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EDITORIAL (BY INVITATION)

Advancing vessel wall imaging in intracranial aneurysms: a crucial step towards improved patient management?

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Intracranial aneurysms pose a significant challenge in neurosurgical practice due to their potential for rupture with possible catastrophic consequences. The management of these aneurysms requires a comprehensive understanding of the intricate pathology involved. Vessel wall imaging (VWI), using so-called using dedicated MRI sequences, has emerged as a promising new tool that can provide valuable insights into the pathophysiology and natural history and may guide treatment strategies for unruptured and ruptured intracranial aneurysms.

Traditionally, the evaluation of intracranial aneurysms using imaging has primarily focused on luminal abnormalities documented by CTA, by MRA, and, most accurately, by DSA. In addition to clinical risk factors, such as smoking, high blood pressure, family history, and PHASES score, morphologic criteria such as location, size, shape, and specific geometric features including aspect ratio have been used to identify aneurysms with a potential to either growth or rupture [11]. More than a decade ago, computational fluid dynamics (CFD) have become a significant research field to explore various hemodynamic parameters including wall shear stress, oscillating wall shear stress, aneurysm growth factor, and others as potential biomarkers for growth and rupture of cerebral aneurysms [9, 12].

However, since inflammatory processes in the aneurysmal wall have been identified as key driving factors in aneurysmal pathophysiology [15], recent studies have emphasized a novel and critical role of vessel wall imaging [11, 13, 17]. Techniques, such as high-resolution magnetic resonance imaging (MRI) including so-called black blood (BB) technique, enable direct visualization of the aneurysm wall, providing novel valuable information about its morphology, thickness, composition, and, most importantly, and the state of inflammation [10]. The latter is of particular interest as there is increasing evidence that activation of macrophages in the aneurysm wall could play a role in its destabilization leading to progressive weakening with subsequent growth and rupture [6, 8]. As demonstrated by Dinia et al., VWI may allow to differentiate between asymptomatic ("stable") and symptomatic ("unstable") aneurysms. Therefore, by studying the vessel (aneurysm) wall itself, for the first time, clinicians could gain insights into the underlying pathology of cerebral aneurysms and acquire knowledge with the potential to enhance risk stratification, guide treatment decisions, and improve patient outcomes. This information aids in tailoring individualized treatment plans, ranging from conservative management and surveillance to endovascular coiling or surgical clipping. Accurate risk stratification reduces the uncertainty surrounding treatment decisions and enhances patient safety by identifying high-risk (symptomatic, ruptured or "unstable") lesions that may benefit from early intervention. At the same time, it would enable to follow low-risk (asymptomatic or "stable") lesions with serial imaging and to either ensure long-term aneurysm stability or identify residual or recurrent pathology and adapt the management strategy accordingly. By facilitating early detection of instability or aneurysm recurrence, vessel wall imaging may help to improve patient outcomes and may reduce the need for invasive follow-up procedures.

While VWI holds great promise, there are numerous challenges that need to be addressed before its widespread clinical implementation. Spatial resolution of current 3-T MRI scanners is limited, and the question arises whether a very thinned aneurysmal wall of 0.02–0.50 mm could accurately be imaged in clinical practice (even 7-T systems may not always be sufficient). Intraaneurysmal flow pattern may affect the MRI signal and cause false-positive results, especially in larger aneurysms where the flow near the wall is slow and likely simulates VW enhancement [2, 3]. Increased signal intensity by clot material inside or outside the aneurysm may hinder reliable assessment of wall thickness and could mimic wall enhancement. Furthermore, pulsation

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artifacts can cause "increased wall thickness," which possibly could be compensated by cardiac gating. The so-called circumferential aneurysmal wall enhancement (CAWE), described by some investigators as surrogate marker for aneurysm instability [4], was not specifically used in the study presented here. In addition, the number of aneurysms undergoing histologic studies was relatively small to send a strong message and more such data are certainly needed. More longitudinal studies to monitor VWI findings in untreated non-ruptured aneurysms over longer time frames must be conducted [17]. Standardization of imaging protocols, interpretation criteria (focal or circumferential aneurysmal WE), and the development of dedicated software for image analysis are necessary steps towards ensuring consistency and reliability across institutions.

Additionally, advancements in imaging technology, such as increased spatial resolution and faster acquisition techniques, will further enhance the diagnostic accuracy and efficiency. Correlation with other imaging modalities such as dynamic contrast enhanced MRI [14, 16], 4D-MRI [1], and CFD [18] would be beneficial for better understanding of both signs and pitfalls.

