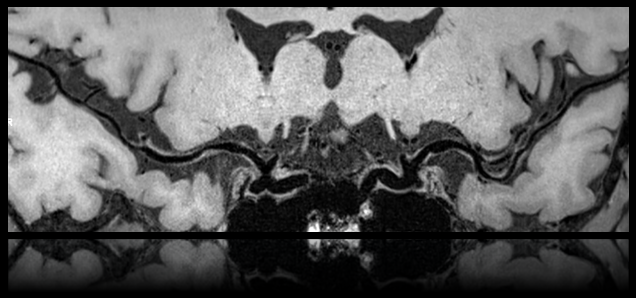
High-resolution Vessel Wall Imaging in Intracranial Vasculopathies



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Director, MR Imaging Research

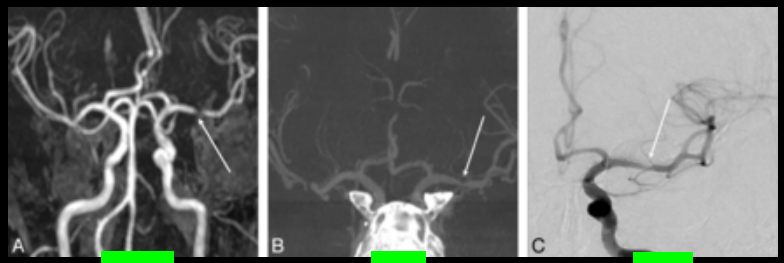
Radiology & Radiation Oncology

Jan 27, 2021

Keck School of Medicine of USC

Why Do We Need Vessel Wall Imaging?

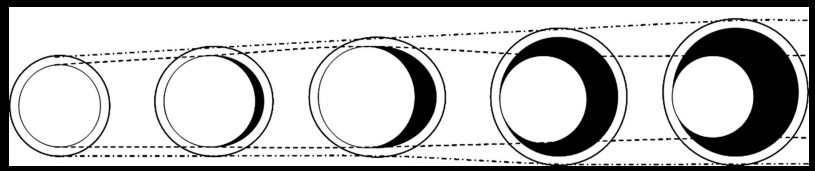
- **Limited information on wall pathologies from luminal imaging**
  - **Stenosis or luminal irregularity can be caused by diverse etiologies**
    - Atherosclerosis
    - Dissection
    - Moyamoya's
    - Vasculitis
    - Vasospasm



A 55-year-old man presented with right-sided hemiparesis.[1]

- **Stenotic severity is not equal to disease severity or risk**

Positive Remodeling[2]



1. Jeon JS et al. Am J Neuroradiol 2013;34:129

2. Glagov et al. N Engl J Med. 1987;316:1371

Why Do We Need Vessel Wall Imaging?

- In 10-40% ischemic stroke, the cause cannot be determined after a standard diagnostic evaluation.

The NEW ENGLAND JOURNAL of MEDICINE

CLINICAL PRACTICE

Caren G. Solomon, M.D., M.P.H., *Editor*

Cryptogenic Stroke

Jeffrey L. Saver, M.D.

Cryptogenic mechanisms account for 10 to 40% of all ischemic strokes.[1-4] This range reflects varying definitions across series, evolution in diagnostic technology, differing conceptions of adequate etiologic investigation, and the fact that there are more than 200 known causes of ischemic stroke potentially requiring exclusion.[5,6] In general, the percentage of ischemic strokes that are classified as crypto-

forming extensive testing.[3,4] However, stroke that is cryptogenic after a standard diagnostic evaluation remains a common clinical challenge, accounting for 20 to 30% of all ischemic strokes[7] and therefore occurring in 120,000 to 180,000 patients each year in the United States.

N Engl J Med 2016;374:2065

- Direct visualization of the vessel wall can provide invaluable insights

- Method-of-Choice -- Magnetic Resonance (MR) vessel wall imaging (VWI)
  - Noninvasive
  - Radiation free
  - Black-blood contrast: blood signal is suppressed
  - Flexible soft tissue contrast: T1w, T2w

MR Vessel Wall Imaging (VWI)

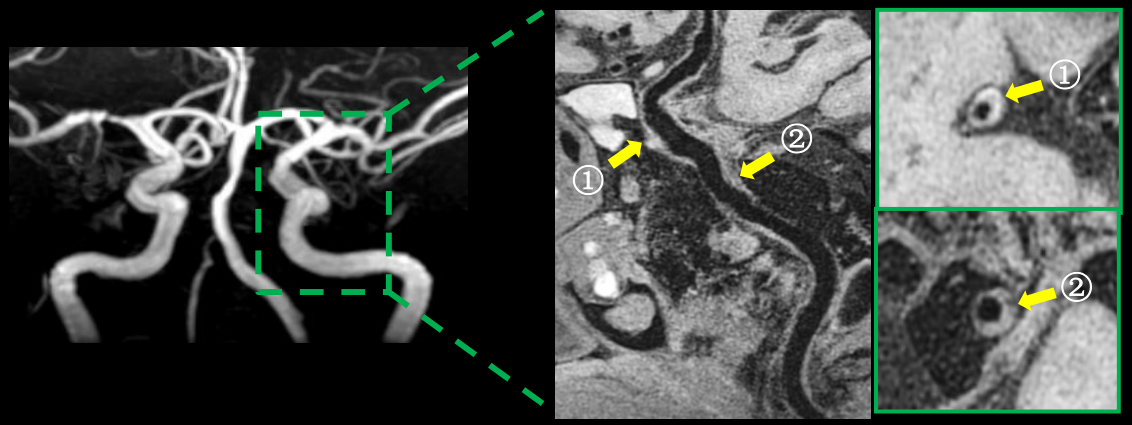
❖ Imaging markers beyond vessel lumen

❖ Vessel wall geometric features[1]:

thickness, area, remodeling index, normalized index, …

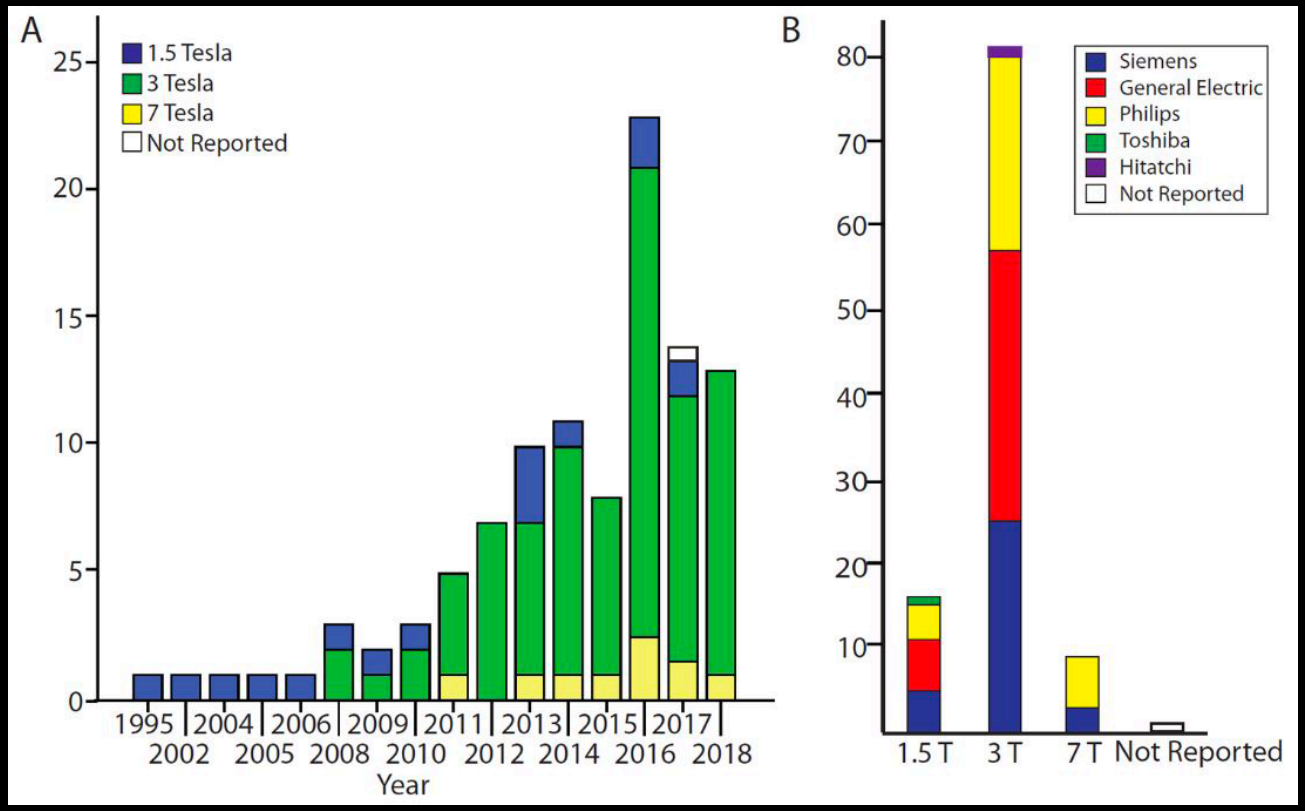
❖ Vessel wall signal features[2,3]:

hyper-intense feature (intraplaque hemorrhage), post-contrast enhancement (inflammation)

