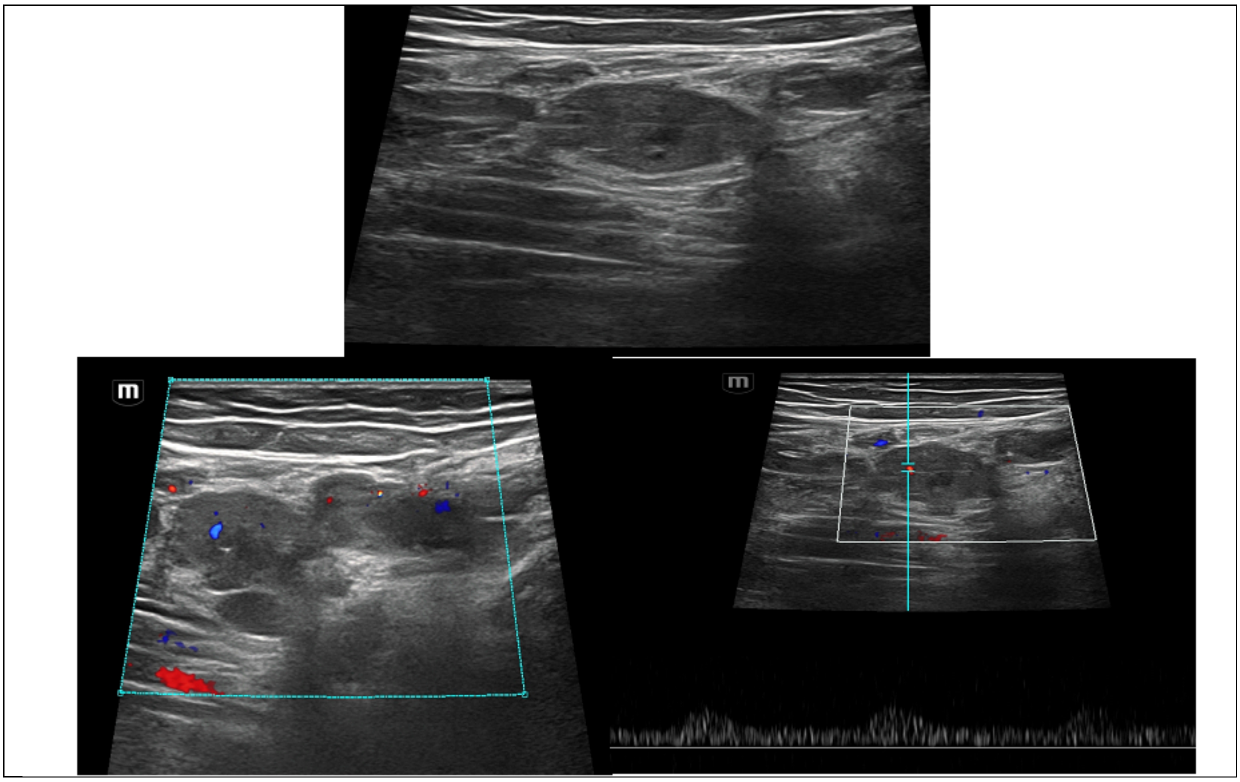

Figure 5:

Illustration 3: Poorly defined heteroechoic lesion with multiple tubular cystic spaces within it, on color doppler study shows slow flow and monophasic waveform.

Lymphatic Malformations (LM): Lymphatic malformations were the second most common subtype in our study, accounting for 15 cases (24%). They were categorized as macrocystic, microcystic, or mixed types. Macrocystic lesions appeared as multiloculated, anechoic cysts with thin septations, while microcystic lesions were more echogenic due to multiple tiny cysts; mixed forms combined both features. Secondary complications such as infection or haemorrhage were detected in some cases, producing altered echotexture or fluid–fluid levels.

Doppler typically showed no internal flow, confirming their avascular nature, though minimal peripheral vascularity could beseen with inflammation. Our findings of macrocystic predominance in children are consistent with earlier reports [10,11]. These sonographic features were critical in distinguishing LMs from cystic neoplasms or abscesses and in guiding managementas described in illustration 4.