It should be noted that aneurysm wall enhancement per se could be a reflection of microvascular changes and, therefore, be seen as an indirect sign rather than a direct specific marker for an inflammatory process. Therefore, a more direct approach to detect macrophages activity using ferumoxytol [5] or as recently demonstrated, oxidatively activated Fe-PyC3A [7], could help to further validate this new promising imaging modality.

Vessel wall imaging may represent a paradigm shift in the management of unruptured and ruptured intracranial aneurysms, allowing clinicians to move beyond luminal assessment and gain a deeper understanding of the underlying pathology. By providing crucial insights into aneurysm stability and detecting developing instability, treatment planning and monitoring patients could be substantially improved. Although the study of Dinia et al. has some limitations, it adds valuable information to our existing knowledge of the subject matter. Further research and collaboration among clinicians, radiologists, and MRI physicists are essential to refine the techniques, develop standardized protocols, and establish the full potential of VWI in the management of unruptured and ruptured intracranial aneurysms.

References

1. Castle-Kirszbaum M et al (2020) Four-Dimensional Magnetic Resonance Imaging Assessment of Intracranial Aneurysms: A State-of-the-Art Review. Neurosurgery 87(3):453–465
2. Cornelissen BM et al (2019) Insufficient slow-flow suppression mimicking aneurysm wall enhancement in magnetic resonance vessel wall imaging: a phantom study. Neurosurg Focus 47(1):E19
3. Cornelissen BM et al (2019) Vessel wall enhancement of intracranial aneurysms: fact or artifact? Neurosurg Focus 47(1):E18
4. Edjlali M et al (2014) Does aneurysmal wall enhancement on vessel wall MRI help to distinguish stable from unstable intracranial aneurysms? Stroke 45(12):3704–3706
5. Hasan D et al (2012) Early change in ferumoxytol-enhanced magnetic resonance imaging signal suggests unstable human cerebral aneurysm: a pilot study. Stroke 43(12):3258–3265
6. Kim NH et al (2023) The role of vessel wall imaging in determining the best treatment approach for coexisting aneurysms and subarachnoid hemorrhage. Acta Neurol Belg 123(3):933–938
7. King RM et al (2023) Molecular Magnetic Resonance Imaging of Aneurysmal Inflammation Using a Redox Active Iron Complex. Investig Radiol 58(9):656–662
8. Larson AS, Lehman VT, Lanzino G, Brinjikji W (2020) Lack of Baseline Intracranial Aneurysm Wall Enhancement Predicts Future Stability: A Systematic Review and Meta-Analysis of Longitudinal Studies. AJNR Am J Neuroradiol 41(9):1606–1610
9. Mantha A et al (2006) Hemodynamics in a cerebral artery before and after the formation of an aneurysm. AJNR Am J Neuroradiol 27(5):1113–1118
10. Matouk CC et al (2013) Vessel wall magnetic resonance imaging identifies the site of rupture in patients with multiple intracranial aneurysms: proof of principle. Neurosurgery 72(3):492–496 discussion 496
11. Maupu C, Lebas H, Boulaftali Y (2022) Imaging modalities for intracranial aneurysm: more than meets the eye. Front Cardiovasc Med 9:793072
12. Meng H, Tutino VM, Xiang J, Siddiqui A (2014) High WSS or low WSS? Complex interactions of hemodynamics with intracranial aneurysm initiation, growth, and rupture: toward a unifying hypothesis. AJNR Am J Neuroradiol 35(7):1254–1262
13. Molenberg R et al (2021) Intracranial aneurysm wall enhancement as an indicator of instability: a systematic review and meta-analysis. Eur J Neurol 28(11):3837–3848
14. Qi H et al (2019) Complementary Roles of Dynamic Contrast-Enhanced MR Imaging and Postcontrast Vessel Wall Imaging in Detecting High-Risk Intracranial Aneurysms. AJNR Am J Neuroradiol 40(3):490–496
15. Tulamo R, Frosen J, Hernesniemi J, Niemela M (2018) Inflammatory changes in the aneurysm wall: a review. J Neurointerv Surg 10(Suppl 1):i58–i67
16. Vakil P et al (2015) Quantifying Intracranial Aneurysm Wall Permeability for Risk Assessment Using Dynamic Contrast-Enhanced MRI: A Pilot Study. AJNR Am J Neuroradiol 36(5):953–959
17. Vergouwen MD et al (2019) Gadolinium Enhancement of the Aneurysm Wall in Unruptured Intracranial Aneurysms Is Associated with an Increased Risk of Aneurysm Instability: A Follow-Up Study. AJNR Am J Neuroradiol 40(7):1112–1116
18. Xiao W et al (2018) Low Wall Shear Stress Is Associated with Local Aneurysm Wall Enhancement on High-Resolution MR Vessel Wall Imaging. AJNR Am J Neuroradiol 39(11):2082–2087