Stroke-Related Vascular MRI

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Outline

- Background on Stroke
- MR Luminal Imaging
  - Non-contrast MRA
  - Contrast-enhanced MRA
  - Susceptibility-based imaging
- MR Vessel Wall Imaging (VWI)
  - Carotid VWI
  - Intracranial VWI
  - Aortic VWI
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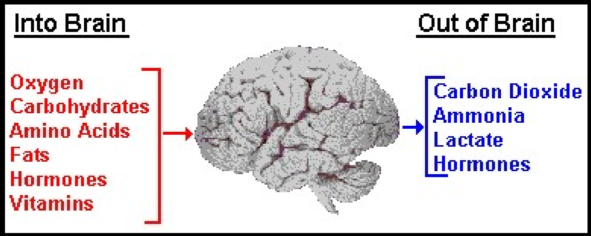
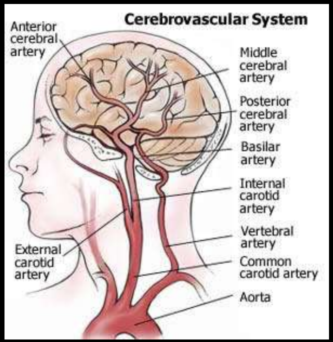
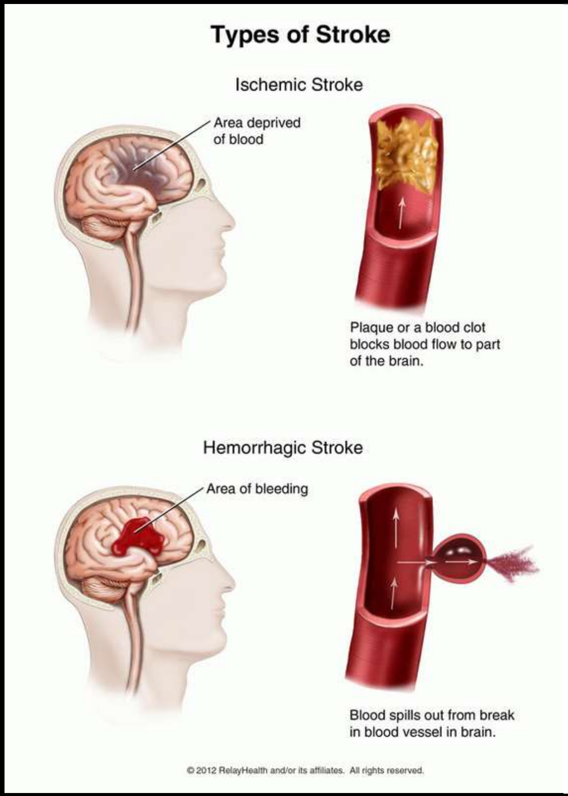
Stroke

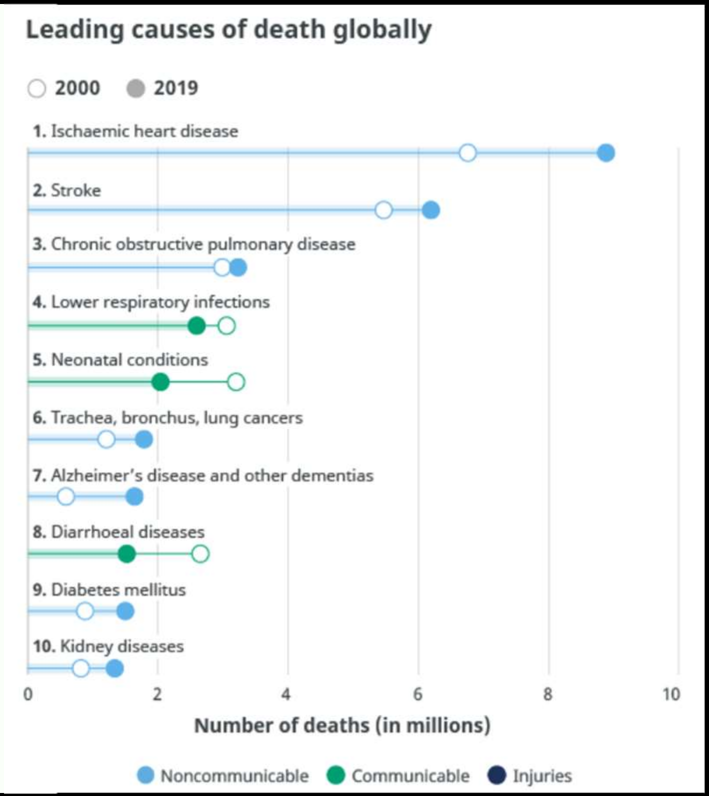
Facts about our brain:

- 2% of body weight
- Consumes 50% of glucose
- Consumes 20% of oxygen
- All nutrients supplied by the blood
- 15% cardiac output





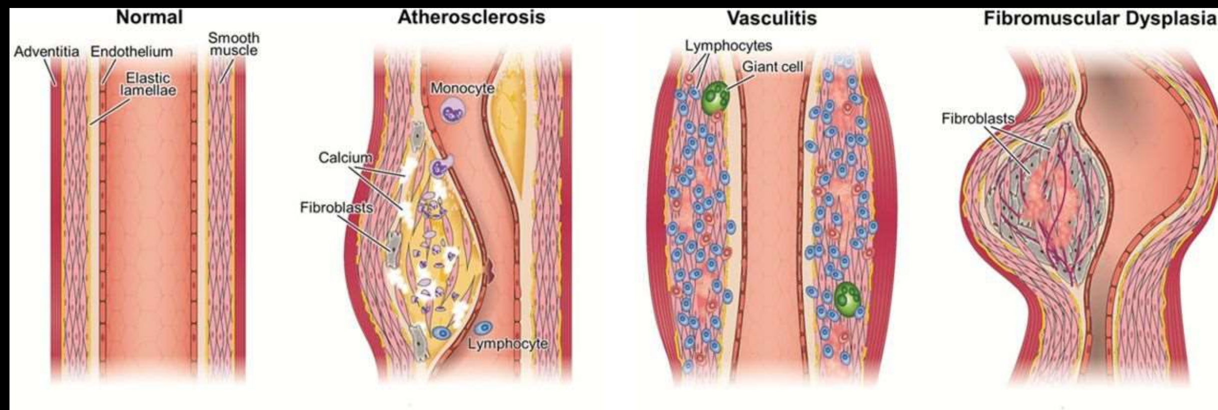




WHO Statistics

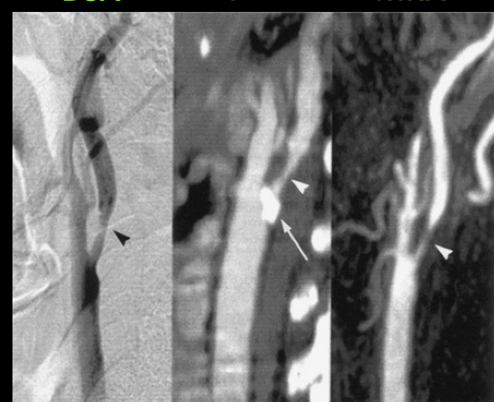
Major Causes of Stroke: Vascular Pathologies

- Atherosclerosis
- Dissection
- Vasculitis
- Vasospasm
- Aneurysm
- Moyamoya disease
- Kawasaki disease
- …

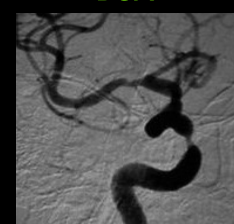


Luminal narrowing, dilation, or irregularity

DSA CTA MRA

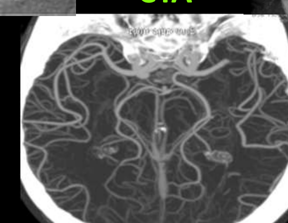


DSA



MRA

CTA



DSA: digital subtraction angiography; CTA: CT angiography; MRA: MR angiography

Routine Imaging Techniques for Diagnosing Vascular Diseases

❖ X-ray Angiography – the gold standard

Advantages
- High spatial resolution
- High temporal resolution

Disadvantages
- Invasive, high cost (used with therapeutic intervention)
- Ionizing radiation
- Nephrotoxic iodinated contrast agents

❖ Transcranial Doppler

Advantages
- Non-invasive, low cost, easy

Disadvantages
- Operator expertise dependent

❖ CT Angiography (CTA)

Advantages
- High spatial resolution
- Non-invasive
- Speed of examination

Disadvantages
- Ionizing radiation
- Nephropathy
- Blooming artifacts due to calcium

❖ MR Angiography (MRA)

Advantages
- Non-invasive
- No radiation exposure
- 3D evaluation

Disadvantages
- Low spatial resolution
- Unsuited for arteries with metallic stents
- Potential risk of nephrotoxic systemic fibrosis

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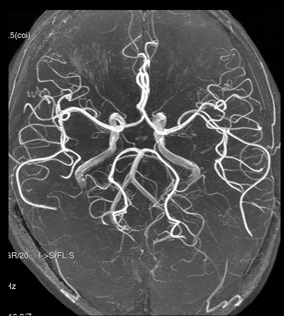
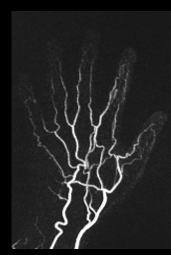
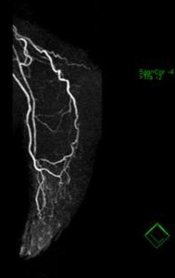
Luminal Imaging

- To visualize the vessel lumen to detect any luminal abnormalities
  - Stenosis
  - Occlusion
  - Dilation
  - Rupture
  - Anastomosis
  - …
- Approaches
  - Non-contrast MRA
  - Contrast-enhanced MRA
  - Susceptibility-based imaging

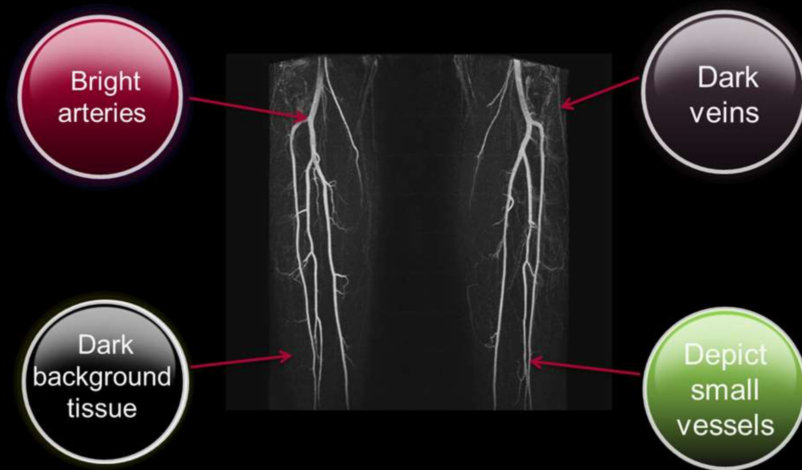
MRA







Technical Considerations

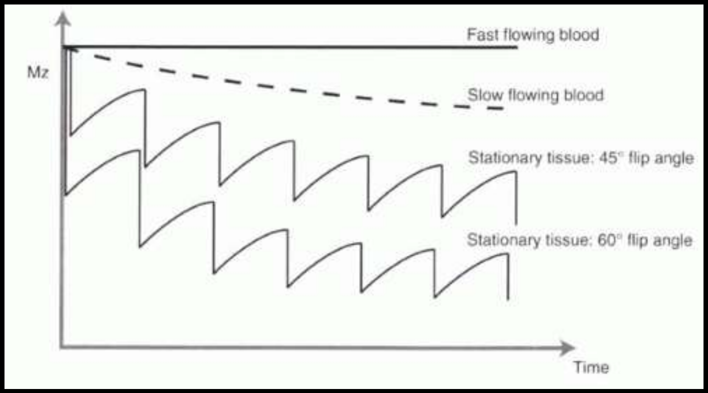


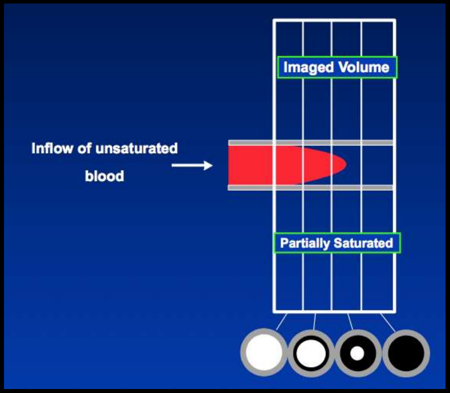
Time-of-Flight (TOF) MRA – A Non-contrast MRA Method

- ❖ "TOF" relates to time of inflow
- ❖ Gradient-recalled echo (GRE) with repetitive RF pulses excitations
- ❖ TR short relative to tissue T1
  - Static tissue is saturated ➔ weak signal
- ❖ TR long enough for flow to replenish slice
  - TR > (slice or volume thickness / flow speed)

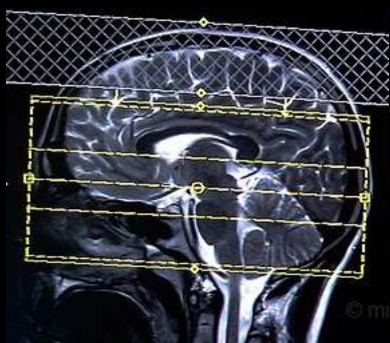
➔

- ❖ TOF signals are flow direction dependent
- ❖ TOF signals are flow speed dependent





3D TOF MRA

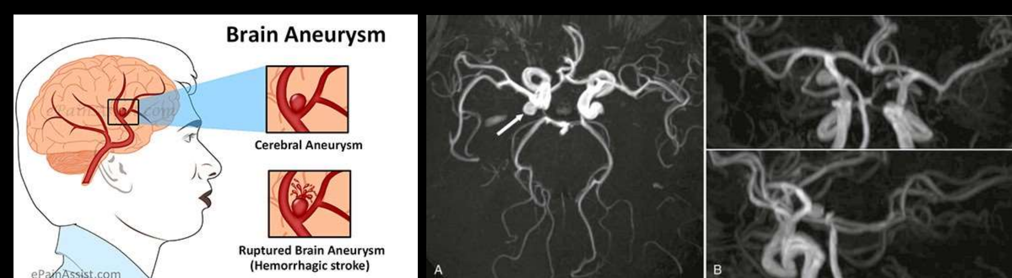


❖ Advantages

- Higher spatial resolution
- Good for intermediate and fast flow
- Multi-slab for more coverage