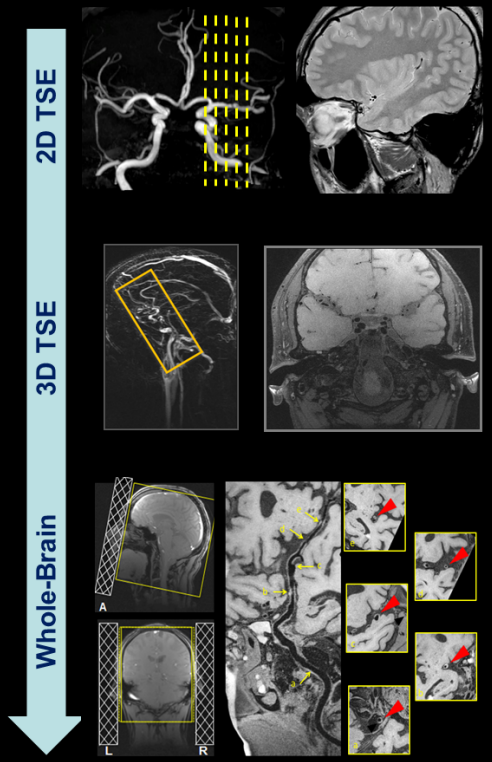


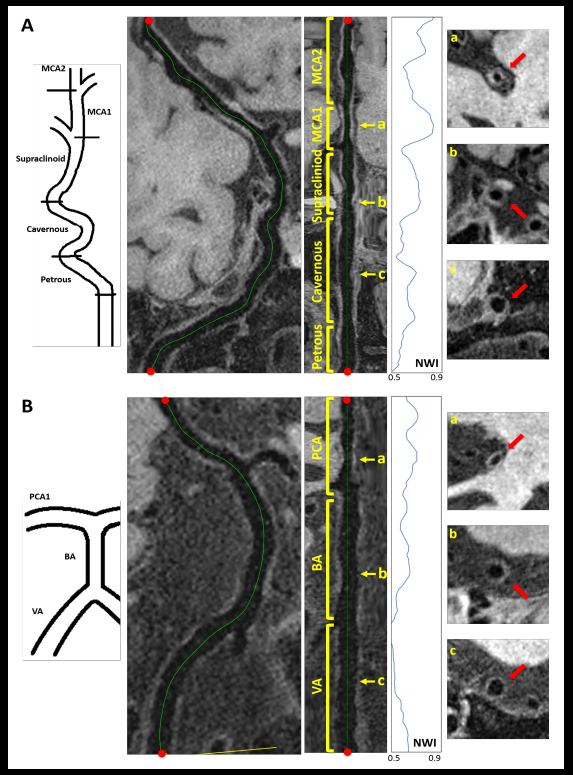
1. Xu WH et al. Atherosclerosis 2010; 2. Xu WH et al. Ann Neurol 2012; 3. Swartz RH et al. Neurology 2009

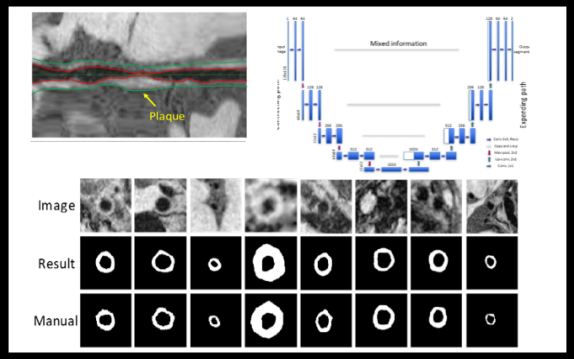
Intracranial VWI

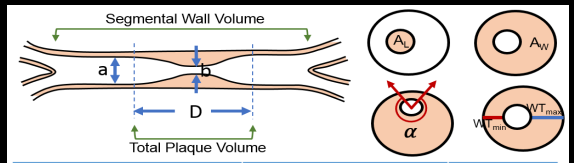


Technical Evolvement of Intracranial VWI





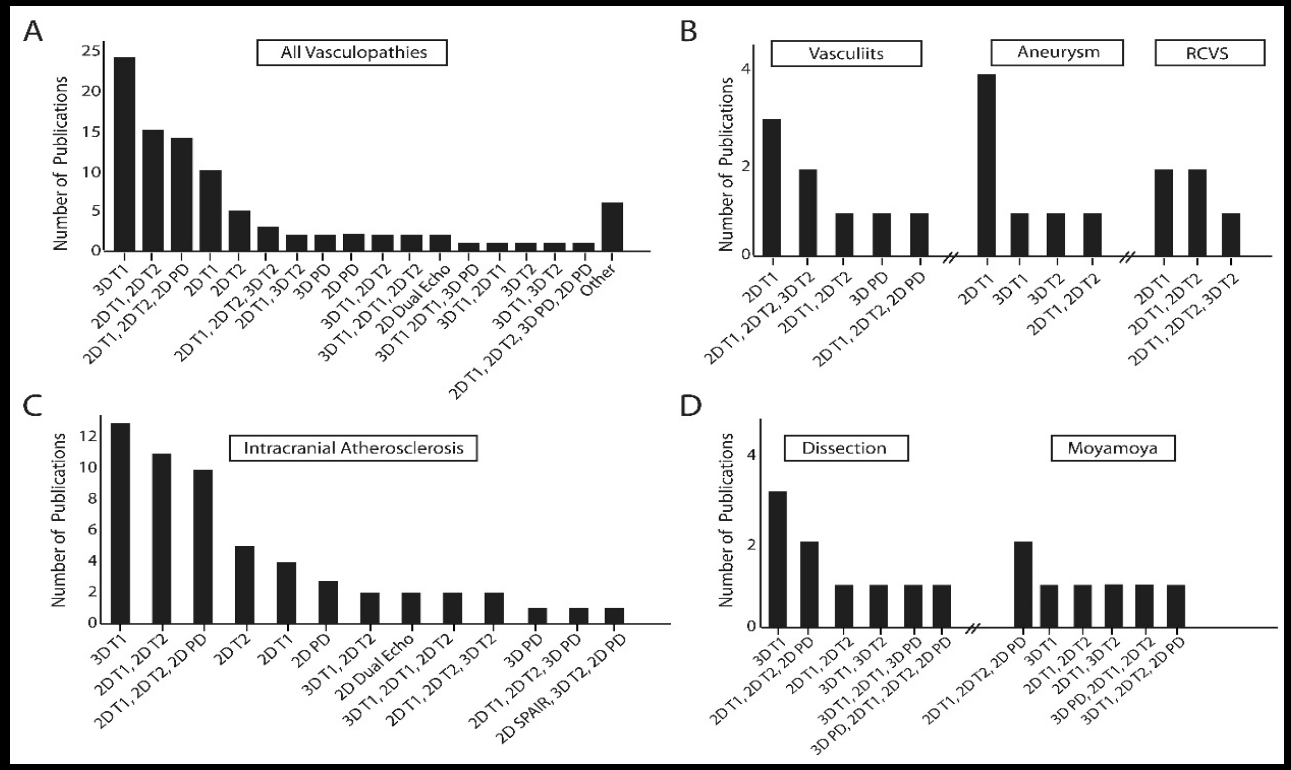




	Quantitative Features	Definition	Potentially Associated Stroke Mechanisms*
1	Diameter Stenosis	(a-b)/a x 100%	I, III
2	Normalized Wall Index (NWI)	$A_W/(A_W+A_L)$	I, II, III
3	Eccentricity Index (EI)	$(WT_{max} - WT_{min})/WT_{max}$	I, II
4	Remodeling Ratio (RR)	$(A_W+A_L)_{plaque}/(A_W+A_L)_{reference}$	I, II
5	Angular Involvement (AI)	α (0 – 360 °)	I, II
6	Diffuseness	D	I, II, III
7	Total Plaque Volume (TPV)	Wall volume for the focal plaque	I, II, III
8	Segmental Wall Volume (SWV)	Wall volume for the segment	I, II, III
9	Plaque-Wall Contrast Ratio (CR)	$Signal_{plaque}/Signal_{wall}$	I
10	Contrast Enhancement Ratio (ER)	$(Normalized\ Signal_{plaque})_{post}$ / $(Normalized\ Signal_{plaque})_{pre}$	I

1. Fan Z et al. Magn Reson Med. 2017;77:1142. *2. Yang Q, Fan Z et al. J Magn Reson Imaging 2017;46;751.* *3. Shi F, Fan Z, et al. IEEE Trans Biomed Eng 2019;66:2840*

Clinical Protocol of Intracranial VWI



Song JW, Fan Z, et al J Neuroimaging 2020;30:428-442

Assessment of Intracranial Vasculopathies with MR VWI @ 3T

- Intracranial Atherosclerosis Disease (ICAD)
- Dissection
- Vasculitis
- Moyamoya Vasculopathy
- Intracranial Aneurysm
- Reversible Cerebral Vasoconstriction Syndrome

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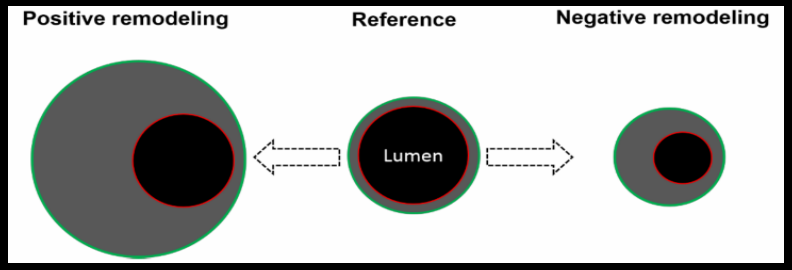
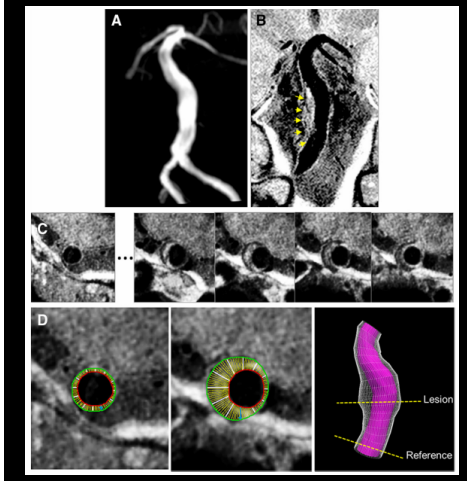
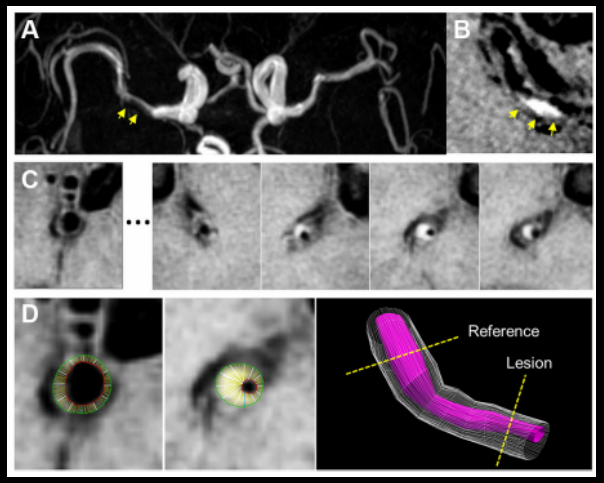
Remodeling in Atherosclerotic Plaque



