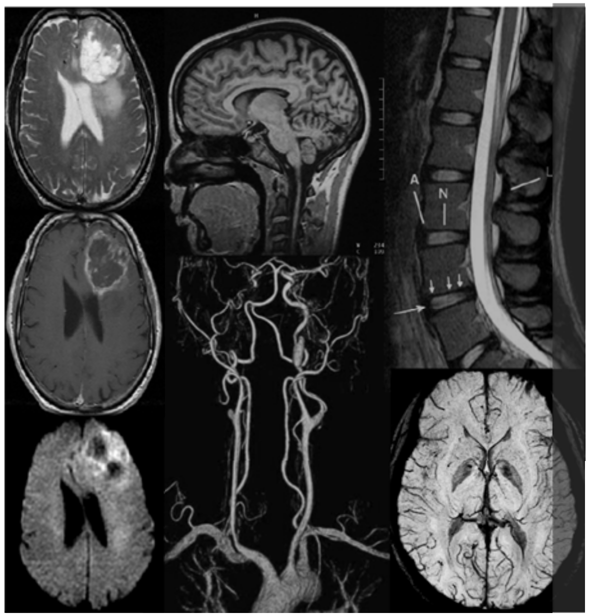

磁振影像學MRI
流體現象

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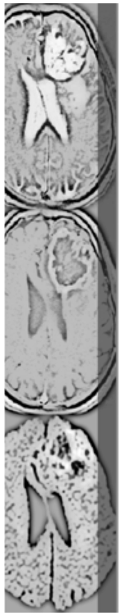
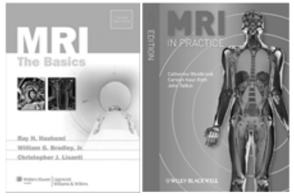


本週課程內容 http://www.ym.edu.tw/~cflu

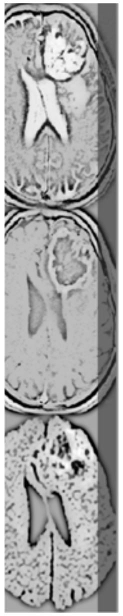
- 流體現象
- 磁振血管攝影簡介

- MRI The Basics (3rd edition)
  - Chapter 26: Flow phenomena
- MRI in Practice, (4th edition)
  - Chapter 6: Flow phenomena



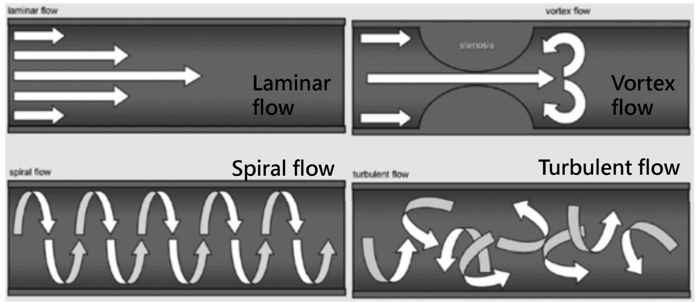
流體現象

Flow Phenomena



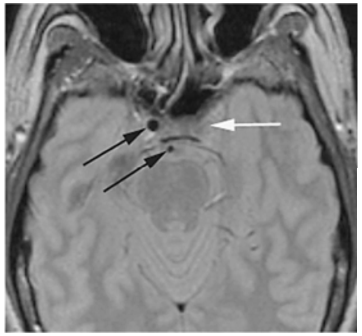
Flow phenomena

- Sources: Flowing blood or cerebrospinal fluid (CSF)
- Phenomena: become dark or bright in MRI