Atherosclerosis

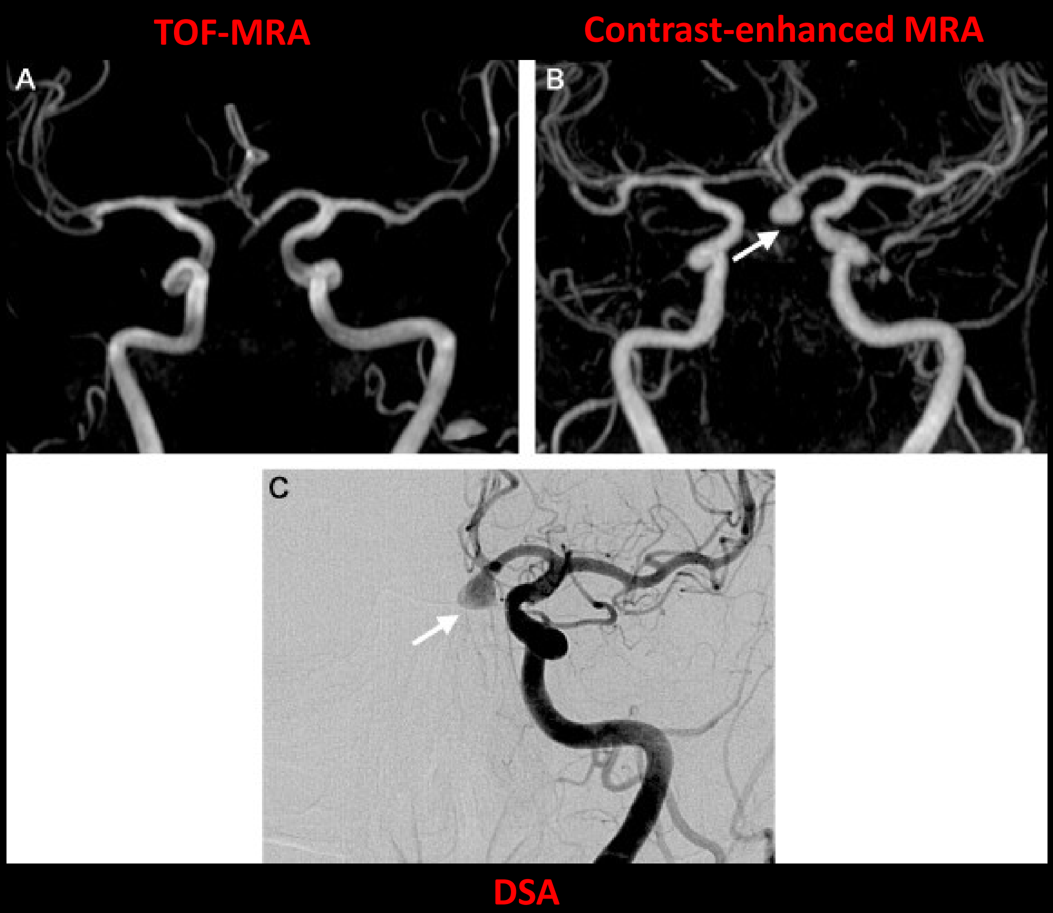
Aneurysm



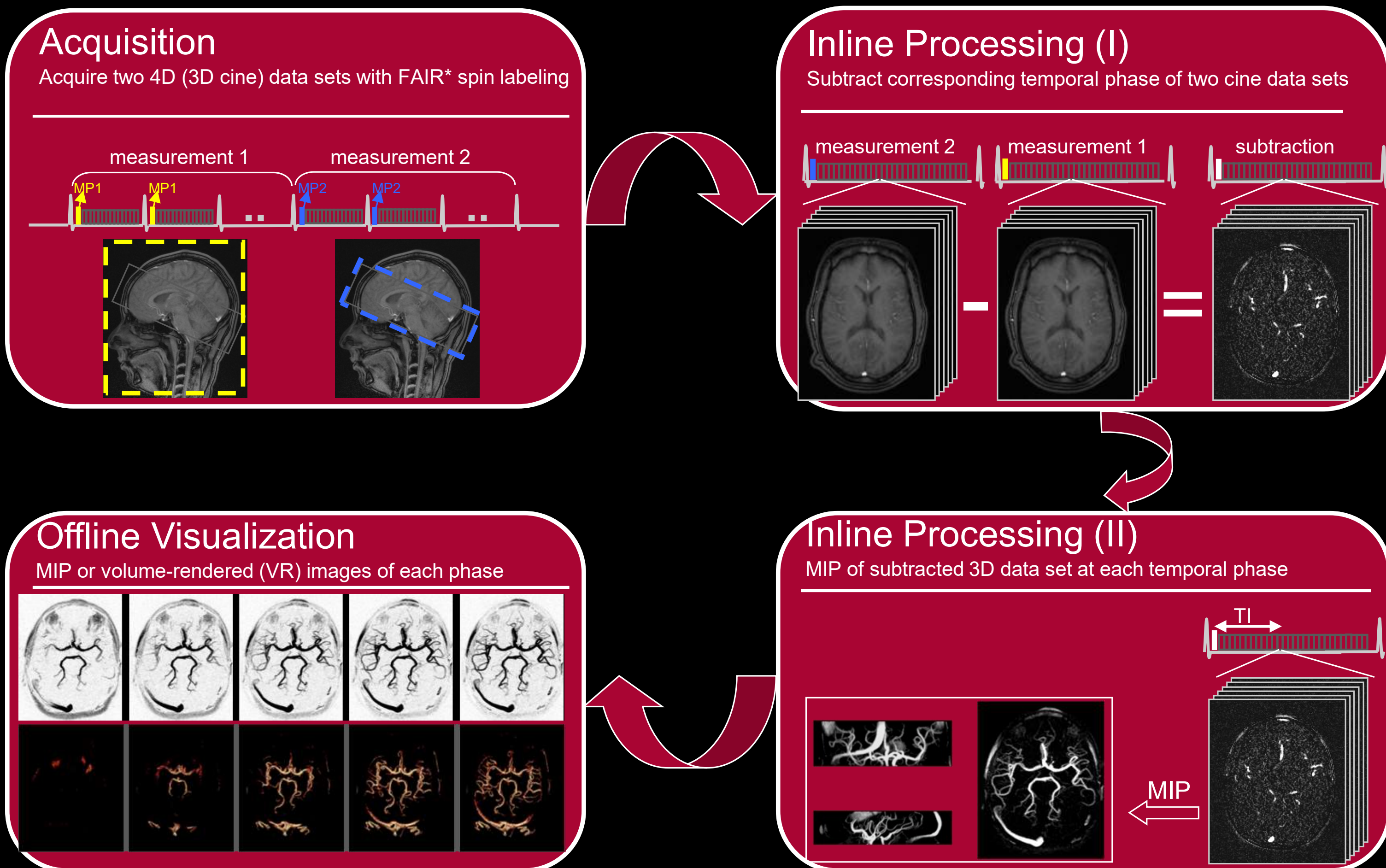
3D TOF MRA

❖ Disadvantages

- Poor for slow flow
- More susceptible to motion



Non-contrast 4D MRA

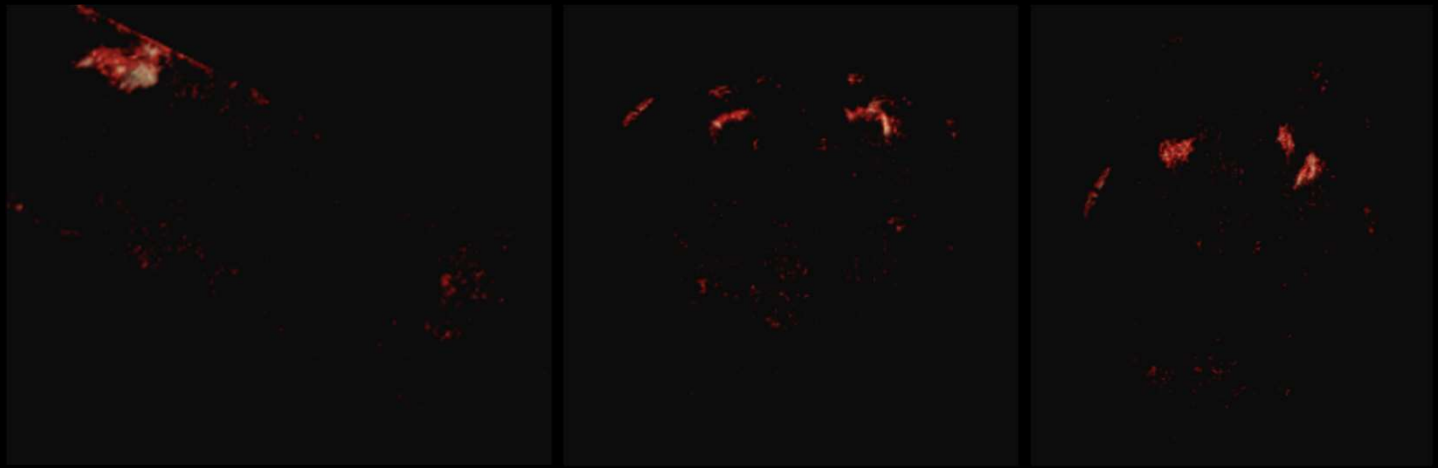


Non-contrast 4D MRA

Temporal resolution: 51.4 msec

Voxel size: 1.25 x 1.25 x 1.25 mm^3

Imaging time: 5’12”

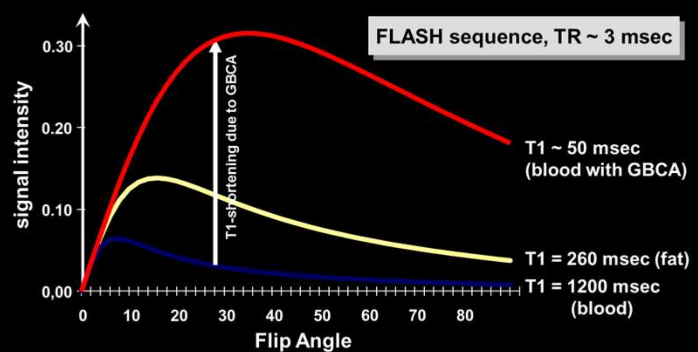


VR images reformatted using InSpace software (Siemens AG Healthcare)

Bi X et. al, MRM 63: 835; 2010

Contrast-Enhanced (CE) MRA

Use gadolinium-based contrast agent, T1-weighted sequence.



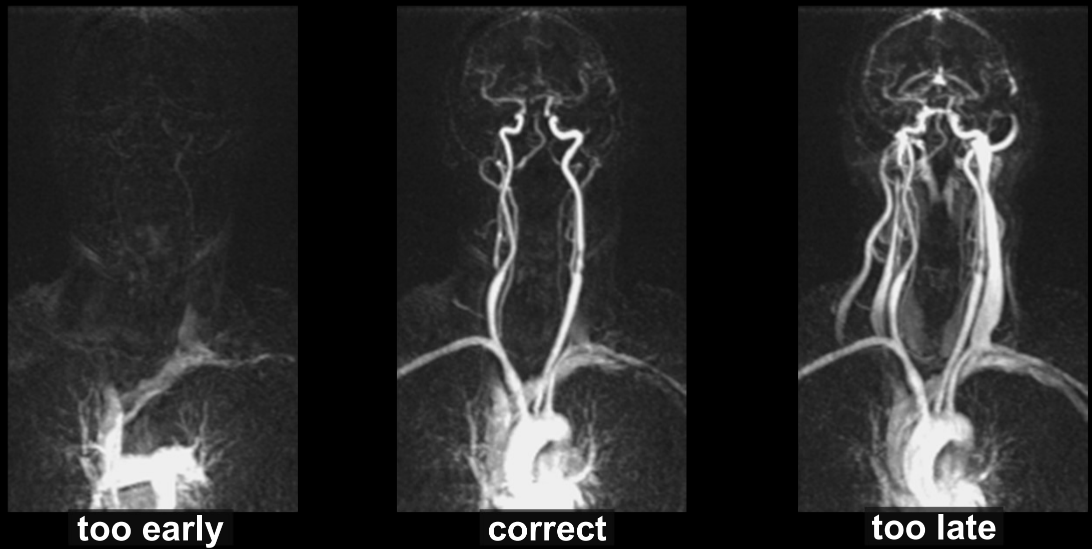
Single Slice

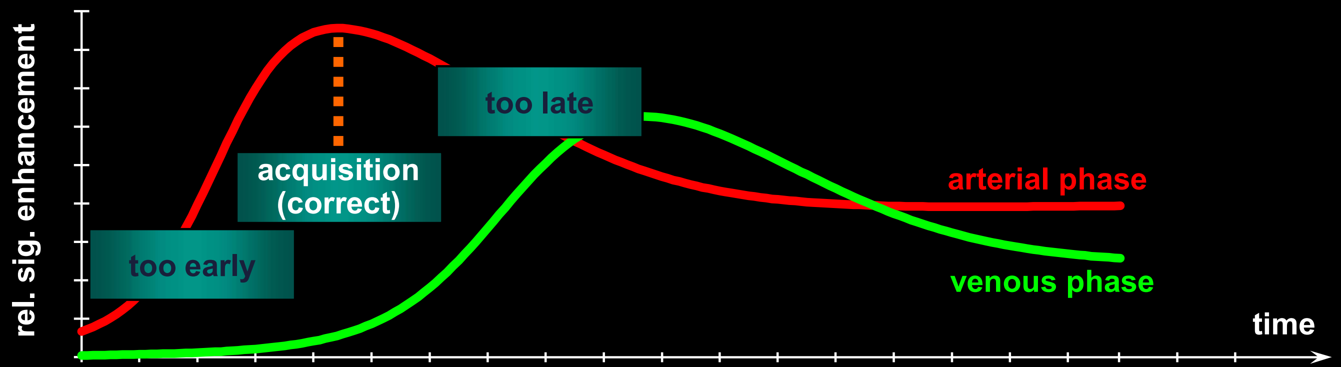
Maximum-intensity Projection (MIP)

Before contrast injection

Right after contrast injection

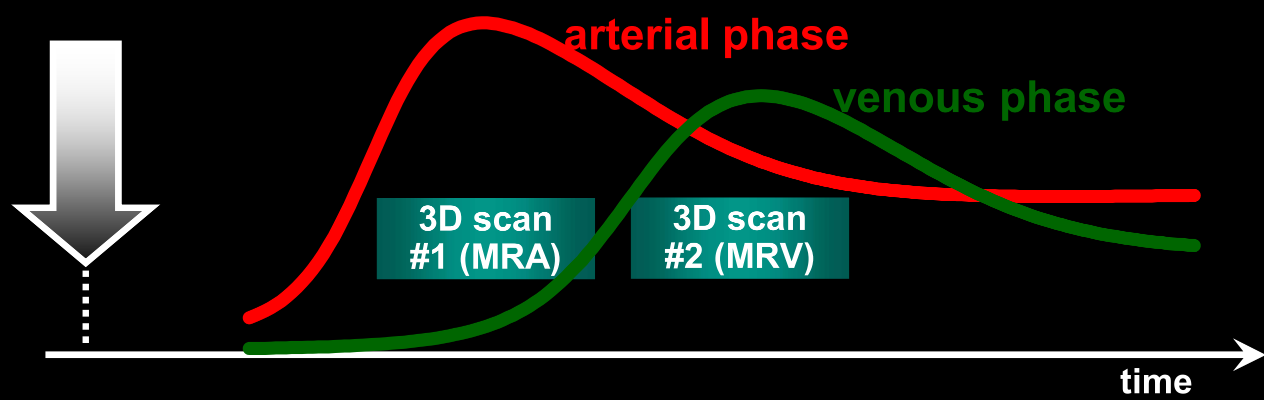
Contrast Timing is Extremely Important



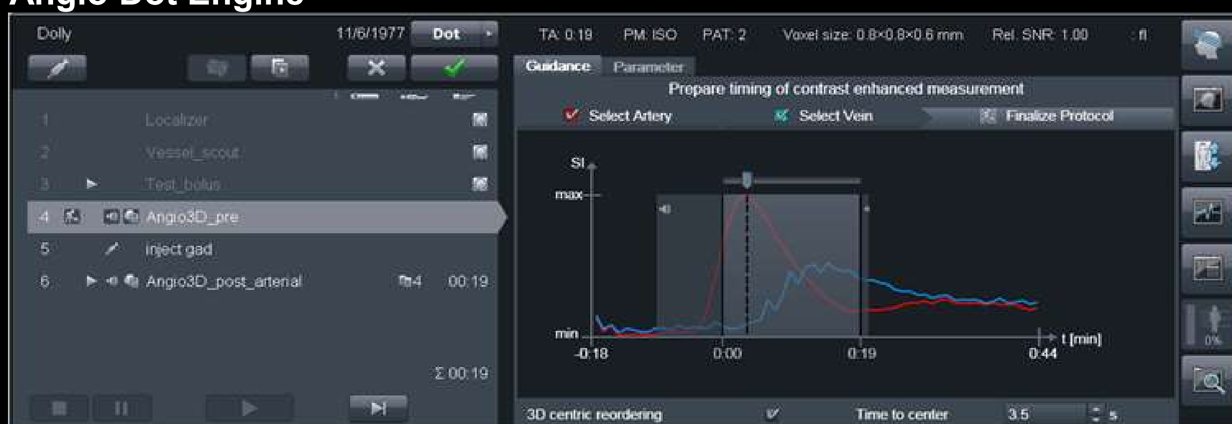


Timing Strategy

3D measurement with user-specified timing (test bolus, care bolus)

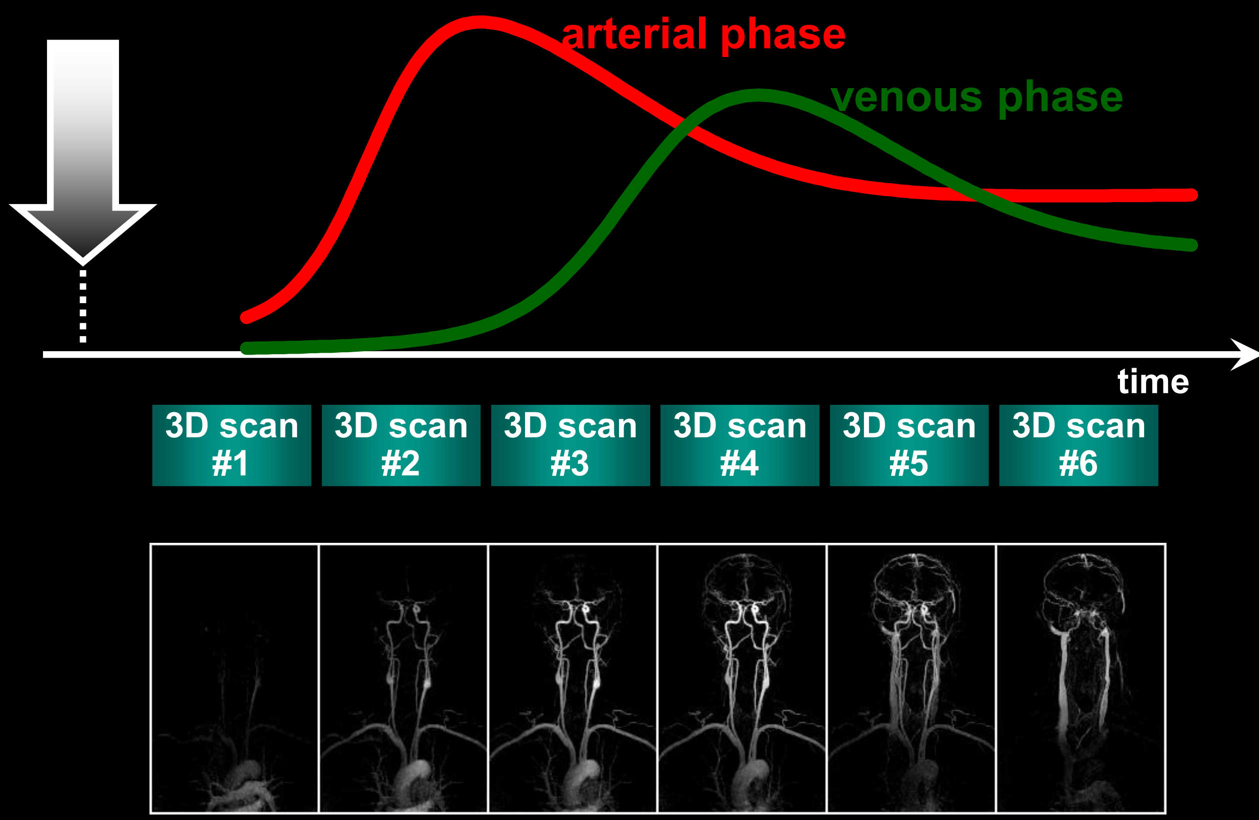


Angio Dot Engine

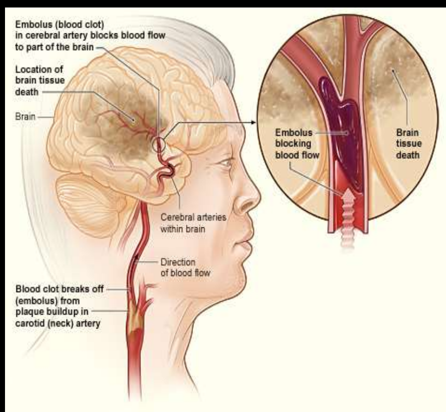


Timing Strategy

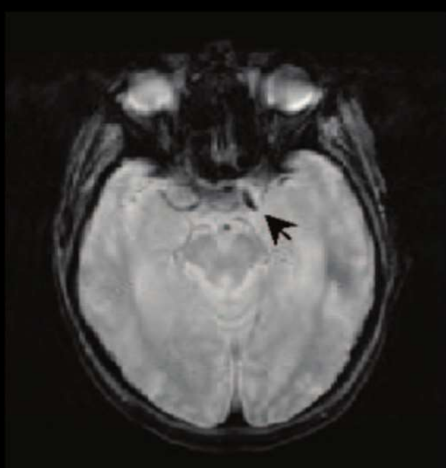
Time-resolved 3D measurements (TWIST): both vessel patency and functional information



Susceptibility-based Imaging



- ❖ T2* shortening in thrombus due to susceptibility effect of deoxyHb or metHb
- ❖ Susceptibility vessel sign (SVS): hypointensity within the course of an artery



MR SVS

DSA

The mean length:

SVS: 17.1 $\pm$ 7.2 mm vs.

