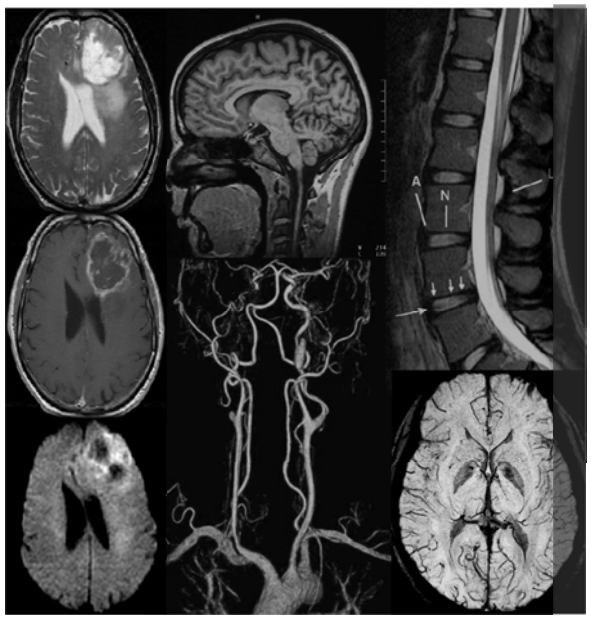

Magnetic Resonance in Medicine
MR Angiography

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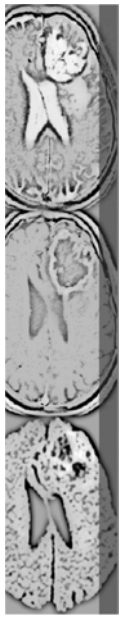
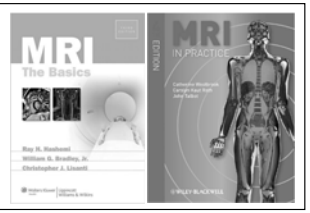
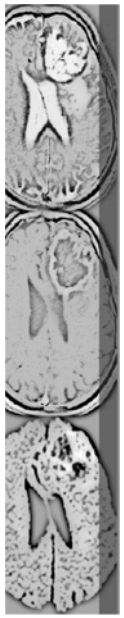


Content http://cflu.lab.nycu.edu.tw/

- **MR Angiography**
  - **Unenhanced Angiography 非對比劑增強磁振血管攝影**
  - **Contrast-enhanced Angiography 對比劑增強磁振血管攝影**

- **MRI The Basics (3rd edition)**
  - Chapter 27: MR Angiography
- **MRI in Practice, (4th edition)**
  - Chapter 8: Vascular and cardiac imaging

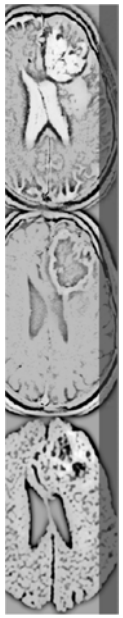




MR Angiography

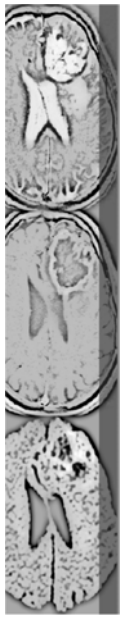
- **Unenhanced MRA**: Rely on flow effects (the movement of blood)
  - TOF (time of flight) MRA
  - PC (phase contrast) MRA

- **Contrast-enhanced MRA**
  - IV injection of gadolinium



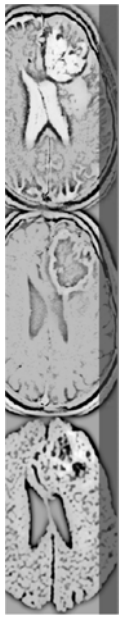
Unenhanced MRA

- Amplitude effects (TOF)
  - Blood flowing into or out of a chosen slice has a different **longitudinal magnetization (M_z)** compared to stationary spins.
  - Depend on the duration of stay (time-of-flight) in the slice
- Phase effects (Phase contrast)
  - Blood flowing along the direction of a magnetic field gradient changes its **transverse magnetization (M_{xy})** compared to stationary spins.
  - Motion-induced phase change