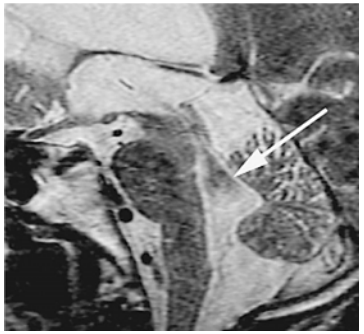
Flow phenomena in MRI

Left internal carotid artery occlusion



PDW, absence of flow void

Normal pressure hydrocephalus



T2W, intravoxel dephasing

Characteristic Factors

- Velocity
- Pulse sequence (SE vs. GRE)
- Slice Position (containing the vessel relative to the rest of the slices)
- Contrast (TR and TE)
- Echo number (even or odd)
- Slice thickness
- Flip angle
- Gradient strength and rise time
- Use of gradient moment nulling (flow compensation) techniques
- Use of spatial presaturation
- Use of cardiac gating
- Chance of cardiac gating (pseudogating)

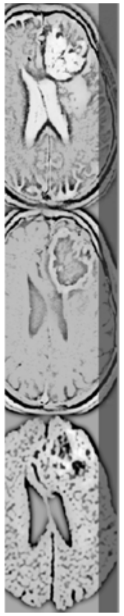
Velocity vs. Flow

- Velocity (in cm/sec), v
- Volumetric flow (in cm^3/sec), Q
- Cross-sectional area of the vessel (in cm^2), A

$$v = Q / A$$

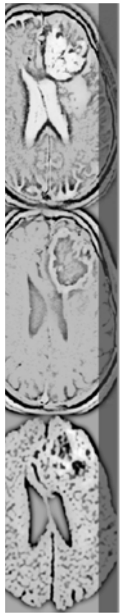
Appearance of flowing blood

- Flow effects can be attributed to
  - Time of flight (TOF) effects, M_z
  - Motion-induced phase changes (phase contrast), M_{xy}
- TOF effects
  - Signal loss (high-velocity signal loss or TOF loss)
  - Signal gain (flow-related enhancement, FRE)

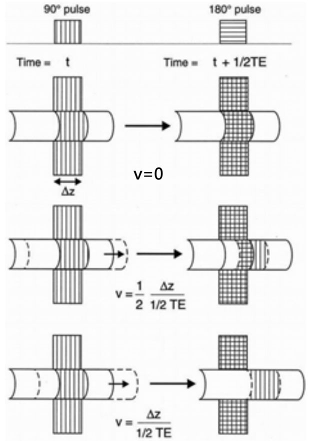


TOF effects

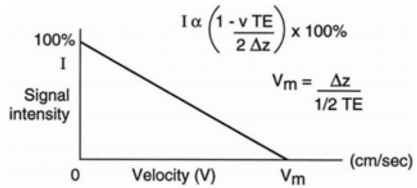
- Decreased signal intensity (dark) of flowing blood
  - High velocity
  - Turbulent flow
  - Dephasing (odd-echo dephasing and intravoxel dephasing)
- Increased signal intensity (bright) of flowing blood
  - Even-echo rephasing
  - Diastolic pseudogating
  - Flow-related enhancement (FRE)

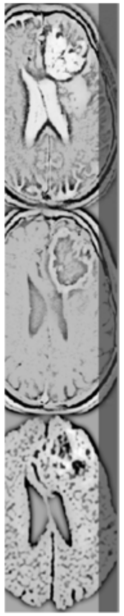


High-velocity signal loss



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

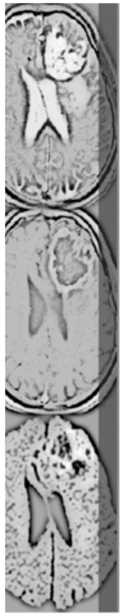




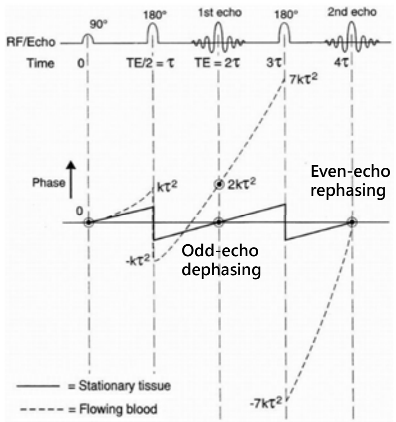
Velocity (v) and phase (φ)

$$\varphi = \int \omega dt = \int (\gamma G v t) dt = \gamma G v \int t dt = \gamma G v (t^2/2)$$

