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ORIGINAL ARTICLE

Role of imaging in the diagnosis and treatment of brain vascular malformations.

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ABSTRACT… Objective: To evaluate the effectiveness of advanced MRI sequences and DSA in the detection, classification, and treatment planning of brain vascular malformations, and to compare their diagnostic value with ultrasonography. **Study Design:** Observational study. **Setting:** Bajwa Trauma Centre & Teaching Hospital, Sargodha. **Period:** 1st November 2024 to 1st May 2025. **Methods:** Involving 59 patients clinically suspected of harboring brain vascular malformations. All patients underwent MRI using a comprehensive protocol including T1, T2, SWI, DWI, contrast-enhanced 3D sequences, and ANGIO TWIST. Ultrasonography was used as a preliminary modality, while DSA was performed in selected cases for confirmatory vascular mapping. Data were analyzed for lesion detection rate, subtype classification, and contribution to treatment planning. **Results:** MRI demonstrated high sensitivity (91.5%) in detecting vascular lesions, with susceptibility-weighted imaging (SWI) accurately identifying hemosiderin in 94.4% of cavernomas and 4D flow/ANGIO TWIST detecting arteriovenous shunting in 88% of AVMs. DSA, while more invasive, remained critical for confirming angioarchitecture and dynamic flow patterns. Ultrasonography offered supportive but limited diagnostic specificity. AVMs were the most common lesion type (42.4%), followed by cavernous malformations (30.5%) and DVAs (16.9%). Additional findings such as intracranial hemorrhage (33.9%) and perilesional edema (23.7%) were also characterized. **Conclusion:** Advanced imaging modalities, especially MRI with SWI and dynamic sequences, play a pivotal role in the early and accurate diagnosis of brain vascular malformations. DSA remains indispensable for treatment confirmation. The integration of radiomics and machine learning, as supported by current literature, offers promising directions for individualized risk stratification and therapeutic planning.

Key words: AVM, Brain Vascular Malformations, DSA, Machine Learning, MRI, Personalized Treatment Planning, Radiomics, Susceptibility-weighted Imaging, 4D Flow Imaging.

INTRODUCTION

Brain vascular malformations such as arteriovenous malformations (AVMs), cavernous malformations, developmental venous anomalies, and other dysmorphic vascular communications are a heterogeneous group of lesions that, if not correctly diagnosed and treated, may cause severe neurological morbidity and mortality.[1,2] These malformations are a frequent etiology of spontaneous hemorrhage within the brain, especially in younger patients, and thus detection and characterization are essential for directing appropriate treatment plans.[3,4]

Imaging is fundamental to the diagnosis, classification, and treatment of brain vascular malformations. Magnetic resonance imaging (MRI), with specialized methods like susceptibility-weighted imaging, arterial spin labeling, and 4D flow imaging, offers high-resolution anatomical and functional data for accurate localization and discrimination of lesion types. MRI is beneficial in detecting findings like multiple hemorrhages with differing ages and hemosiderin deposition, necessary for the identification of malformation subtypes.[3-6]

Digital subtraction angiography (DSA) remains the gold standard for diagnosing and characterizing AVMs and dural arteriovenous fistulas, offering high-resolution visualization of vascular architecture and shunting.[4,7,8]

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Recent advances, including postcontrast susceptibility-weighted MRI and 3D printed models, have improved the detection of arteriovenous shunting and facilitated treatment planning and monitoring.[6,8] Imaging findings are essential not only for diagnosis but also for risk stratification, treatment planning, and long-term surveillance, especially since lesion angioarchitecture may evolve over time or after therapy.[7,9]

Moreover, emerging technologies such as radiomics and machine learning have shown promise in enhancing diagnostic precision, predicting treatment outcomes, and personalizing management strategies for patients with brain vascular malformations.[10,11]

Proper characterization of these lesions using imaging ensures the right therapy is decided on, whether it is surgery, endovascular or conservative.[1,2,7] When medicine and therapies improve, imaging is vital to catch the lesions early, track changes and provide the most appropriate care.[6,10]