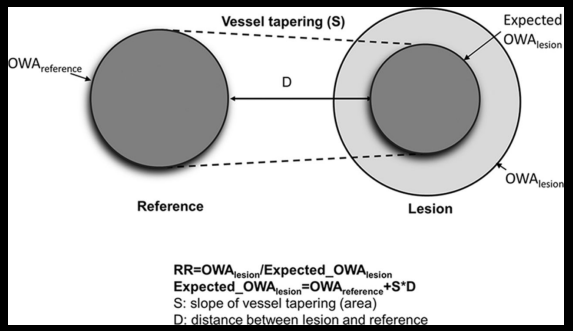


Positive Remodeling



Negative Remodeling

Remodeling ratio



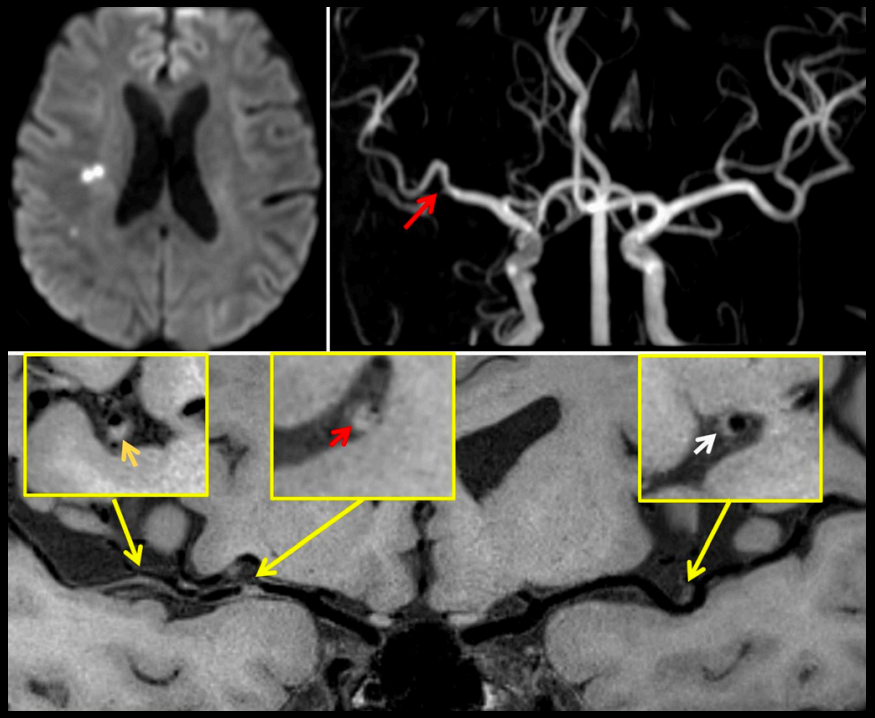
Clinical Study:

- 42 patients with TIA or ischemic stroke
- 137 plaques (87 anterior; 50 posterior)

	Anterior Circulation (87 Plaques)	Posterior Circulation (50 Plaques)	*P* Value*
Stenosis (diameter, WASID)	35.2±25.4	41.9±27.0	0.10
Arterial remodeling ratio (RR)	0.95±0.32	1.15±0.38	0.002

Qiao Y et al. Stroke 2016;47:434

Thickening in Atherosclerotic Plaque



A 62 yo male, right ischemic stroke

The thickening pattern:

- Type 1 (<50% cross-sectional wall involvement)
- Type 2 (≥50% cross-sectional wall involvement)

Clinical Study:

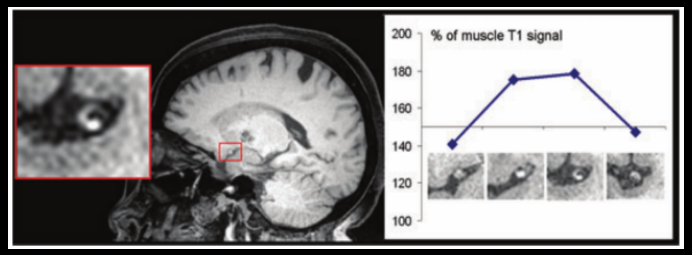
- **52 patients with < 30 days unilateral ischemic stroke** in the territory of the anterior circulation.
- **178 plaques**: 107 (60.1%) on the symptomatic side, 71 (39.9%) on the asymptomatic side.
- **Culprit: 52**, probably culprit: 51, nonculprit: 75

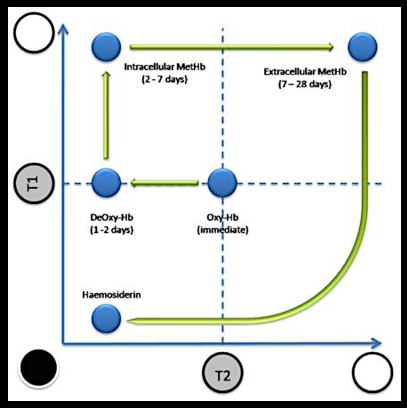
Variable	Culprit Lesions	Probably Culprit Lesions	Nonculprit Lesions
Thickening pattern			
Type 1	12 (23.1)	36 (70.6)	61 (81.3)
Type 2	40 (76.9)	15 (29.4)	14 (18.7)

Wu F, Fan Z et al. J Am Heart Assoc. 2018;7:e009705

High T1-signal Feature in Atherosclerotic Plaque

Turan TN et al. Journal of Neuroimaging 2011;21:e159

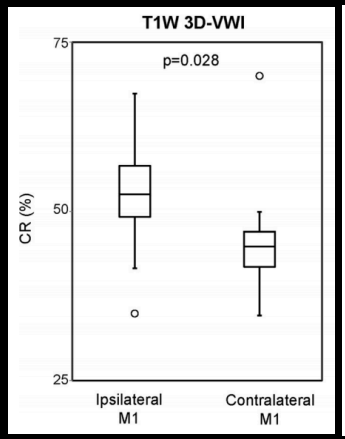


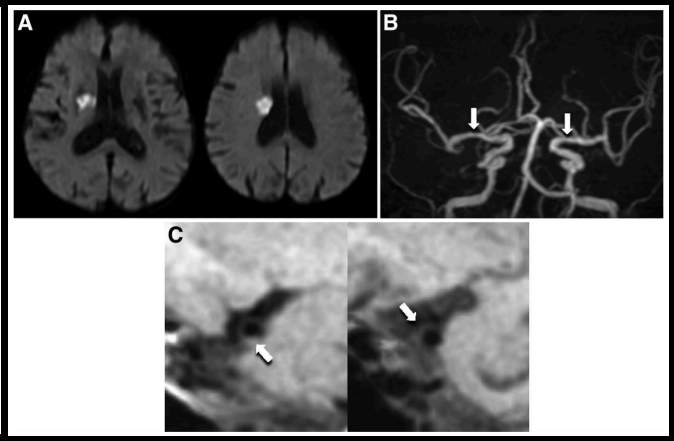


Natori T et al. J Stroke Cerebrovasc Dis 2014;23:706

18 consecutive patients with acute noncardioembolic stroke in the MCA territory

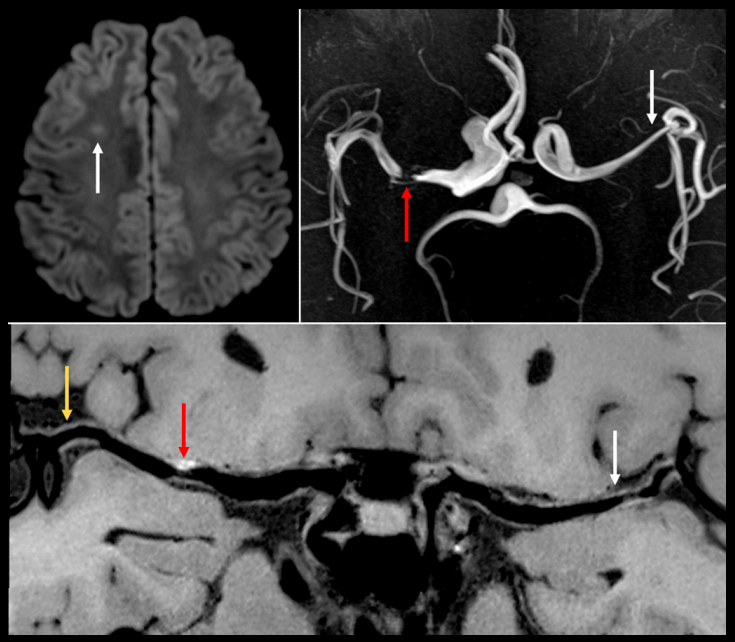
Contrast ratio: CR = (S_{plaque}/S_{cc})x100,
S_{plaque} and S_{cc} denotes signal intensity of plaque and corpus callosum