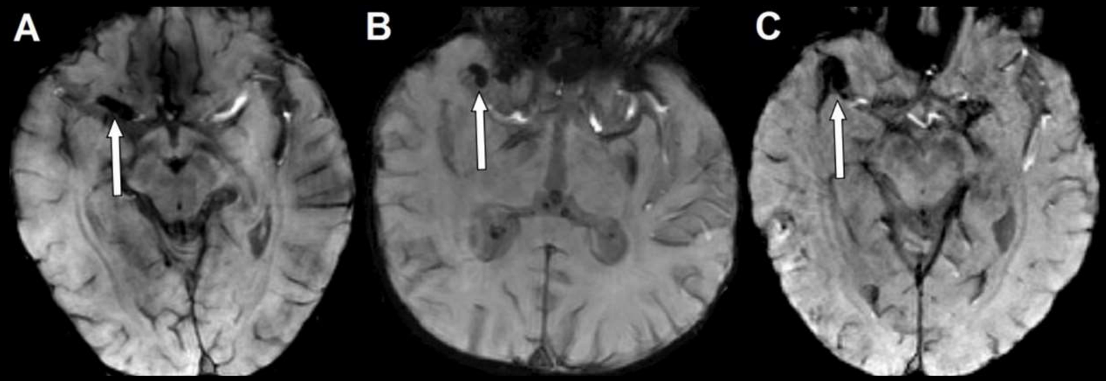
DSA: 15.4 $\pm$ 7.1 mm

ICC = 0.88

Schellinger PD et al. AJNR 2005;26:618-624

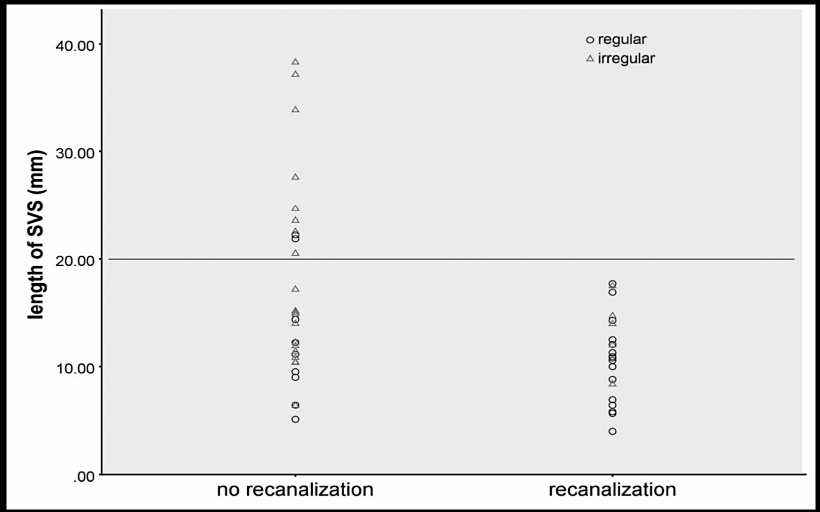
Naggara O et al. PLOS ONE 2013;8(10):e76727

Susceptibility-based Imaging



Long vs. Short SVS

Regular vs. Irregular SVS



- None of the patients with an MCA SVS >20 mm achieved recanalization 24hr after IV-tPA

  → direct triage patient to endovascular therapy ?

- For patients with SVS < 20 mm, the recanalization rate for the irregular groups was 29.4% versus 69.6% for the regular group

  → need ancillary endovascular therapy?

Yan S et al. Stroke 2014;45:2795

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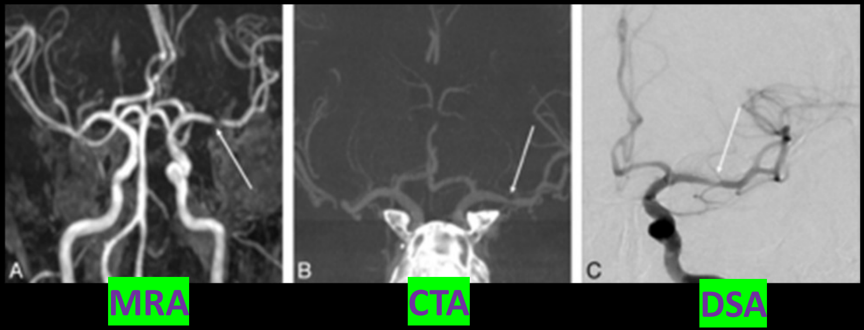
Why Do We Need MR-VWI

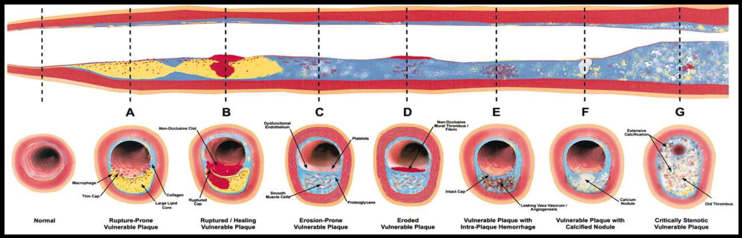
- **Limited information on wall pathologies from luminal imaging**
  - **Stenosis or luminal irregularity can be caused by diverse etiologies**
    - Atherosclerosis
    - Dissection
    - Moyamoya's
    - Vasculitis
    - Vasospasm



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*

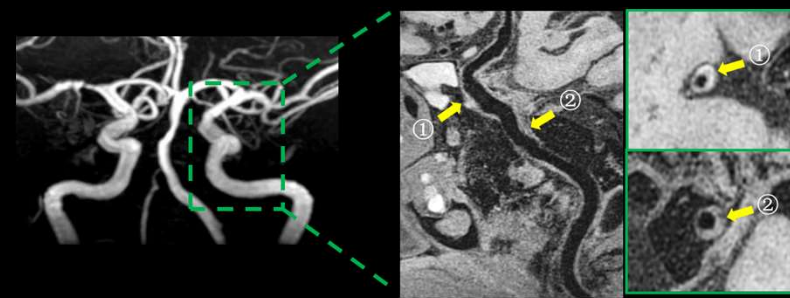
VWI – Beyond the Lumen

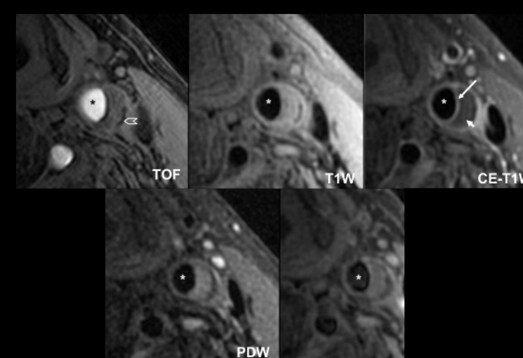
- Black-blood contrast (blood signal is suppressed) → direct visualization of the vessel wall
- Flexible soft-tissue contrast → easy identification of wall pathologies and characterization of severity and vulnerability
- Provide geometric and signal features associated with various vascular diseases

Black-Blood Contrast in Cardiovascular MRI

Markus Henningsson, PhD,[1,2,3*] Shaihan Malik, PhD,[3] Rene Botnar, PhD,[3] Daniel Castellanos, MD,[4] Tarique Hussain, MD,[4,5] and Tim Leiner, MD, PhD[6]

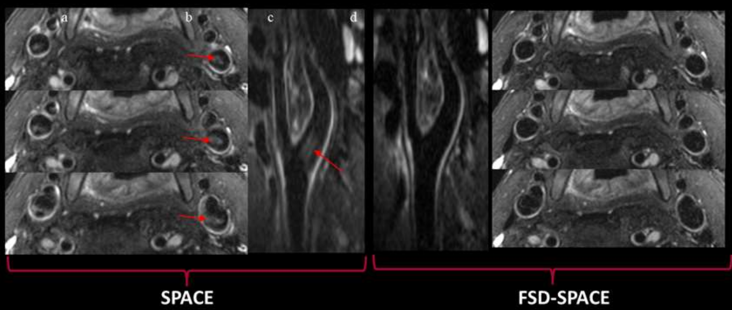
J. MAGN. RESON. IMAGING 2020.



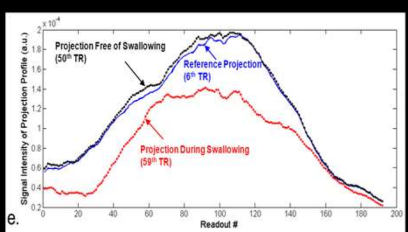


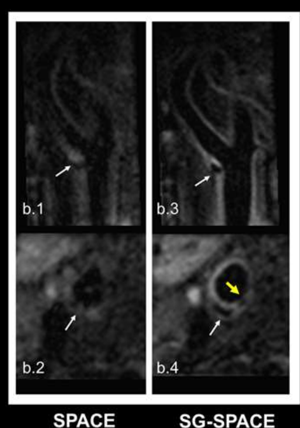
Wide Application of VWI

Carotid VWI



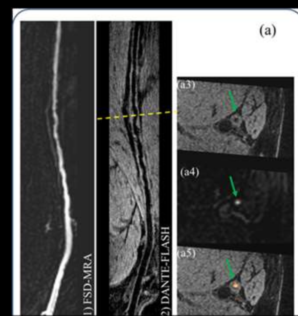
Fan Z et al. J Magn Reson Imaging 2010;31:645





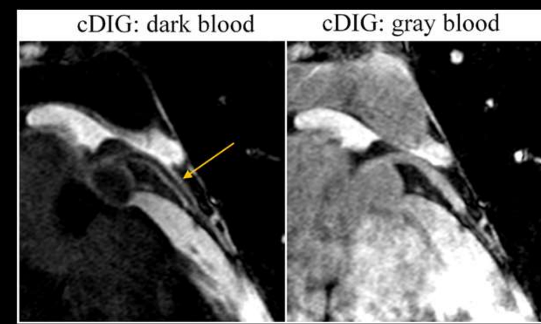
Fan Z et al. Magn Reson Med. 2012;67:490

Peripheral VWI



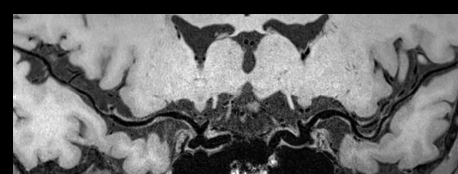
Xie G, Fan Z et al. J Magn Reson Imaging 2016;43:343

Coronary VWI



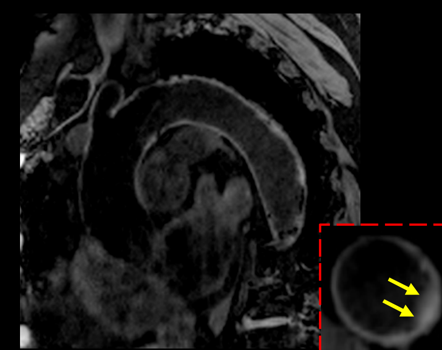
Xie G, Fan Z et al. Magn Reson Med. 2016;75:997

Intracranial VWI



Fan Z et al. Magn. Reason. Med. 2017;77:1142

Aortic VWI



Hu Z, Fan Z et al. Magn Reson Med 2020;84:2376-2388
Hu Z, Fan Z et al. Magn Reson Med 2022; Nov 6.

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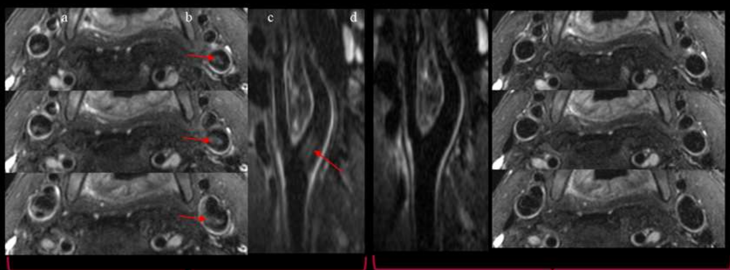
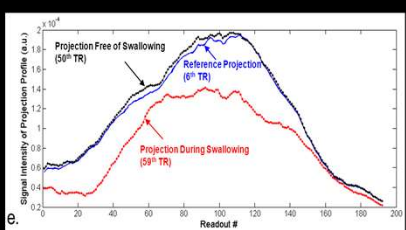
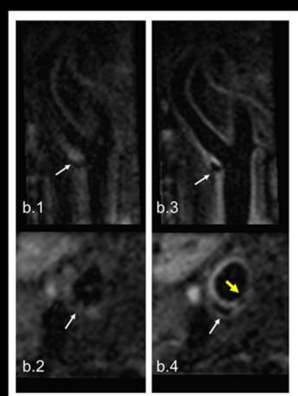
Carotid VWI



SPACE FSD-SPACE

Fan Z et al. J Magn Reson Imaging 2010;31:645

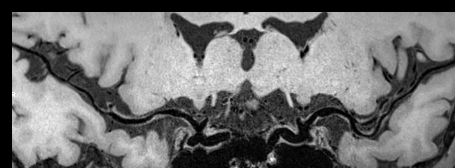




SPACE SG-SPACE

Fan Z et al. Magn Reson Med. 2012;67:490

Intracranial VWI



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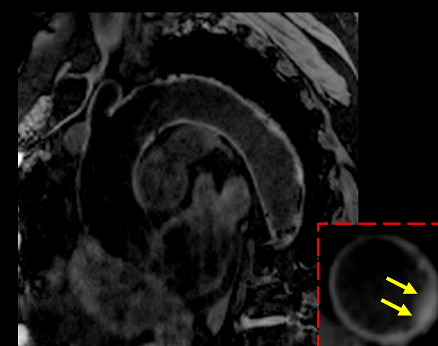
Aortic VWI

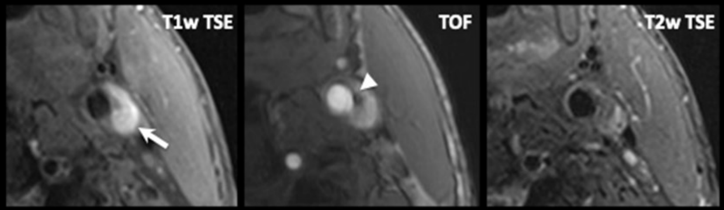


Hu Z, Fan Z et al. Magn Reson Med 2020;84:2376-2388
Hu Z, Fan Z et al. Magn Reson Med 2022; Nov 6.

Carotid VWI

❖ **Multi-contrast atherosclerosis characterization (MATCH)**

Conventional approach: Multiple 2D scans with >15 min



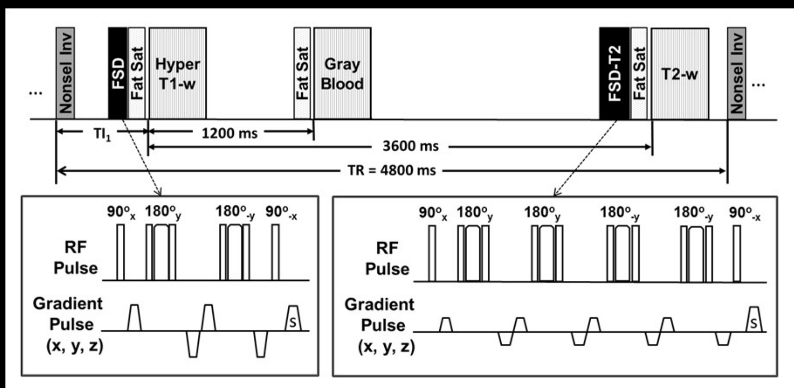
Component	Conventional Multi-Contrast			
	T1-w	T2-w	TOF	CE
IPH	+	-/+	+	=
CA	-	-	-	-
LM	=	+	=	+
LRNC w/o IPH	=/+	-	=	-

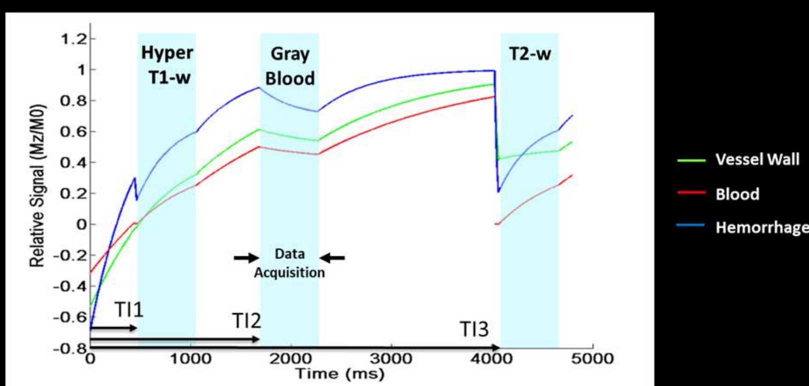
IPH: intraplaque hemorrhage, CA: calcification, LRNC: lipid-rich necrotic core, +: hyperintense; -: hypointense; =: isointense

Fan Z et al. J Cardiovasc Magn Reson 2014;16:53

Carotid VWI

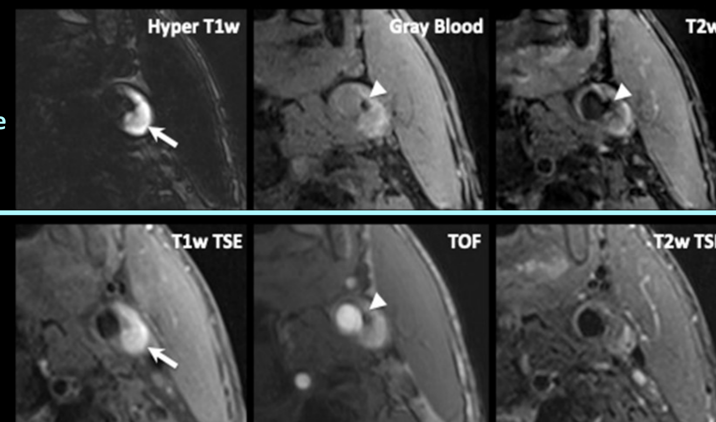
❖ Multi-contrast atherosclerosis characterization (MATCH)





MATCH:
Multi-contrast 3D imaging within one 5-min scan

Conventional approach:
Multiple 2D scans with >15 min



Component	MATCH				Conventional Multi-Contrast			
	Hyper T1-w	Gray Blood	T2-w		T1-w	T2-w	TOF	CE
IPH	+		+ (recent) -/= (acute)		+	-/+	+	=
CA		-			-	-	-	-
LM	=		+		=	+	=	+
LRNC w/o IPH	=		-		=/+	-	=	-