Case 4: Lymphatic malformation in neck:

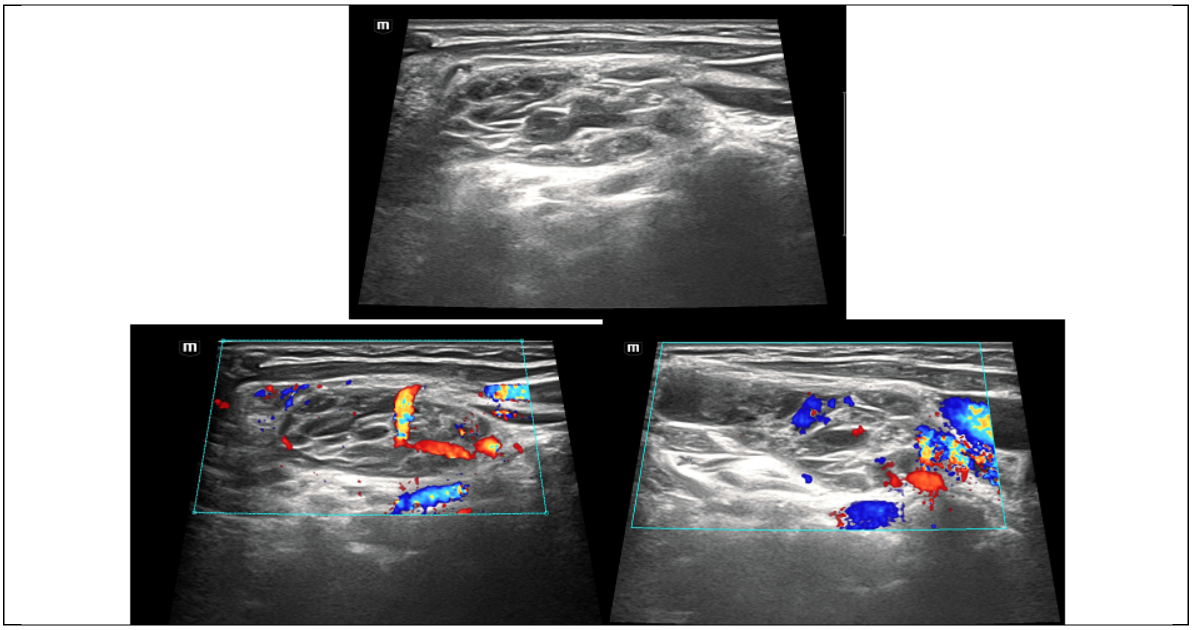

Figure 6:

Illustration 4: Multiloculated cystic septated avascular lesion withvariable sized cystic spaces, some of which appear to be intercommunicating and shows septal vascularity on color doppler study.

Venolymphatic Malformations (VLM): VLMs were identified in 4 cases (7%) and showed overlapping features of venous and lymphatic malformations. On gray-scale USG, they appeared as partially solid and partially cystic lesions, with variable compressibility. Some lesions demonstrated phleboliths, while others contained cystic components with thin septations. The dual morphology often posed a diagnostic challenge.

On Doppler, sluggish venous flow was noted within vascular components, whereas cystic areas remained avascular, confirming the mixed nature. Recognition of both elements was crucial, as management often required a multimodality approach rather than a single treatment strategy [12,13]as described in illustration 5.

Case 5: Venolymphatic malformation:

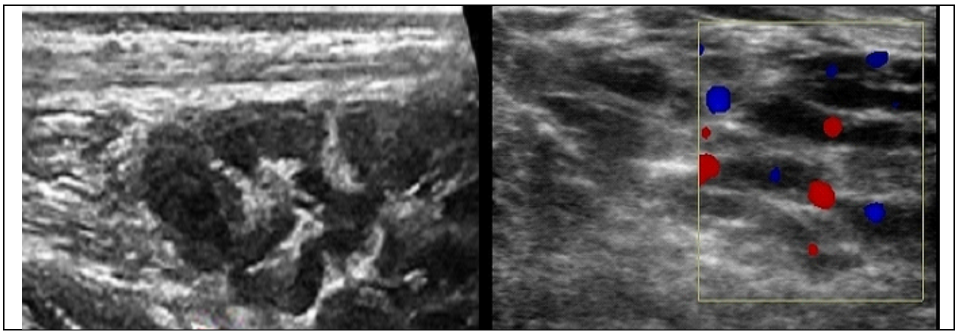

Figure 7:

Illustration 5: Multiloculated cystic lesion with variable sized cystic spaces (lymphatic component) and few interspread echogenic foci (venous component) within the soft tissue, some of which appear to be intercommunicating.