- Phase and velocity are proportional
- A quadratic relationship exists between phase and time, i.e., $\varphi = kt^2$



Echo number effects



- $t = \tau = \frac{1}{2}TE$ → assume $\varphi = k\tau^2$
- $t = [\tau, 2\tau]$ → $\varphi = [k(2\tau)^2 - k\tau^2] = 3k\tau^2$
- $t = [2\tau, 3\tau]$ → $\varphi = [k(3\tau)^2 - k(2\tau)^2] = 5k\tau^2$
- $t = [3\tau, 4\tau]$ → $\varphi = [k(4\tau)^2 - k(3\tau)^2] = 7k\tau^2$

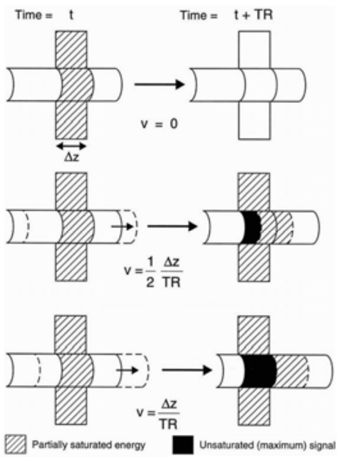
Echo number effects

- Assume velocity of blood flow is constant
- Odd-echo → dephasing → signal decrease
- Even-echo → rephasing → signal gain

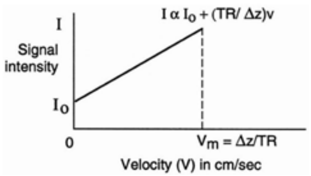
Diastolic pseudogating

- Systole (rapid) vs. diastole (slower)
- In diastole, the TOF effects result in higher intravascular signal.
- Use cardiac gating to acquire slice at a fixed point in the cardiac cycle.
  - TR=1/(heart rate)

Flow-related enhancement (FRE)

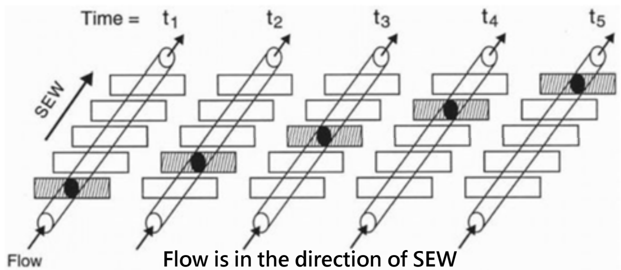


- In GRE
- Also called entry phenomenon
- The fresh inflowing blood that enters the first slice is totally un saturated (by last RF excitation)
- If v ≥ Δz / TR → maximal signal
- $I \propto I_0 + v(TR/\Delta z)$



Cocurrent Flow

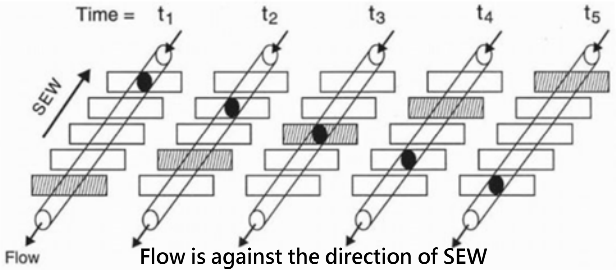
- The slice excitation wave (SEW) is the direction of successive 90° excitation pulses.
- If flow is perpendicular to the slices…



