

MR Imaging of Atherosclerotic Plaques



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MRI for Carotid Atheroma

- Excellent tissue contrast (fat, fibrous tissue, collagen, thrombus)
- Noninvasive
- More accurate and objective estimation of stenosis degree than US

Carotid MRI at 1.5T

- Experiences for a decade
- MRI has shown capability to detect vulnerable plaques with large lipid/necrotic cores, intraplaque hemorrhage and plaque cap rupture.
- 3.0 T MRI is expected to show higher resolution enough for smaller arteries.

SENS-Flex-M Coil

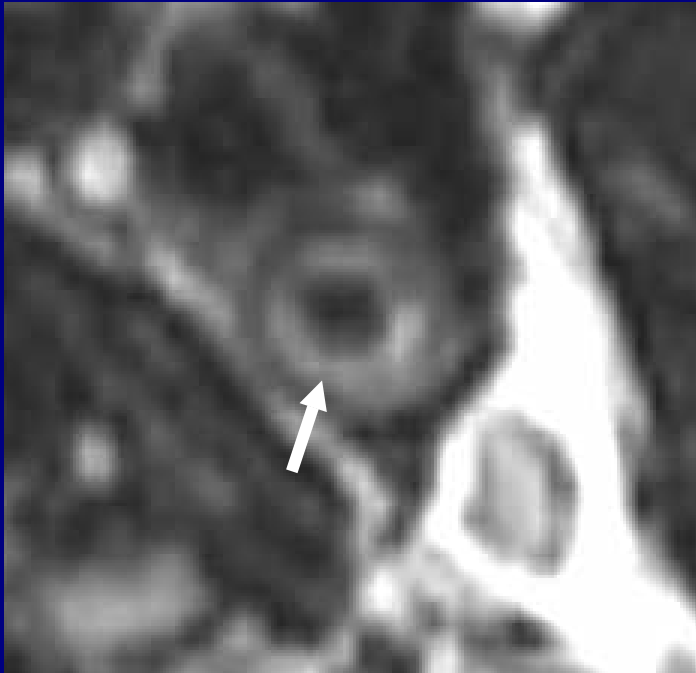


MRI Appearance of Plaque Components on Various Imaging Sequences

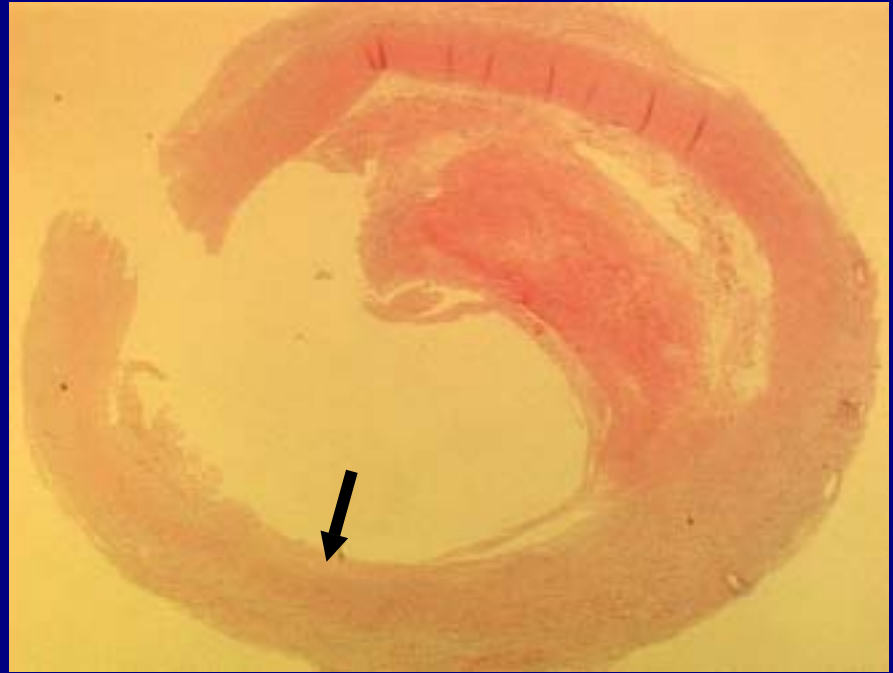
Plaque Components	<i>T2WI</i>	<i>T1WI</i>	<i>T1WI, Fat-Suppr.</i>	<i>Proton WI</i>	<i>TOF</i>	<i>CE on Post-Contrast</i>
Recent Hemorrhage	Variable	H-to-M	H	Variable	H	No
Lipid-rich Necrotic Core	Variable (L)	H	M-to-H	H	M	No
Fibrous Tissue	Variable	M	M	H	M-to-L	Yes
Calcification	L	L	L	L	L	No

Tissue contrast is relative to SI of muscle

Stable Plaque

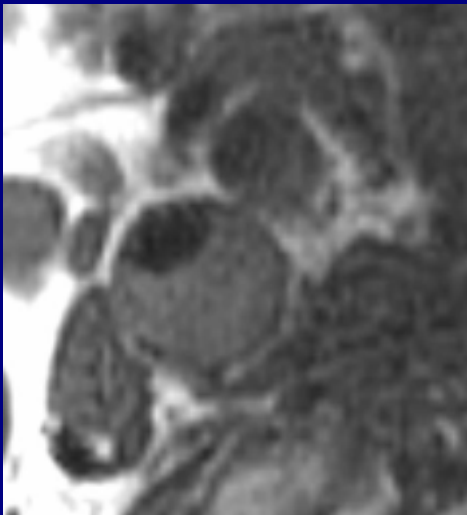


T2WI

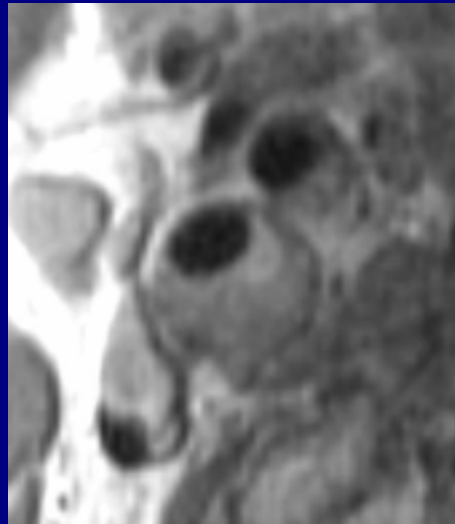


Pathology

Lipid-rich Plaque



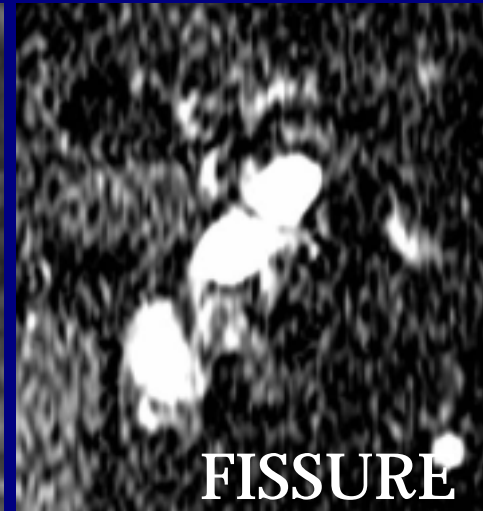
T1WI



Proton-WI



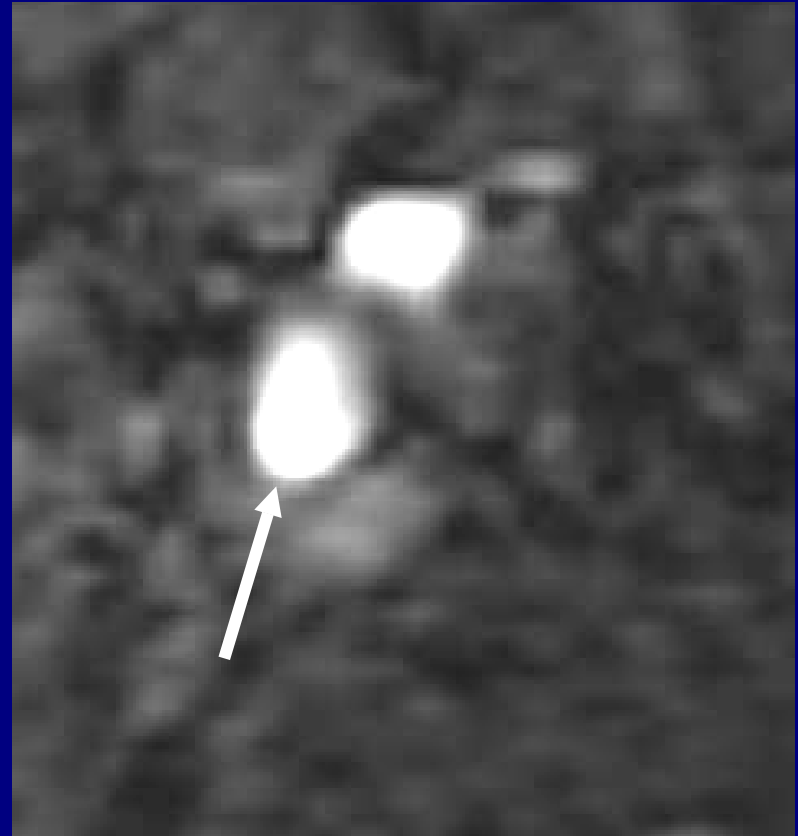
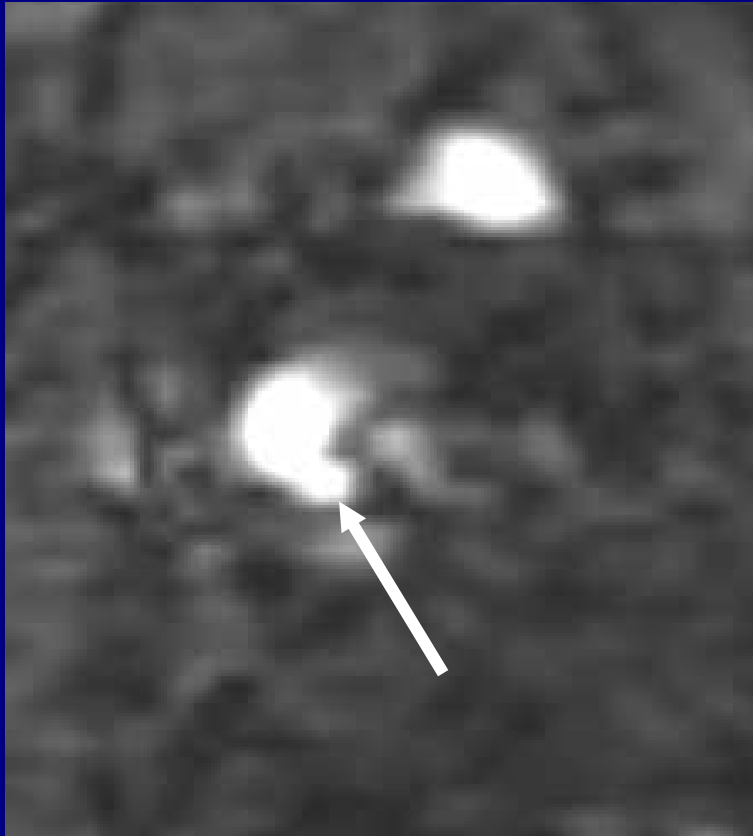
T2WI