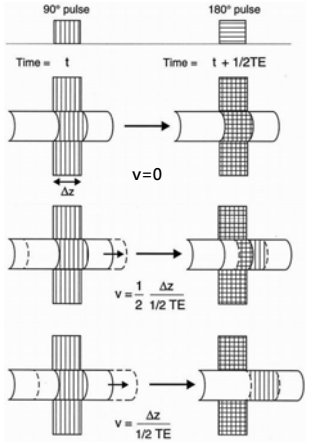


Appearance of flowing blood

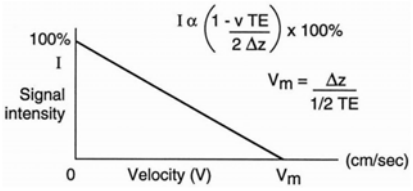
- Time-of-flight (TOF) effects
  - Signal loss (high-velocity signal loss or TOF loss)
  - Signal gain (flow-related enhancement, FRE)

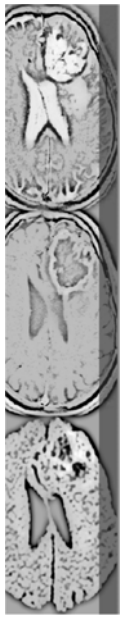


High-velocity signal loss

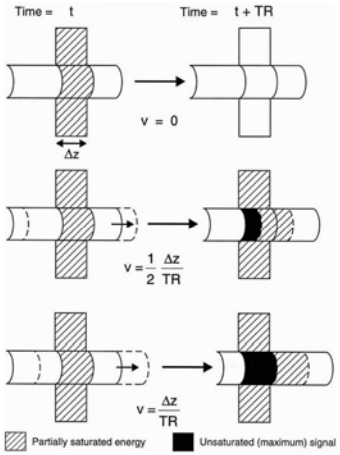


- For spin echo (SE) imaging
- Slice-selective refocusing RF
- If v ≥ Δz / (TE/2) → flow void
- $I \propto (1 - v/(2\Delta z/TE))$

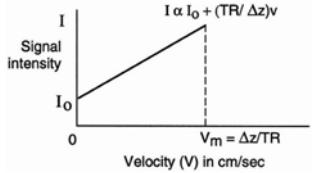


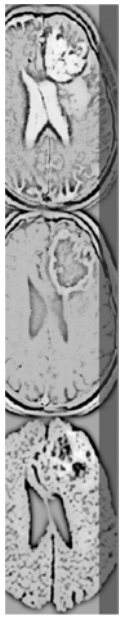


Flow-related enhancement (FRE)



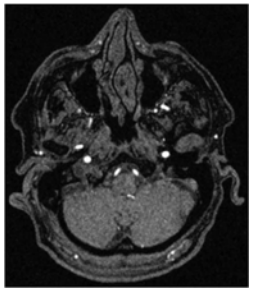
- In GRE
- Also called entry phenomenon
- The fresh inflowing blood that enters the first slice is totally unsaturated (by last RF excitation)
- If v ≥ Δz / TR → maximal signal
- $I \propto I_0 + v(TR/\Delta z)$



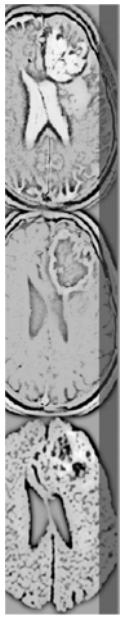


Flow-related signal enhancement

- The FRE occurs both with SE and GRE sequences.
- However, the competing TOF loss in SE tends to overbalance the FRE at higher flow velocities, leading to decreased flow signal.
- **TOF angiography**
  - GRE sequences
  - Bright-blood images
  - Endogenous contrast agent