Brain vascular malformations are not easy to diagnose or treat because every case is different. For this reason, advanced imaging techniques are vital for precise diagnosis, risk assessment and planning treatment for each patient which helps patients get better and reduces the risks linked to the disease and its treatments. Therefore, the To evaluate the effectiveness of advanced imaging modalities—particularly multiparametric MRI sequences such as susceptibility-weighted imaging (SWI) and 4D flow (ANGIO TWIST)—in accurately detecting, classifying, and guiding the treatment planning of brain vascular malformations, and to assess the complementary role of digital subtraction angiography (DSA) in confirming angioarchitecture and dynamic flow patterns. The study also aimed to compare the diagnostic contributions of ultrasonography, MRI, and DSA in a clinical setting.

METHODS

This observational study was conducted at Bajwa Trauma Centre & Teaching Hospital, Sargodha between 1st November 2024 to 1st May 2025 after approval from ethical committee. A total of 59 participants clinically suspected of having brain vascular malformations were recruited from the outpatient and inpatient departments. Recruitment was based on thorough clinical assessments supported by preliminary radiological evaluations, including computed tomography (CT) and ultrasonography where appropriate. The sample size of 59 was determined to achieve adequate statistical power, assuming a 95% confidence level, 80% power, and a medium effect size to ensure sensitivity in detecting meaningful differences in diagnostic outcomes.

- Expected diagnostic accuracy of MRI: 90%
- Expected diagnostic accuracy of baseline imaging (e.g., USG): 70%
- Significance level (α): 0.05
- Power (1-β): 0.80
- Two-sided test

$$n = \left[\frac{(Z_{1-\alpha/2} + Z_{1-\beta})^2 \cdot (p_1(1-p_1) + p_2(1-p_2))}{(p_1 - p_2)^2}\right]$$

Where:

- $Z_{1-\alpha/2} = 1.96$
- $Z_{1-\beta} = 0.84$
- $p_1 = 0.9, p_2 = 0.7$

$$n \approx \left[\frac{(1.96 + 0.84)^2 \cdot (0.9 \cdot 0.1 + 0.7 \cdot 0.3)}{(0.9 - 0.7)^2}\right] = \left[\frac{7.84 \cdot (0.09 + 0.21)}{0.04}\right] = \frac{7.84 \cdot 0.3}{0.04} = \frac{2.352}{0.04} \approx 59$$

Inclusion criteria comprised all patients, regardless of age or gender, who presented with clinical or radiological features suggestive of intracranial vascular malformations such as arteriovenous malformations (AVMs), cavernous malformations, developmental venous anomalies (DVAs), and other vascular anomalies. Exclusion criteria included contraindications to MRI, such as the presence of pacemakers, ferromagnetic implants, metallic foreign bodies, claustrophobia, severe hemodynamic instability, or inability to remain still during imaging. Ethical approval was obtained from the Institutional Ethics Committee (BTC/10/25), and written informed consent was secured from all participants. Magnetic Resonance Imaging (MRI) was performed according to Hospital Protocol. Patients were positioned head-first in the supine position, and specialized coils were used based on lesion location to optimize image quality. The MRI protocol included a wide range of sequences such as T1-weighted fast spin echo (FSE), T2-weighted FSE, T2-weighted gradient recalled echo (GRE), diffusion-weighted

imaging (DWI), susceptibility-weighted imaging (SWI), and contrast-enhanced sequences like 3D T1-weighted post-contrast imaging and ANGIO TWIST (time-resolved angiography with interleaved stochastic trajectories). These sequences enabled detailed assessment of lesion morphology, hemorrhagic components, calcifications, vascular flow dynamics, and enhancement patterns. Ultrasonography was performed in all patients for preliminary screening and correlation with MRI findings. Digital Subtraction Angiography (DSA) was performed in selected cases (n = 30) where detailed vascular mapping or confirmation of MRI findings was required. All imaging studies were reviewed independently by experienced radiologists to ensure diagnostic consistency. Data collected included demographic variables (age, sex), clinical presentation (symptoms, lesion location), MRI signal characteristics, presence of hemorrhage or edema, enhancement patterns, and lesion classification. Comorbid conditions, if present (e.g., genetic syndromes), were also recorded. Imaging findings were statistically analyzed using IBM SPSS Statistics for Windows, Version 26.0. Descriptive statistics such as frequencies, percentages, means, and standard deviations were used to summarize the data.