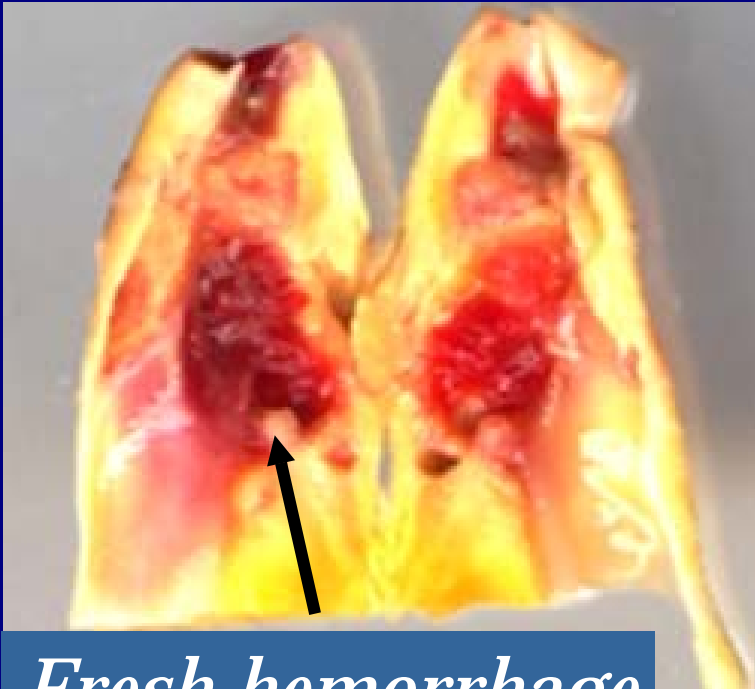
FISSURE

TOF

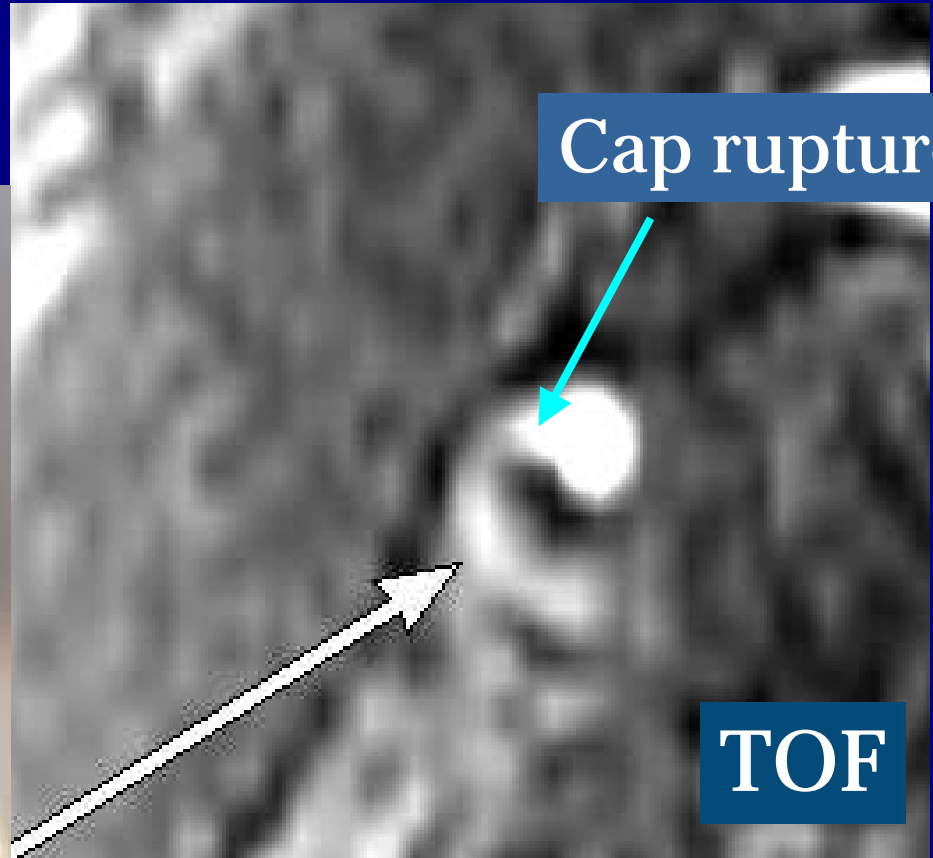
Fibrous Cap on MRI



Fresh Intraplaque Hemorrhage with Fibrous Cap Rupture



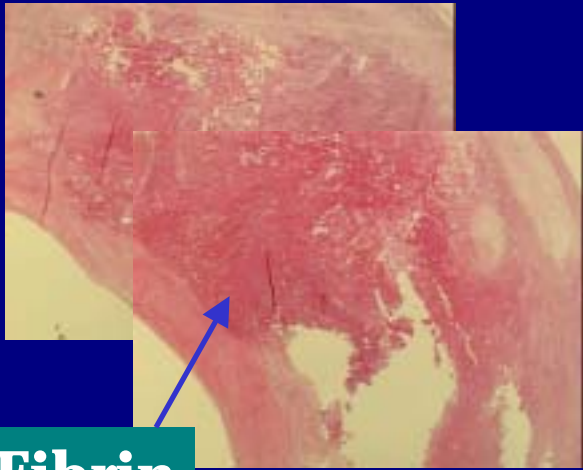
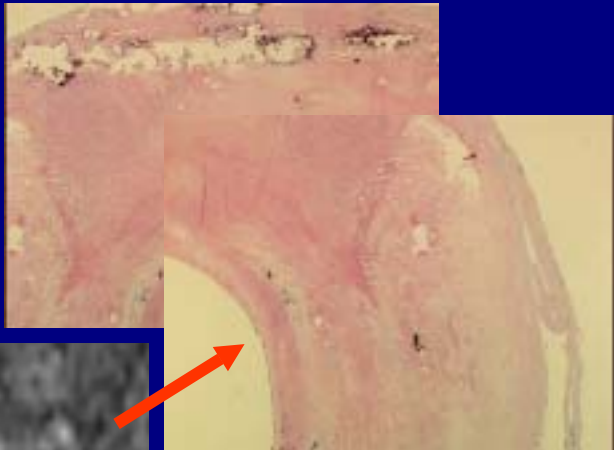
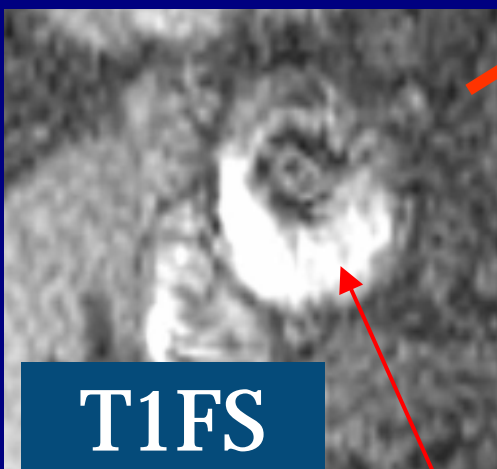
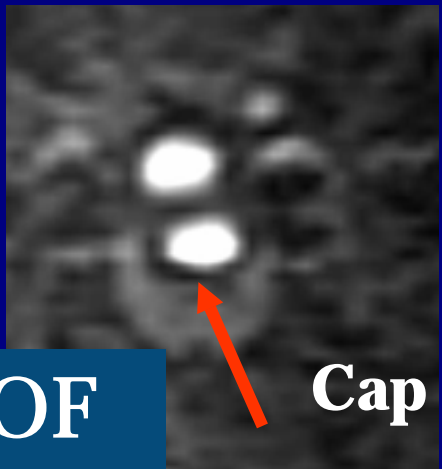
Fresh hemorrhage



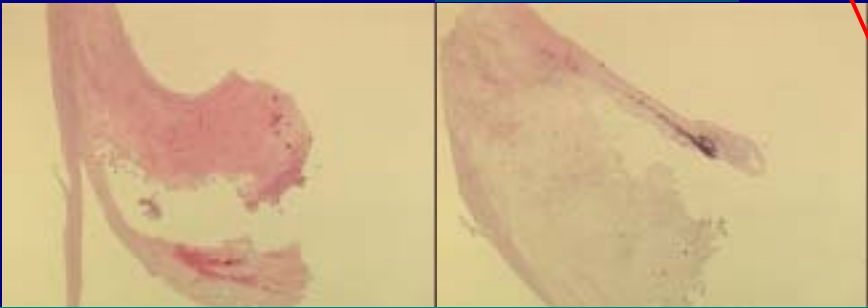
Cap rupture

TOF

Intact Plaque Cap with Intraplaque Hemorrhage (fibrin)

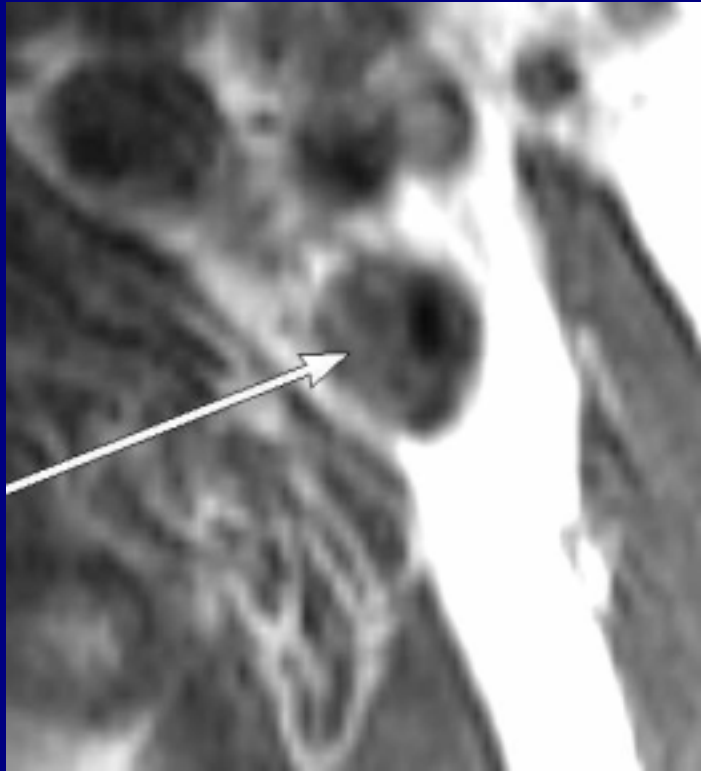


Fibrin

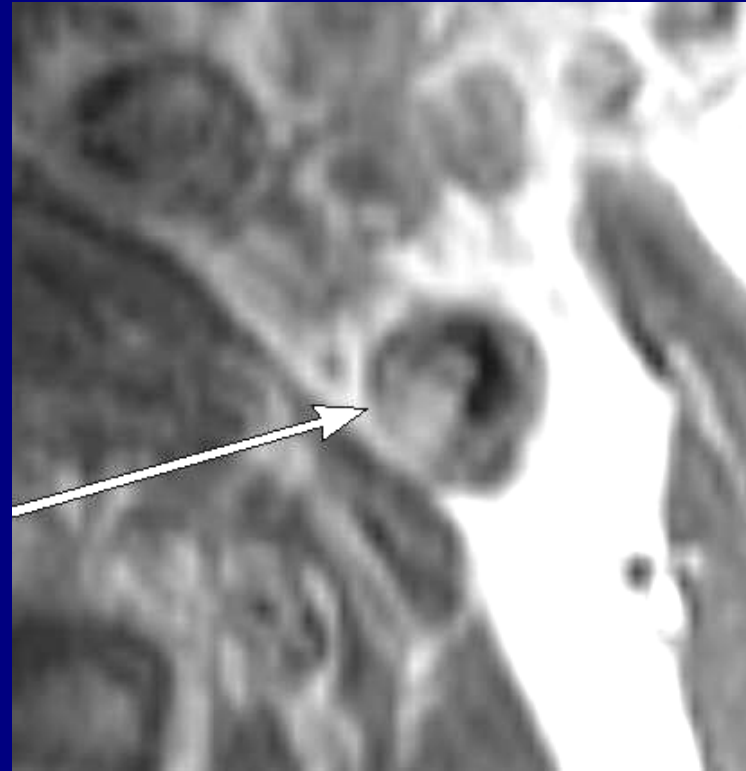


Hemorrhage in 31% of 153 endarterectomy specimens

Contrast-enhancement in Fibrous Component



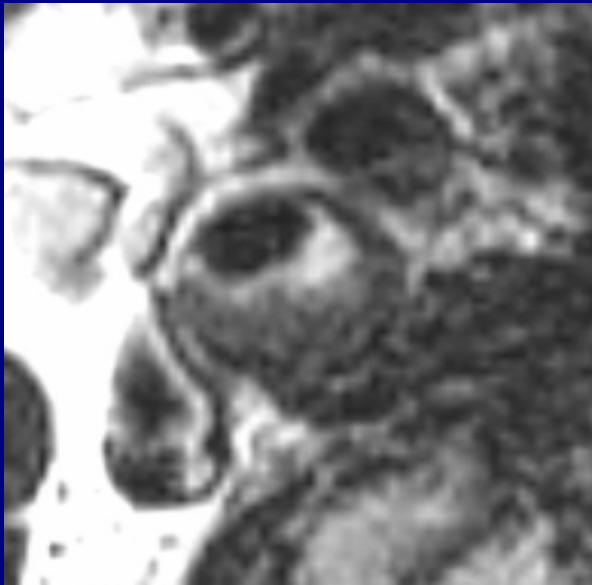
Pre



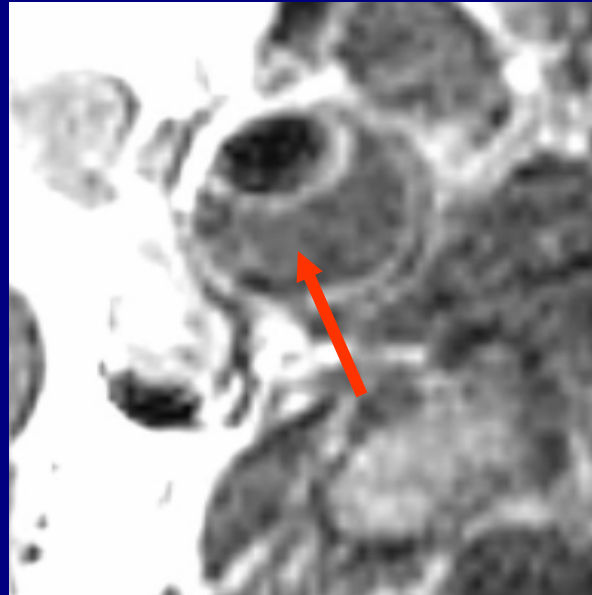
Post

- Increased neovascularity within plaque may contribute to plaque instability.
- Contrast-enhancement represents neovasculature in the histopathology (sensitivity 76%, specificity 79% by Yuan).
- Contrast-enhancement improves differentiation of tissue types (fibrous tissue, necrotic core, calcifications).

Large Necrotic Core without Significant Contrast Enhancement

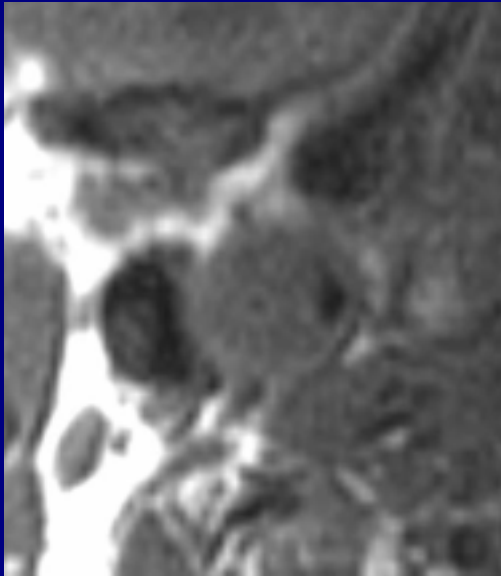


T2WI

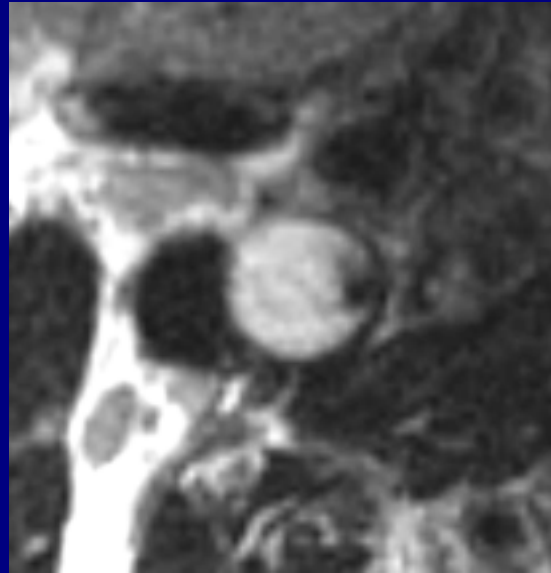


T1WI, PC

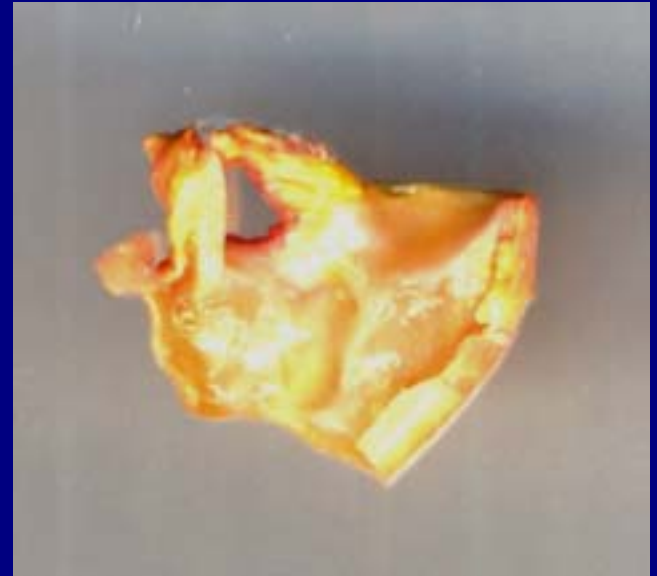
Hydrophilic Necrosis



T1WI



T2WI



Specimen

MRI Accuracy

- Ex vivo T2WI: Accurate for fibrocalcific plaques (90% sensitivity, 100% specificity) -Serfaty et al
- In vivo multispectral MRI for lipid-rich cores and intraplaque hemorrhage: overall accuracy 87%, sensitivity 85%, specificity 92% -Yuan et al

Fibrous Cap Rupture at MRI and Recent TIA or Stroke

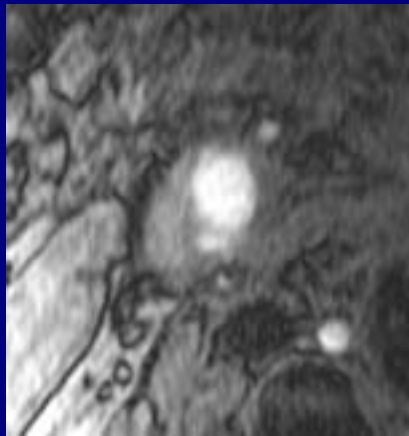
(Yuan, Circulation 2002)

	% Symptomatic	Likelihood to have TIA/stroke	Odds Ratio
Intact thick FC (n = 11)	9	1X	
Intact thin FC (n = 12)	50	10X (95% CI = 1.0, 104)	6
Ruptured FC (n = 30)	70	23X (95% CI = 3, 210)	18

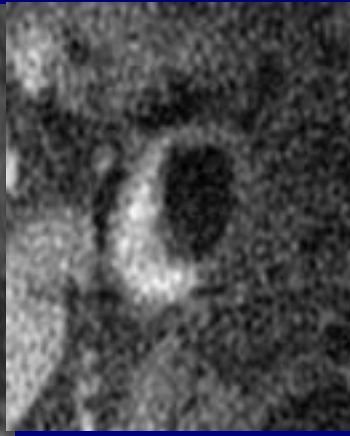
Brain MR imaging in Pts with Unstable Carotid Plaques

- In 153 patients, carotid MRI-MRA and carotid endarterectomy were performed.
- 97 atheromas (72%): histologically unstable plaque
- Good agreement between MR imaging and histologically vulnerable plaque
- 59 (61%) showed acute ischemic lesions in the brain on diffusion MR imaging.