Increase the possibility of saturation → Weak FRE

Countercurrent Flow

- If flow is perpendicular to the slices…



Reduce the possibility of saturation → Strong FRE

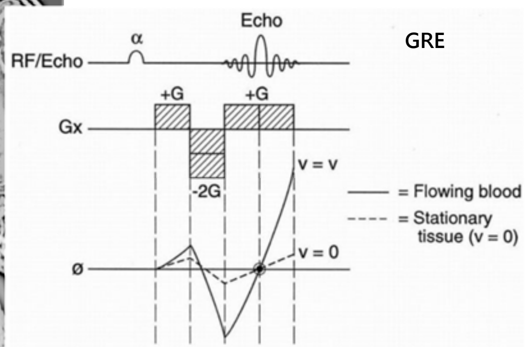
Flow Compensation (FC)

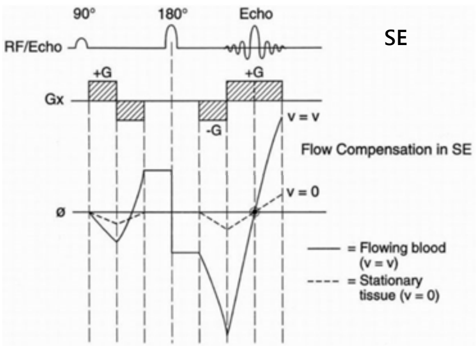
- Gradient Moment Nulling is one method of minimizing flow motion artifacts.
- Add extra gradient pulses to produce the even-echo rephasing effect on the first echo.
  - First-order FC: for constant velocity
  - Second-order FC: for constant acceleration
  - Third-order FC: for turbulence (jerk) flow

- Can be applied to all the three coordinates
- FC lobes lengthen the TR/minimum TE

FC gradients: first-order

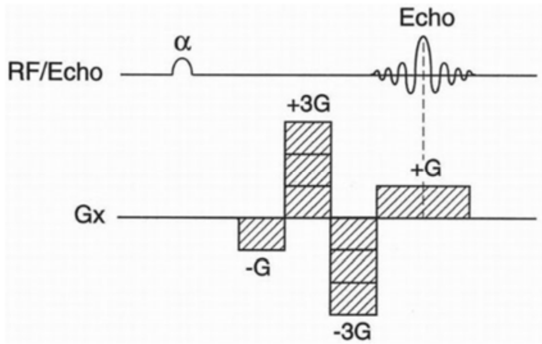
- 1 <u>2</u> 1 gradient lobes





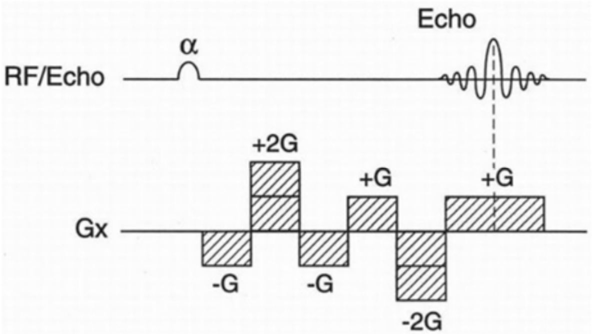
FC gradients: second-order

- <u>1</u> 3 <u>3</u> 1 gradient lobes



FC gradients: third-order

- <u>1</u> 2 <u>1</u> 1 <u>2</u> 1 gradient lobes



磁振血管攝影

MR Angiography

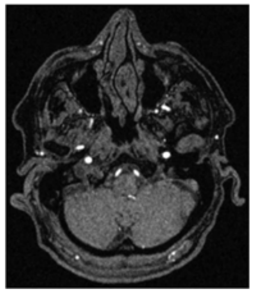
Unenhanced MRA

- Rely solely on flow effects (the movement of blood)

- Amplitude effects
  - Blood flowing into or out of a chosen slice has a different **longitudinal magnetization** compared to stationary spins.
  - Depend on the duration of stay (time-of-flight) in the slice
- Phase effects
  - Blood flowing along the direction of a magnetic field gradient changes its **transverse magnetization** compared to stationary spins.