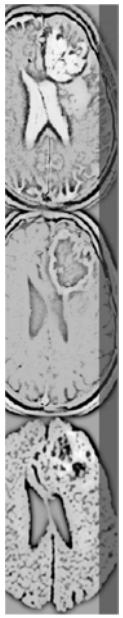


Bright vessels
Gray/black background



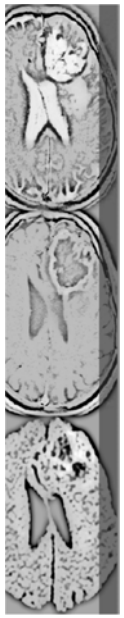
TOF Angiography

- Spoiled GRE sequences
  - No TOF loss phenomenon
  - Short TR (<40 msec) to efficiently saturate stationary tissues
  - Short TE (< 5 msec) to reduce spin dephasing
  - Short acquisition time to acquire 3D datasets
  - Flow compensation (refocus unwanted phase accumulations)
- TOF techniques can be divided into 3 groups
  - Sequential 2D multi-slice method
  - 3D single-slab method
  - 3D multi-slab method



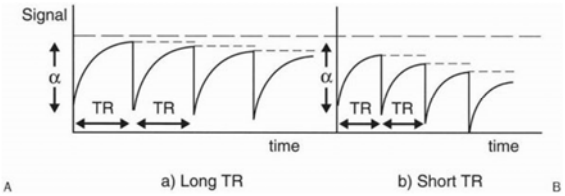
Sequential 2D technique

- Larger flip angle (30^o~70^o)
- Thicker slice thickness (2~3 mm) to achieve better SNR
- Best suited for imaging vessels that are straight and perpendicular to the slices.
  - Carotid arteries or vessels in the lower extremities.
- It is necessary to synchronize the acquisition of data to the cardiac cycle (ECG gating).

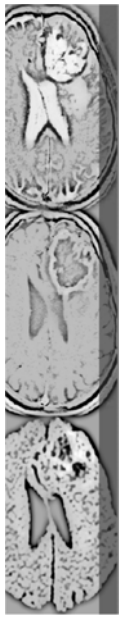


Saturation effects in 2D acquisition

- When…
  - (2D acq.) Flowing blood travels within (rather than through) a slice
  - (3D acq.) blood travels though a thick imaging volume (or slab)
- The gradual loss of longitudinal magnetization caused by repeated excitation radio frequency (RF) pulses.
  - → the distal/in-plane portion of a vessel not to be displayed.



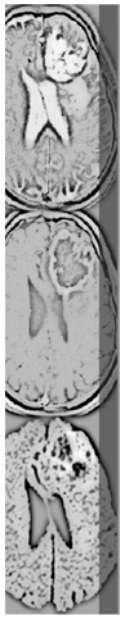
Two main causes
- Decreasing TR
- Increasing α



In-Plane Saturation Artifact

- When vessels travel within plane, their blood may become saturated like stationary tissues, resulting in decreased signal.

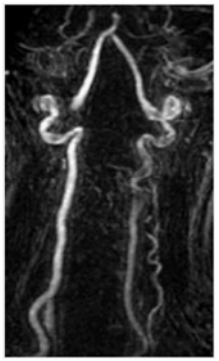
http://mri-q.com/mra-artifacts-tof.html



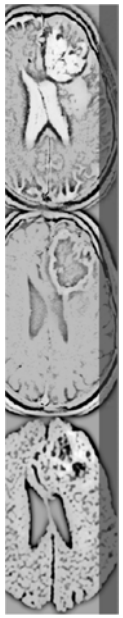
Flow-Reversal Artifact

2D TOF MRA shows only right vertebral artery. No flow related signal in the left vertebral artery is seen.

Contrast-enhanced MRA shows retrograde filling of left vertebral artery (subclavian steal phenomenon)