IPH: intraplaque hemorrhage, CA: calcification, LRNC: lipid-rich necrotic core,
+: hyperintense; -: hypointense; =: isointense

Fan Z et al. J Cardiovasc Magn Reson 2014;16:53

Carotid VWI

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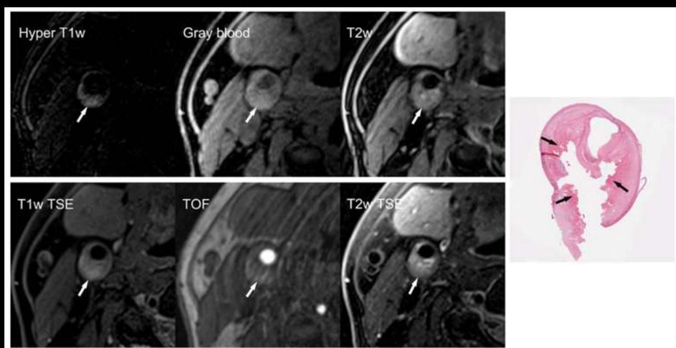
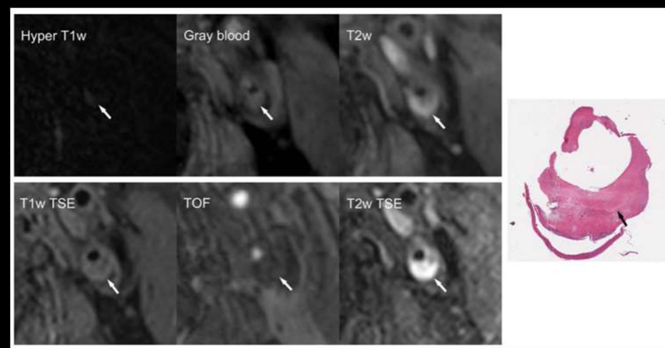
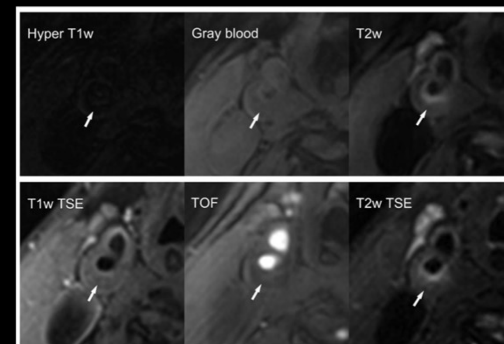
IPH



Loos matrix



LRNC



CA

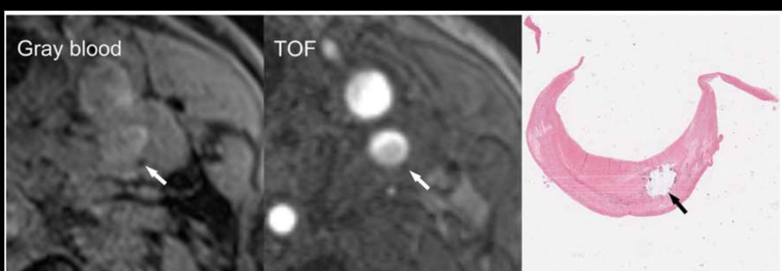


TABLE 2. Comparison of MATCH and Conventional Multicontrast Protocol in Identifying Plaque Components Using Histological Findings as Reference Standard

	Accuracy (%)		Sensitivity (%)		Specificity (%)		PPV (%)		NPV (%)	
	MATCH	Conv.	MATCH	Conv.	MATCH	Conv.	MATCH	Conv.	MATCH	Conv.
IPH	82.5	77.5	84.2	73.7	81.0	81.0	80.0	77.8	85.0	77.3
LRNC	82.5	80.0	84.2	77.3	81.0	83.3	80.0	85.0	85.0	75.0
LM	80.0	90.0	90.9	81.8	75.9	93.1	58.8	81.8	95.7	93.1
CA	90.0	82.5	100.0	82.4	81.8	82.6	81.8	77.8	100.0	86.4

Conv.: conventional multicontrast protocol; IPH: intraplaque hemorrhage; LRNC: lipid-rich necrotic core; LM: loose matrix; CA: calcification; PPV: positive predictive value; NPV: negative predictive value.

Dan Y et al. J Magn Reason Imaging 2017;45:764

Carotid VWI

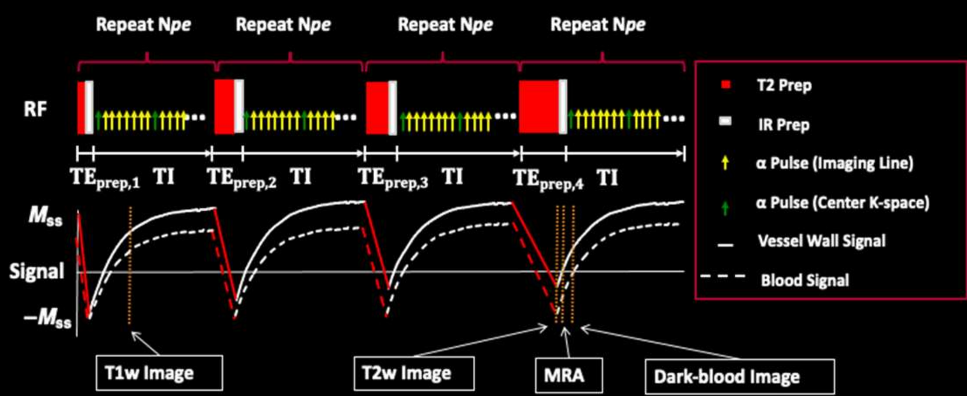
❖ Multi-contrast atherosclerosis characterization (MATCH)

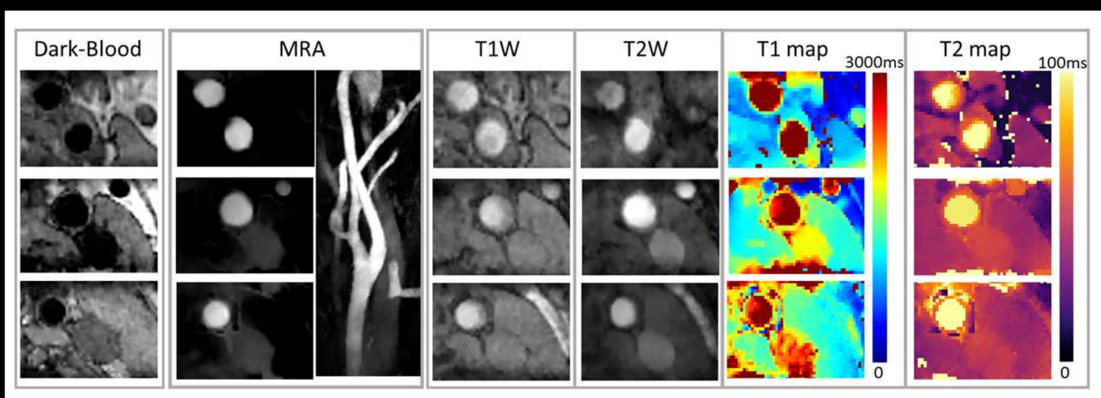
Parameter	Reader	Protocol	Mean ± SD	95% CI of difference	P-value	ICC (95% CI)	P-value
Total vessel wall volume (mm³)	1	Multi-sequence	1335.1±379.5	(-140.6)-(-31.6)	0.003	0.93 (0.89-0.96)	<0.01
		MATCH	1421.3±433.0				
	2	Multi-sequence	1453.7±307.7	(-230.0)-(31.0)	0.01	0.76 (0.58-0.86)	<0.01
		MATCH	1584.2±474.1				
Total LRNC volume (mm³)	1	Multi-sequence	67.8±174.4	(-8.5)-(29.9)	0.27	0.95 (0.92-0.97)	<0.01
		MATCH	57.1±146.2				
	2	Multi-sequence	50.5±154.5	(-19.8) - (31.2)	0.7	0.88 (0.79-0.93)	<0.01
		MATCH	44.8±115.2				
Total IPH volume (mm³)	1	Multi-sequence	30.1±94.1	(-10.1)-(5.8)	0.60	0.97 (0.96-0.99)	<0.01
		MATCH	32.2±95.6				
	2	Multi-sequence	24.0±94.1	(-15.3)-(27.0)	0.6	0.84 (0.77-0.90)	<0.01
		MATCH	17.5±44.4				
Total calcifications volume (mm³)	1	Multi-sequence	24.1±37.5	(-91.2)-(32.9)	0.35	0.38 (0.23-0.46)	0.4
		MATCH	53.2±226.5				
	2	Multi-sequence	23.5±39.9	(-58.5)-(-13.7)	<0.01	0.37 (-0.1-0.64)	0.06
		MATCH	59.6±80.4				
Total fibrous tissue volume (mm³)	1	Multi-sequence	1227.8±345.4	(-336.6)-(-90.6)	0.001	0.59 (0.29-0.76)	<0.01
		MATCH	1441.5±473.0				
	2	Multi-sequence	1369.6±283.8	(-161.8)-(33.8)	0.2	0.70 (0.48-0.83)	<0.01
		MATCH	1433.6±428.2				
Percent wall volume (PWV) %	1	Multi-sequence	57.6±9.0	(-3.7)-(-0.2)	0.03	0.85 (0.74-0.91)	<0.01
		MATCH	59.5±8.8				
	2	Multi-sequence	60.5±7.8	(-3.4)-(-0.6)	<0.01	0.87 (0.78-0.93)	<0.01
		MATCH	62.5±7.3				
Normalized wall index (NWI)	1	Multi-sequence	0.58±0.1	(-0.5)-(0.0)	0.06	0.85 (0.74-0.91)	<0.01
		MATCH	0.60±0.1				
	2	Multi-sequence	0.60±0.1	(-0.04)-(-0.0)	0.01	0.82 (0.68-0.90)	<0.01
		MATCH	0.62±0.1				

Kassem M, ... Fan, Z, Kooi M, ISMRM 2022;1747

Carotid VWI

❖ qMATCH* for carotid T1/T2 mapping (Yibin Xie et al. Cedars-Sinai)

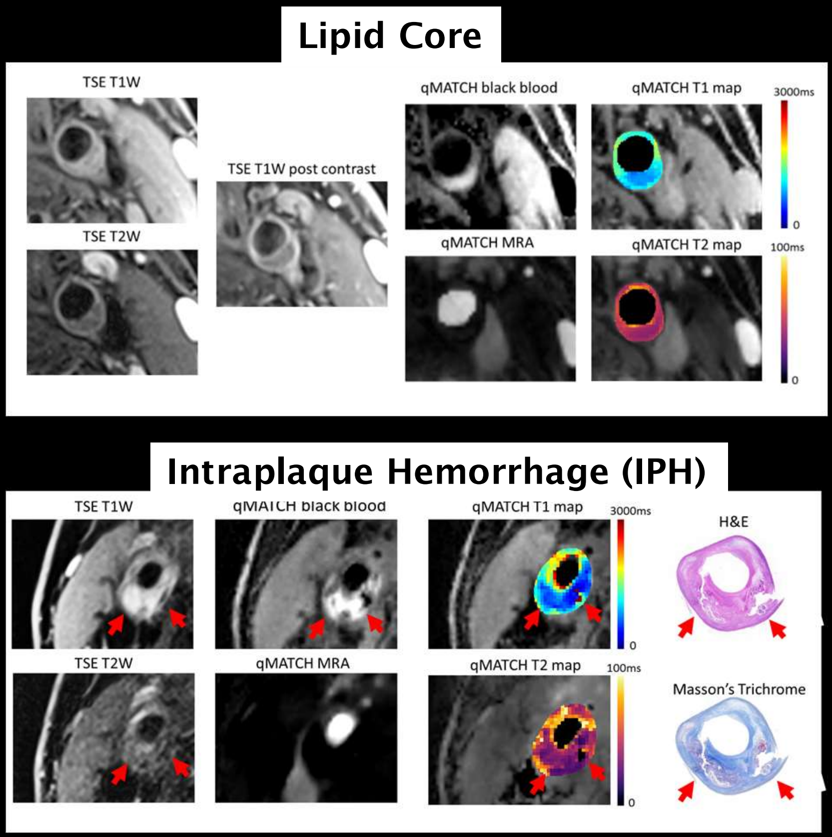


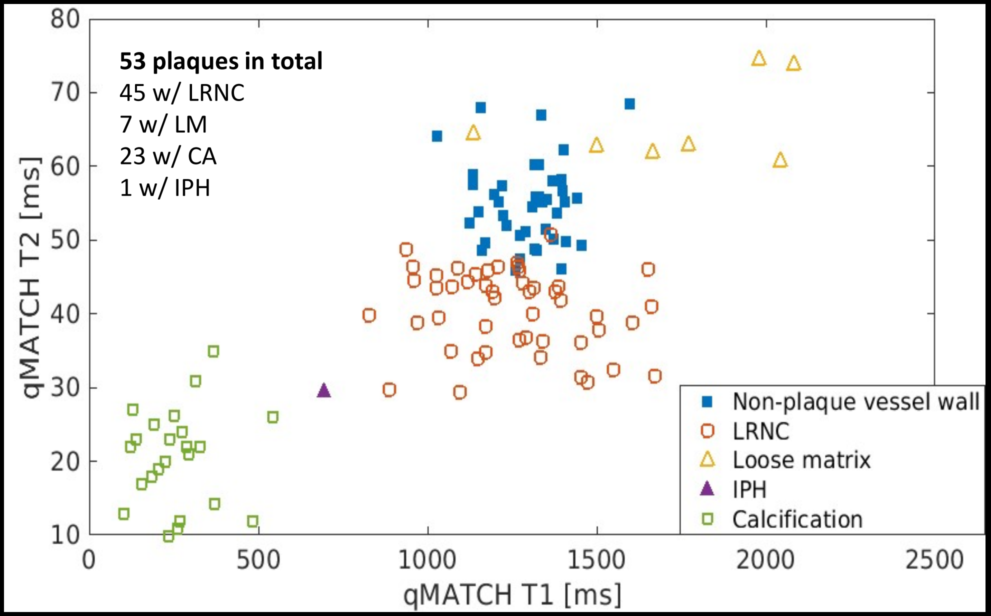


Xie Y et al. ISMRM 2017;3122. Christodoulou, AG., et al. Nature Biomedical Engineering 2.4 (2018): 215.

Carotid VWI

❖ qMATCH* for carotid T1/T2 mapping (Yibin Xie et al. Cedars-Sinai)