A 84 yo female, right ischemic stroke

High T1-signal Feature in Atherosclerotic Plaque



A 46 yo male, right ischemic stroke

Clinical Study:

- **52 patients with < 30 days unilateral ischemic stroke** in the territory of the anterior circulation.
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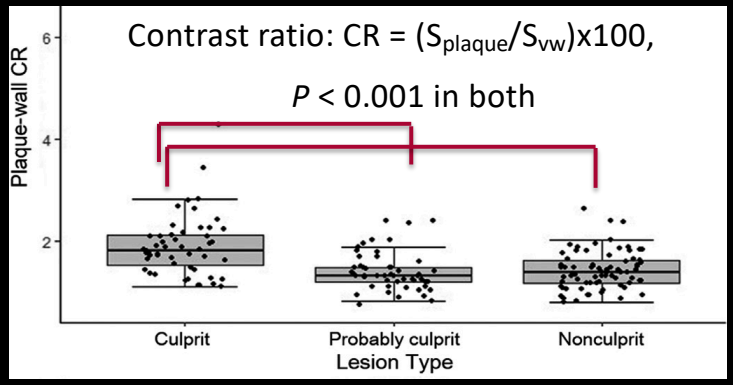
- **Culprit: 52**, probably culprit: 51, nonculprit: 75



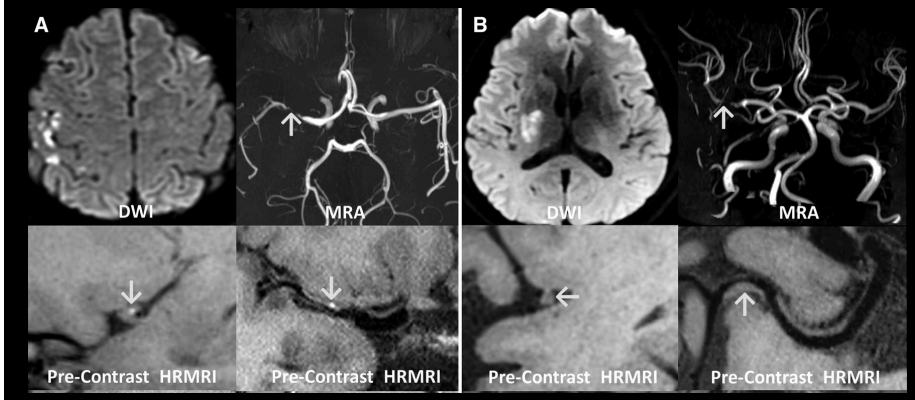
Wu F, Fan Z et al. J Am Heart Assoc. 2018;7:e009705

High T1-signal Feature in Atherosclerotic Plaque

Hyperintense Plaque on Intracranial Vessel Wall Magnetic Resonance Imaging as a Predictor of Artery-to-Artery Embolic Infarction

Fang Wu, MD*; Haiqing Song, MD*; Qingfeng Ma, MD; Jiayu Xiao, MD; Tao Jiang, MD; Xiaoqin Huang, MD; Xiaoming Bi, PhD; Xiuhai Guo, MD; Debiao Li, PhD; Qi Yang, MD; Xunming Ji, MD; Zhaoyang Fan, PhD; on behalf of the WISP Investigators†

Stroke 2018:49:905



A-to-A embolic **Non-A-to-A embolic**

74 patients with MCA territory stroke were divided into A-to-A embolic infarction and non–A-to-A embolic infarction groups based on diffusion-weighted imaging findings

	Univariate			Multivariate		
WB-HRMRI Characteristics	A-to-A Embolism	Non–A-to-A Embolism	*P* Value	OR	95% CI	*P* Value
No. of plaques, n (%)	36 (48.6)	38 (51.4)		…	…	…
Location				…	…	…
MCA, n (%)	30 (83.3)	38 (100)				
Intracranial ICA, n (%)	6 (16.7)	0 (0)				
Presence of HIP, n (%)	27 (75.0)	8 (21.1)	< 0.001	11.2	3.5–36.2	< 0.001

Plaque Surface Irregularity in Atherosclerotic Plaque

Hyperintense Plaque on Intracranial Vessel Wall Magnetic Resonance Imaging as a Predictor of Artery-to-Artery Embolic Infarction

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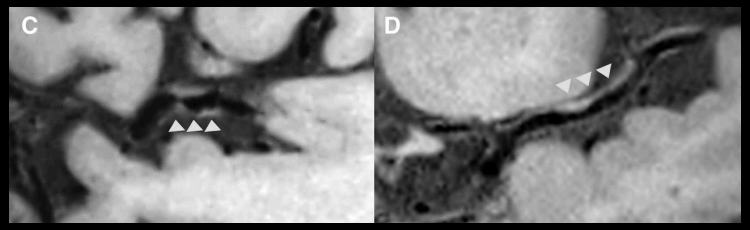
Stroke 2018:49:905



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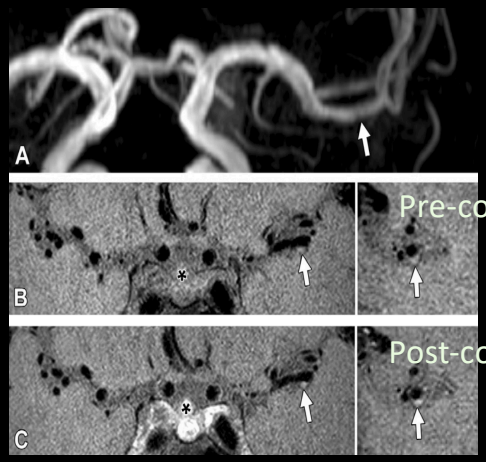
Intracranial ICA, n (%)	6 (16.7)	0 (0)				
Presence of HIP, n (%)	27 (75.0)	8 (21.1)	< 0.001	11.2	3.5–36.2	< 0.001
Plaque surface irregularity, n (%)	15 (41.7)	7 (18.4)	0.029	3.7	1.0–13.0	0.045

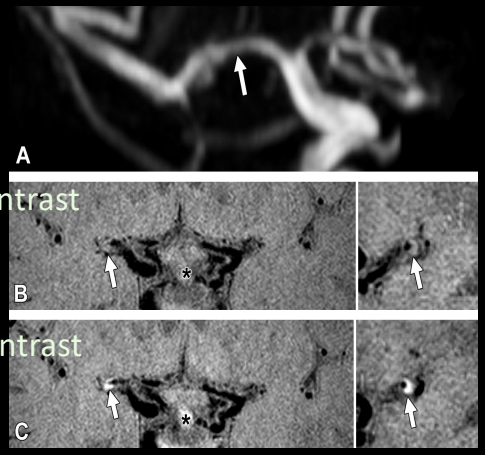
Contrast Enhancement in Atherosclerotic Plaque

Clinical Study:

- **20 patients with acute stroke.**
- **78 plaques**
- **Culprit: 21**, probably culprit: 12, nonculprit: 45



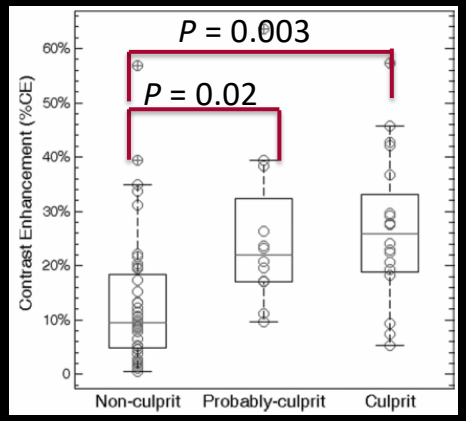
A 42 yo male,
Grade 1 enhancement



A 61 yo female,
Grade 2 enhancement

$CE = (S_{postBBMR}-S_{preBBMR})/S_{preBBMR} \times 100\%$

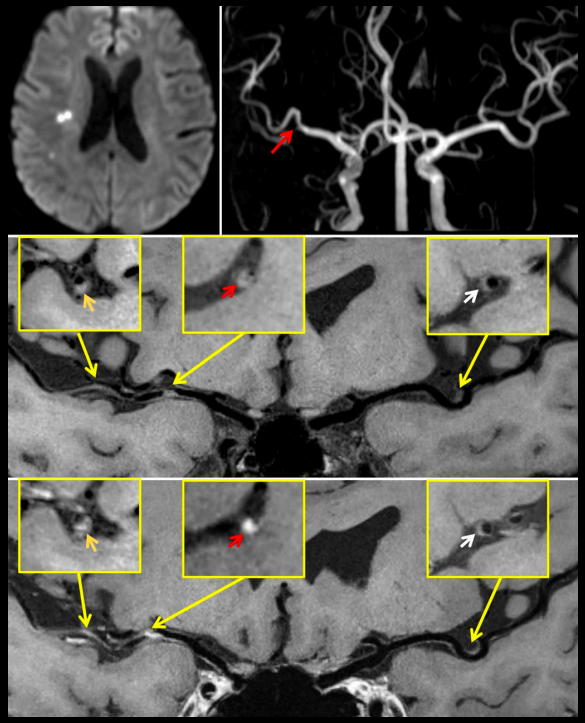
Grade 0: < CE of normal wall
Grade 1: > CE of normal wall, and
< CE of pituitary infundibulum
Grade 2: > CE of pituitary infundibulum



Grade 2 contrast enhancement was independently associated with culprit plaques (odds ratio 34.6; 95% CI: 4.5-266.5; p = 0.001).

Qiao Y et al. Radiology. 2014;271:534-42.