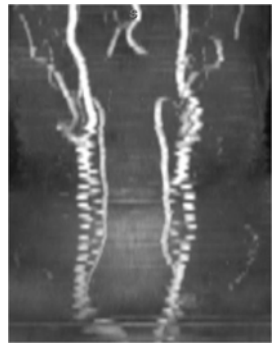
http://mri-q.com/mra-artifacts-tof.html



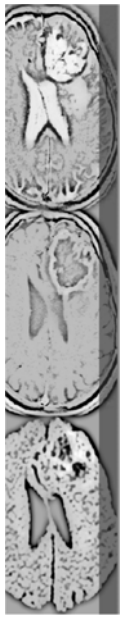
Motion Artifact

Mild motion artifact causing horizontal banding on this 2D-TOF MRA of the aorta

Severe artifacts with jagged edges due to gross motion for carotid TOF MRA study

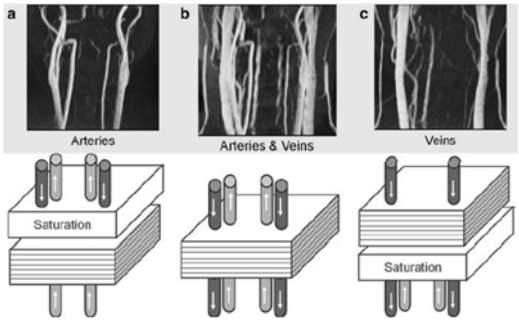


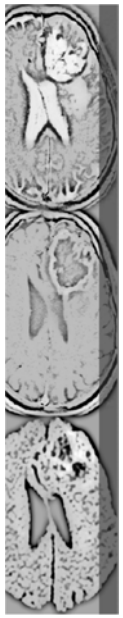
http://mri-q.com/mra-artifacts-tof.html



Spatial saturation pulse

- Superior saturation pulses are used to suppress the signal from veins above the heart, and arteries below the heart
- Inferior saturation pulses are used to suppress the signal from arteries above the heart and veins below the heart

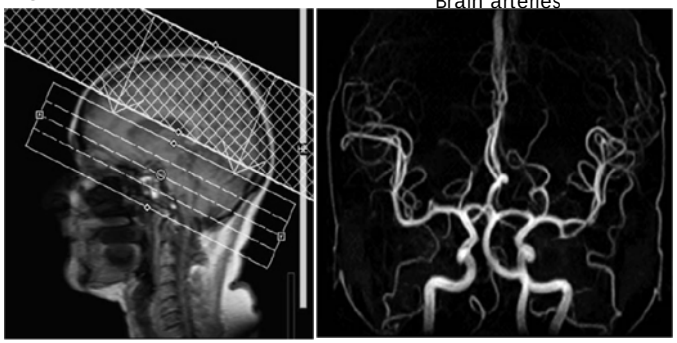


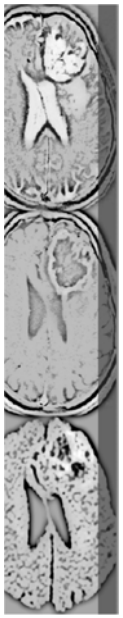


3D multi-slab method

- Presaturation slab above the imaging volume suppresses the signal of venous flow.

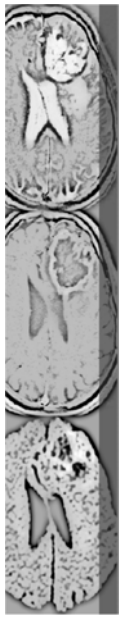
Brain arteries





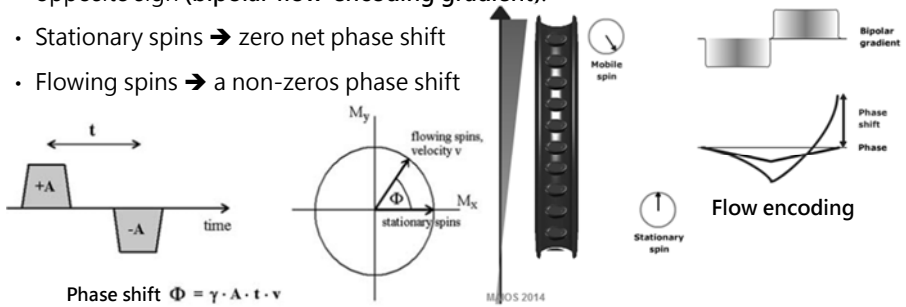
Comparison between 2D and 3D TOF

	2D-TOF MRA	3D-TOF MRA
Advantages	Faster scanning	Higher SNR because signal is acquired from a larger volume
	Maximized FRE because each slice is an entry slice	Improved spatial resolution
Disadvantages	In plane saturation effects	More susceptible to saturation effects
		Less sensitive to slow flow