RESULTS

The study analyzed 59 patients with clinically suspected brain vascular malformations. Among these, arteriovenous malformations (AVMs) were the most common, accounting for 42.4% of the cases. This was followed by cavernous malformations (30.5%), developmental venous anomalies (DVAs) (16.9%), and a smaller proportion of other vascular anomalies (10.2%). MRI emerged as the most sensitive imaging modality, successfully detecting vascular lesions in 91.5% of patients. All patients underwent ultrasonography (100%), which provided supportive anatomical information but had lower diagnostic specificity compared to MRI. Digital Subtraction Angiography (DSA) was performed in approximately half the cohort (50.8%), primarily in cases where detailed vascular mapping was required. DSA served as a valuable confirmatory tool for MRI findings.Among the MRI sequences, Susceptibility Weighted Imaging (SWI) played a critical role, identifying hemosiderin deposits in 94.4% of cavernomas, which are indicative of prior microhemorrhages. Likewise, 4D Flow and ANGIO TWIST sequences were instrumental in detecting arteriovenous shunting in 88% of AVM cases, confirming their utility in dynamic vascular assessment. Additional pathological features were also noted: intracranial hemorrhage was observed in 33.9% of patients, especially in symptomatic AVMs and cavernomas. Perilesional edema was detected in 23.7%, suggesting local inflammatory or reactive changes. (Table-I)

The diagnostic performance analysis highlights that MRI as a whole demonstrated high sensitivity (91.5%) for detecting brain vascular malformations, underscoring its value as a frontline imaging modality. Among the MRI sequences, SWI was particularly effective in identifying cavernomas, with a sensitivity of 94.4%, while ANGIO TWIST/4D Flow showed strong sensitivity (88.0%) for detecting arteriovenous shunting in AVMs. When comparing magnet strengths, 3T MRI outperformed 1.5T MRI, offering higher sensitivity (85.7% vs. 72.7%) and perfect specificity and positive predictive value (100%), though with a lower negative predictive value. (Table-II)

DISCUSSION

Our study substantiates the pivotal role of multimodal imaging—particularly advanced MRI sequences and Digital Subtraction Angiography (DSA)—in the accurate diagnosis, classification, and management of brain vascular malformations (BVMs). We found that MRI demonstrated a sensitivity of 91.5%, with SWI detecting hemosiderin in 94.4% of cavernomas and ANGIO TWIST/4D Flow sequences identifying arteriovenous shunting in 88% of AVMs. These figures are consistent with previous research and highlight the superiority of modern MRI techniques over conventional modalities.

Our findings closely mirror those of Martín-Noguerol et al. who emphasized the utility of SWI and time-resolved MRA in detecting hemorrhagic residues and dynamic vascular anomalies in BVMs, particularly cavernomas and AVMs.[8]

Parameter	Number of Patients	Percentage (%)
Total Patients	59	100
Types of Brain Vascular Malformations		
- Arteriovenous Malformations (AVMs)	25	42.4
- Cavernous Malformations	18	30.5
- Developmental Venous Anomalies (DVAs)	10	16.9
- Other vascular anomalies	6	10.2
Imaging Modalities Performed		
- MRI Detected Lesions	54	91.5
- DSA Performed	30	50.8
- Ultrasonography Performed	59	100
Key MRI Sequences & Diagnostic Contribution		
- SWI Detected Hemosiderin (Cavernomas)	17/18	94.4
- 4D Flow / ANGIO TWIST Identified AV Shunting	22/25	88
Additional MRI Findings		
- Intracranial Hemorrhage	20	33.9
- Perilesional Edema	14	23.7

Table-I. Summary of patient characteristics, imaging modalities, and key findings (N = 59)

Imaging Parameter	No. of Positive Cases	Sensitivity	Specificity	PPV	NPV
MRI as a whole	54	91.5%	N/A	N/A	N/A
SWI (for Cavernomas)	17	94.4%	N/A	N/A	N/A
ANGIO TWIST / 4D Flow (for AVMs)	22	88.0%	N/A	N/A	N/A
1.5T MRI	31	72.7%	92.9%	94.1%	68.4%
3T MRI	28	85.7%	100.0%	100.0%	50.0%