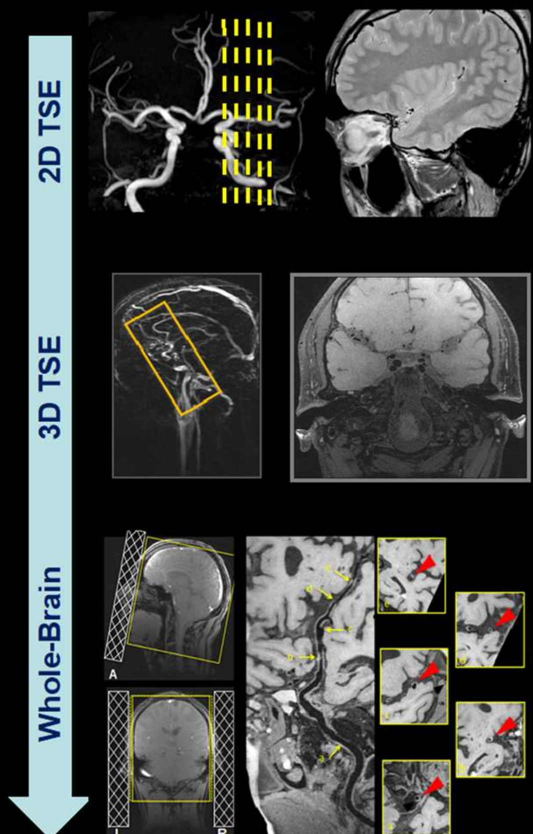


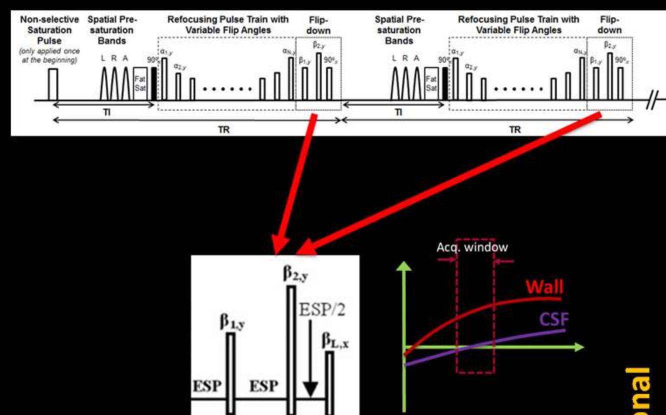


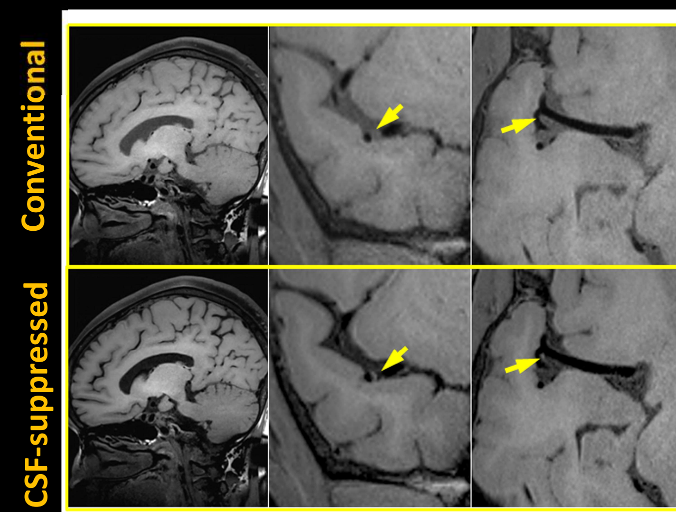
Break

Intracranial VWI

❖ Whole-brain VWI with CSF suppression



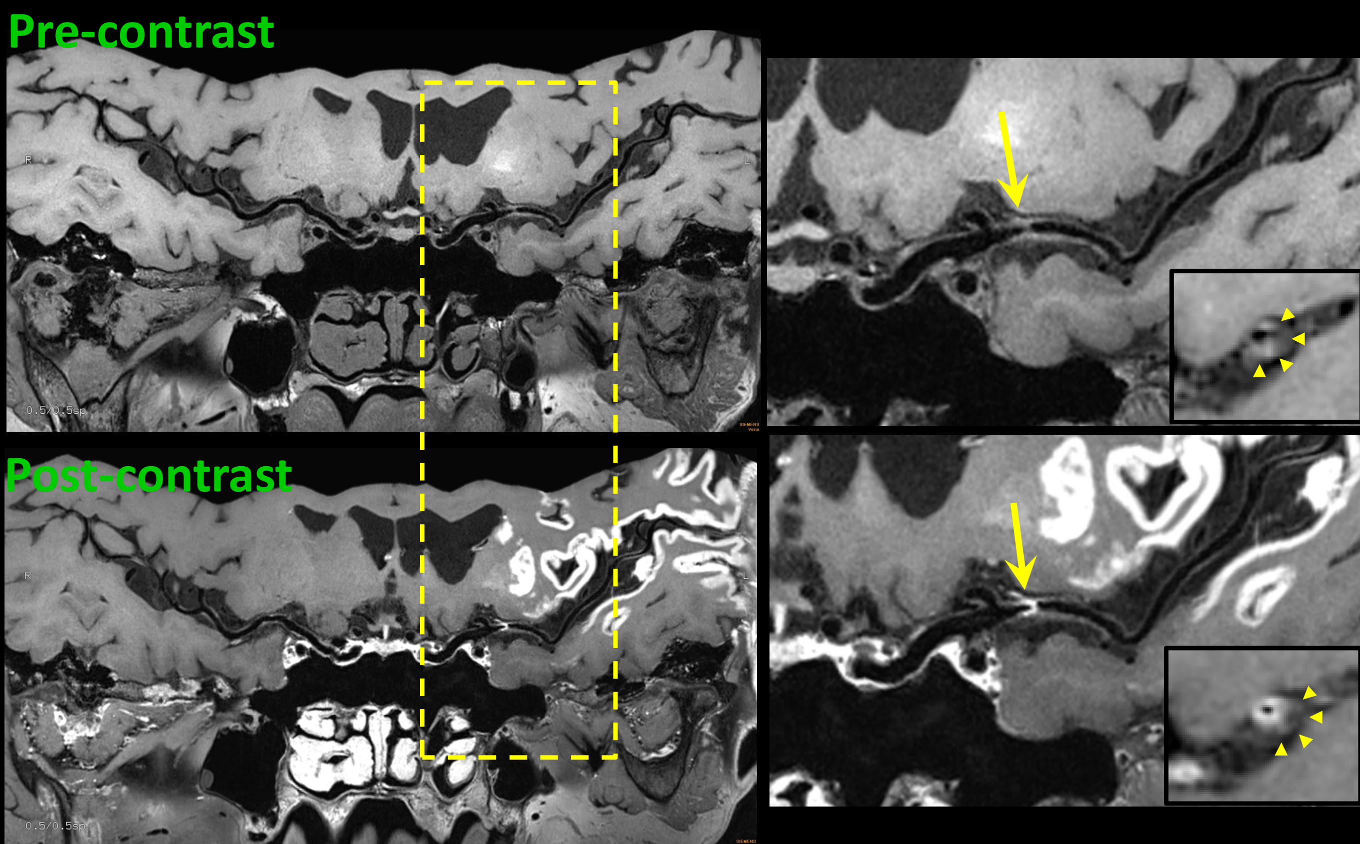


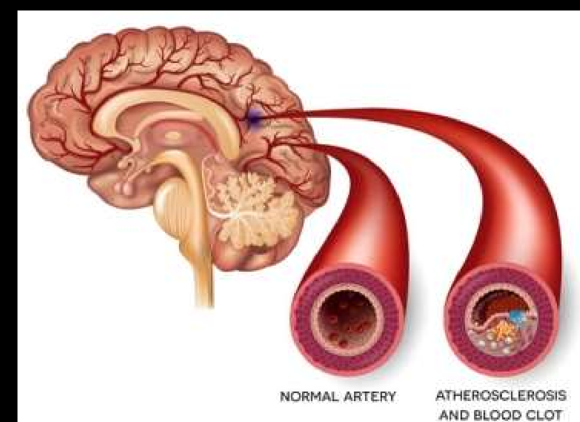


Fan Z et al. Magn. Reason. Med. 2017;77:1142 (submitted Sept 2015, accepted Feb 2016)

Intracranial VWI

- Whole-brain VWI with CSF suppression



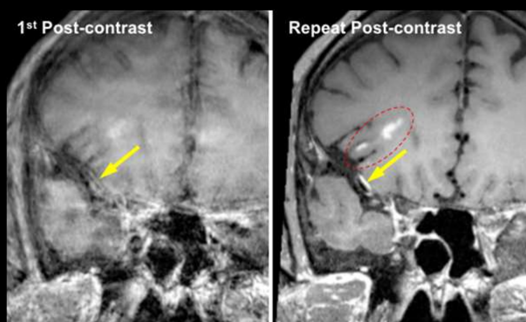


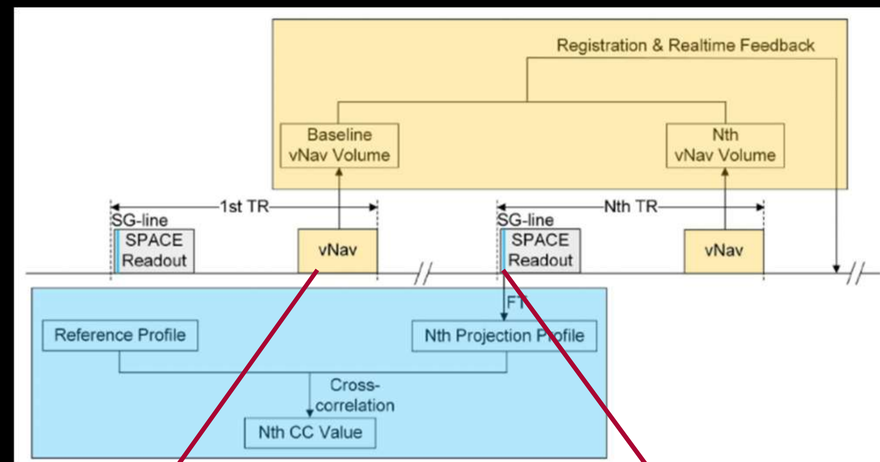
Fan Z et al. Magn. Reason. Med. 2017;77:1142

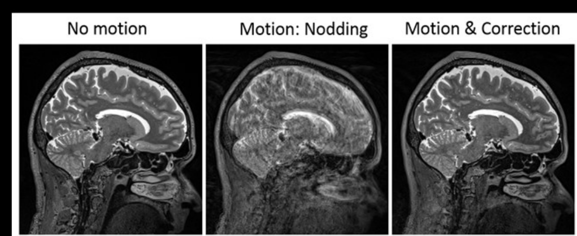
Intracranial VWI

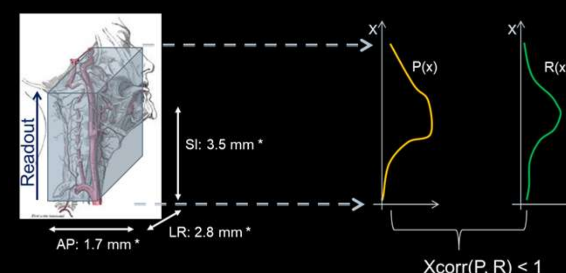
❖ Motion compensation

- Motion (bulk motion, swallow, cough) is common during neuroanatomical MRI
- 3D imaging is inherently motion susceptible
- Higher risk of motion due to the lengthy scan









- **Our solution**:

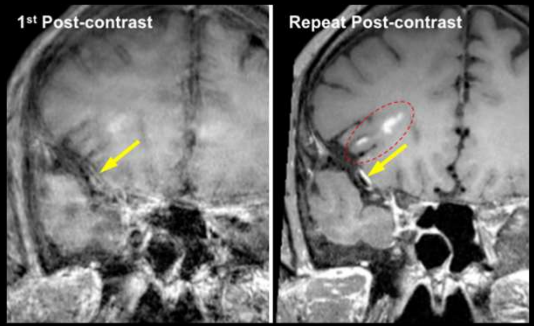
  Self-gating (SG) + volumetric navigator (vNav)

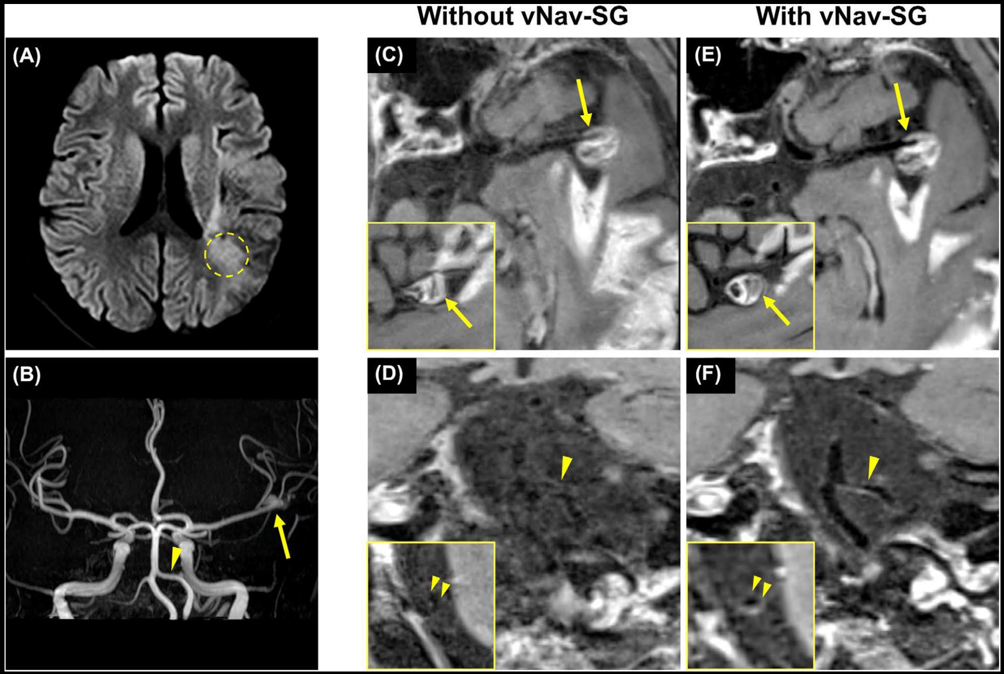
Hu Z, Fan Z et al. Magn. Reson. Med. 2021;86:637-647

Intracranial VWI

❖ Motion compensation

- Motion (bulk motion, swallow, cough) is common during neuroanatomical MRI
- 3D imaging is inherently motion susceptible
- Higher risk of motion due to the lengthy scan





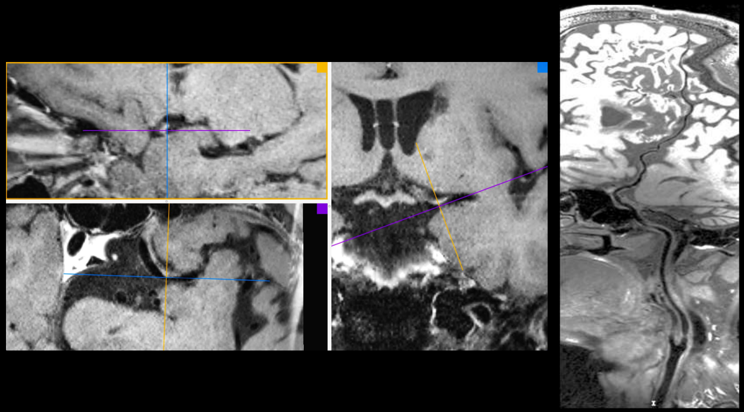
- **Our solution**:

  Self-gating (SG) + volumetric navigator (vNav)

Intracranial VWI

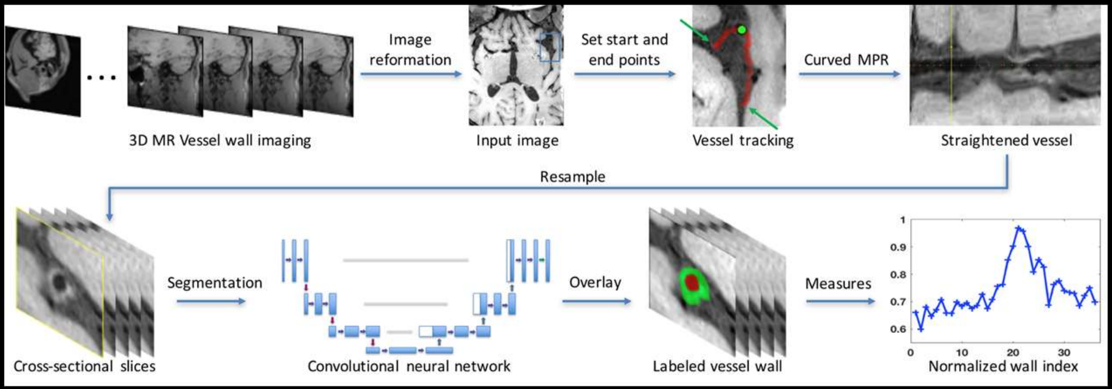
❖ Automated vessel wall analysis

- Manual image processing and review: time-consuming.
- Qualitative disease evaluation: experience-dependent.
- Not well reproducible and not suited for longitudinal studies.



- **Our solution:**

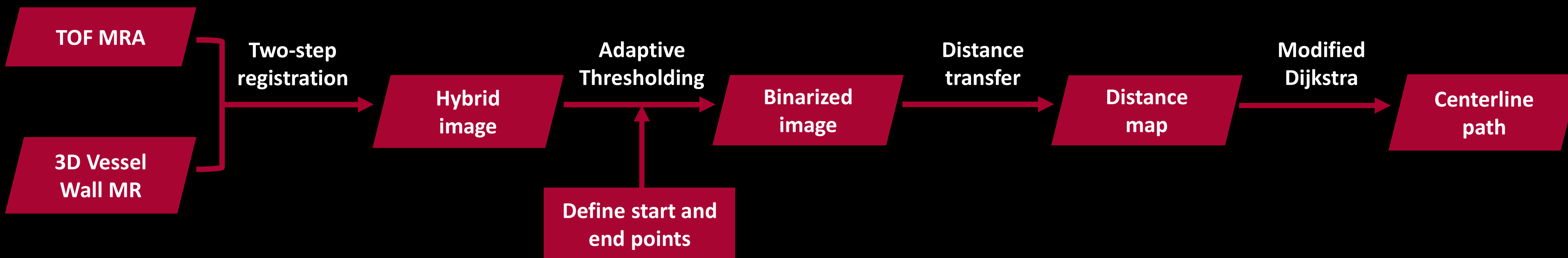
Machine learning-driven automatic or semi-automatic review and analysis.

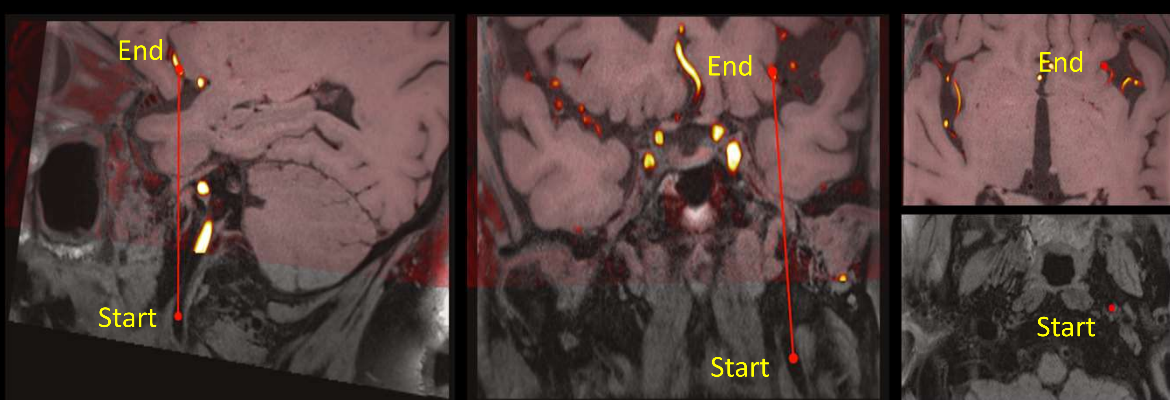


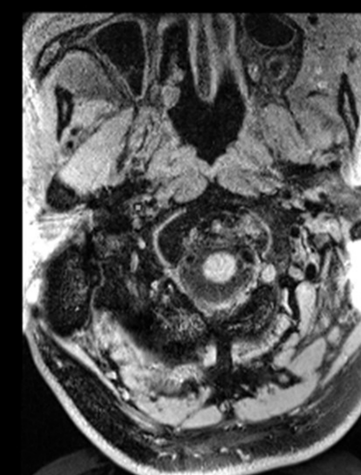
Shi F, Fan Z et al. IEEE Trans Biomed Eng 2019;66:2840

Intracranial VWI

❖ Automated vessel center-line tracking



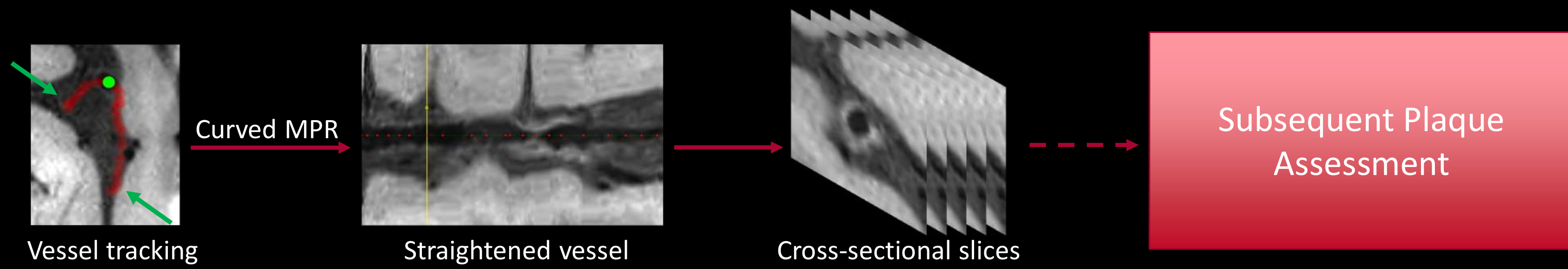




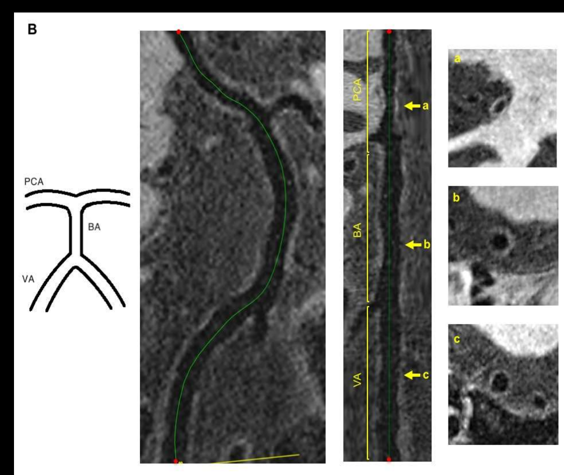
Shi F, Fan Z et al. IEEE Trans Biomed Eng 2019;66:2840

