Chapter 24
MRA and Flow quantification

Yongquan Ye, Ph.D.
Assist. Prof.
Radiology, SOM
Wayne State University

- **Previous classes**
  - Flow and flow compensation (Chap. 23)
  - Steady state signal (Cha. 18)
- **Today's content**
  - MRA techniques
  - Phase contrast flow quantification (PC FQ)

MR Angiography

- Bright blood methods
  - Time-of-flight (TOF)
  - Contrast enhanced MRA (CE MRA, Gd based)
  - SSFP (T2/T1 weighted)

- Dark blood methods
  - Double inversion recovery (DIR)
  - Flow dephasing
  - Saturation band
  - SWI (for veins)
  - Contrast enhanced (iron based USPIO)

- Quantitative
  - PC Flow quantification (FQ)
  - 4D FQ

Time-of-flight (TOF)

- Inflow & outflow effect
  - Critical speed: $v_c \equiv TH/T_R$
  - Inflow: unexcited/unsaturated blood
  - Outflow: excited blood

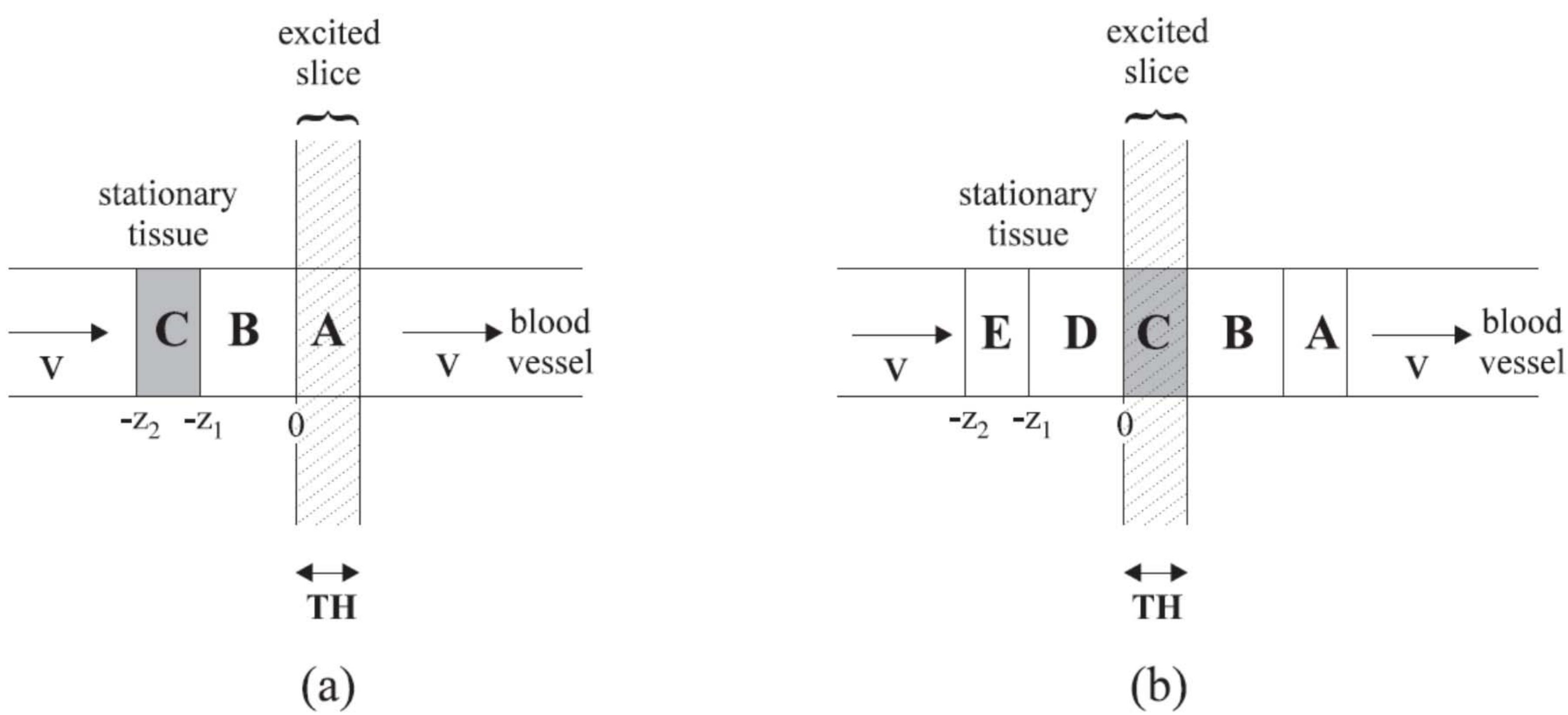
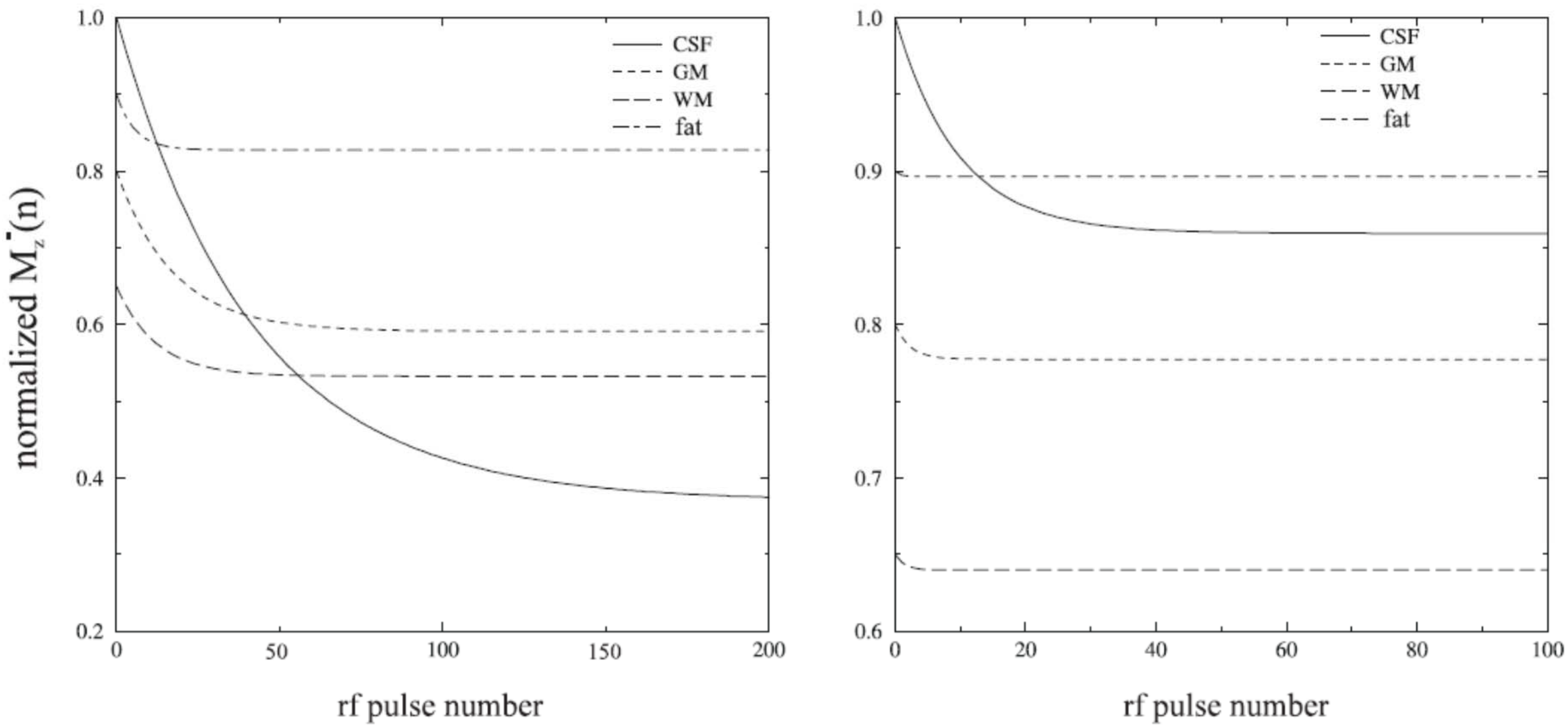


Fig. 24.1

Time-of-flight (TOF)

- SSI signal built-up: revisit



(a) TR=40ms

(b) TR=400ms

Fig. 18.5

Time-of-flight (TOF)