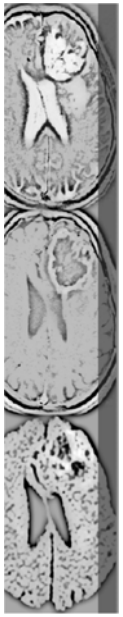


Phase effects

- Phase effects concern the transverse magnetization.
- Apply a pair of gradients with identical strength and duration but opposite sign **(bipolar flow-encoding gradient)**.
- Stationary spins ➔ zero net phase shift
- Flowing spins ➔ a non-zeros phase shift

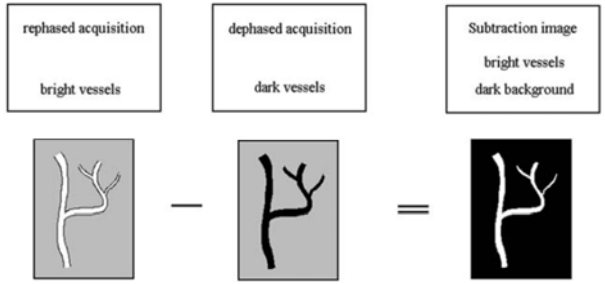


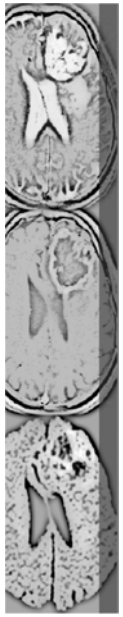
http://www.imaios.com/en/e-Courses/e-MRI/MR-Angiography-Flow-imaging/phase-contrast-mra



Magnitude contrast method

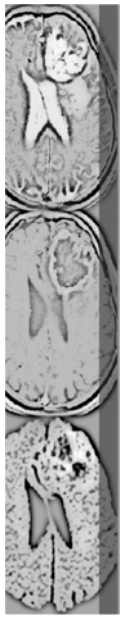
- Acquire two datasets
  - Flow-rephased images: flow compensation, bright-blood image
  - Flow-dephased images: strong flow-sensitive bipolar gradients, velocity-dependent phase shifts, dark-blood image.





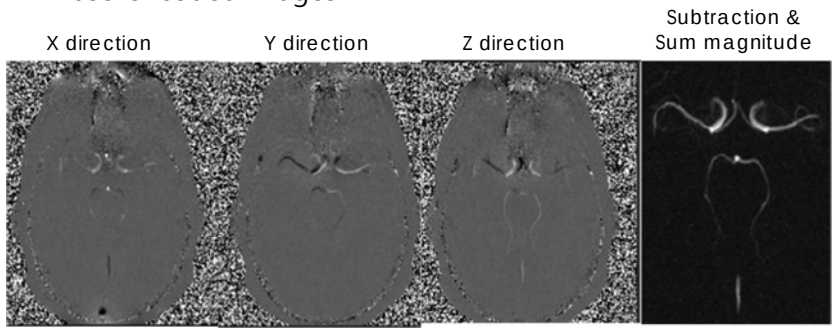
Phase contrast method

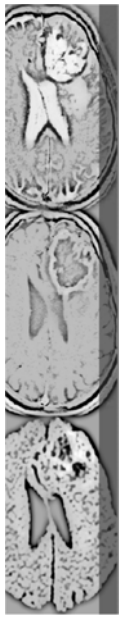
- A direct quantitative measure of the velocity of the flowing blood
- No restriction on image orientation (not dependent on infow effects)
- Velocity encoding (VENC)
  - The velocities between –VENC and +VENC are encoded by the phase shifts between -180° and +180°.
  - The flow velocity exceeded the VENC value ➔ aliasing
- General velocity
  - Arterial flow 40~60 cm/s
  - Venous flow 20~30 cm/s