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

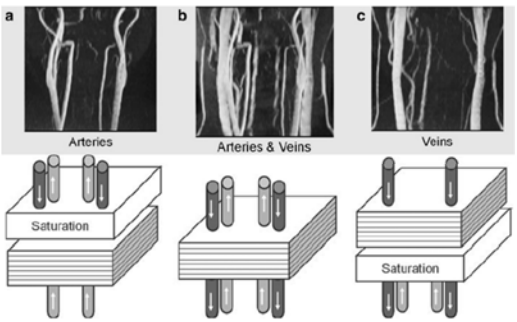
- Spoiled GRE sequences
  - No TOF loss phenomenon
  - Short TR (<40 msec) to efficiently saturate stationary tissues
  - Short TE (< 5 msec) to reduce spin dephasing
  - Short acquisition time to acquire 3D datasets
  - Flow compensation (refocus unwanted phase accumulations)
- TOF techniques can be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

Sequential 2D technique

- Larger flip angle ($30^o \sim 70^o$)
- 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).

Spatial saturation pulse

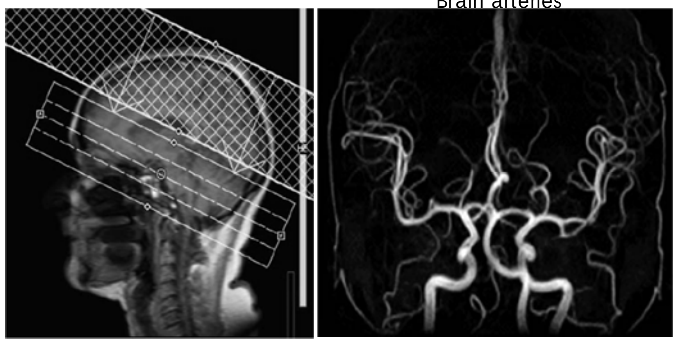
- Superior saturation pulses are used suppress the signal from veins above the heart, and arteries below the heart
- Inferior saturation pulses are used to suppress the signal from arteries above the heart and veins below the heart



3D multi-slab method

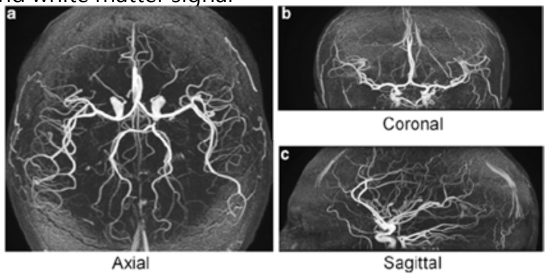
- Presaturation slab above the imaging volume suppresses the signal of venous flow.