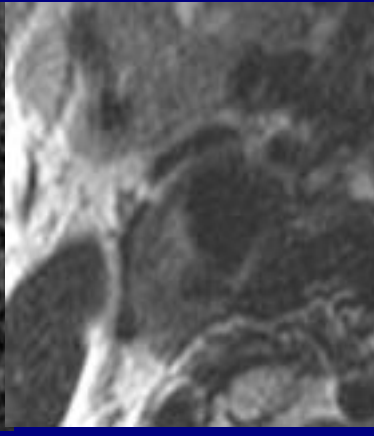
Case 1, Ulcerative Plaque with Hemorrhage



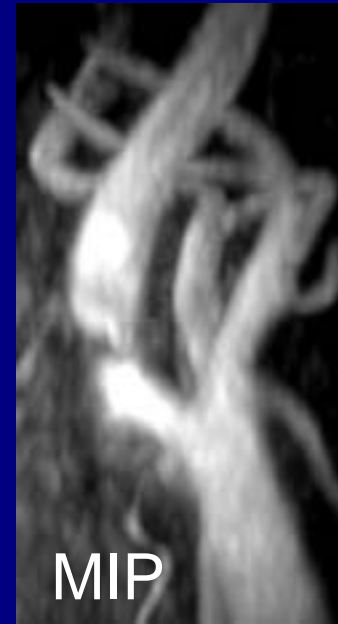
TOF



T1FS

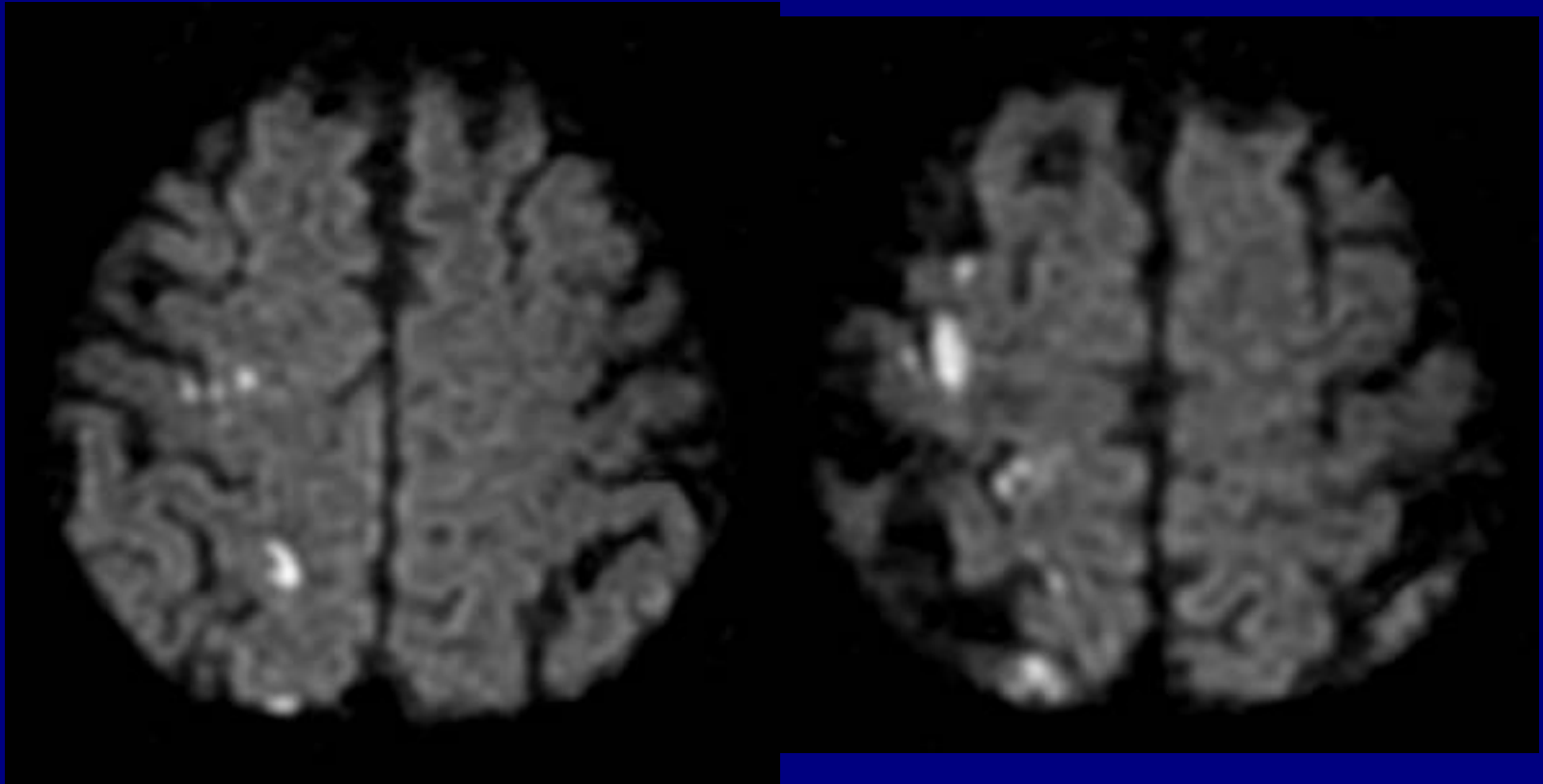


T2

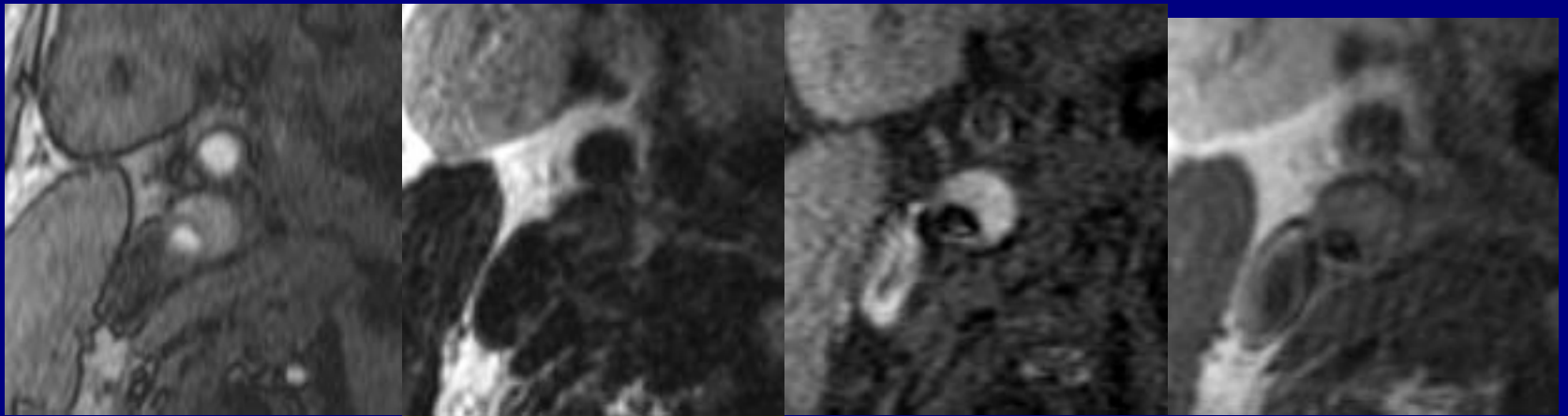


MIP

Multifocal Recent Infarctions on Diffusion-weighted MRI



Case 2, Hemorrhagic Plaque

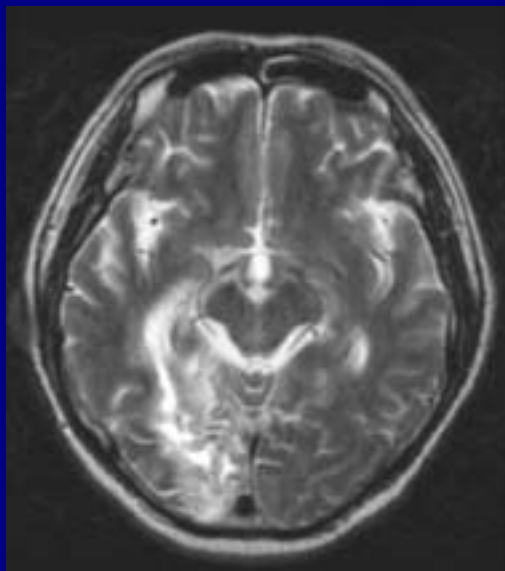


TOF

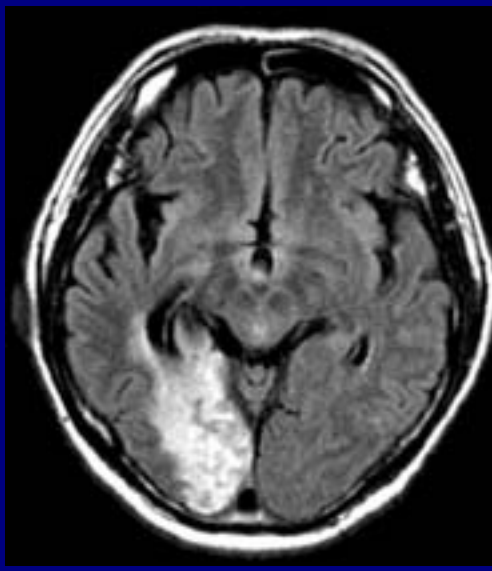
T2

T1FS

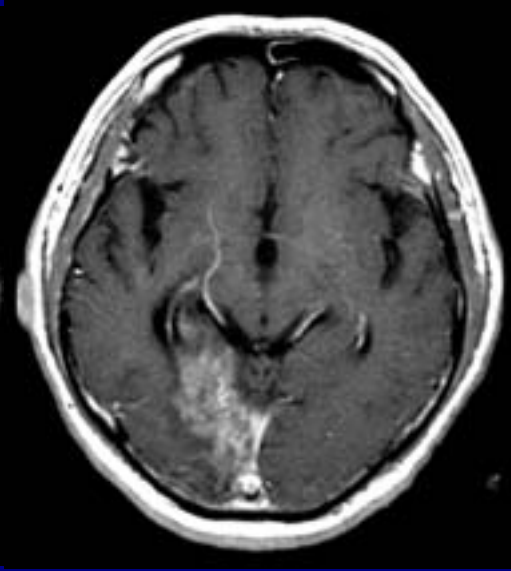
T1CE



T2

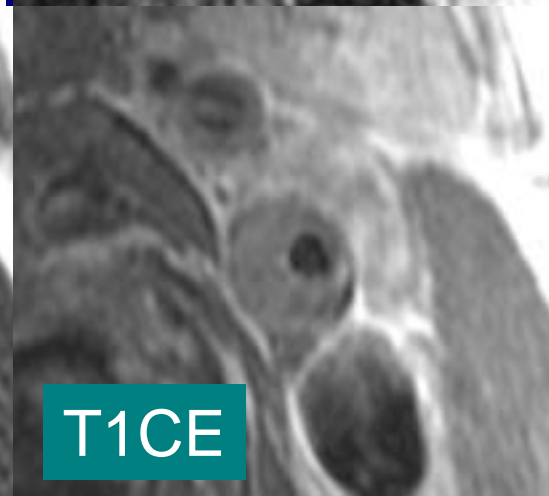
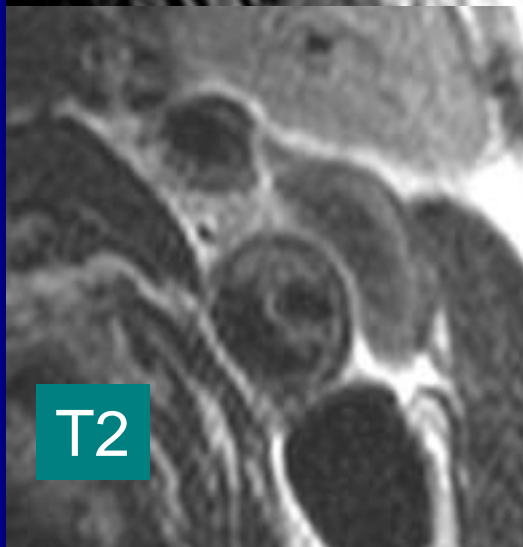
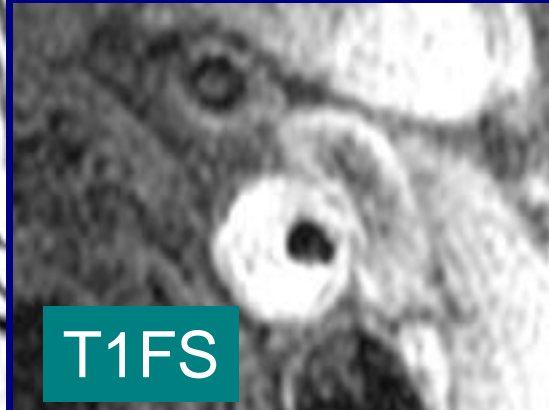
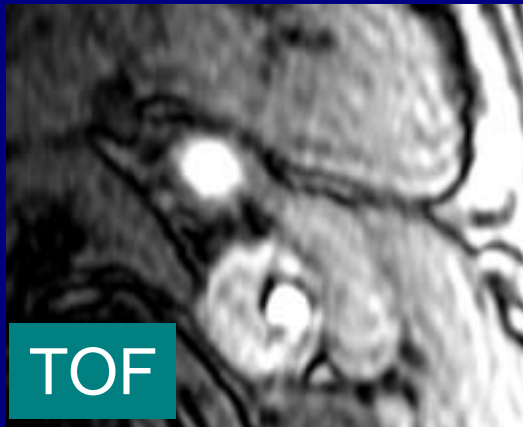