Intracranial VWI

❖ Automated vessel center-line tracking



Anterior Circulation



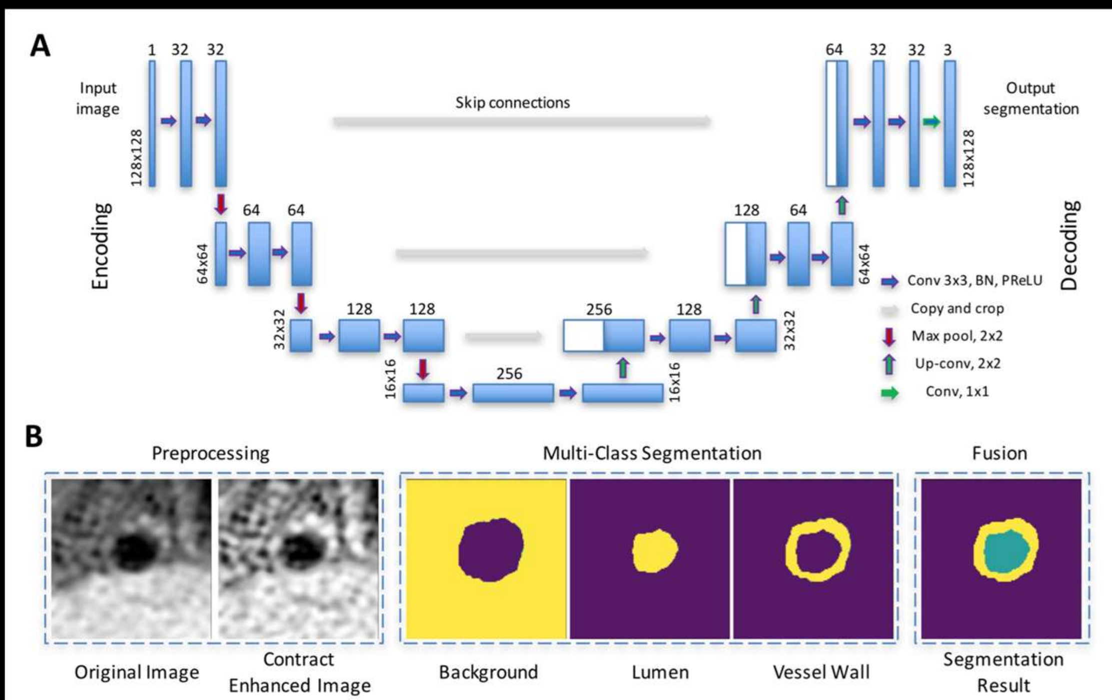
Posterior Circulation

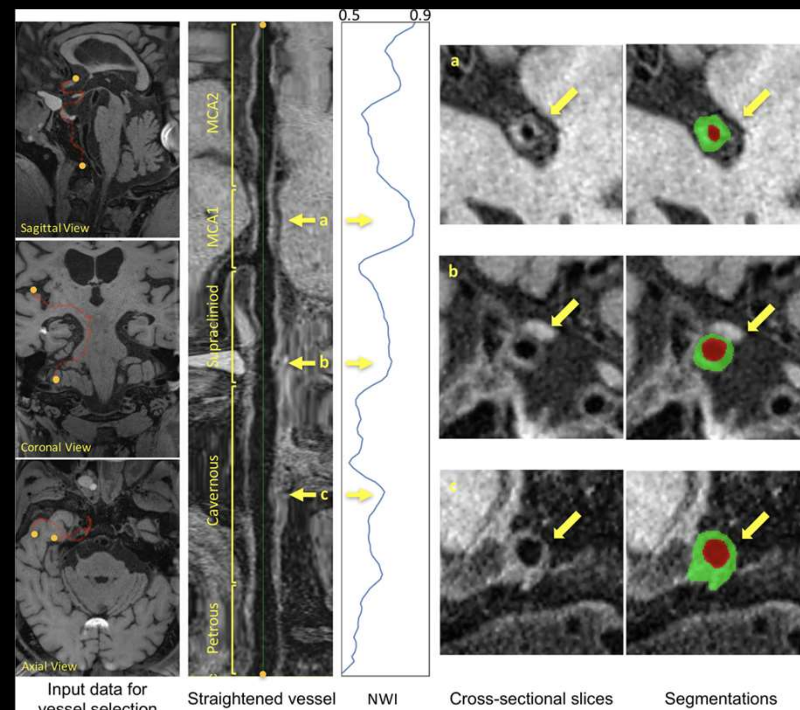
Shi F, Fan Z et al. IEEE Trans Biomed Eng 2019;66:2840

Intracranial VWI

❖ Automated vessel segmentation

2D Unet Model (Fully convolutional network)





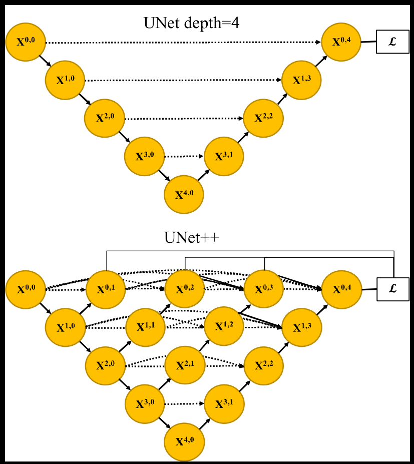
DICE Coefficient: 0.889 (lumen) and 0.767 (vessel wall)

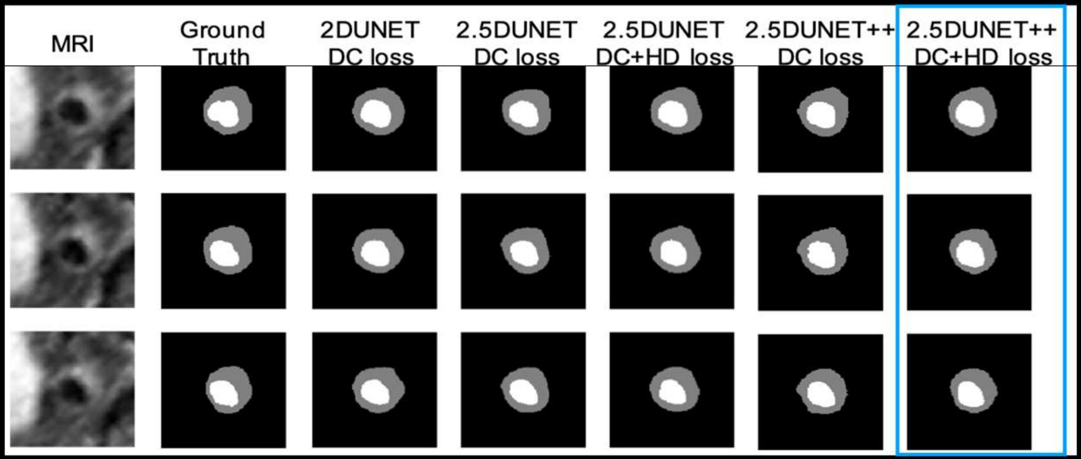
USC

Shi F, Fan Z, et al. ISMRM 2017; Shi F, Fan Z et al. IEEE Trans Biomed Eng 2019;66:2840

Intracranial VWI

❖ Automated vessel segmentation



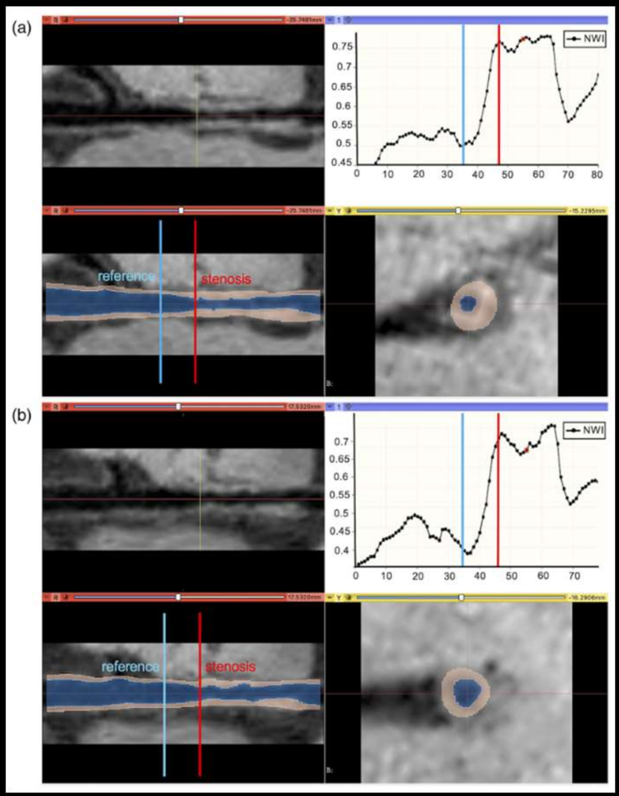


Model	Loss Function	Class	Metric			
			DSC	HD_95 (mm)	MSD (mm)	MAE_NWI
2D UNet	DC	Lumen	0.9163 ± 0.0522	0.3467 ± 0.5173	0.1034 ± 0.0787	0.0732 ± 0.0294
		Vessel Wall	0.7452 ± 0.1046	0.6146 ± 0.7147	0.1764 ± 0.1270	
2.5D UNet++	DC + HD	Lumen	0.9172 ± 0.0598	0.3252 ± 0.5071	0.0940 ± 0.0781	0.0725 ± 0.0333
		Vessel Wall	**0.7833 ± 0.0867**	0.4914 ± 0.5743	**0.1408 ± 0.0917**	

Zhou H, Fan Z et al. IEEE ISBI 2021 *Zhou H, Fan Z et al. Medical Physics 2022;1-11*

Intracranial VWI

❖ VWI-APP: Vessel wall imaging–dedicated automated processing pipeline for intracranial atherosclerotic plaque quantification



	DS (%)		NWI		RR		CR		TPV (mm^3)	
Patient	Manual	Pipeline	Manual	Pipeline	Manual	Pipeline	Manual	Pipeline	Manual	Pipeline
1	18.65	7.20	0.773	0.679	1.007	1.081	1.879	1.929	91.34	86.44
2	30.63	47.61	0.621	0.708	0.778	0.437	1.496	1.812	100.94	115.72
3	12.28	11.28	0.684	0.640	1.317	1.289	1.337	1.391	48.91	48.19
4	18.83	19.59	0.783	0.633	0.885	0.763	1.937	2.302	110.55	95.34
5	27.41	28.73	0.950	0.820	1.286	1.094	1.749	1.953	100.55	105.83
6	22.94	16.71	0.729	0.693	0.924	0.911	1.929	1.741	32.16	28.63
7	63.35	58.52	0.913	0.895	0.793	0.834	1.809	1.664	84.51	86.89
8	35.01	37.46	0.853	0.807	1.055	1.123	1.297	1.475	109.16	98.74
9	67.21	52.86	0.961	0.929	0.816	0.782	1.235	1.150	449.26	495.60
10	41.55	40.69	0.842	0.841	1.075	1.000	2.978	2.678	183.36	186.95
MAE	6.02 ± 6.10		0.064 ± 0.047		0.099 ± 0.095		0.188 ± 0.105		10.71 ± 12.81	
ICC	0.890		0.813		0.827		0.891		0.991	
CI_95	[0.62, 0.97]		[0.41, 0.95]		[0.45, 0.95]		[0.62, 0.97]		[0.96, 1.00]	

Abbreviations: CI, confidence interval; CR, plaque wall contrast ratio; DS, diameter stenosis; ICC, intraclass correlation coefficient; MAE, mean absolute error; NWI, normalized wall index; RR, remodeling ratio; TPV, total plaque volume.

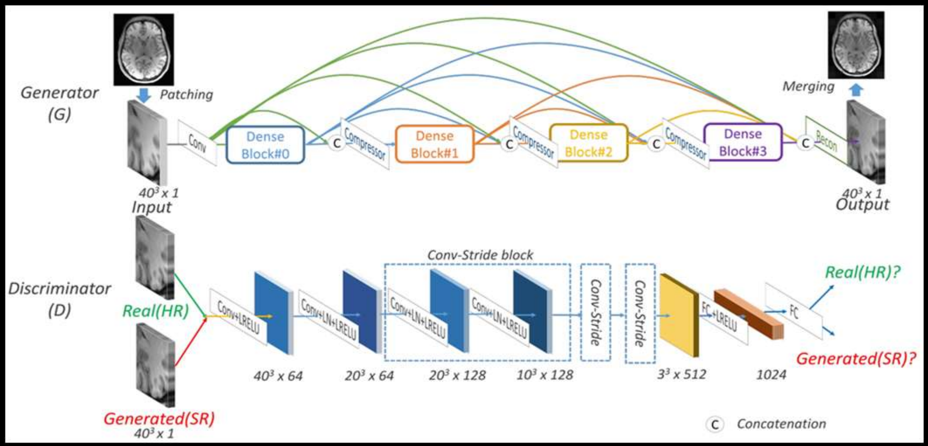
675.7±204.0 s with manual quantification
238.3±77.8 s with VWI-APP quantification

Zhou H, Fan Z et al. Medical Physics 2022

Intracranial VWI

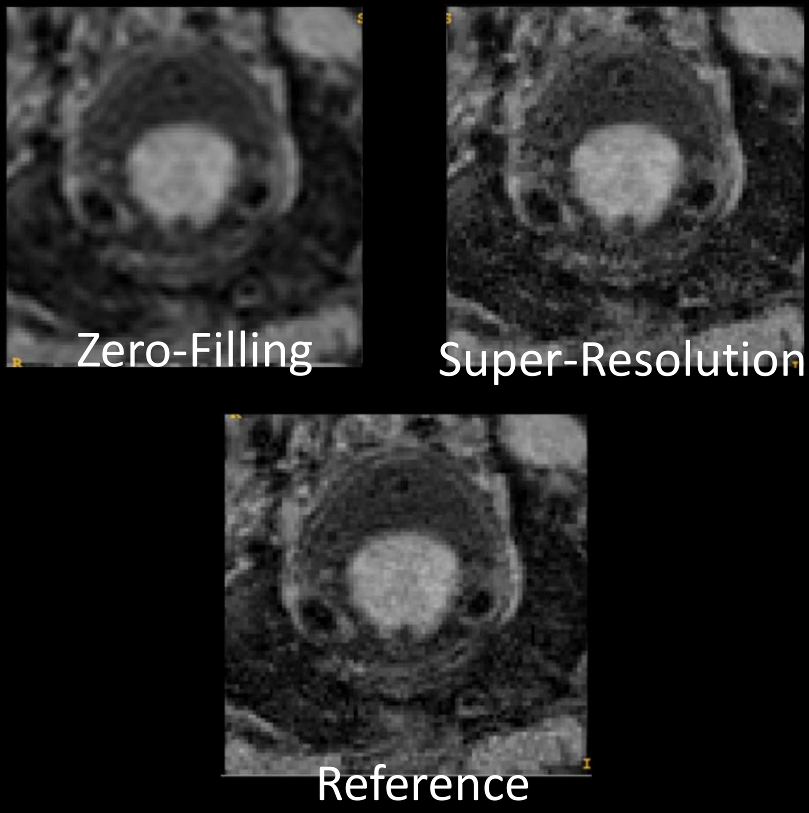
❖ Super-resolution in VWI

mDCSRN-GAN



Potential benefits:

- **Acquire a lower-resolution image: shorter scan time, higher signal-to-noise ratio, improved success rate**
- **Acquire a regular-resolution image and further increase to higher one**

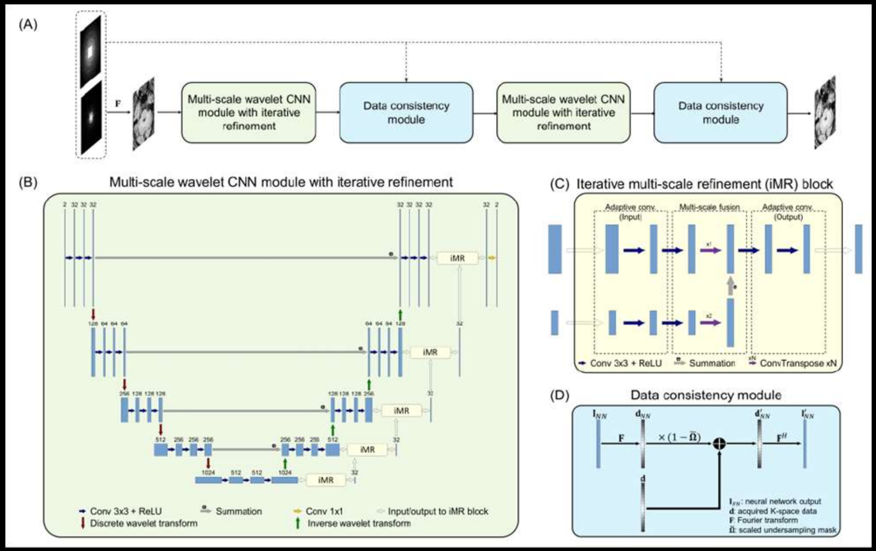


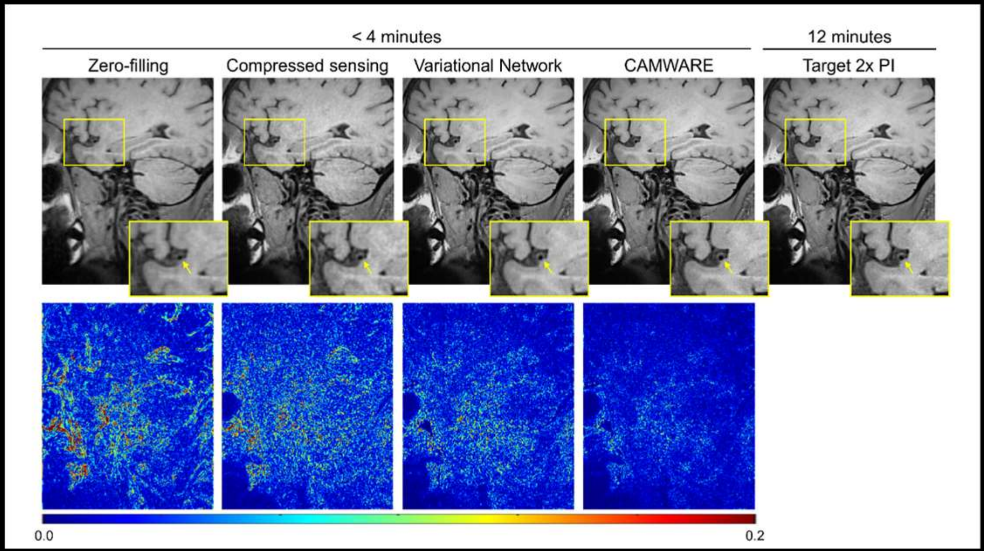
Chen Y, Fan Z et al. ISMRM Annual Meeting 2018