Contrast Enhancement in Atherosclerotic Plaque

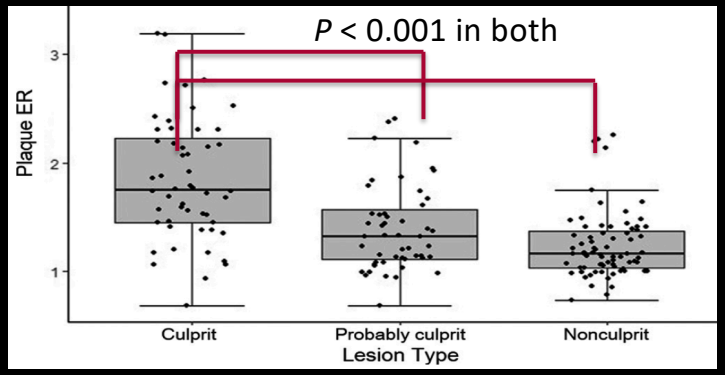


A 62 yo male, right ischemic stroke

Grade 2 enhancement

Clinical Study:

- **52 patients with < 30 days unilateral ischemic stroke** in the territory of the anterior circulation.



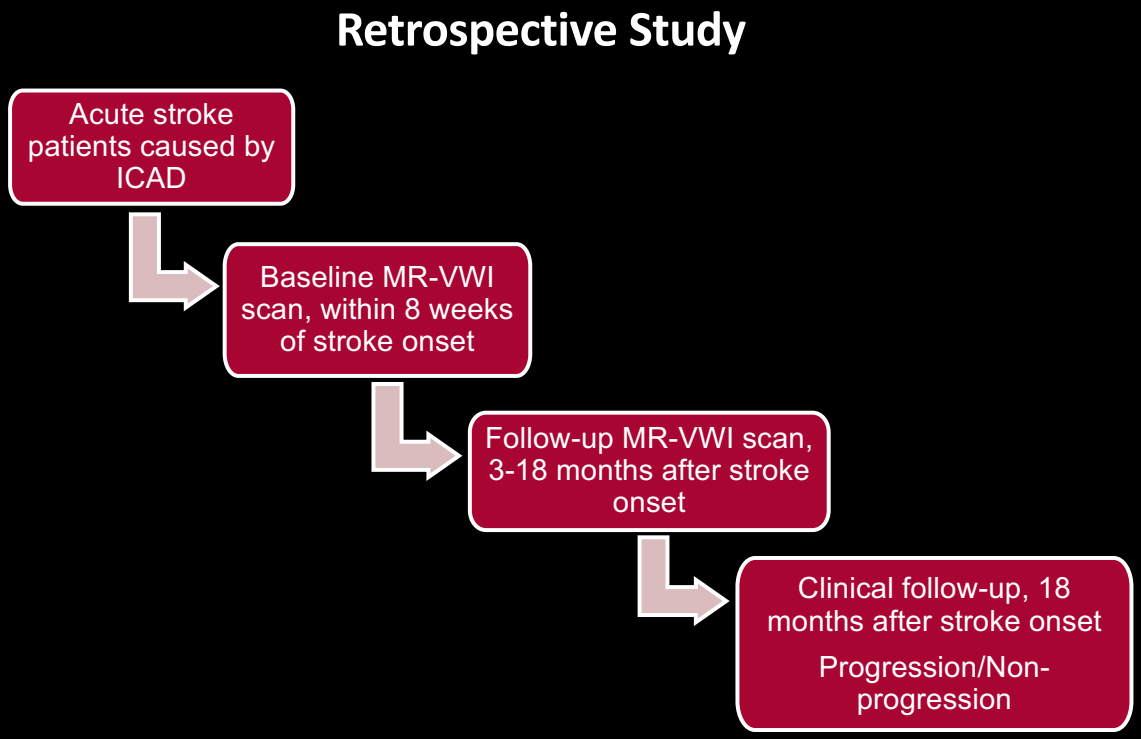
Grade 2 contrast enhancement (OR, 17.4; 95% CI, 1.8–164.9; *p*=0.013) was independently associated with culprit lesions.

Wu F, Fan Z et al. J Am Heart Assoc. 2018;7:e009705

Monitoring Medical Therapy in Symptomatic ICAD Patients

- Despite intensive medical management, the rate of recurrent stroke is 13% in the 1st year and as high as 35% in certain populations by 2 years.[2]

- Can we quantitatively monitor therapeutic response of plaques with VWI?

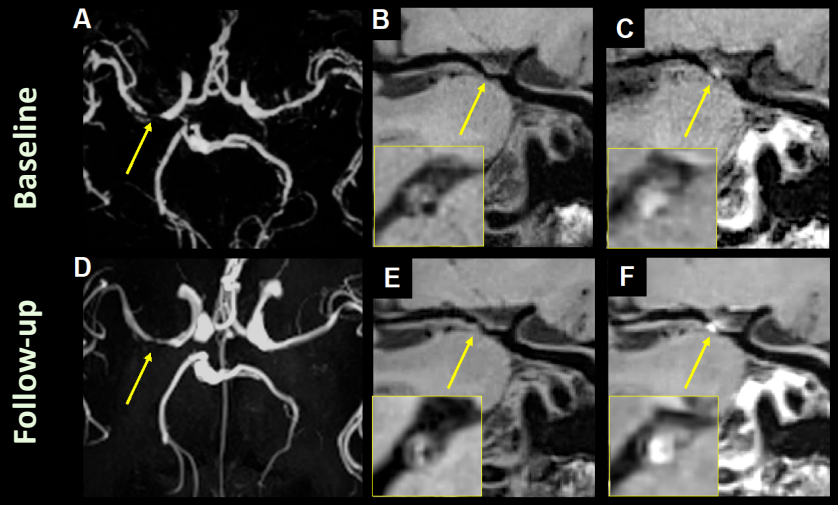


Xiao J, Fan Z, et al. Paper under review

Monitoring Medical Therapy in Symptomatic ICAD Patients

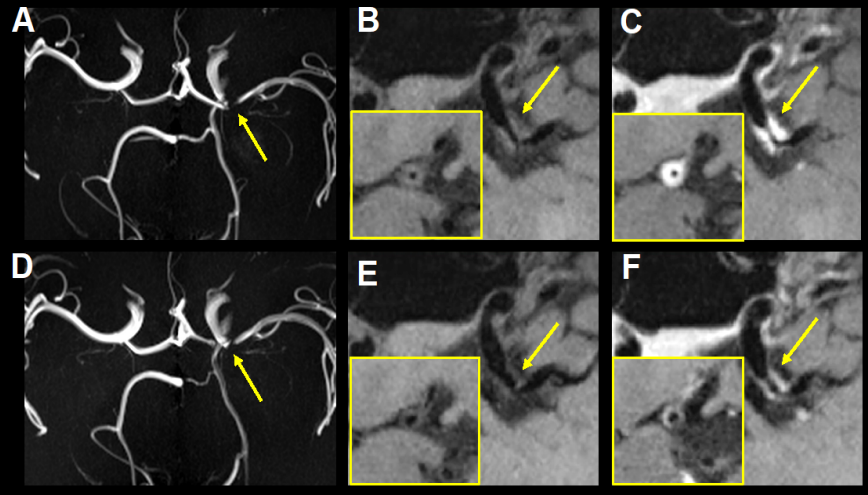
❖ Progression patient

64- year-old male
baseline scan (A-C)-- 7 days after stroke onset stroke recurrent 10 months later
follow-up scan (D-F)-- 4 days after recurrence



❖ Non-progression patient

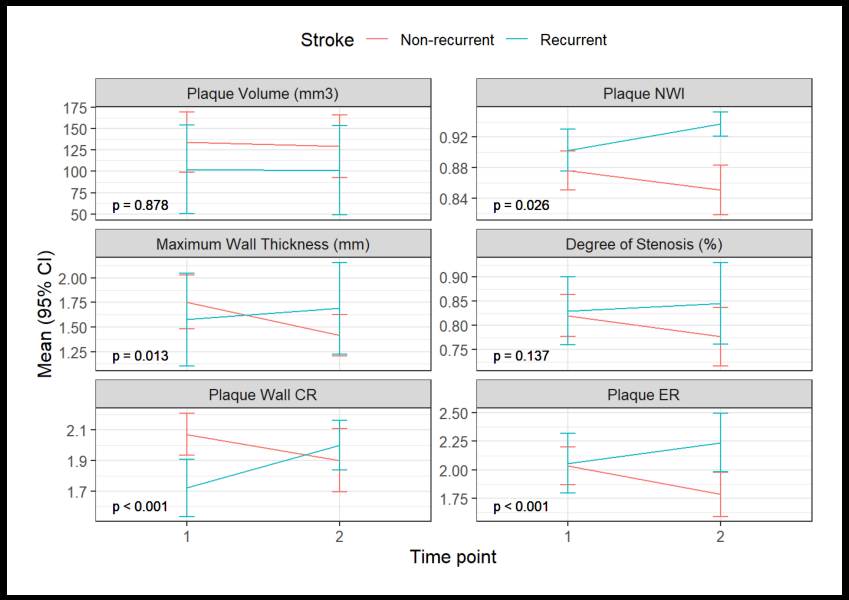
32- year-old female
baseline scan (A-C)-- 24 days after stroke onset
follow-up scan (D-F)– 9 months after stroke
no recurrence within18 months clinical follow-up

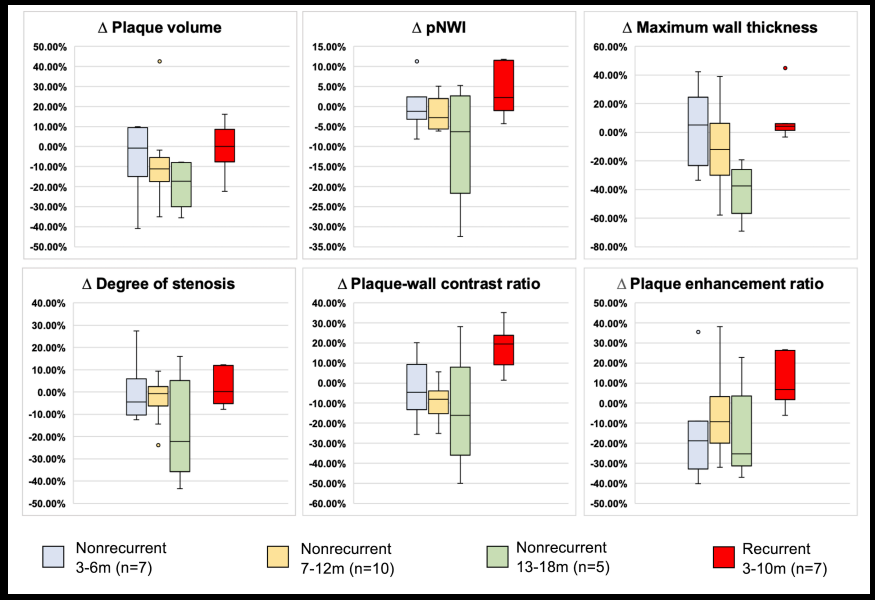


Xiao J, Fan Z, et al. Paper under review

Monitoring Medical Therapy in Symptomatic ICAD Patients

29 patients: 22 nonrecurrent vs. 7 recurrent





Univariable logistic regression showed that the increases in pNWI, plaque-wall CR, and plaque ER were related to stroke recurrence.