FLAIR

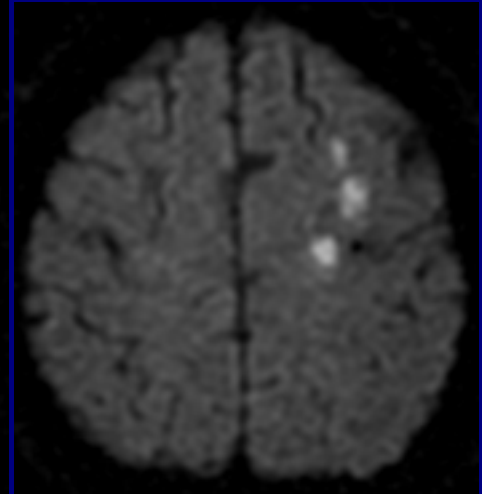
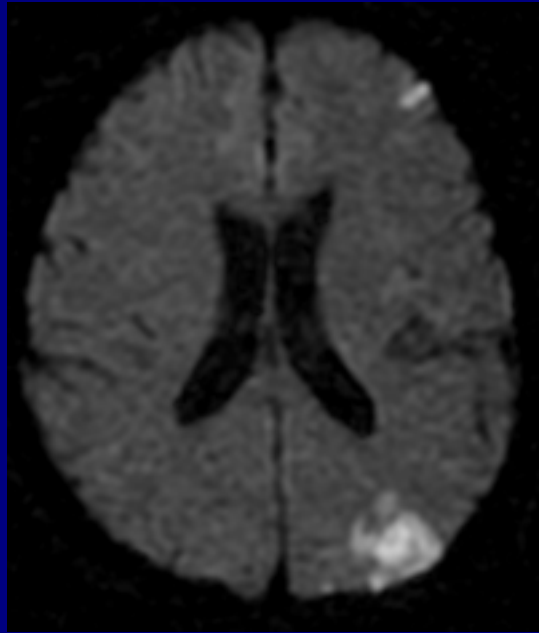
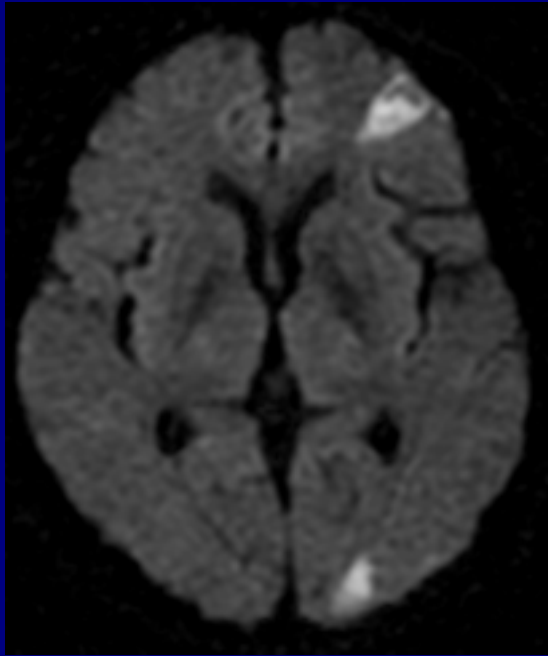


T1CE

Case 3, Hemorrhagic Plaque



Multiple New Infarctions



MRA of Intraplaque Hemorrhage

Materials & Methods

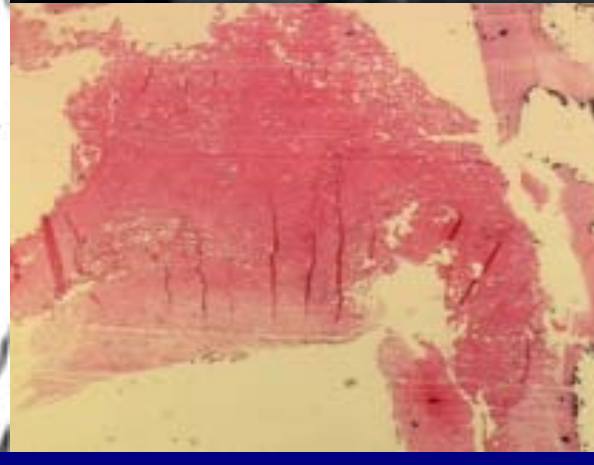
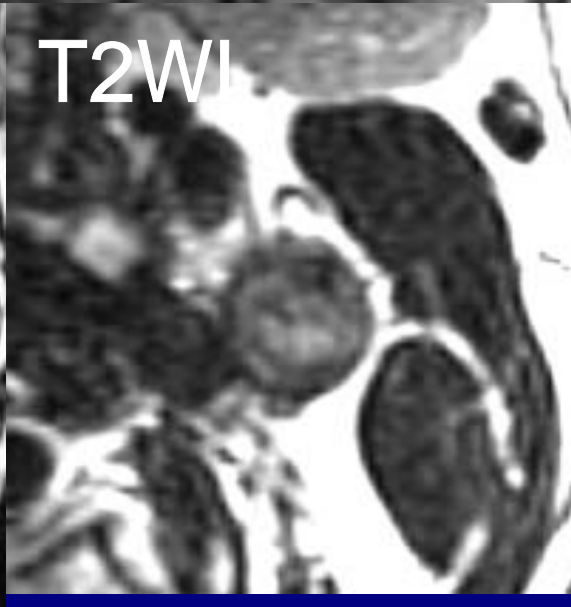
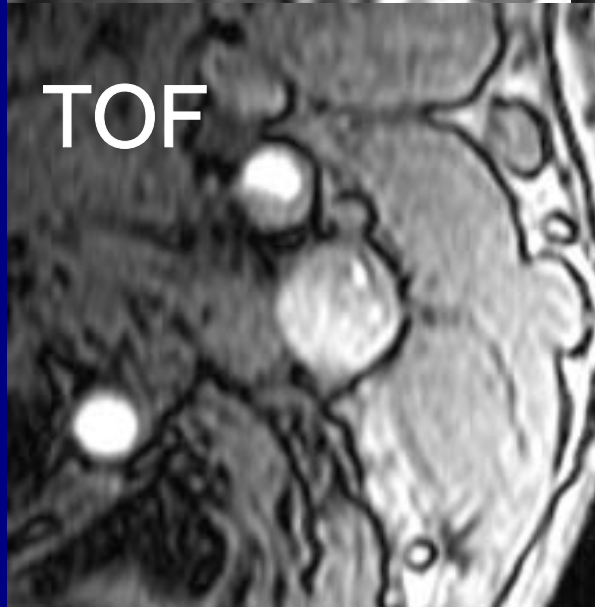
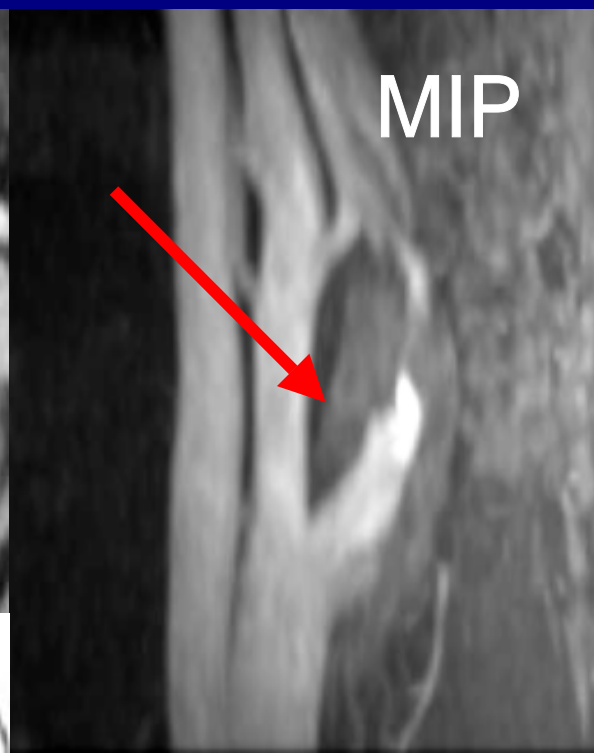
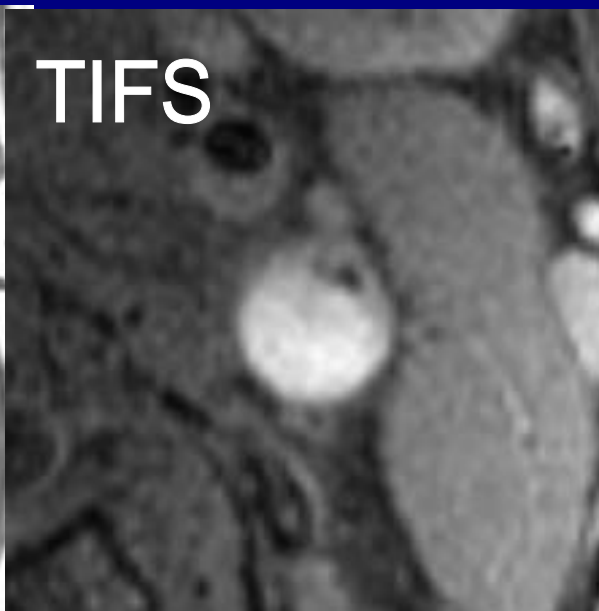
- 153 consecutive patients who underwent MRI and carotid endarterectomy were included in this study.
- Performed high-resolution MR imaging before carotid surgery.
- Findings on surgery, MRI (in vivo, specimen), and pathology were correlated.
- Analysis of carotid bifurcation and proximal ICA

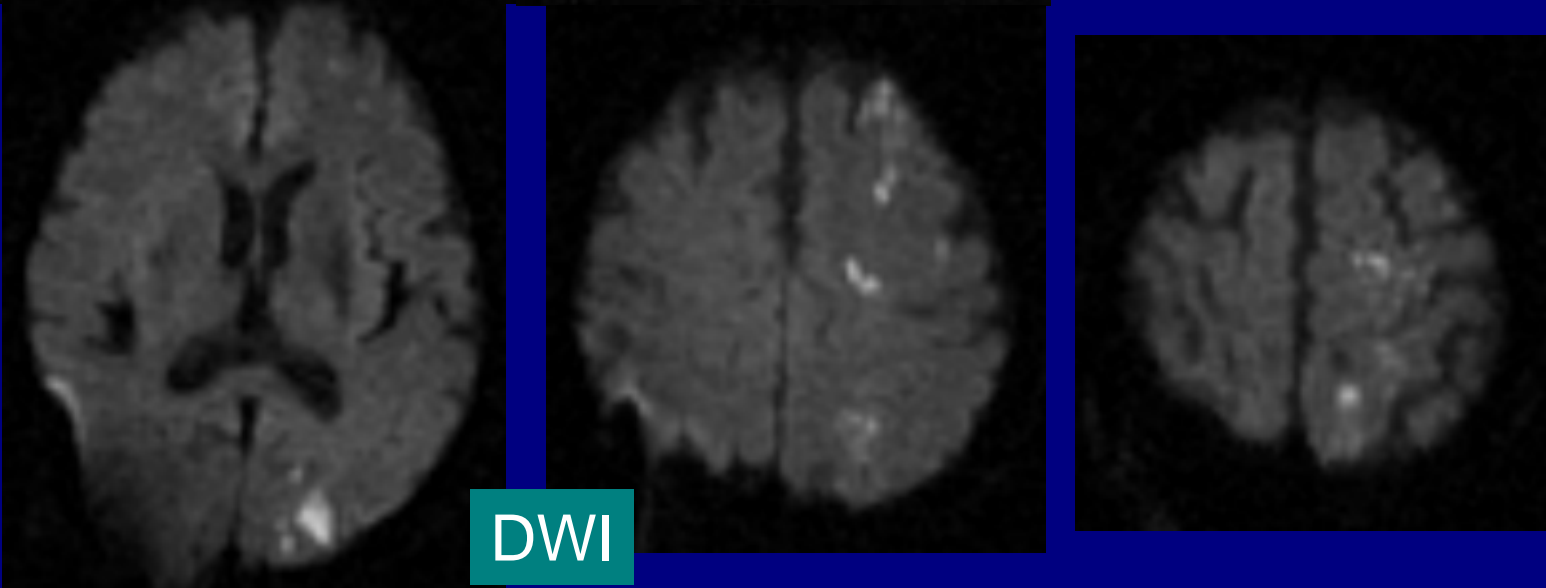
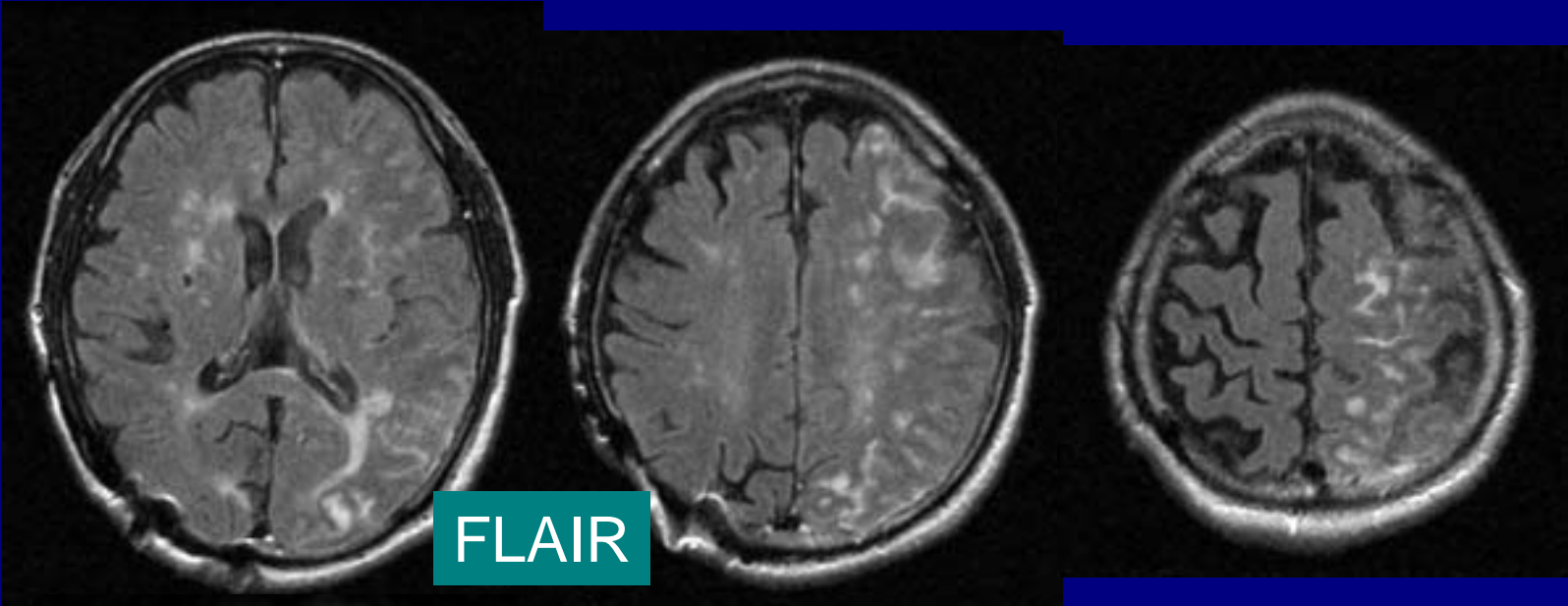
Results