Hemangiomas: Hemangiomas were identified in 12 cases (19%) and represented vascular tumors distinct from malformations. They typically presented in infants and young children within the first weeks of life. On gray-scale USG, they appeared as well-defined, solid, hypoechoic lesions with heterogeneous echotexture, sometimes showing echogenic striations from fibrous septa.

Their solid morphology and vascular channels aided differentiation from low-flow malformations. Doppler consistently revealed prominent hypervascularity with both arterial and venous signals.

During the proliferative phase, high-velocity arterial waveforms were observed, while involuting hemangiomas showed reduced vascularity. These

Doppler features were valuable for staging and for monitoring therapeutic response.

Our findings corroborated earlier observations emphasizing the role of USG with Doppler in differentiating hemangiomas from vascular malformations and in tracking involution over time [14,15] as described in illustration 6.

Case 6 : Hemangioma:

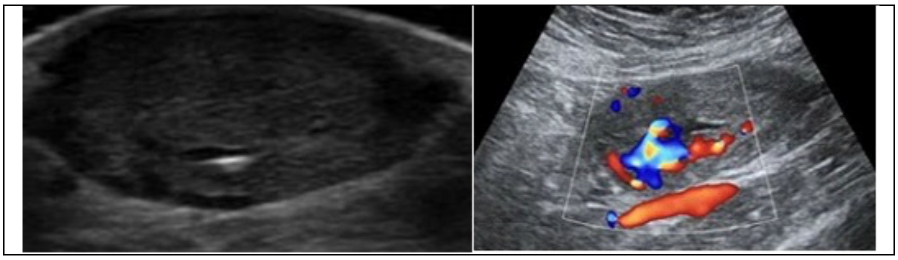

Figure 8:

Illustration 6: Well defined isoechoic lesion which shows few internal vascular channels on color doppler having high vascularity.

Case 7 : Hemangioma:

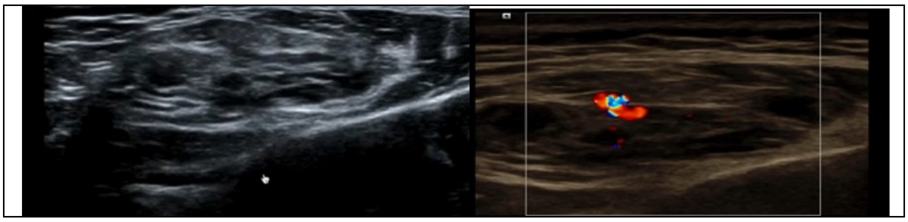

Figure 9:

Illustration 7: Well defined isoechoic lesion which shows few internal vascular channels on color doppler having high vascularity.

Clinical Implications

The ability of USG and Doppler to differentiate high-flow from low-flow lesions has direct therapeutic implications. High-flow AVMs often require interventions such as embolization or surgery due to their aggressive clinical course, whereas low-flow lesions are typically managed with sclerotherapy or conservative approaches. Accurate classification prevents mismanagement, reduces complications, and optimizes patient outcomes [2,5,10].

Doppler also allows assessment of therapeutic response. In our study, follow-up of hemangiomas demonstrated reduced vascularity on Doppler, corresponding with clinical involution. Similarly, treated venous malformations showed decreased size and loss of internal flow. Thus, USG and Doppler are valuable not only for diagnosis but also for monitoring.

Advantages over Other Modalities

MRI provides superior anatomical detail and is useful for deep or extensive lesions; however, it is costly, less accessible, and lacks the dynamic assessment provided by ultrasound. CT, while useful for osseous involvement, exposes patients to ionizing radiation and contrast-related risks. Conventional angiography remains the gold standard for pre-interventional planning but is invasive. In contrast, USG with Doppler is safe, repeatable, and ideal as a first-line modality [1,3].