Xiao J, Fan Z, et al. Paper under review

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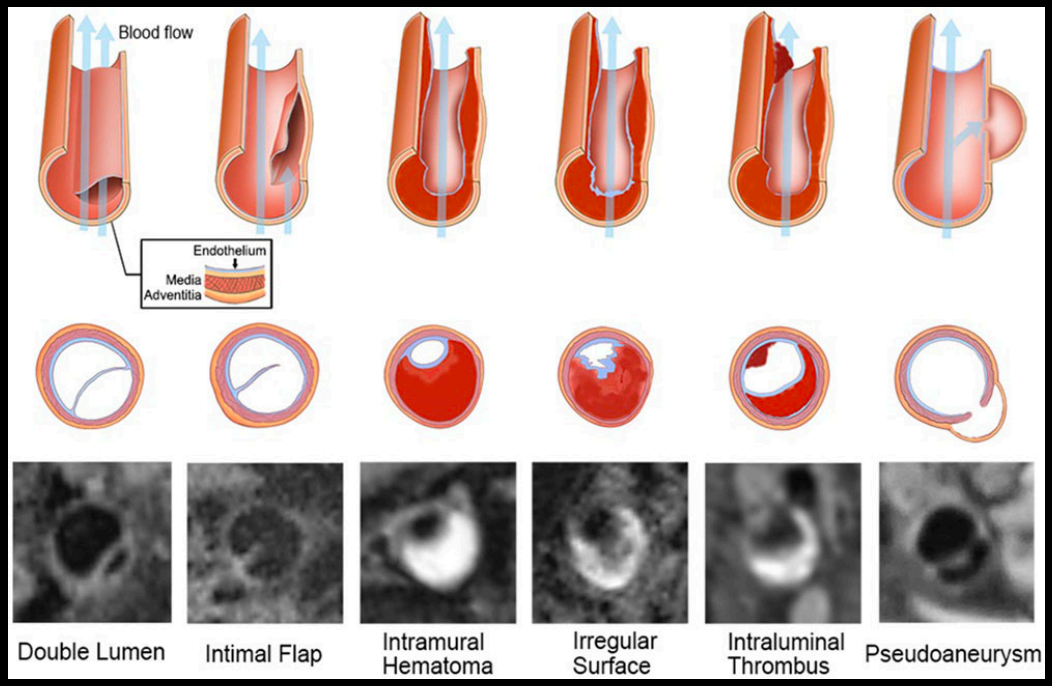
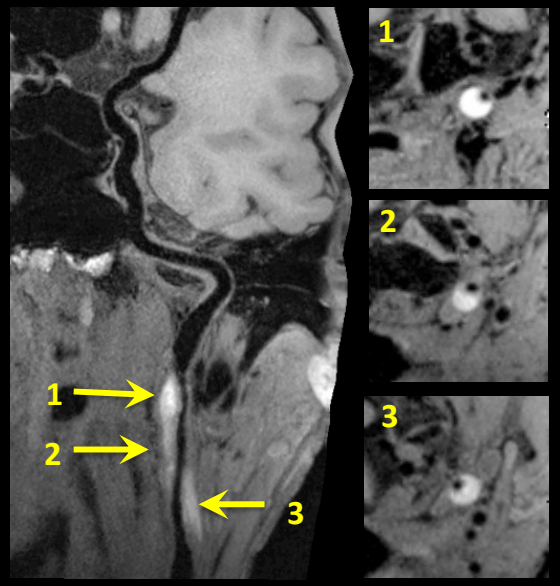
Dissection



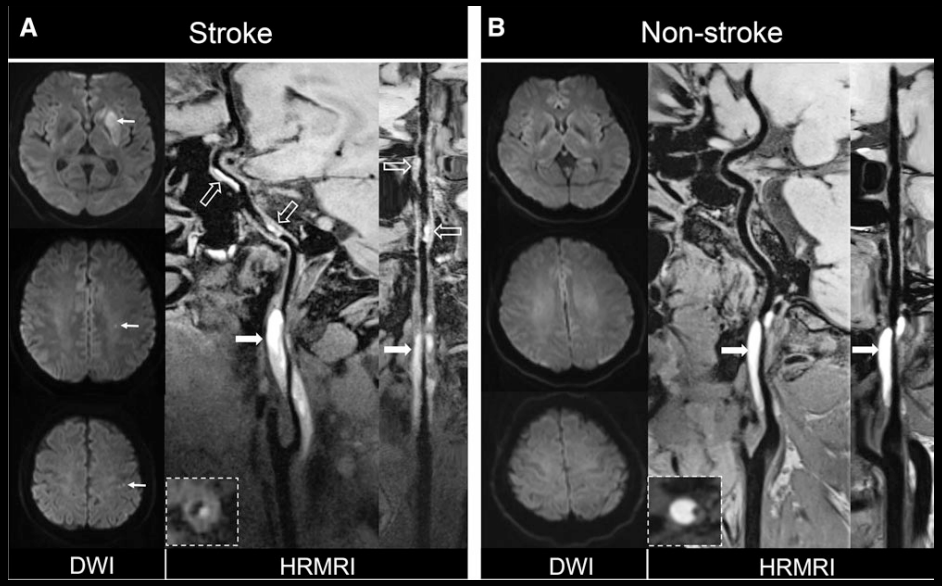
Wu Y, Fan Z, et al. Stroke 2019;50:3101

Crescent-shaped, hyperintense intramural hematoma



A 51 yo male patient with dissection at the left ICA

Dissection



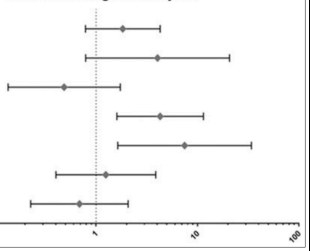
A 48 yo male patient with dissection at the left ICA

A 37 yo female patient with dissection at the right ICA

Clinical Study:

- **118 patients with cervicocranial artery dissection (CCAD)**: 71 pts with stroke, 47 pts without stroke but with neurological symptoms.
- **145 dissecting arteries identified.**

variables	OR (95% CI)	P value
Anterior circulation	1.837(0.788, 4.284)	0.159
Intramural hematoma	4.045(0.790, 20.725)	0.094
Pseudoaneurysm	0.485(0.136, 1.736)	0.266
Irregular surface	4.289(1.605, 11.462)	0.004
Intraluminal thrombus	7.476(1.640, 34.074)	0.009
stenosis degree：50%~69%/≤ 49%	1.251(0.403, 3.881)	0.698
stenosis degree：70%~100%/≤ 49%	0.687(0.227, 2.077)	0.506