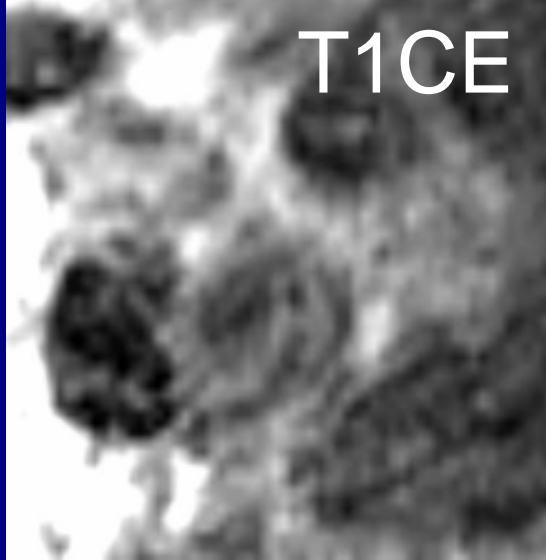
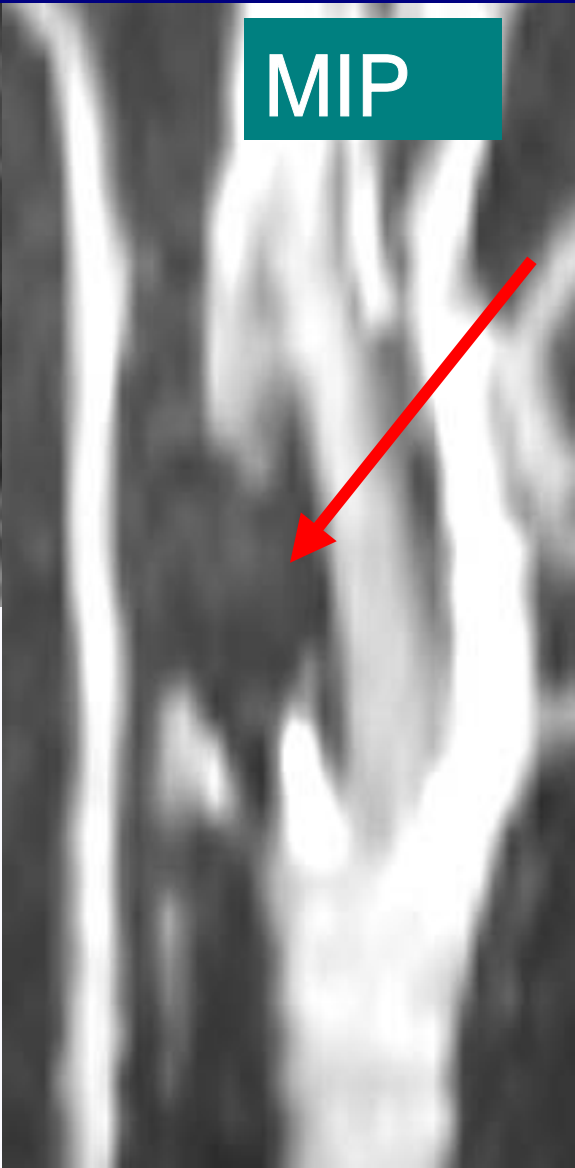
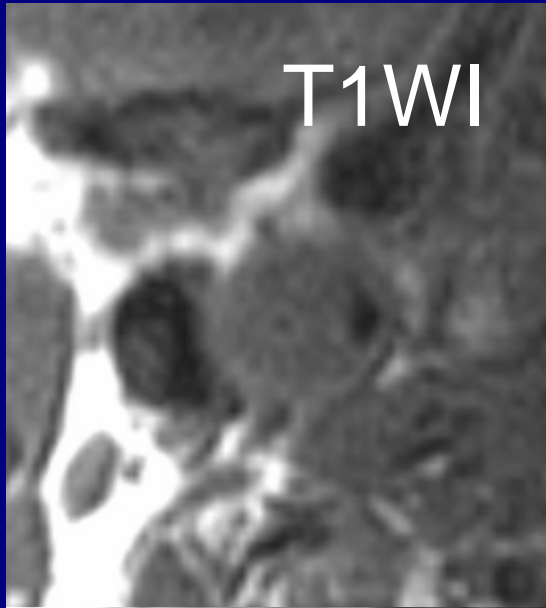
- 42 atheromas (31%) had intraplaque hemorrhage on surgicopathological findings.
- 38 (90.5%) showed high signal intensity halo around the carotid artery on TOF MR angiography.
- Additional sequence of T1-weighted fat-saturated spin echo images also revealed evidence of intraplaque hemorrhage by showing unsaturated high signal intensity in the plaque in 71% of patients.

Results

- **Correlated with surgical and histopathological findings, MIP images of TOF MR angiography demonstrated**
 - sensitivity = 91%,
 - specificity = 91%,
 - negative predictive value = 77%,
 - positive predictive value = 93%.
- **The combination of high signal intensity areas on T1-WI with fat suppression, low signal intensity areas on T2-WI, and high SI areas on source images of the 3 D time-of-flight MRA sequence also can suggest intraplaque hemorrhage.**







Conclusions

- High-resolution MR imaging can help identify intraplaque hemorrhage noninvasively.
- High SI on source images of 3D-TOF MRA and fat-suppressed T1WI can suggest intraplaque hemorrhage.
- Maximum intensity projection images of TOF MR angiography are useful in noninvasive detection of carotid intraplaque hemorrhage.

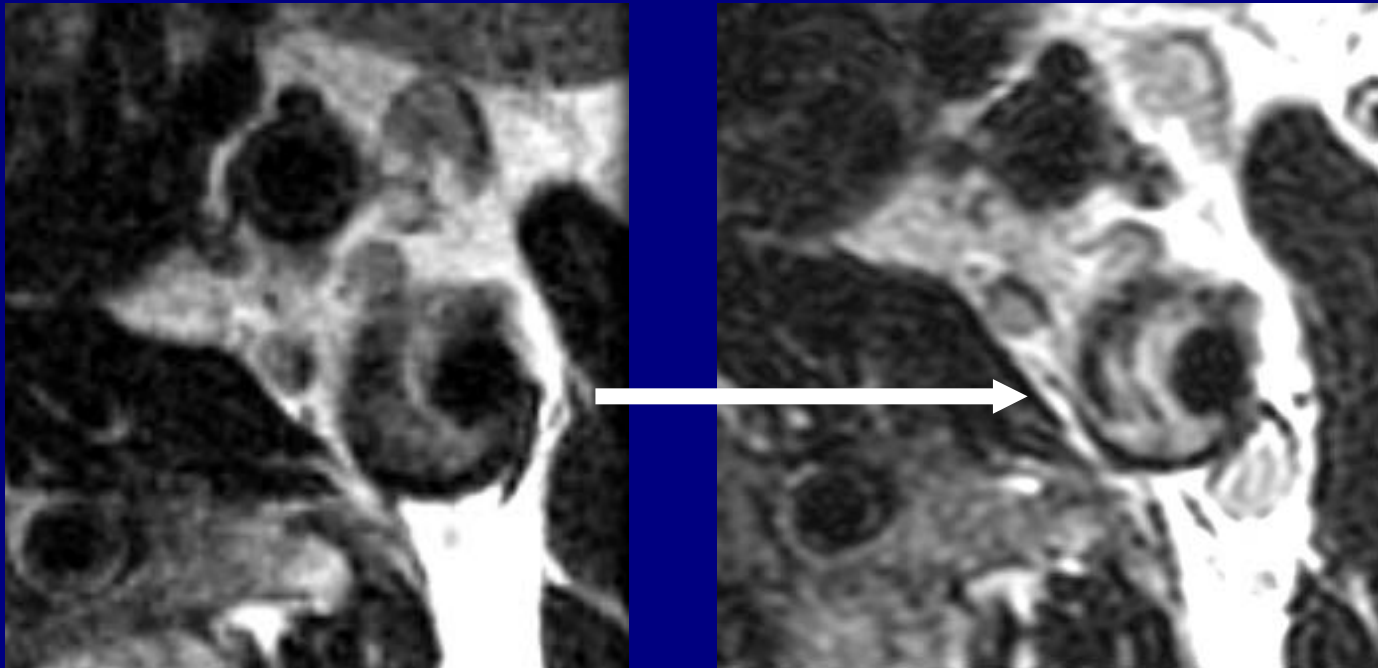
Changes in Carotid Plaques after Statin Therapy: MRI Evaluation

- 45 pts with 30-70% stenosis
- PreTx (Simvastatin 20 mg) and F-up MRI (19 ± 7.5 m)
- Decreased mean total chol., LDL, & CRP compared with control group:
Total Chol = 188 ± 26 vs 158 ± 50 , $p < .001$
LDL = 125 ± 23 vs 110 ± 42 , $p < .001$
CRP = 0.41 ± 0.59 vs 0.10 ± 1.3 , $p < 0.01$

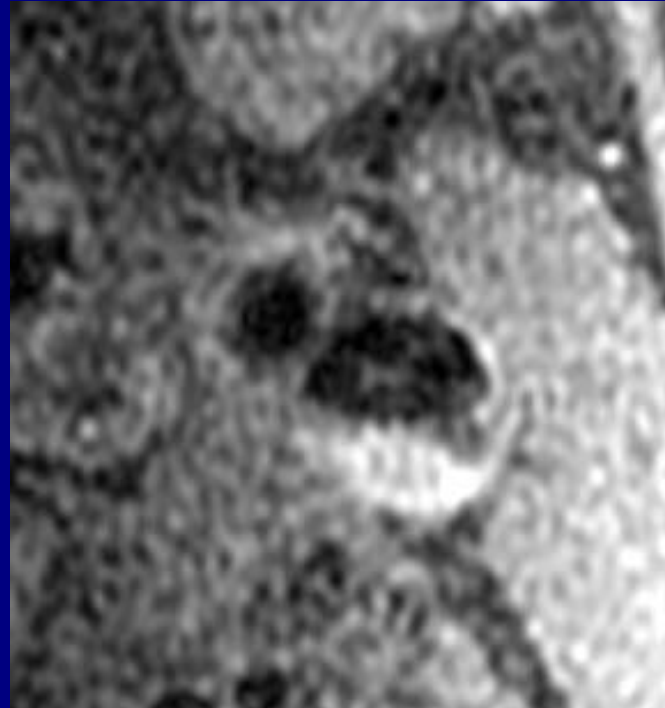
Results

- Stabilization of plaque components on MRI in 16% (7/45)
- Decreased plaque thickness:
4.2 mm \pm 1.0 vs 3.4 mm \pm 1.3, $p < 0.001$

Increased Fibrotic Component on T2WI at 20 m f-up



Improved Wall Thickness, at 1 y (0.5 mm)



3.0 T for Atherosclerotic Plaque Imaging

- Higher signal-to-noise ratio
- Better background suppression
- Shorter scan time
- Higher resolution

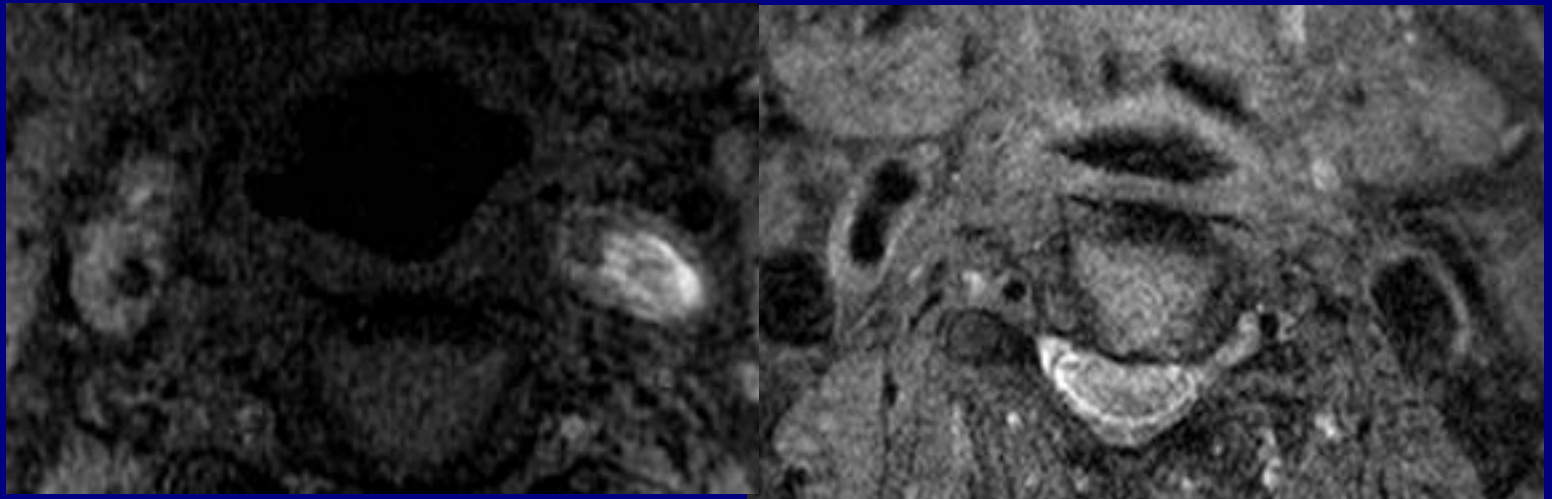
Carotid MRI Techniques at 3.0 T

- T1-weighted spin echo imaging (precontrast axial, again with fat-saturation, postcontrast axial)
- T2-weighted spin echo imaging (axial)
- Proton-WI (axial)
- 3D time-of-flight MRA (source and 3D images)
- Two 15-cm phased-array coils, bilateral application
- Field of view: 12-15 cm x 12-15 cm
- Slice thickness = 2 mm, 256×203 matrix, NEX = 1