- Inflow saturation effect (2D)

$$S(p \geq n) = \Lambda \frac{\sin\theta}{n} \sum_{m=1}^{n} \left(M_{ze} + (M_0 - M_{ze}) q^{m-1} \right)$$
$$= \Lambda \sin\theta \left(M_{ze} + (M_0 - M_{ze}) \frac{1 - q^n}{n(1-q)} \right)$$

n is maximal RF number the blood sees while in the slice
$q \equiv E1cos\theta$

Therefore, for a thin 2D slice (relative to the flow velocity), very high signal can be obtained for vessels, while tissues are T1 saturated

$$T_{1,flow} \equiv \frac{TH}{v} \quad \Rightarrow \quad \frac{1}{T_{1,eff}} = \frac{1}{T_1} + \frac{1}{T_{1,flow}}$$

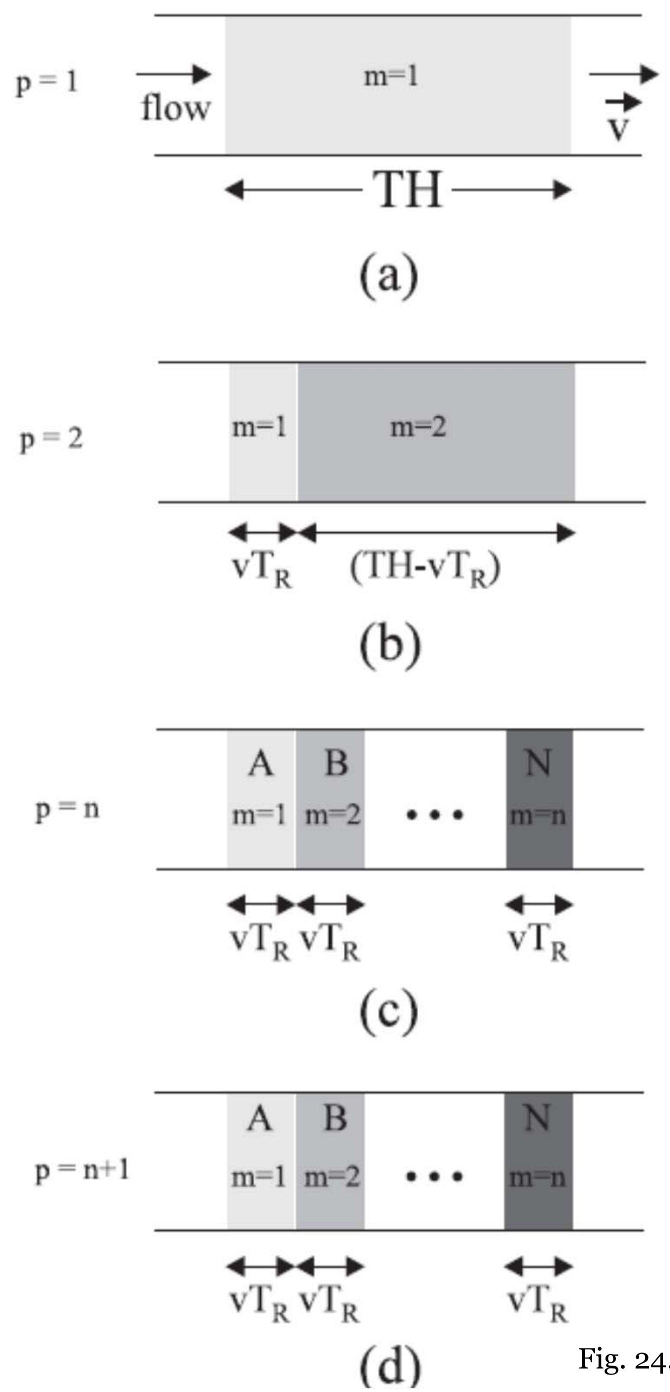
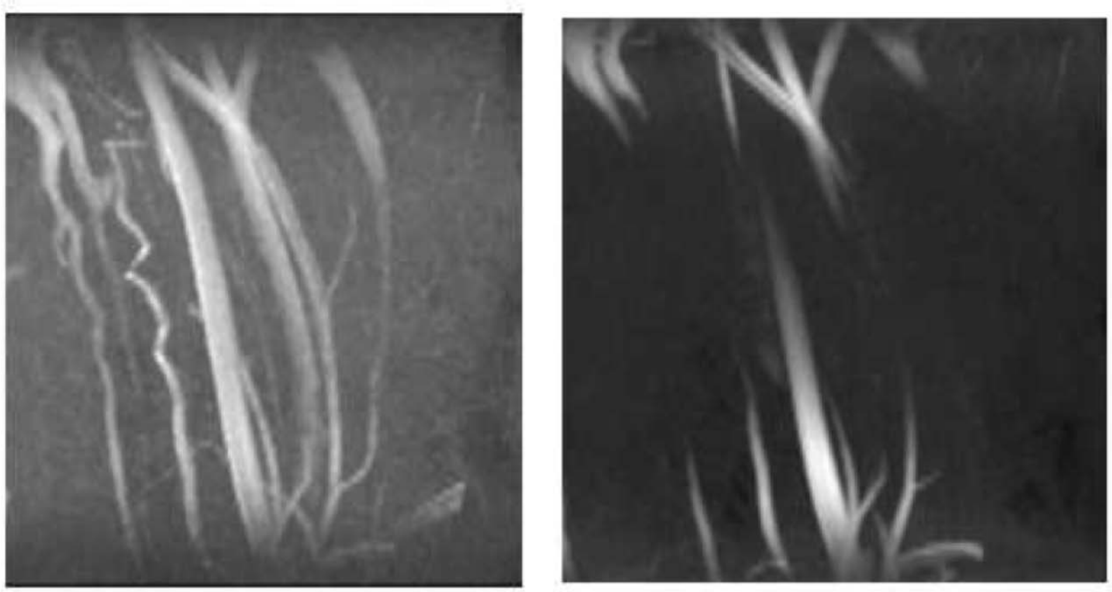