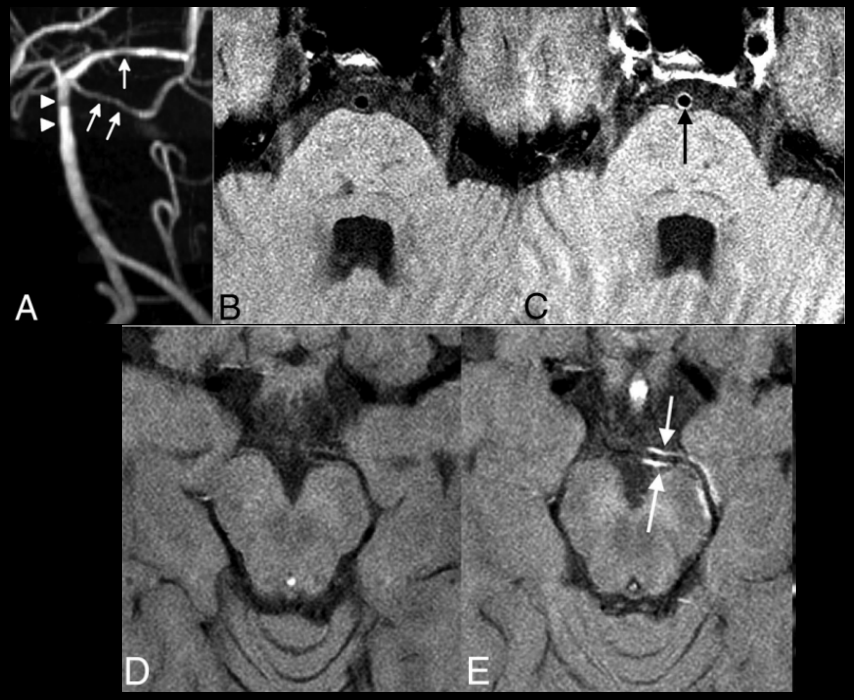
Wu Y, Fan Z, et al. Stroke 2019;50:3101

Assessment of Intracranial Vasculopathies with MR VWI @ 3T

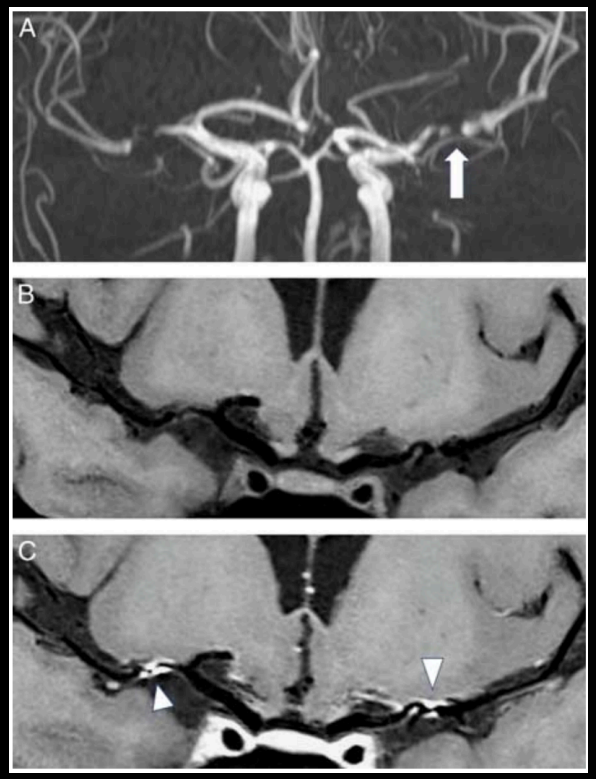
- Intracranial Atherosclerosis Disease (ICAD)
- Dissection
- **Vasculitis**
- Moyamoya Vasculopathy
- Intracranial Aneurysm
- Reversible Cerebral Vasoconstriction Syndrome

Vasculitis

Characteristics: Diffuse, concentric wall thickening and contrast enhancement, severe luminal constriction.



Vasculitis



A 41 yo obese female presented with recurrent left hemispheric TIA:
With uncontrolled arterial hypertension and 20-pack-year tobacco smoking.

MRA demonstrated bilateral MCA stenoocclusive disease. Patient refused DSA due to its invasiveness.

VWI revealed uniform contrast enhancement and concentric thickening of the arterial walls of bilateral MCAs. More suggestive of a vasculitic process rather than atherosclerotic plaque?

Detailed rheumatologic investigation and CSF analysis was undertaken. A chronic calf rash biopsy ultimately revealed chronic superficial perivascular dermatitis with focal interface change, and a diagnosis of unspecified connective tissue disease.

Treated with immunosuppressant (mycophenolate mofetil) in addition to antiplatelet, statin, antihypertensive agents, and lifestyle modification. She had **no further neurological symptoms**.

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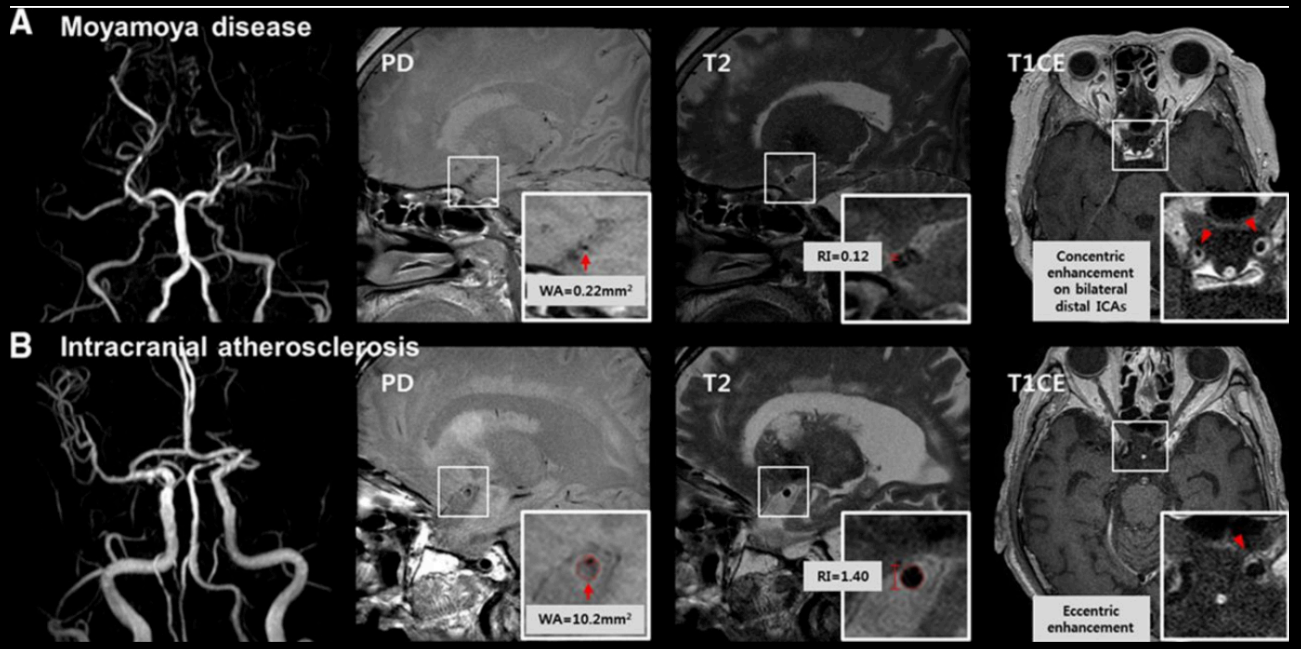
Moyamoya Disease

Characteristics: Concentric enhancement on bilateral distal ICA and MCA, and shrinkage of MCA.

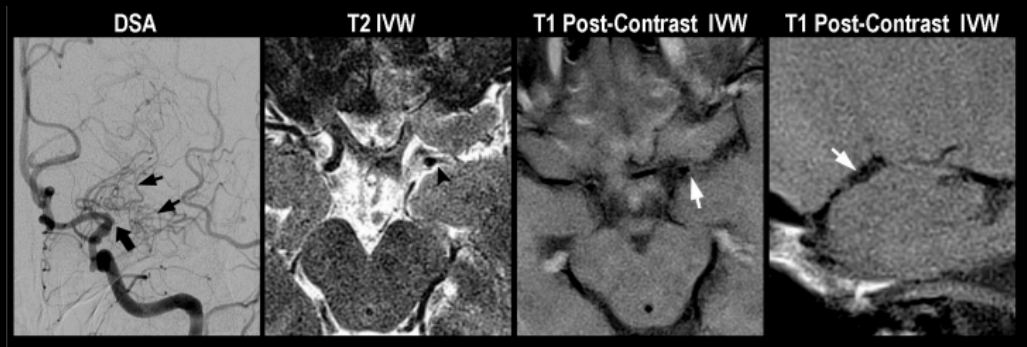


Ryoo S, Bang OY et al. Stroke 2014;45:2457.

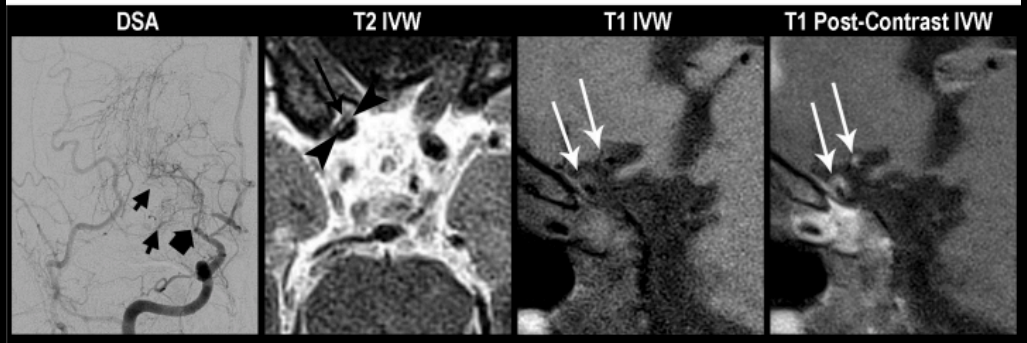
Moyamoya Disease

Characteristics: rarely enhanced, noneccentric, nonremodeled.