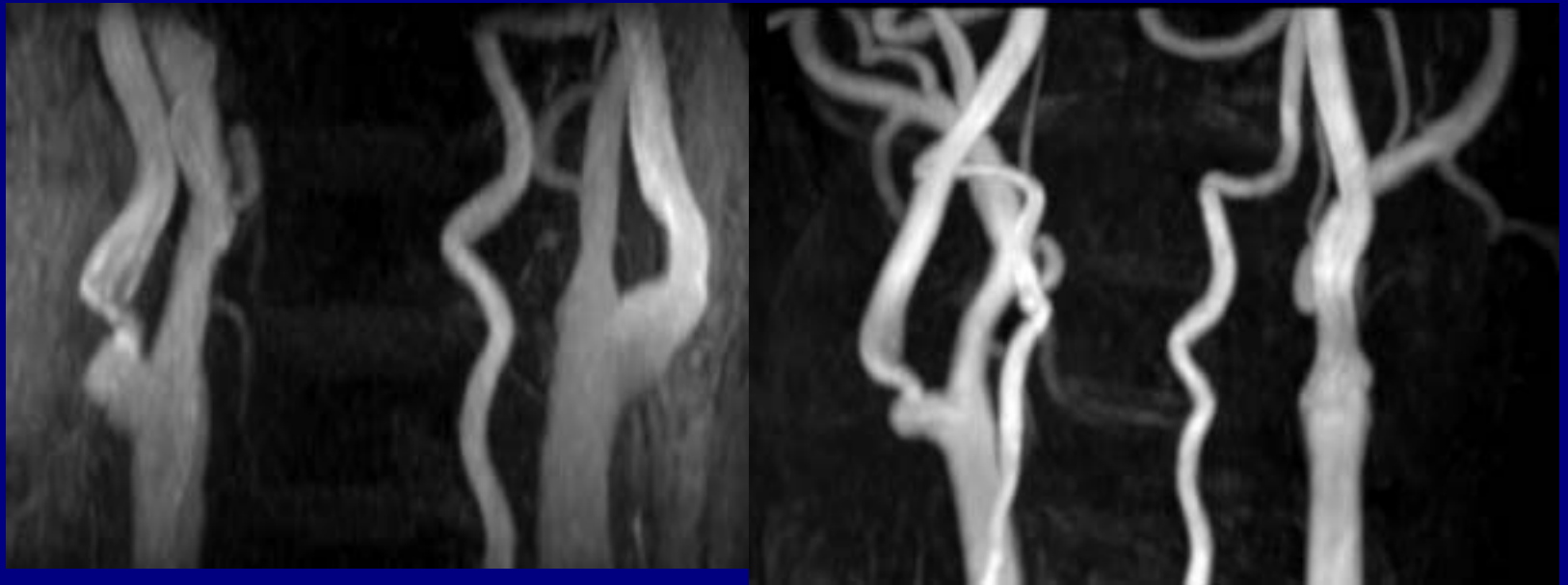
SMC Experience of 3.0 T MRI in Carotid Plaque Imaging

- Image quality is generally compatible with 1.5 T's.
- Higher resolution and tissue contrast with 3.0 T MRI

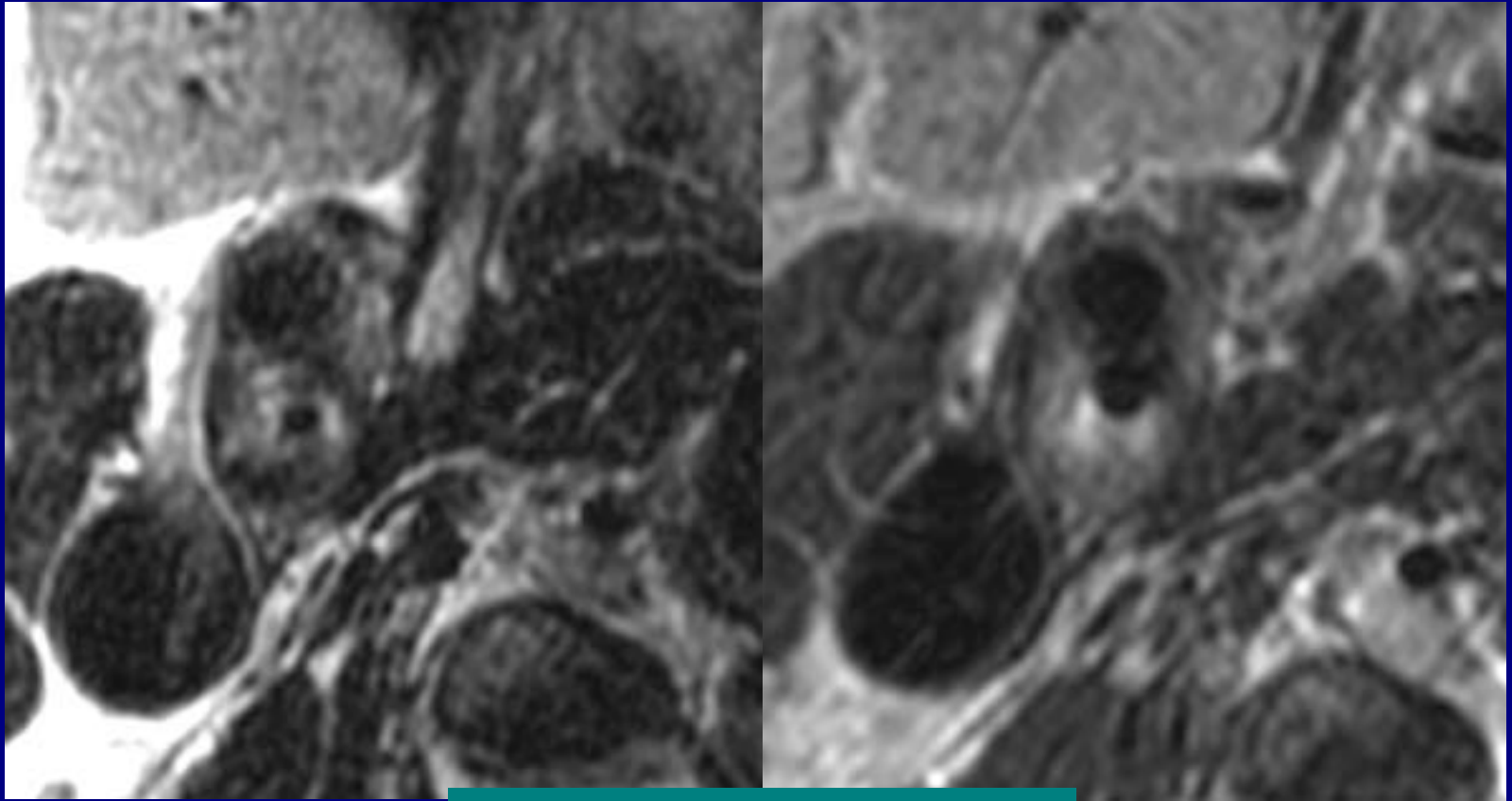
R ICA Plaque, 1.5T vs 3.0T



T1WI, fat-saturation @1.5 T vs 3.0 T



MIP of 3D-TOF MRA @1.5 T vs 3.0 T



T2WI @ 1.5 T vs 3.0 T

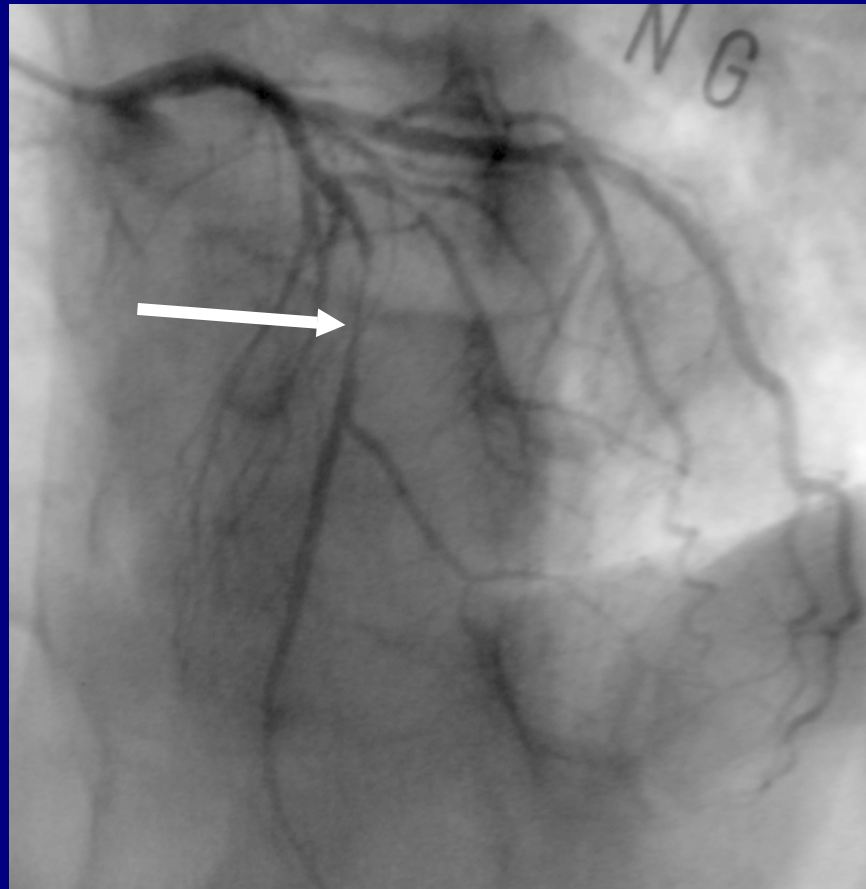
Coronary Artery Plaque MRI

- High-resolution of 3.0 T system is most beneficial in coronary artery plaque imaging.
- Can knowledge of carotid plaque MRI be applied to coronary artery imaging?

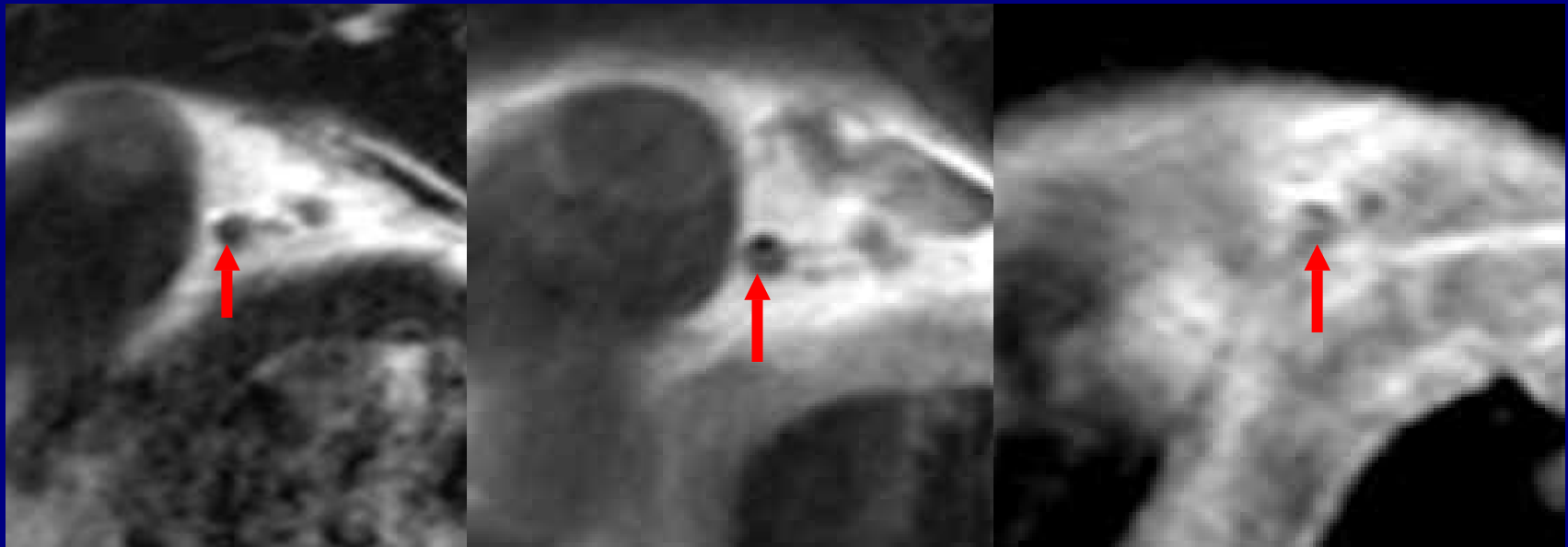
Imaging Protocol

- Coronary MRA using 3-point technique
- Black-blood plaque imaging on the stenotic segments
 - T1WI, precontrast (DBIR)
 - T2WI
 - T1WI, postcontrast
 - TFE
- Slice thickness, 1.5-2 mm; image matrix, 256x256, FOV 35 cm, en = 1