Phase contrast MRA

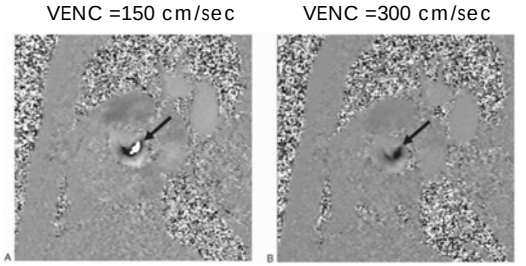
- Phase-encoded images



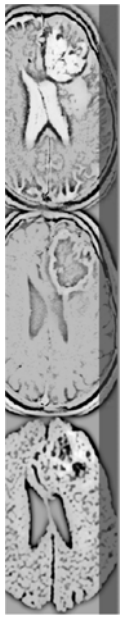


Aliasing

- Aliased velocity = VENC − actual velocity
- May apply two different VENCs—a small VENC and a large VENC in the same FOV

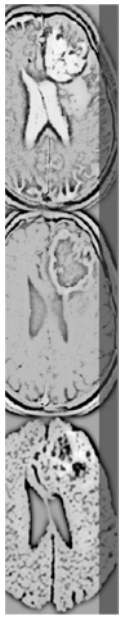


The root of aorta (in a patient with aortic stenosis)



TOF vs. phase contrast MRA

	TOF-MRA	Phase contrast MRA
Advantages	Simple to implement, robust	No saturation effects
	High spatial resolution	Excellent background suppression
	Shorter acquisition time (in 3D)	Enables quantitative flow measurement
Disadvantages	Reduced sensitivity to slow flow	Prior knowledge about flow rates
	Restrictions to size and orientation of the imaging volume	Very long acquisition times for 3D techniques
	Short T1 tissue may be mistaken for flowing blood	Susceptible to phase errors

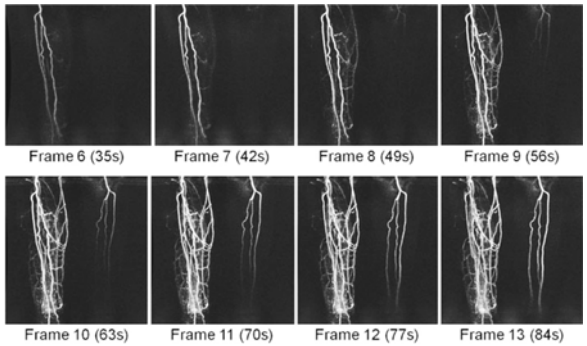


Contrast-enhanced MRA

- Avoidance of blood signal saturation
- Better turbulent flow imaging
- Injection a contrast material intravenously (IV) to selectively shorten the T1 of the blood ➔ brighter signal in T1W images.
- Gadolinium-chelate (Gd) contrast agents
  - Seven unpaired electrons ➔ paramagnetic, shorten T1 and T2
  - Injection rate: 0.5~4.0 ml/s
  - Injection volume: 0.1~0.3 mmol/kg body weight, typically 20~40 ml
  - Computer-controlled power injector
  - Examine the patient's renal function before scanning!

Contrast-enhanced MRA

- 3D, RF-spoiled, fast gradient-echo imaging sequences ➔ T1W images (FSPGR, FLASH, or T1 FFE)



Mask subtraction

TOF-MRA vs CE-MRA

Carotid bifurcations, **detection of ulcer**

AJNR Am J Neuroradiol 34:177–84, 2013.

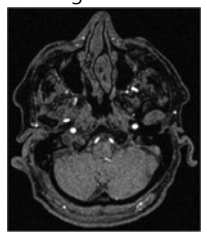
CE-MRA

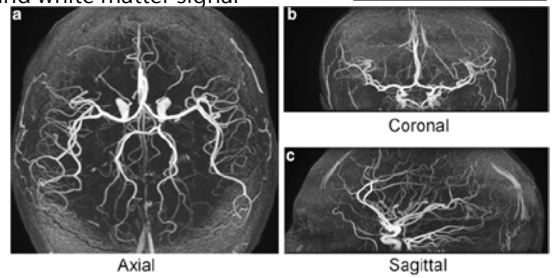
	CE-MRA
Advantages	Rapid technique
	Resistant to dephasing (e.g. from turbulent flow)
	Large FOV with good resolution
	Excellent SNR
Disadvantages	Dependent on timing (venous contamination may occur)
	Require intravenous injection for administration of gadolinium
	No directional information