Fig. 24.3

Time-of-flight (TOF)

- Inflow saturation effect (3D)



(a) (b)

Fig. 24.6

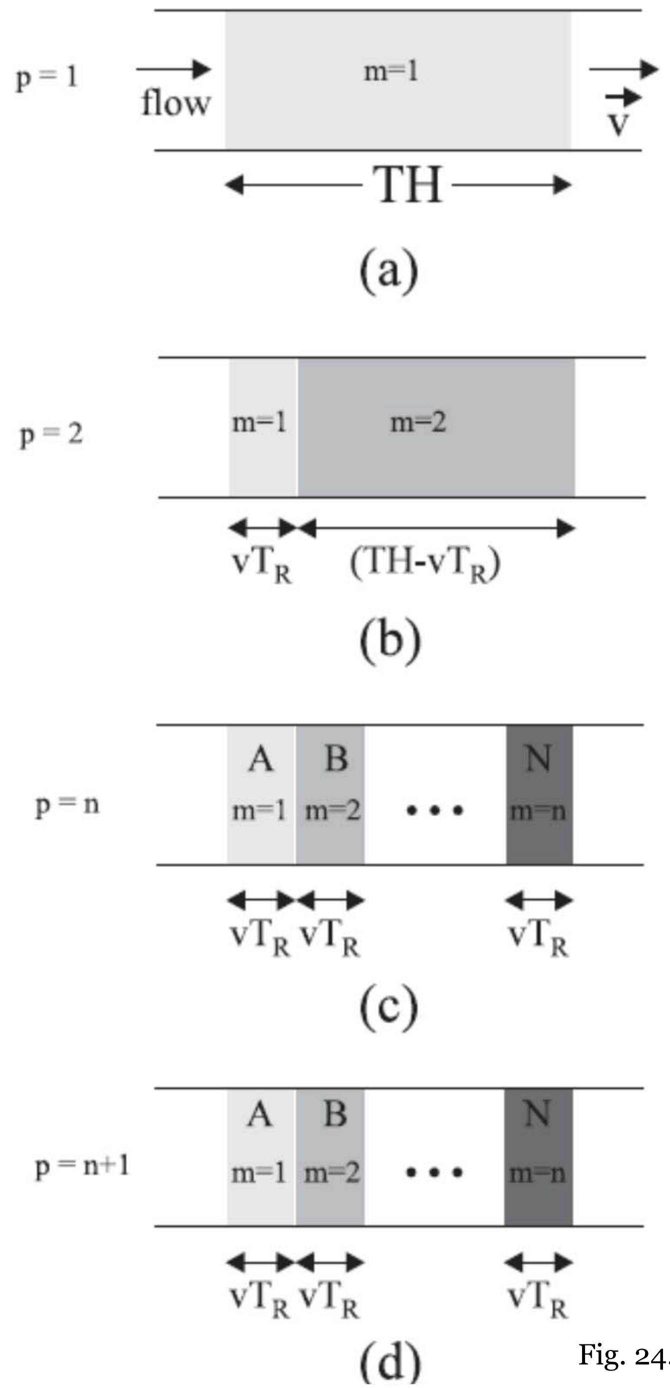


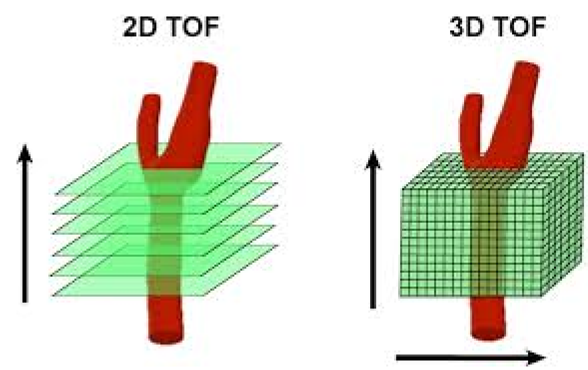
Fig. 24.3

Time-of-flight (TOF)

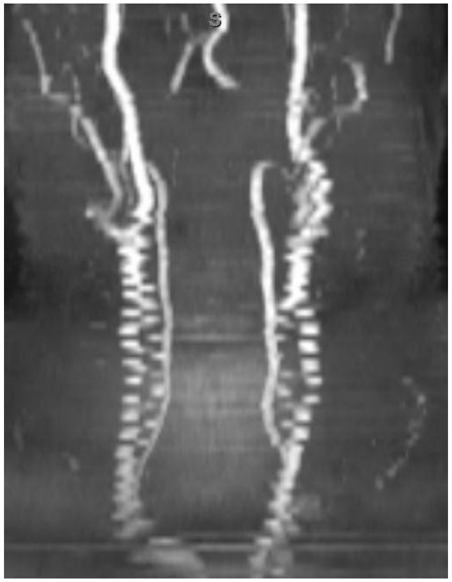
- TOF MRA has low tissue signal at steady state (saturated), but high inflow blood signal before steady state (unsaturated)

- Sequence and imaging consideration
  - Flow compensation
  - Perpendicular inflow
  - Multiple thin slabs
  - Short TE, short TR, properly small flip angle