Coronary Artery Plaque Imaging: LAD Stenosis on CAG



Coronary Plaque Imaging at 3.0T

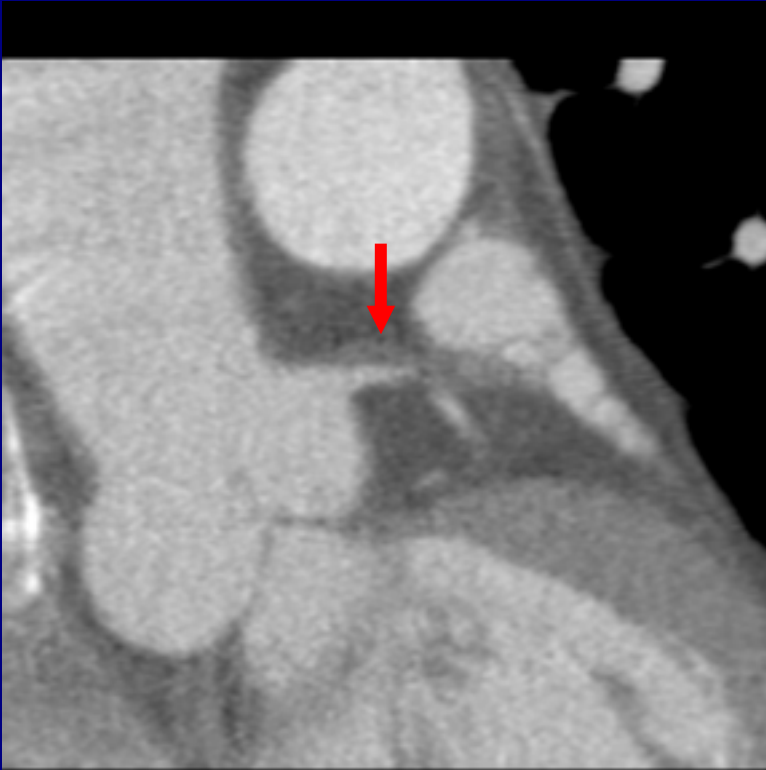


T2WI

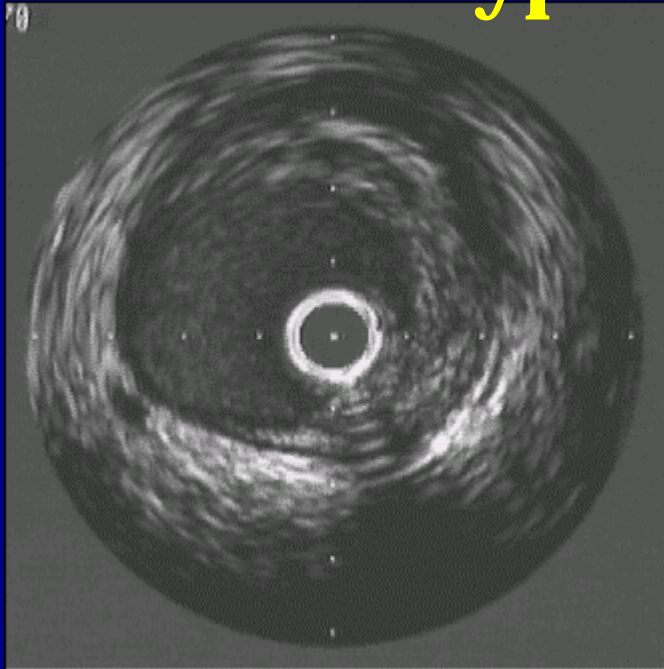
T1WI-preContrast

T1WI-postContrast

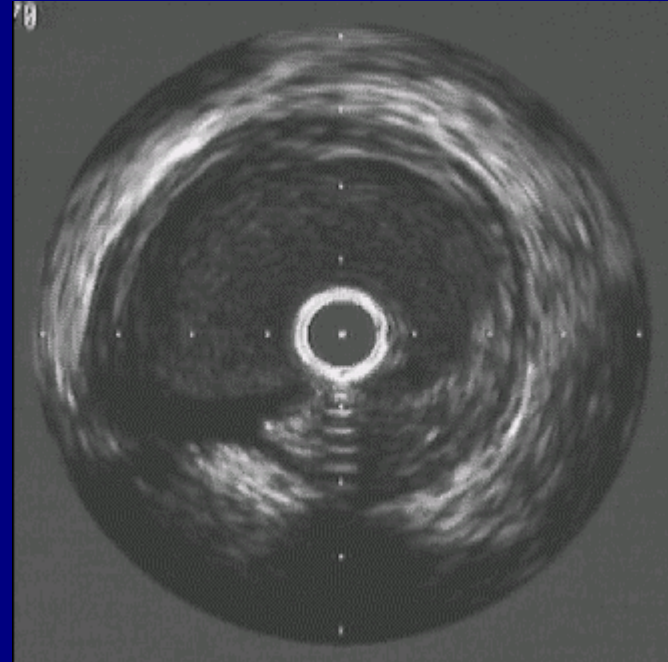
Fibrofatty Plaques (M/48 with Acute MI)



Intravascular US Shows Noncalcified Plaques without Large Hypoechoic Area

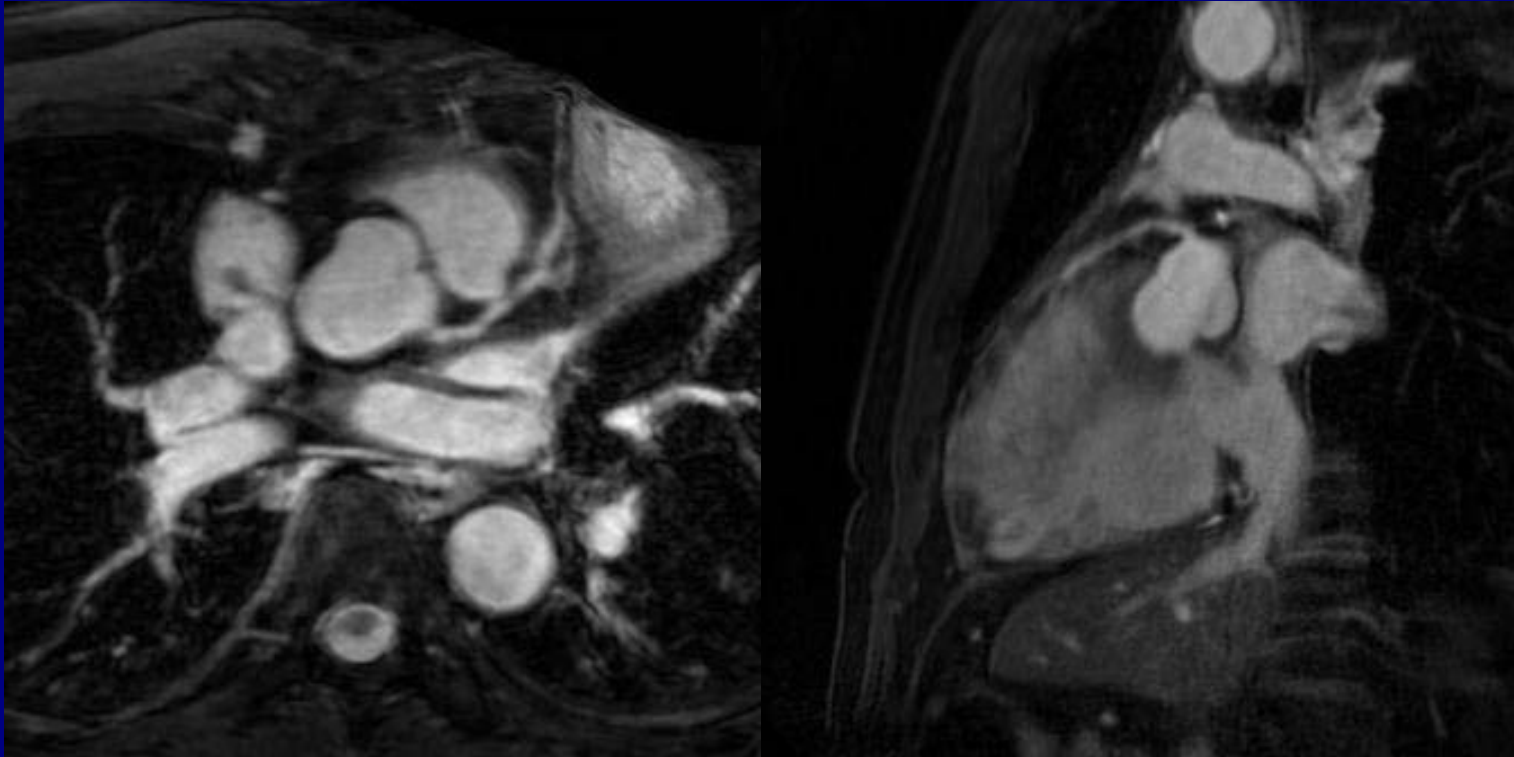


Left main

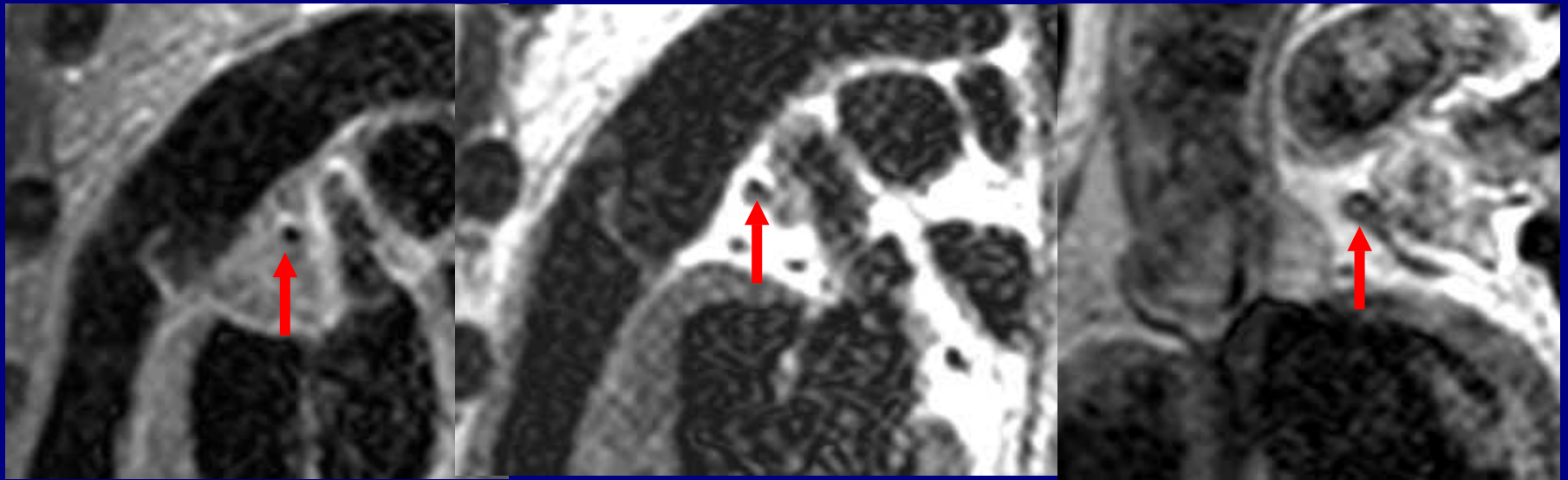


**LAD-LCX (9 o'clock)
bifurcation site
(4-6 o'clock site plaque)**

Coronary MRA



L Main



T2WI, Fat-sat

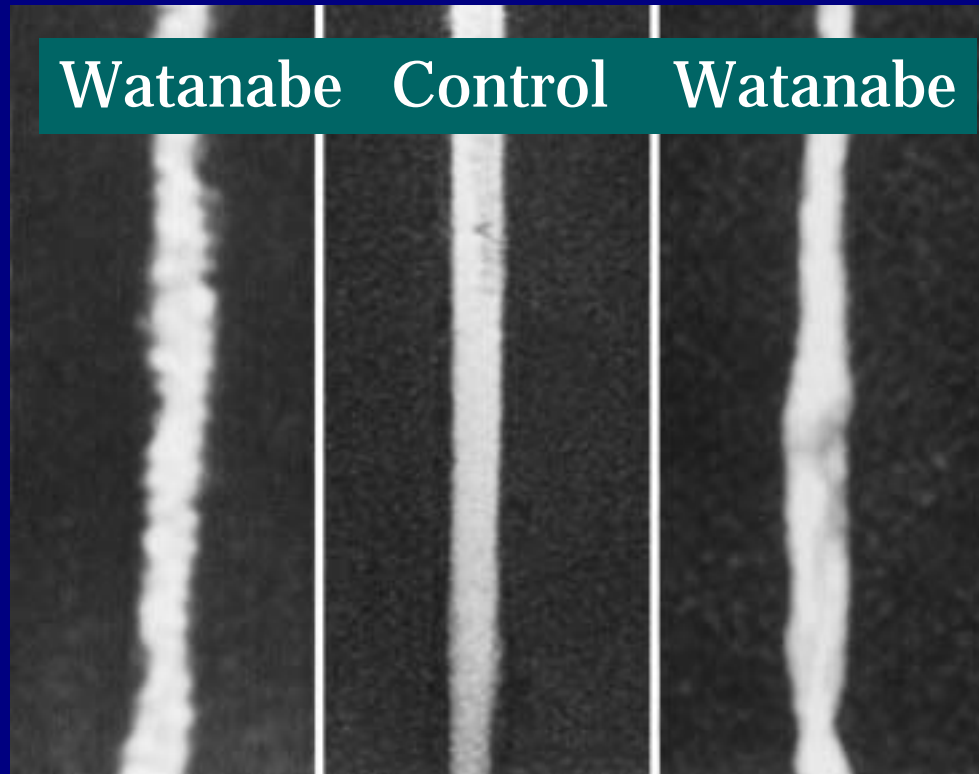
T2WI, 1.5 mm ST

PostContrast

Contrast Agents for MR Imaging of Atherosclerosis

- Ultrasmall superparamagnetic particles of iron oxide (USPIO, Combidex ®)
- Fibrin-specific polypeptide (EPIX)
- Plaque detection by Gadofluorine (Schering)

USPIO in Watanabe Hyperlipidemic Rabbits (5 ds)