Background-blood contrast

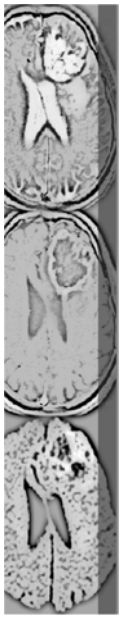
- Magnetization transfer contrast (MTC)
- MTC can further suppress background signal.
  - Reduction of gray and white matter signal by 15-40%
  - But not in blood
- Fat suppression

Original FRE

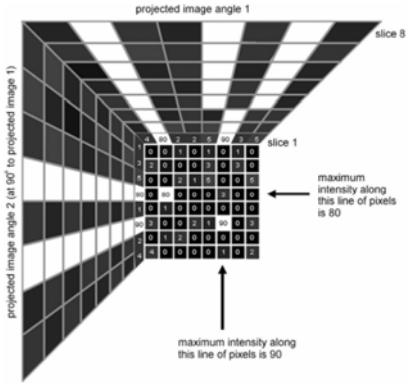


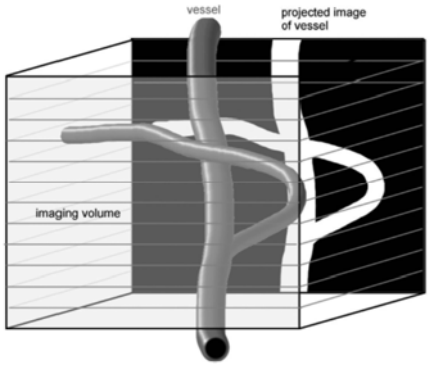


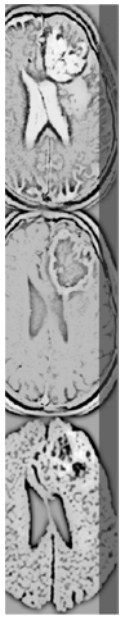
MIP images



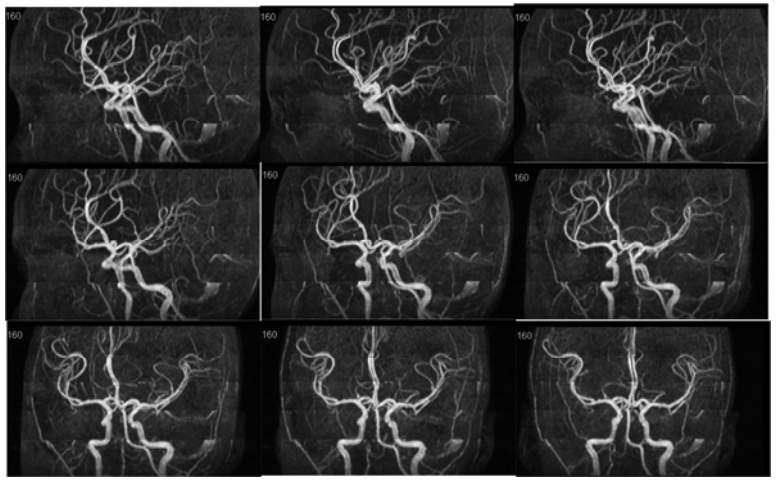
Maximum Intensity Projection (MIP)







MIP from various angles



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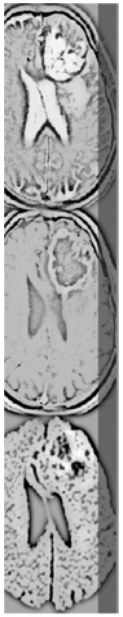

MRA Clinical Applications

Technique	Clinical Applications
2D -TOF MRA	Carotid and vertebral arteries in the neck Venous structures (due to slow flow)
3D -TOF MRA	Intracranial vasculature (circle of Willis) Intracranial vascular malformations and aneurysms
2D -PC MRA	Portal vein CSF flow study Localizer for determining VENC (velocity encoding)
3D -PC MRA	Intracranial vasculature Intracranial vascular malformations and aneurysms
3D -CE MRA	Carotid and vertebral arteries of the neck Aortic arch, renal arteries, and upper or lower extremity runoff

THE END

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