MMD

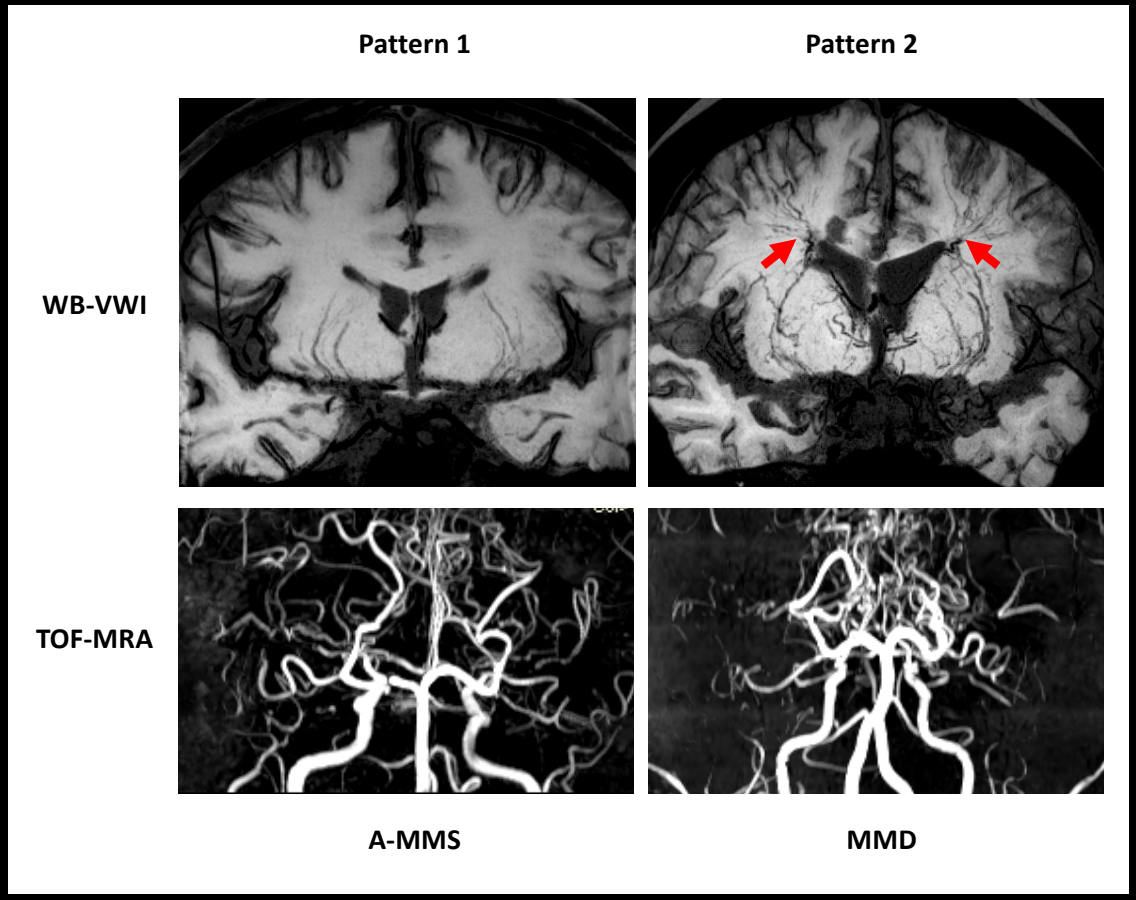


A-MMS (Moyamoya syndrome caused by ICAD)



Mossa-Basha M et al. Stroke 2016;47:1782.

Moyamoya Disease



Assessment of Intracranial Vasculopathies with MR VWI @ 3T

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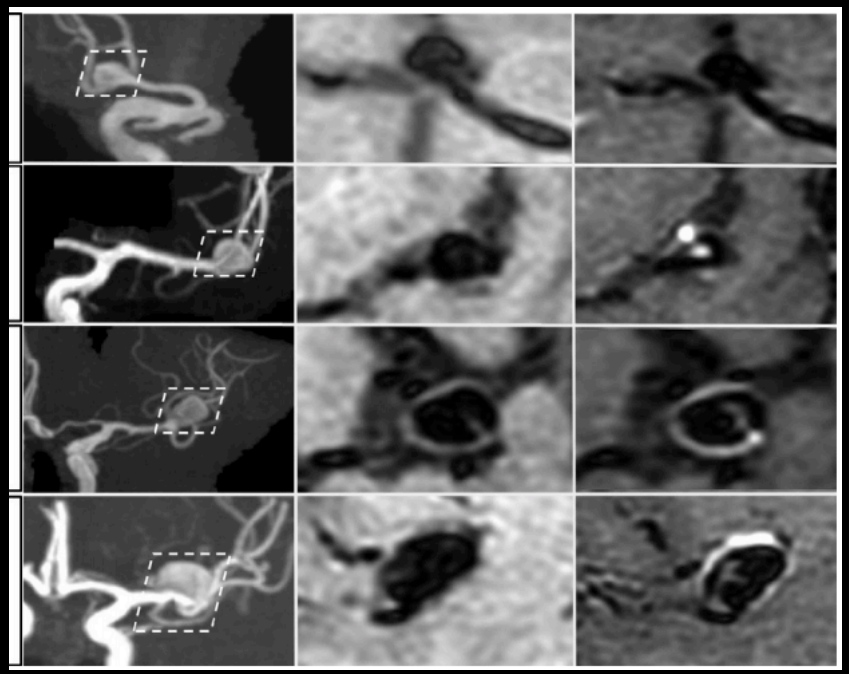
Intracranial Aneurysm



Clinical Study:

- **263 patients with 333 aneurysms.**
- **26 ruptured, 307 unruptured.**

Grade 3 (thick [>1mm], and circumferential) enhancement exhibited the highest specificity (84.4%) and negative predictive value (94.3%) for differentiating between stable and unstable lesions in unruptured intracranial aneurysms (UIAs).

Edjlali M et al. Radiology 2018;289:181.

Assessment of Intracranial Vasculopathies with MR VWI @ 3T

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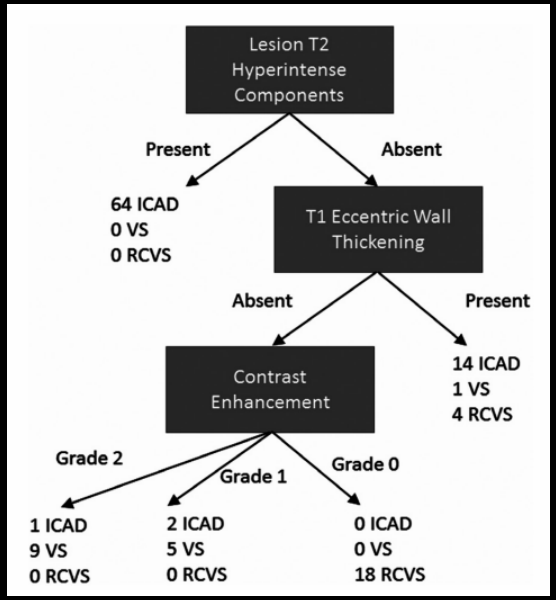
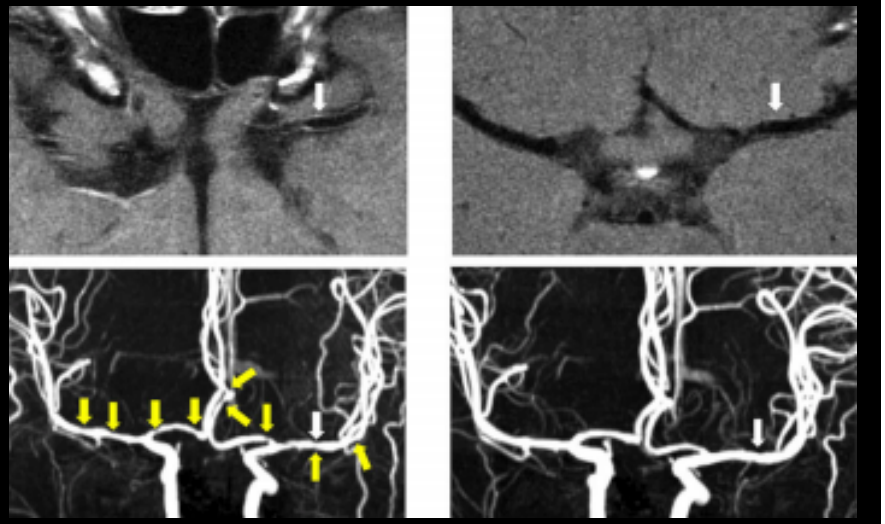
RCVS

Contrast-enhanced or non-enhanced?

- ICAD: intracranial atherosclerotic disease;
- RCVS: reversible cerebral vasoconstriction syndrome;
- VS: vasculitis;



Mossa-Basha M, Yuan C et al. Stroke 2015;46:1567



VWI at 10 days after onset

VWI at 7 years of follow-up

45.8% of patients (n=48) had enhancement

Chen C-Y et al. J Headache Pain 2018;19:74

Value in Stroke Etiology Diagnosis

Published September 5, 2019 as 10.3174/ajnr.A6202

ORIGINAL RESEARCH
ADULT BRAIN

Diagnostic Impact of Intracranial Vessel Wall MRI in 205 Patients with Ischemic Stroke or TIA

J.D. Schaafsma, S. Rawal, J.M. Coutinho, J. Rasheedi, D.J. Mikulis, C. Jaigobin, F.L. Silver, and D.M. Mandell

ABSTRACT

BACKGROUND AND PURPOSE: Secondary prevention of ischemic stroke depends on determining the cause of the initial ischemic event, but standard investigations often fail to identify a cause or identify multiple potential causes. The purpose of this study was to characterize the impact of intracranial vessel wall MR imaging on the etiologic classification of ischemic stroke.

MATERIALS AND METHODS: This was a single-center, retrospective study of 205 consecutive patients who were referred for vessel wall MR imaging to clarify the etiology of an ischemic stroke or TIA. An expert panel classified stroke etiology before and after incorporating vessel wall MR imaging results using a modified Trial of Org 10172 in Acute Stroke Treatment system. We measured the proportion of patients with an altered etiologic classification after vessel wall MR imaging.

RESULTS: The median age was 56 years (interquartile range = 44–67 years), and 51% (106/205) of patients were men. Vessel wall MR imaging altered the etiologic classification in 55% (112/205) of patients. The proportion of patients classified as having intracranial arteriopathy not otherwise specified decreased from 31% to 4% (64/205 versus 9/205; $P < .001$) and the proportion classified as having intracranial atherosclerotic disease increased from 23% to 57% (48/205 versus 116/205; $P < .001$). Conventional work-up classification as intracranial arteriopathy not otherwise specified was an independent predictor of vessel wall MR imaging impact (OR = 8.9; 95% CI, 3.0–27.2). The time between symptom onset and vessel wall MR imaging was not a predictor of impact.

CONCLUSIONS: When vessel wall MR imaging is performed to clarify the etiology of a stroke or TIA, it frequently alters the etiologic classification. This is important because the etiologic classification is the basis for therapeutic decision-making.

Take-home Message

- High-resolution MRI-based 3D vessel wall imaging (VWI) techniques have been available for non-invasive assessment of intracranial arteries.
- Information beyond luminal stenosis can be obtained by VWI and may be utilized to differentiate various intracranial vasculopathies.
- For some vasculopathies, there are conflicting findings. More studies are warranted.

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