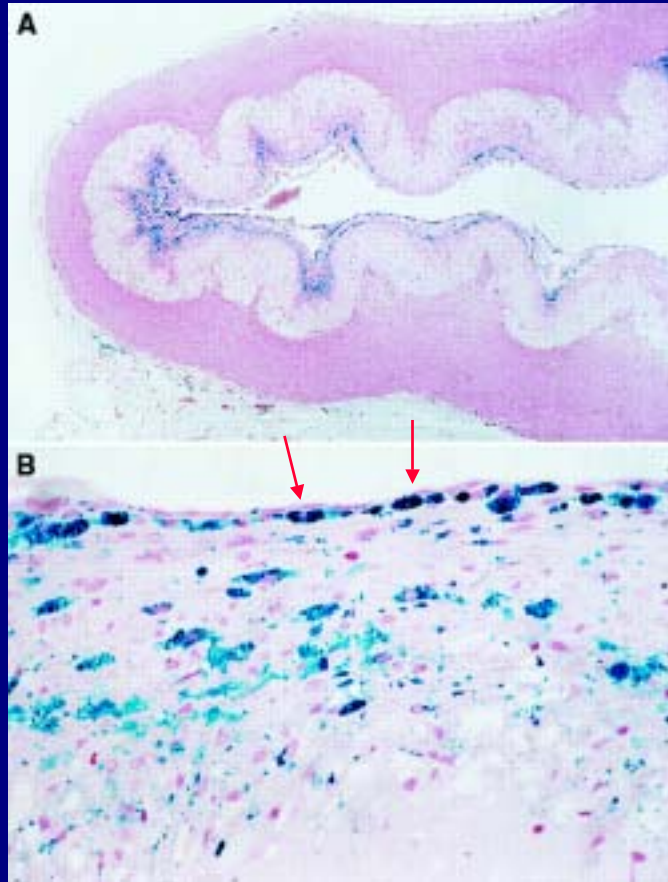
USPIO

USPIO

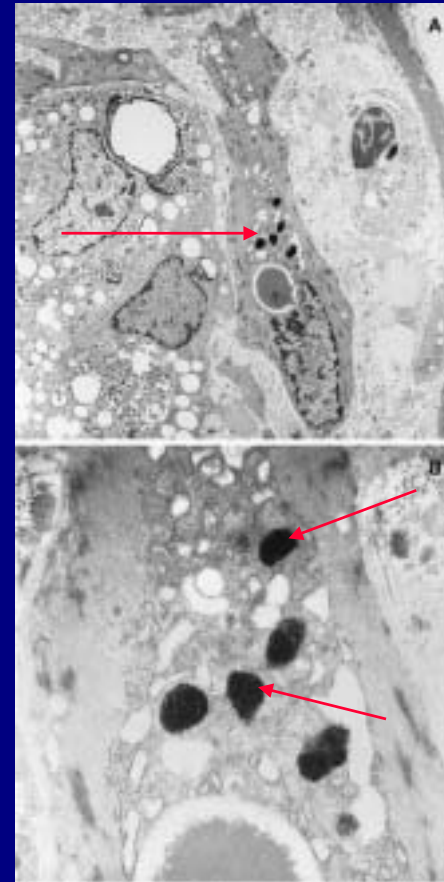
No USPIO

Ruehm et al. Circulation 2001

Fe in Macrophages of Atheroma



Prussian Blue staining

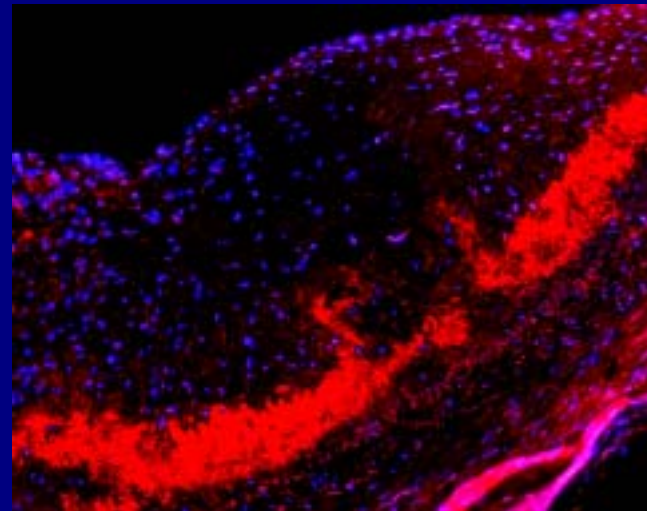
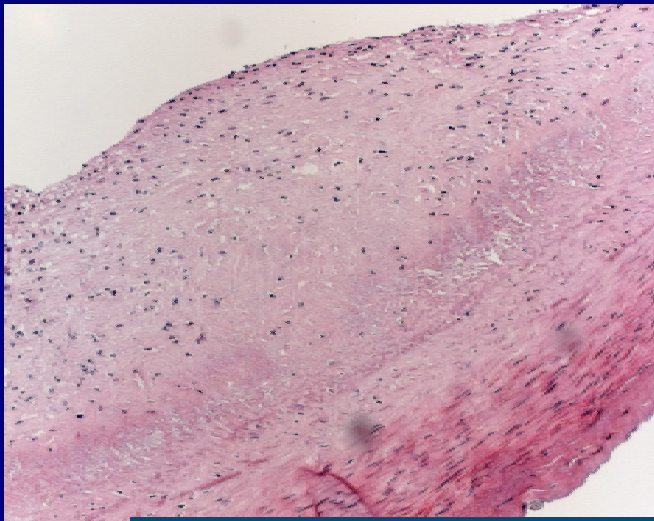


EM

Gadofluorine M

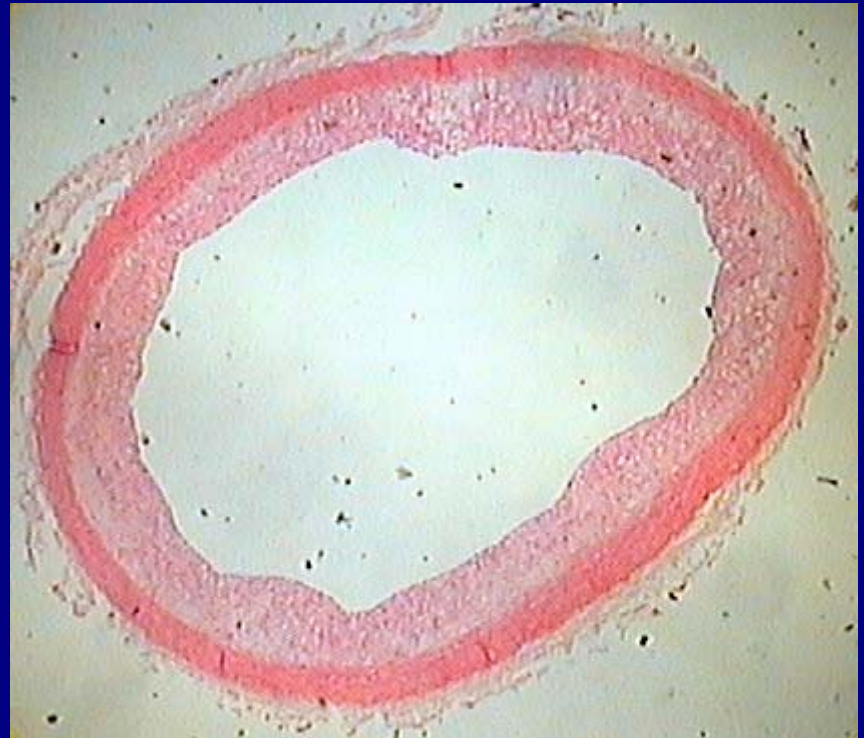
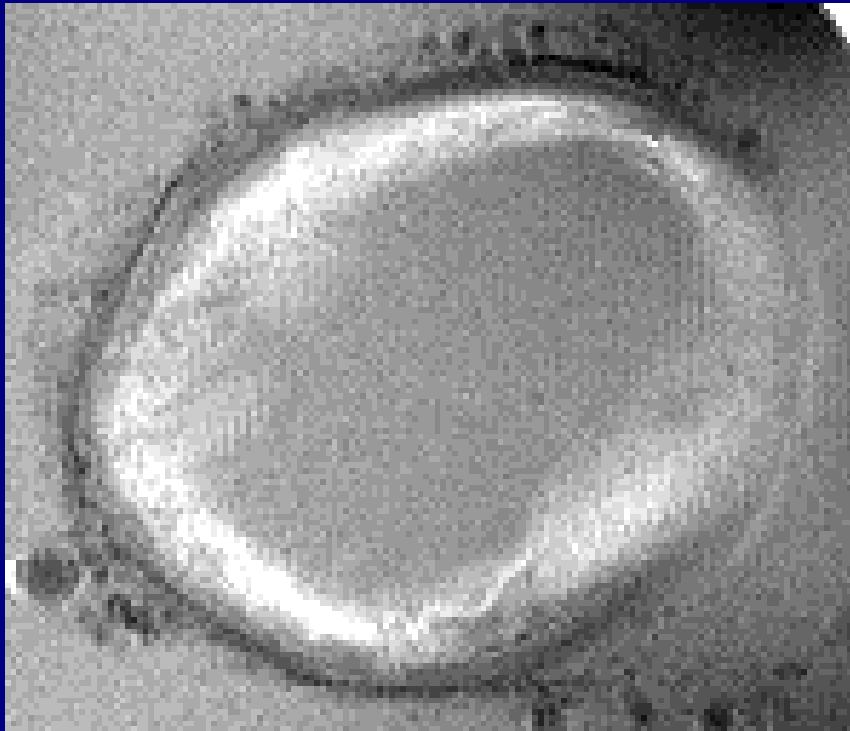
Accumulation in

- necrotic, edematous, lipid rich areas and macrophages (?)



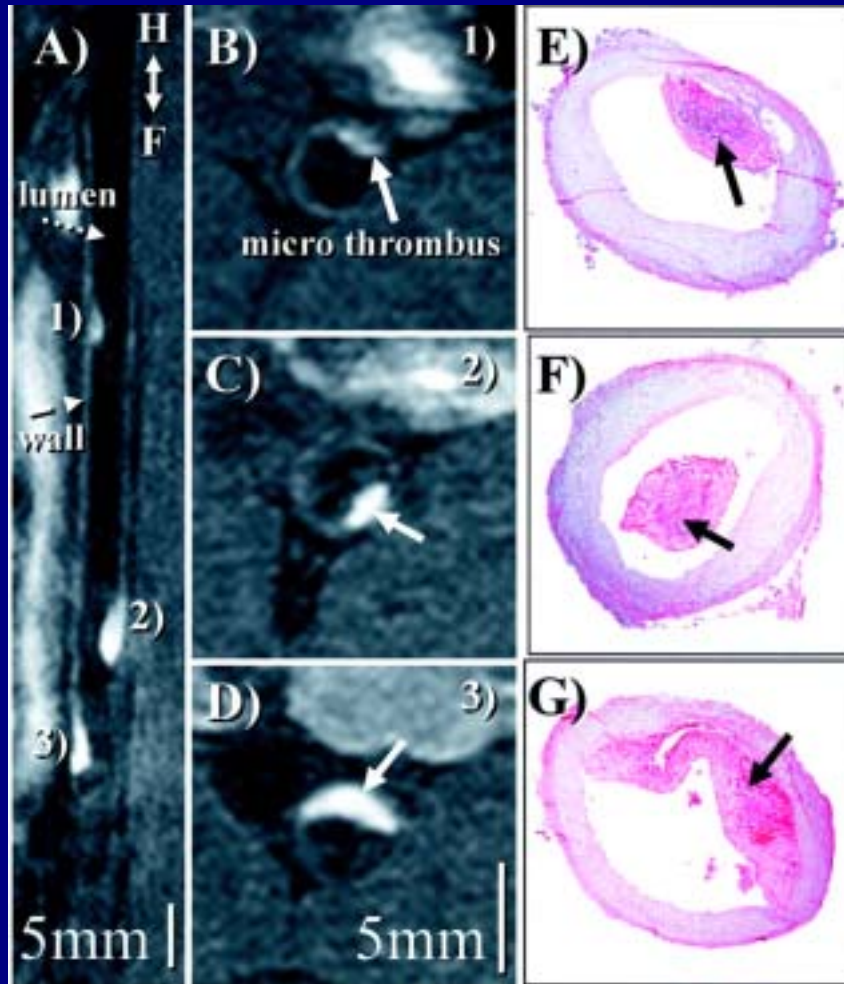
In vitro staining in human coronary artery

2 ds after Gadofluorine M injection in Cholesterol-fed diabetic Rabbit, 14-T MR Microscopy vs Specimen



Courtesy of Dr Whal Lee, Seoul National University

Fibrin-specific polypeptide (20 h post EP-1873, EPIX)

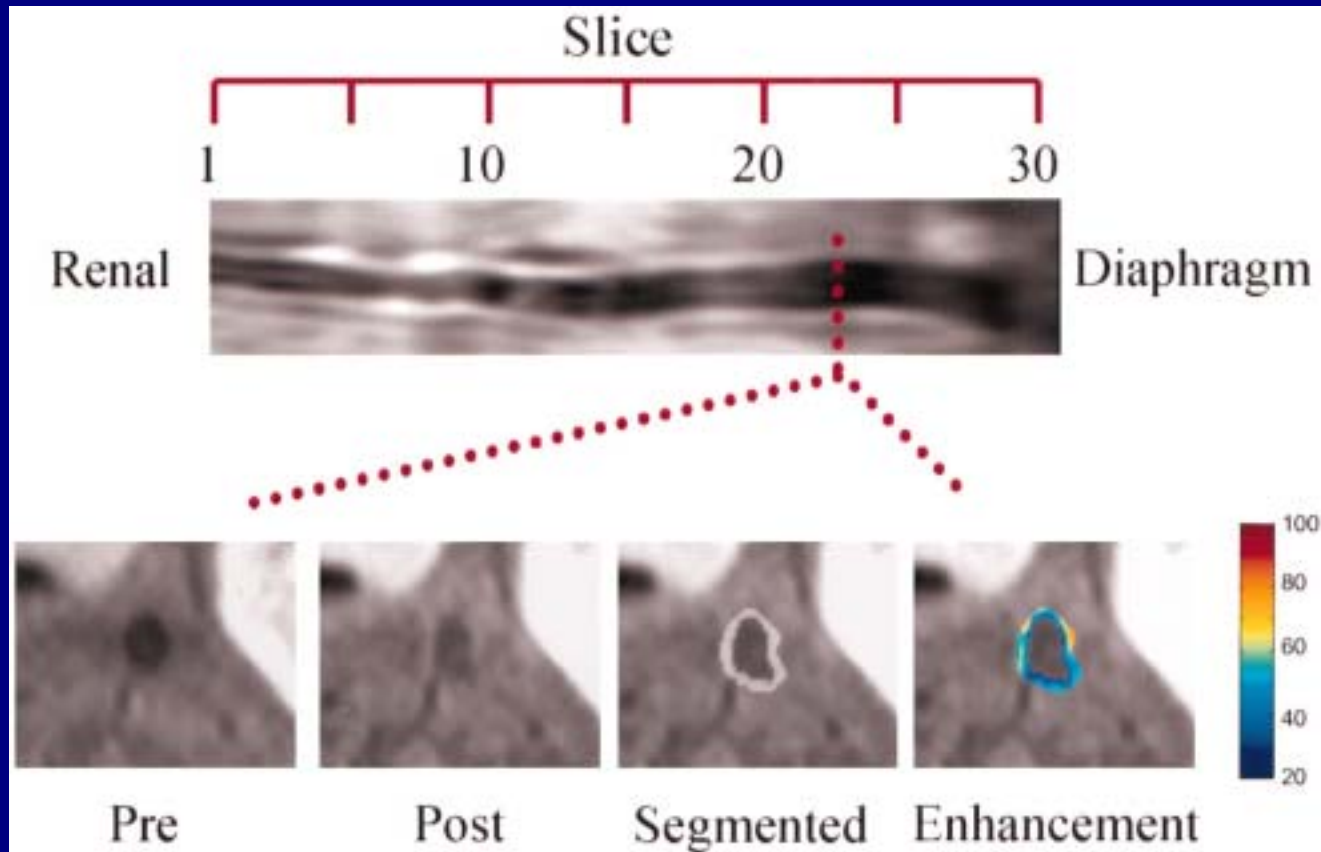


Botnar, Circulation 2004

Alpha_vbeta₃-Integrin-targeted Imaging: significances

- Plaque angiogenesis and expansion of vasa vasorum: critical process for initiation of vascular lesions
- Site-specific drug delivery for early atherosclerotic disease

Alpha_vbeta₃-Integrin-targeted paramagnetic nanoparticles in atherosclerotic rabbits



Conclusions

- High-resolution MRI can identify vulnerable carotid plaques and allows early intervention on unstable plaques.
- 3.0 T MRI allows characterization of atherosclerotic plaques in coronary arteries.