Intracranial VWI

❖ Deep learning-based image reconstruction in VWI

Cascaded Multi-scale Wavelet with iterative Refinement reconstruction network (CAMWARE)





Potential benefits:

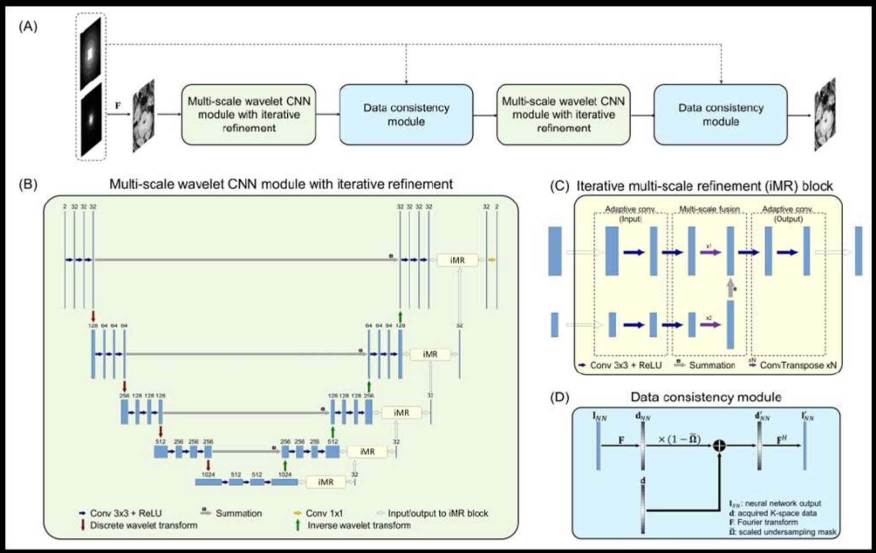
- **Shorter scan time (from 8 min to <4 min), improved success rate and clinical throughput**

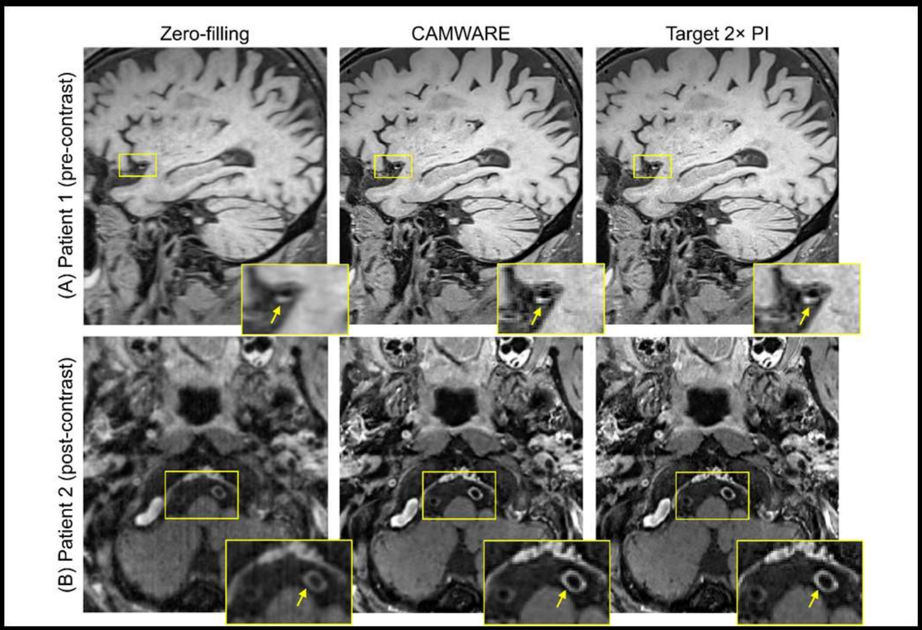
Hu Z, Fan Z et al. ISMRM 2021

Intracranial VWI

❖ Deep learning-based image reconstruction in VWI

Cascaded Multi-scale Wavelet with iterative Refinement reconstruction network (CAMWARE)





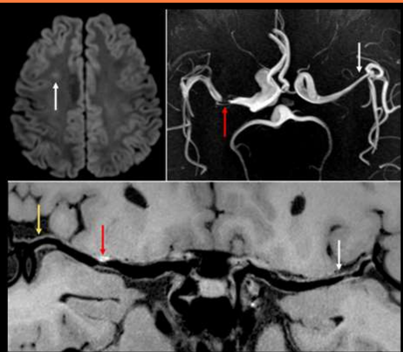
Potential benefits:

- **Shorter scan time (from 8 min to <4 min), improved success rate and clinical throughput**

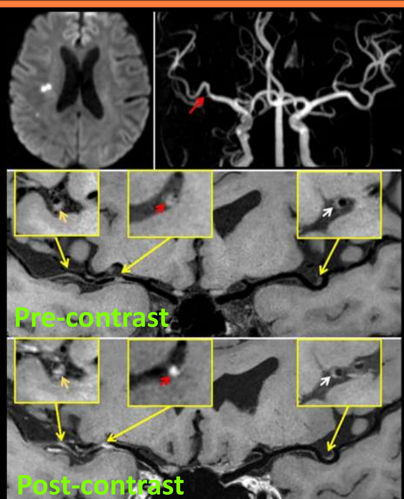
Hu Z, Fan Z et al. ISMRM 2021

Clinical Applications

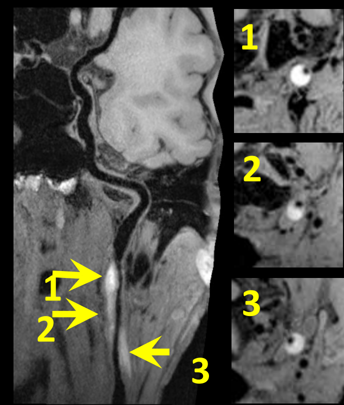
High T1-signal Feature of ICAS



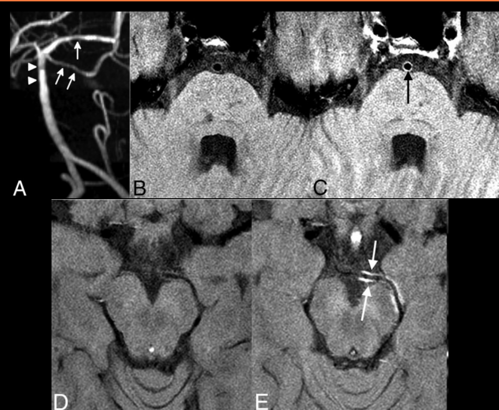
Contrast enhancement feature of ICAS



Dissection



Vasculitis



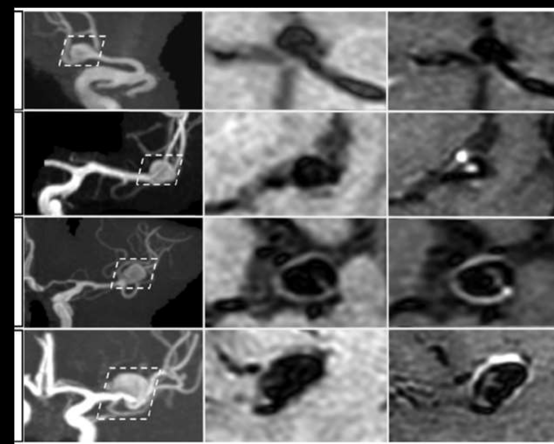
Aneurysm

Grade 0

Grade 1

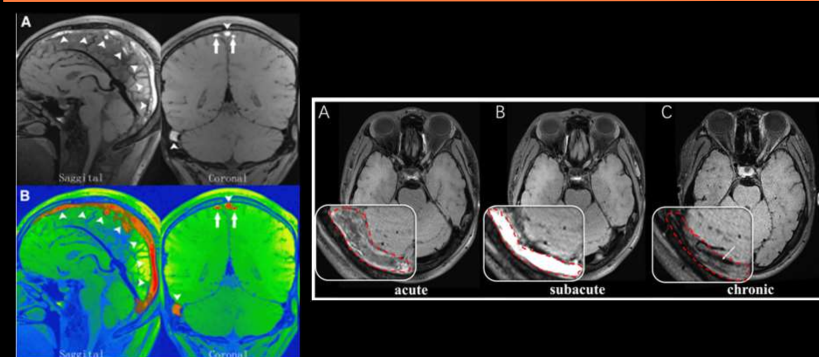
Grade 2

Grade 3



Pre-contrast Post-contrast

Cerebral Venous Thrombosis



1. Wu F, Fan Z et al. J Am Heart Assoc. 2018;7:e009705. 2. Wu F, Fan Z et al. Stroke 2018;49:905. 3. Yang Q, Fan Z et al. Stroke 2016;47:404.

On-going Project

NIH/NHLBI R01HL147355

Longitudinal and quantitative MR plaque imaging for prediction of response to medical management in symptomatic intracranial atherosclerosis

Keck Medicine of USC

Cedars Sinai

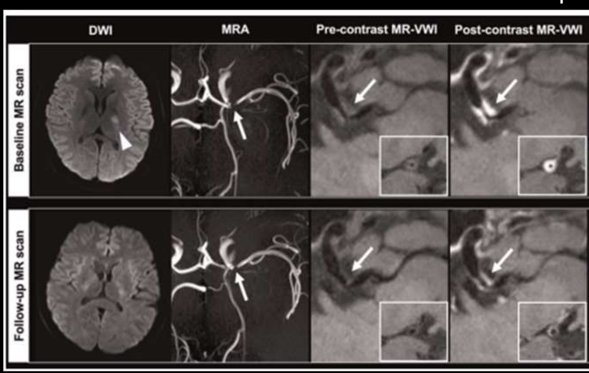
Clinical Aim: Enrollment of **100** patients with acute ischemic events secondary to intracranial atherosclerosis. Vessel wall imaging at 2 weeks (baseline), 3, 6, and 12 months of their index stroke or high-risk TIA

LISIA Study

Longitudinal Imaging of Symptomatic Intracranial Atherosclerosis

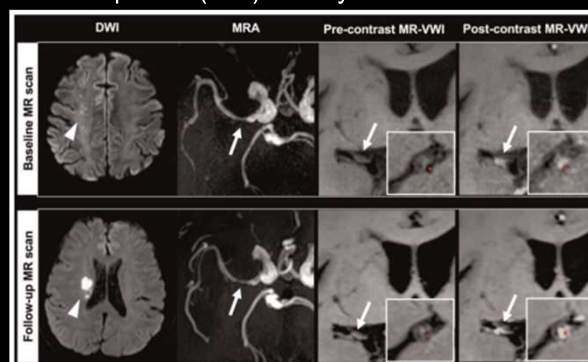
Non-progression patient

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

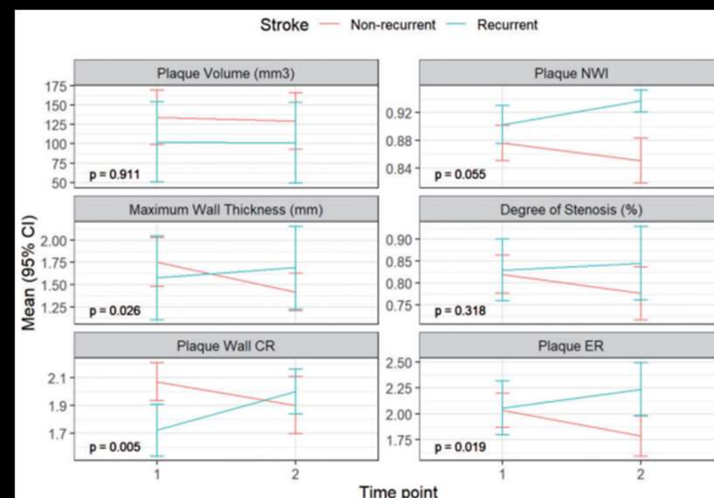


Progression patient

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



Pilot Results

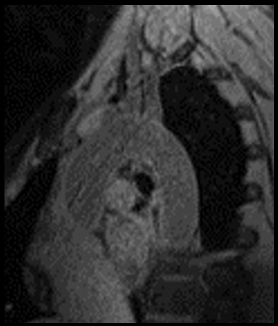


Aortic VWI

❖ **MR imaging is promising for evaluating thoracic aorta diseases**

Bright-blood[1]

Dark-blood[2]



Gray-blood[3]

Cine[4]

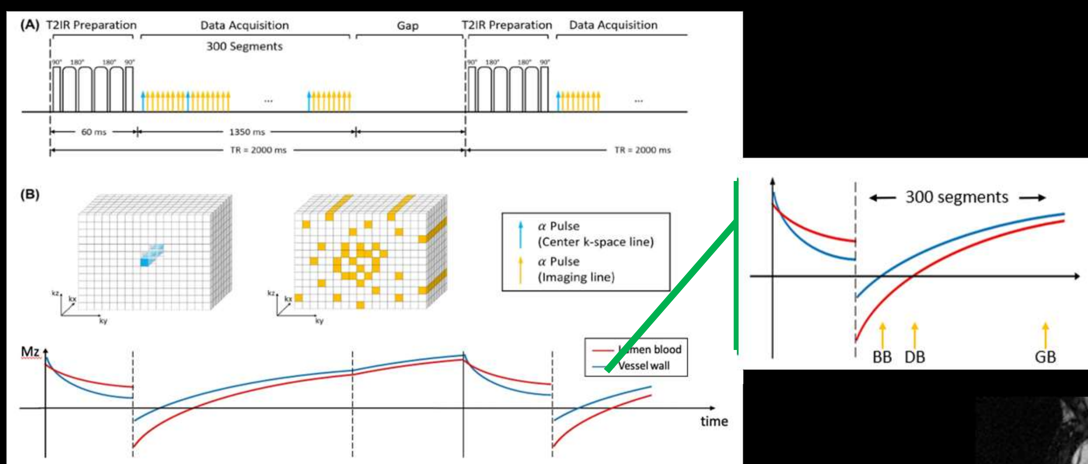
❖ **Clinical adoption of this comprehensive imaging modality is hindered by:**

- Long scan time – motion compensation
- Motion artifacts
- Multiple scans with inter-scan misregistration

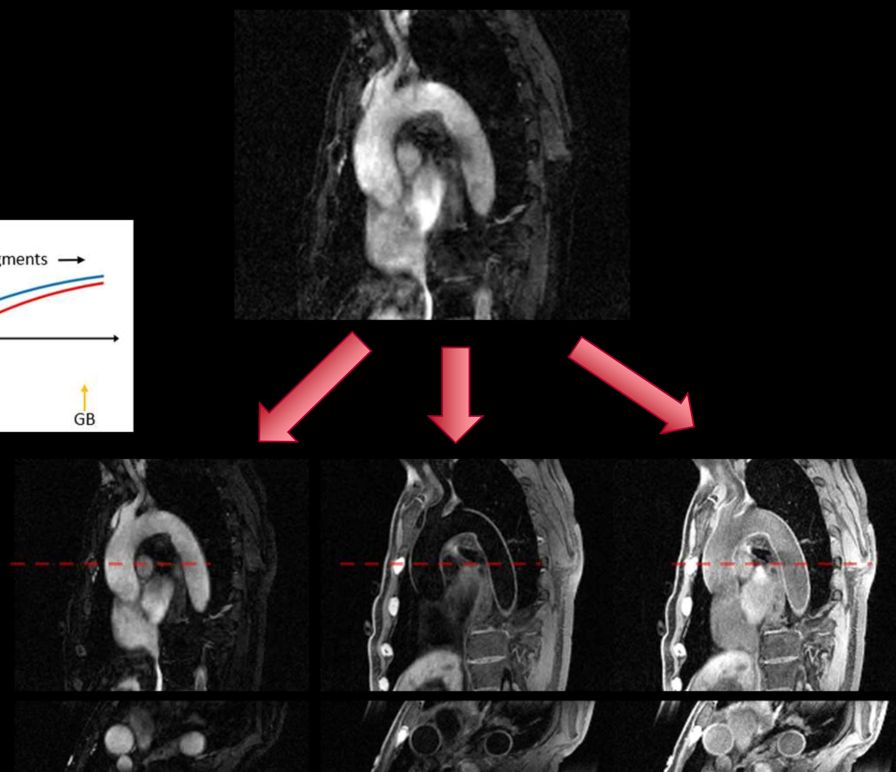
1. Krishnam, MS, et al. European Radiology 20.6 (2010): 1311-1320. 2. Francois, CJ, et al. Cardiology Clinics 25.1 (2007): 171-184.
3. Fan, Z, et al. ISMRM 2018 5589. 4. Dubourg, B, et al. European Congress of Radiology 2016, 2016.