Table-II. Diagnostic performance of key imaging parameters in brain vascular malformations

Similarly, Jagadeesan et al. (2011) demonstrated that post-contrast SWI improves the visualization of arteriovenous shunting—a finding aligned with our 88% detection rate using 4D flow/ANGIO TWIST.[9]

In contrast to ultrasonography, which showed limited specificity in our study, other groups, including Zafar et al., concluded that ultrasound is only valuable as a preliminary screening tool for superficial or neonatal cranial vasculature. The poor intracranial resolution makes it unsuitable for deep-seated malformations or precise subtype classification, which we also observed in our patient cohort.[1]

Our lesion subtype distribution—AVMs (42.4%), cavernomas (30.5%), and DVAs (16.9%)—is highly concordant with systematic analyses by Castillo-Rangel et al.[2] and He et al. (2024)[12], both of whom noted AVMs as the most common symptomatic vascular malformations in neurosurgical referral populations. These results validate our sample composition and emphasize the clinical burden of AVMs as a dominant diagnostic and therapeutic target.

Although invasive, DSA proved indispensable in half of our cases by confirming flow dynamics and angioarchitecture not fully visualized on MRI. This complementarity has been well documented in studies such as Mossa-Basha et al. (2012) and Guest & Krings (2021), who advocate DSA not just for initial diagnosis but also for post-treatment monitoring and embolization planning.[4,7]

ANGIO TWIST and 4D flow sequences offer a promising non-invasive alternative with increasing

accuracy, yet the real-time and dynamic imaging capacity of DSA remains unmatched in certain contexts, particularly for endovascular planning. These findings further justify a hybrid diagnostic workflow, where MRI acts as a high-resolution screening tool, and DSA serves as a confirmatory modality when therapeutic intervention is contemplated.

While not directly applied in our cohort, we included discussion of radiomics and machine learning (ML), technologies gaining traction for their potential in risk stratification, lesion characterization, and outcome prediction. Grossen et al. systematically evaluated ML-based radiomic models and found their utility in differentiating high-risk AVMs based on imaging phenotypes—an area with immense promise for personalized care.[11] Similarly, He et al. suggested that ML-driven platforms can integrate multimodal imaging and clinical parameters to optimize prognostic modeling.[12]

In comparison with a prior study reporting an MRI sensitivity of 80.0%, specificity of 94.4%, positive predictive value (PPV) of 97.3%, and negative predictive value (NPV) of 65.4% for detecting AVMs confirmed by DSA[13], our study demonstrated a higher sensitivity of 91.5% using a comprehensive multiparametric MRI protocol. While the earlier study emphasized high specificity and PPV, our enhanced sensitivity may be attributed to the inclusion of advanced sequences such as SWI and ANGIO TWIST/4D Flow, which are particularly effective in identifying microhemorrhages and arteriovenous shunting.

These advancements support a paradigm shift in neuroimaging from descriptive analysis to predictive and prescriptive analytics, which could eventually reduce dependance on invasive procedures and enable automated surveillance algorithms.

Despite its strengths, this study has several limitations. First, the sample size was relatively small (n = 59), which may limit the generalizability of the findings across broader populations. Second, not all patients underwent DSA, leading to partial comparative data for MRI accuracy confirmation. Third, the study was conducted in a single center, potentially introducing institutional bias in imaging protocols and diagnostic interpretation. Lastly, radiomics and machine learning applications were only discussed contextually and not empirically applied, limiting the evaluation of their actual clinical impact.

Future studies should aim for multicenter collaboration with larger cohorts to validate diagnostic algorithms and imaging performance across various settings. Further integration of artificial intelligence, radiomics, and functional imaging into clinical protocols should be actively pursued and tested for efficacy in both diagnosis and outcome prediction. Additionally, long-term follow-up studies are warranted to assess the prognostic value of initial imaging findings and the impact of imaging-guided treatment planning on clinical outcomes.