Brain arteries



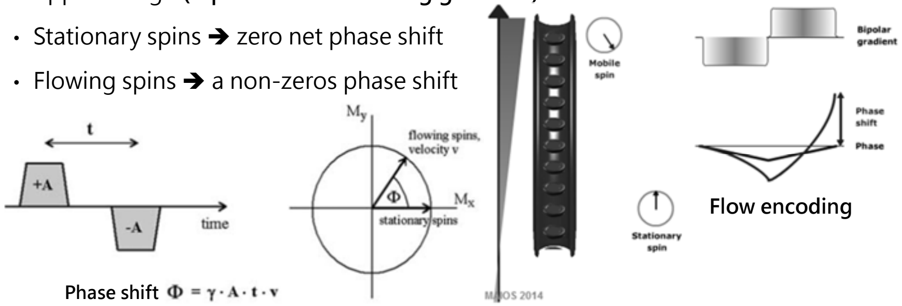
Background-blood contrast

- 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



Phase effects

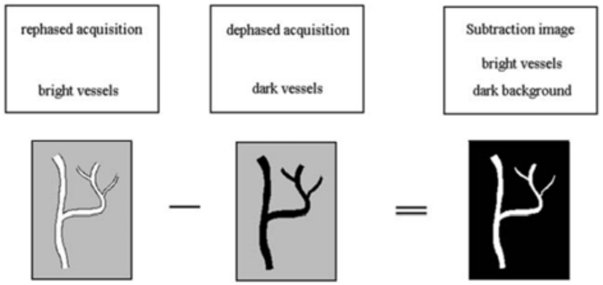
- Phase effects concern the transverse magnetization.
- Apply a pair of gradients with identical strength and duration but opposite sign **(bipolar flow-encoding gradient)**.
- Stationary spins ➔ zero net phase shift
- Flowing spins ➔ a non-zeros phase shift



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

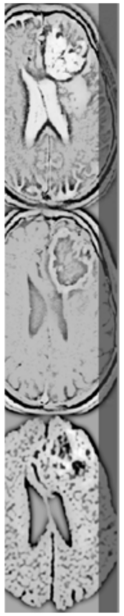
Magnitude contrast method

- 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.



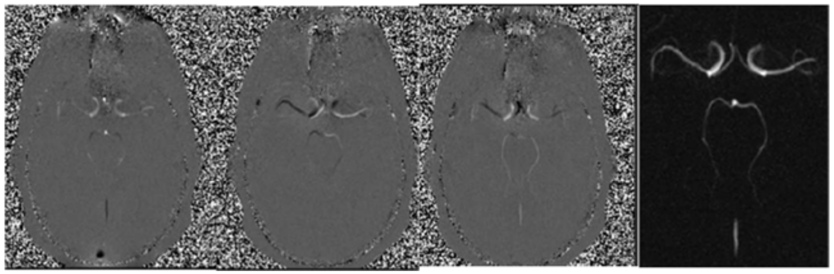
Phase contrast method

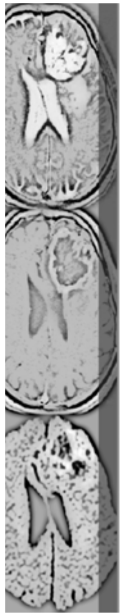
- A direct quantitative measure of the velocity of the flowing blood
- No restriction on image orientation (not dependent on infow effects)
- Velocity encoding (VENC)
  - The velocities between –VENC and +VENC are encoded by the phase shifts between -180^o and +180^o.
  - The flow velocity exceeded the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



Phase contrast MRA

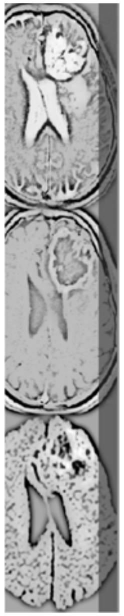
- Phase-encoded images





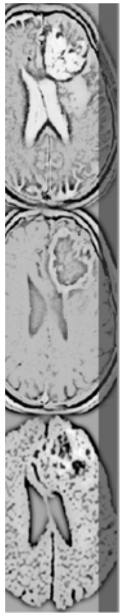
TOF vs. phase contrast MRA

	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



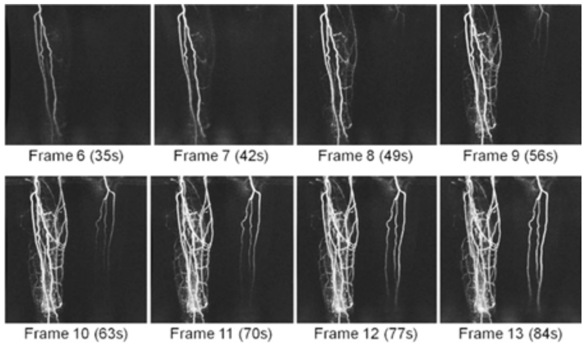
Contrast-enhanced MRA

- 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

THE END

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