Aortic VWI

❖ **MR-Multitasking* based Multidimensional Assessment of Cardiovascular System (MT-MACS)**



Total time	TR/TE	Flip angle	Field of view	Spatial resolution	Bandwidth	Fat-water contrast
6 min	2000ms/2ms	8^0	275×220×75 mm	1.38 mm isotropic	1008 Hz/px	Water excitation

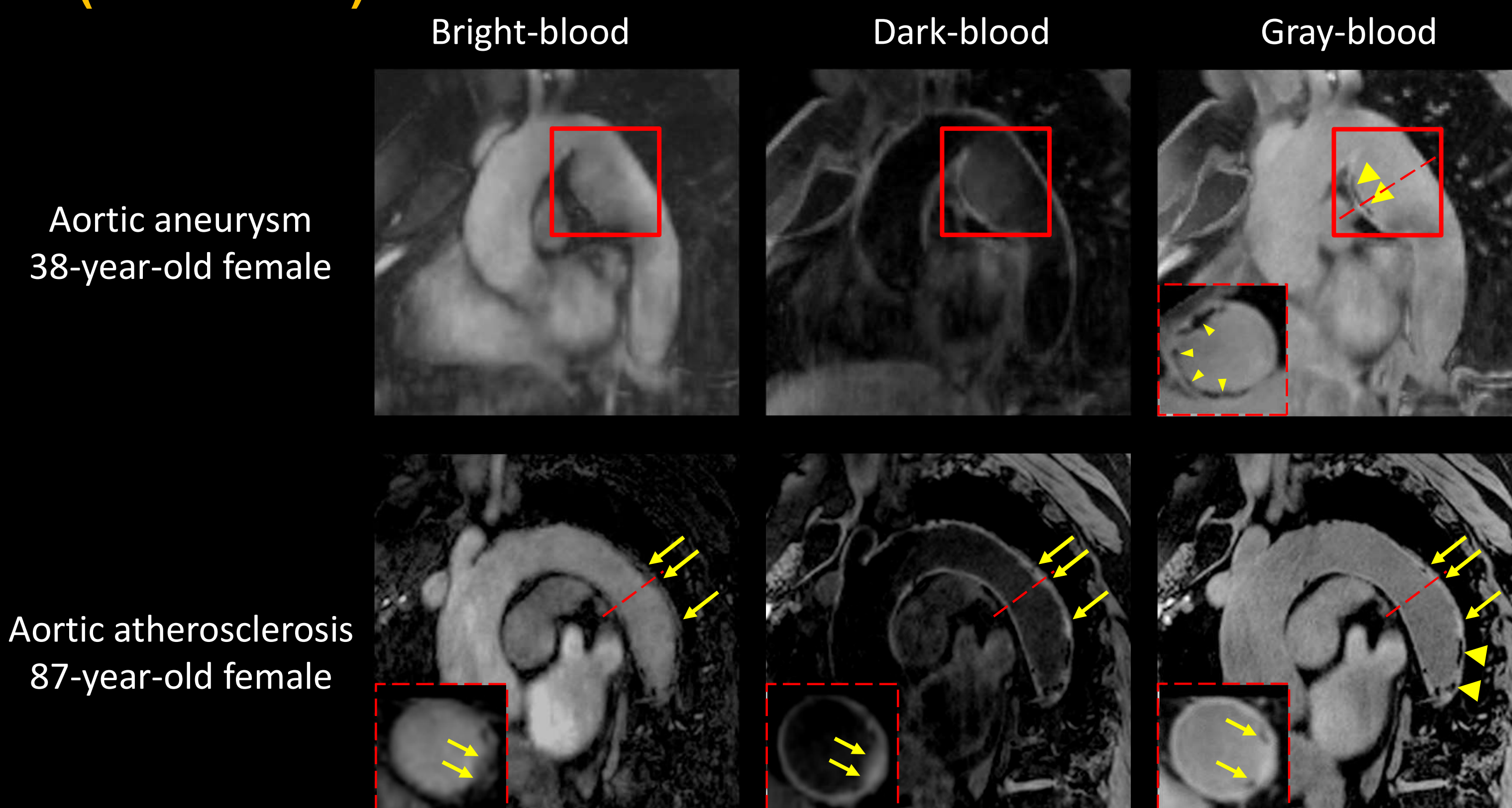


Bright-blood (BB) Dark-blood (DB) Gray-blood (GB)

* *Christodoulou, AG., et al. Nature Biomedical Engineering 2.4 (2018): 215.*

Aortic VWI

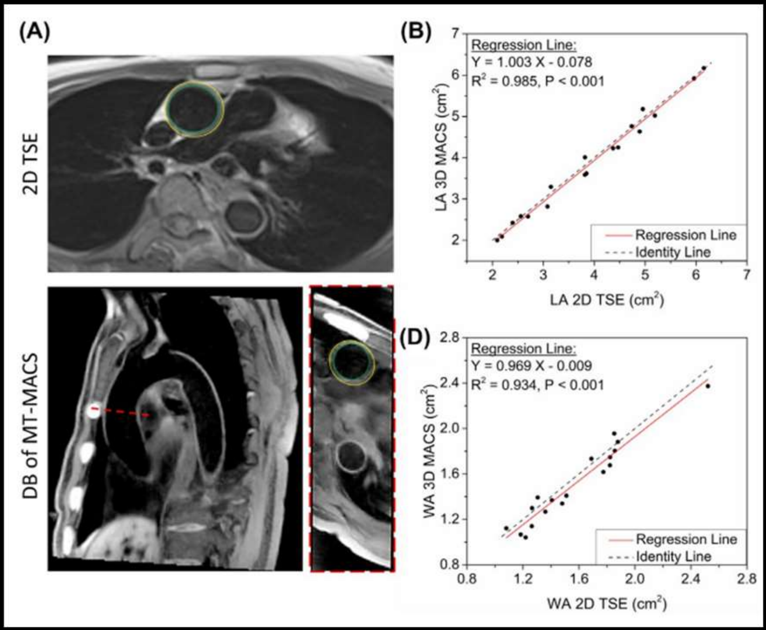
❖ **MR-Multitasking* based Multidimensional Assessment of Cardiovascular System (MT-MACS)**



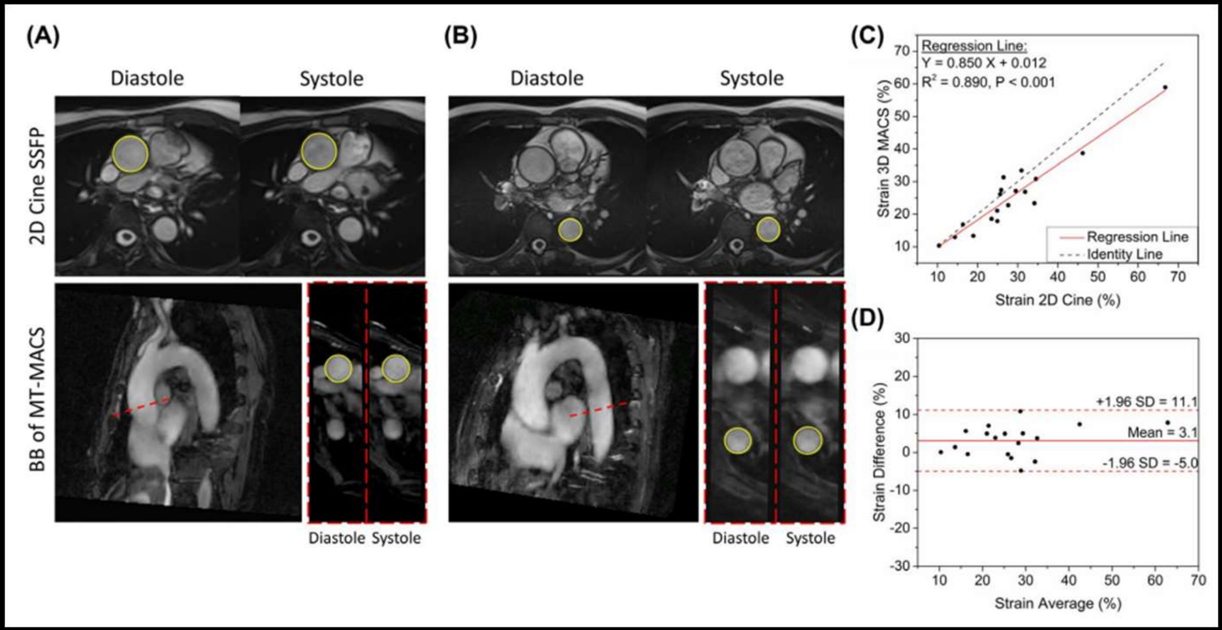
Hu Z, Fan Z et al. MRM 2020;84:2376-2388

Aortic VWI

❖ **MR-Multitasking* based Multidimensional Assessment of Cardiovascular System (MT-MACS)**



Vessel wall/lumen area quantification



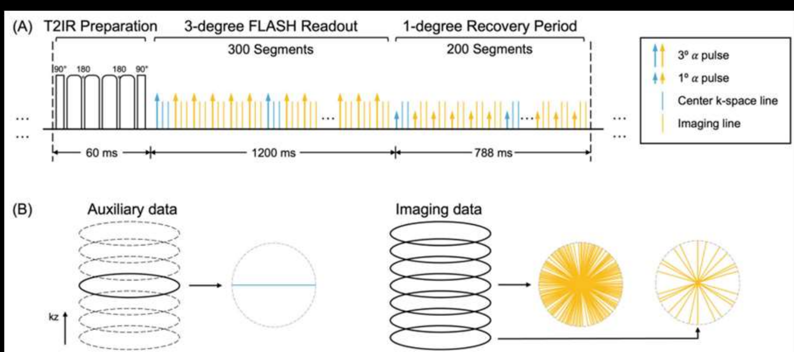
Strain Analysis

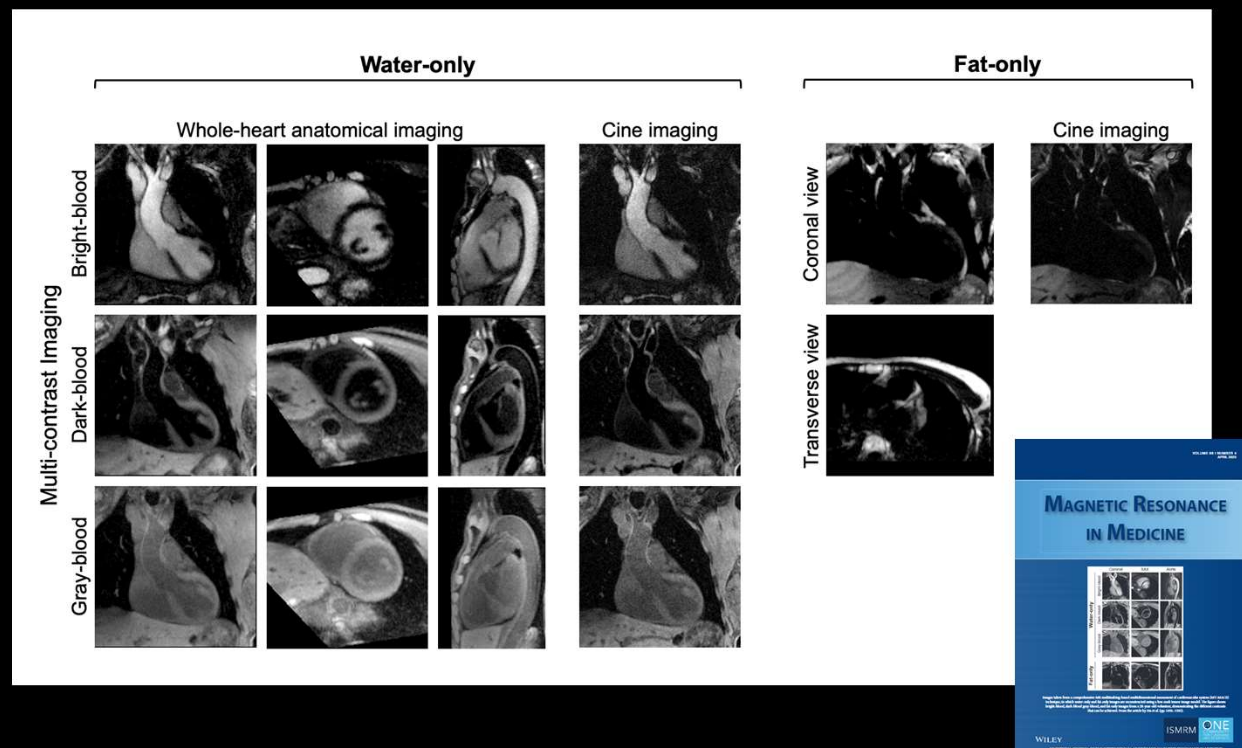
Hu Z, Fan Z et al. MRM 2020;84:2376-2388

Aortic VWI

❖ MT-MACS with <u>extended spatial coverage and water-fat separation</u>

ECG- and respiratory navigator-free, multi-dimensional (multiple contrast weightings, cine series, and water-fat images) imaging with a single 10-min scan.



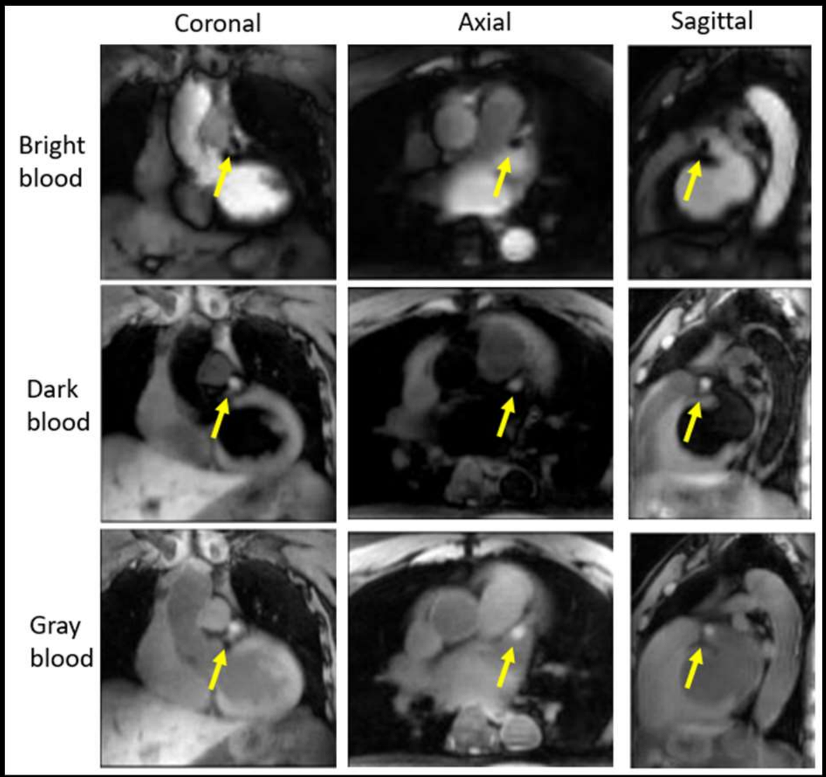


Hu Z, Fan Z et al. MRM 2023;89:1496

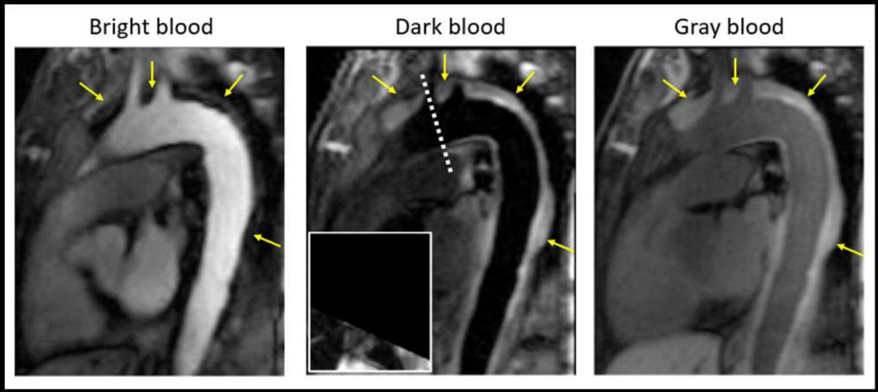
Aortic VWI

❖ **MT-MACS with extended spatial coverage and water-fat separation**

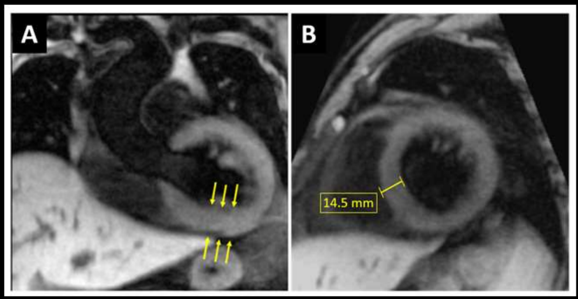
LAA thrombus



Aortic vasculitis



LV hypertrophy



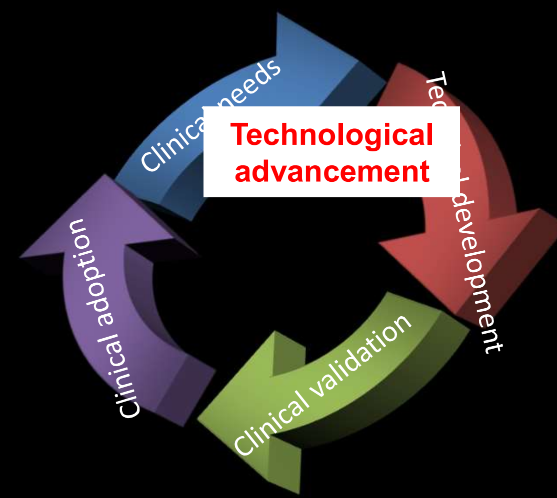
Hu Z, Fan Z et al. MRM 2022 Nov 6.

Outline

- Background on Stroke
- MR Luminal Imaging
  - Non-contrast MRA
  - Contrast-enhanced MRA
  - Susceptibility-based imaging
- MR Vessel Wall Imaging (VWI)
  - Carotid VWI
  - Intracranial VWI
  - Aortic VWI
- Summary

Summary

- MR luminal imaging and vessel wall imaging can be highly useful for non-invasively evaluating vascular abnormalities causing a stroke.
- Vascular MR is becoming faster and more comprehensive through multidimensional imaging (multiple contrasts, multi-parametric mapping, motion resolved, …) and advanced image reconstruction.
- Vascular MR needs to be more easy-to-use: larger spatial coverage, free-breathing, no ECG trigger, co-registered information, automated image analysis.
- Technological advancement is being driven by interdisciplinary collaboration among clinicians, MR scientists, and data scientists.



Thank you!

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