CONCLUSION

In conclusion, imaging—particularly advanced MRI and DSA—plays a critical role in the diagnosis, classification, and treatment planning of brain vascular malformations. SWI and 4D flow sequences significantly enhance detection of cavernomas and AVMs, respectively, while DSA remains essential for confirming shunting and planning interventions. Emerging technologies like radiomics and AI promise a new era of personalized diagnosis and management. Adoption of these imaging strategies can substantially improve clinical outcomes by enabling earlier detection, accurate classification, and more tailored treatment approaches.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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REFERENCES

1. Zafar A, Fiani B, Hadi H, Arshad M, Cathel A, Naeem M, et al. **Cerebral vascular malformations and their imaging modalities.** Neurological Sciences. 2020 Sep; 41:2407-21.

2. Castillo-Rangel C, Marin G, Hernandez-Contreras KA, Zarate-Calderon C, Vichi-Ramirez MM, Cortez-Saldias, et al. **Atlas of nervous system vascular malformations: A systematic review.** Life. 2022 Aug 7; 12(8):1199.

3. Kashiwagi S, van Loveren HR, Tew JM, Wiot JG, Weil SM, Lukin RA. **Diagnosis and treatment of vascular brain-stem malformations.** Journal of Neurosurgery. 1990 Jan 1; 72(1):27-34.

4. Guest W, Krings T. **Brain arteriovenous malformations: The role of imaging in treatment planning and monitoring response.** Neuroimaging Clinics. 2021 May 1; 31(2):205-22.

5. Imakita S, Nishimura T, Yamada N, Naito H, Takamiya M, Yamada Y, et al. **Cerebral vascular malformations: Applications of magentic resonance imaging to differential diagnosis.** Neuroradiology. 1989 Sep; 31:320-5.

6. Li X, Su F, Yuan Q, Chen Y, Liu CY, Fan Y. **Advances in differential diagnosis of cerebrovascular diseases in magnetic resonance imaging: A narrative review.** Quantitative Imaging in Medicine and Surgery. 2023 Feb 22; 13(4):2712.

7. Mossa-Basha M, Chen J, Gandhi D. **Imaging of cerebral arteriovenous malformations and dural arteriovenous fistulas.** Neurosurgery Clinics. 2012 Jan 1; 23(1):27-42.

8. Martín-Noguerol T, Concepción-Aramendia L, Lim CT, Santos-Armentia E, Cabrera-Zubizarreta A, Luna A. **Conventional and advanced MRI evaluation of brain vascular malformations.** Journal of Neuroimaging. 2021 May; 31(3):428-45.

9. Jagadeesan BD, Delgado Almandoz JE, Benzinger TL, Moran CJ. **Postcontrast susceptibility-weighted imaging: a novel technique for the detection of arteriovenous shunting in vascular malformations of the brain.** Stroke. 2011 Nov; 42(11):3127-31.

10. Zafar A, Fiani B, Hadi H, Arshad M, Cathel A, Naeem M, et al. **Cerebral vascular malformations and their imaging modalities.** Neurological Sciences. 2020 Sep; 41:2407-21.

11. Grossen AA, Evans AR, Ernst GL, Behnen CC, Zhao X, Bauer AM. **The current landscape of machine learning-based radiomics in arteriovenous malformations: A systematic review and radiomics quality score assessment.** Frontiers in Neurology. 2024 Jun 10; 15:1398876.

12. He Q, Huo R, Sun Y, Zheng Z, Xu H, Zhao S, et al. **Cerebral vascular malformations: pathogenesis and therapy.** MedComm. 2024 Dec; 5(12):e70027.

13. Vella M, Alexander MD, Mabray MC, Cooke DL, Amans MR, Glastonbury CM, et al. **Comparison of MRI, MRA, and DSA for detection of cerebral arteriovenous malformations in hereditary hemorrhagic telangiectasia.** American Journal of Neuroradiology. 2020 Jun 1; 41(6):969-75.

AUTHORSHIP AND CONTRIBUTION DECLARATION	
1	**Mudassar Ahmed Bajwa:** Data collection, drafting.
2	**Mishal Waheed Butt:** Design, proof reading.
3	**Amina Iqbal:** Data analysis, interpretations.