Limitations

Despite its strengths, USG with Doppler is not without limitations. It is highly operator-dependent, and diagnostic accuracy depends on the skill and experience of the radiologist. Deep-seated or intraosseous lesions may be inadequately assessed. Extremely slow flow may be missed despite optimized settings, and artifacts such as aliasing can complicate interpretation [11,15]. Nevertheless, these challenges can be mitigated by combining ultrasound with other modalities where necessary.

Future Perspectives

The role of advanced ultrasound techniques such as contrast-enhanced ultrasound (CEUS), elastography, and three-dimensional Doppler imaging is expanding. CEUS, in particular, may provide better delineation of lesion perfusion and vascular architecture without ionizing radiation. Elastography can add information about tissue stiffness, potentially aiding differentiation from solid tumors. Artificial intelligence (AI) applications in ultrasound image interpretation hold promise for improving diagnostic accuracy and reducing operator dependency [13,14].

MRI and CT continue to hold adjunctive value, particularly in the assessment of deep or extensive lesions. MRI provides superior soft tissue contrast and anatomical detail, making it useful for surgical planning, while CT is reserved for osseous involvement.

However, both modalities are limited by high cost, reduced accessibility, and in the case of CT, ionizing radiation. Angiography remains the gold standard for interventional planning but is invasive and unsuitable for initial diagnosis. In contrast, USG with Doppler stands out as the safest and most widely accessible first-line modality, capable of providing dynamic evaluation unavailable through static cross-sectional imaging.

Practical Recommendations

For clinicians and radiologists, the practical application of USG and Doppler lies in their routine use for all patients with suspected vascular malformations. Compressibility testing, identification of phleboliths, and careful Doppler interrogation should be standard practice. Power Doppler should be employed to assess low-flow lesions, while spectral Doppler is essential for high-flow lesions. Radiologists should be trained to recognize key waveform characteristics such as arterialized venous signals in AVMs and high-velocity arterial flow in hemangiomas. Integrating these findings into multidisciplinary discussions ensures optimal patient management.

Future Directions

The future of vascular malformation imaging is promising, with advanced ultrasound techniques such as contrast-enhanced ultrasound (CEUS), elastography, and three-dimensional Doppler emerging as valuable tools. CEUS may enhance the ability to map vascular architecture without radiation, while elastography can provide data on tissue stiffness to differentiate malformations from solid neoplasms. Artificial intelligence (AI) applications in image interpretation hold potential to reduce operator dependency and improve diagnostic consistency. These advancements, when combined with the established strengths of USG and Doppler, may revolutionize vascular imaging in the near future.

Conclusion

Ultrasound (USG) with Doppler remains the first-line imaging modality for superficial vascular malformations, offering simultaneous morphological and hemodynamic evaluation in a non-invasive and cost-effective manner [1,2,5].

Findings

Venous malformations were the most frequently observed, characterized by compressibility, phleboliths, and sluggish low-flow signals. Lymphatic malformations typically appeared as anechoic cystic lesions, often macrocystic in pediatric cases. Hemangiomas demonstrated solid morphology with prominent vascularity during the proliferative phase, while arteriovenous malformations (AVMs) revealed arterialized venous signals diagnostic of high-flow shunting [6,7]. Venolymphatic malformations further illustrated the ability of USG to delineate mixed lesions.

Clinical relevance

The classification of malformations into high-flow and low-flow groups is critical for therapeutic planning. High-flow lesions such as AVMs and hemangiomas frequently necessitate intervention, whereas low-flow venous and lymphatic malformations are often managed conservatively or with sclerotherapy. USG with Doppler is equally valuable for follow-up, enabling documentation of treatment response through changes in vascularity and lesion size [8,10].

Comparative role

While MRI provides superior soft tissue contrast and CT aids in evaluating osseous involvement, both are limited by cost and accessibility, with CT additionally involving ionizing radiation. Angiography, though the gold standard for interventional planning, is invasive. USG with Doppler thus remains the most practical and widely available first-line modality [3,9].

Future perspectives

Emerging techniques, including contrast-enhanced ultrasound, elastography, three-dimensional Doppler, and artificial intelligence–assisted image interpretation, hold promise for improving diagnostic accuracy and reducing operator dependency. Integration of these advances with conventional USG is likely to further enhance the evaluation of vascular anomalies [11–13].

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