  - TONE pulse (3D): spatially varying flip angle along slab thickness

Time-of-flight (TOF)



- 3D vs. 2D
  - SNR or resolution (esp. slice sel)
  - Blood saturation effect (or CNR)
  - TONE pulse
  - Vessel contours
  - Imaging time
  - Application dependent
  - Multiple slice / slab imaging
  - Arteries and veins



CE-MRA

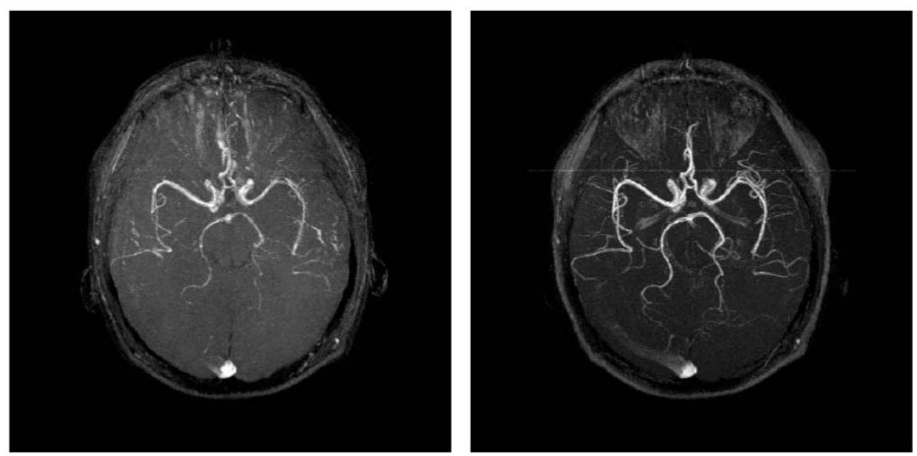
- SSI signal

$$SSI = \frac{M_0(1 - E1)}{(1 - E1cos\theta)} sin\theta E2$$

- To increase SSI signal (theoretically)
  - Short TE
  - Long TR
  - Ernst angle
  - Reduce T1 or increase T2

CE-MRA

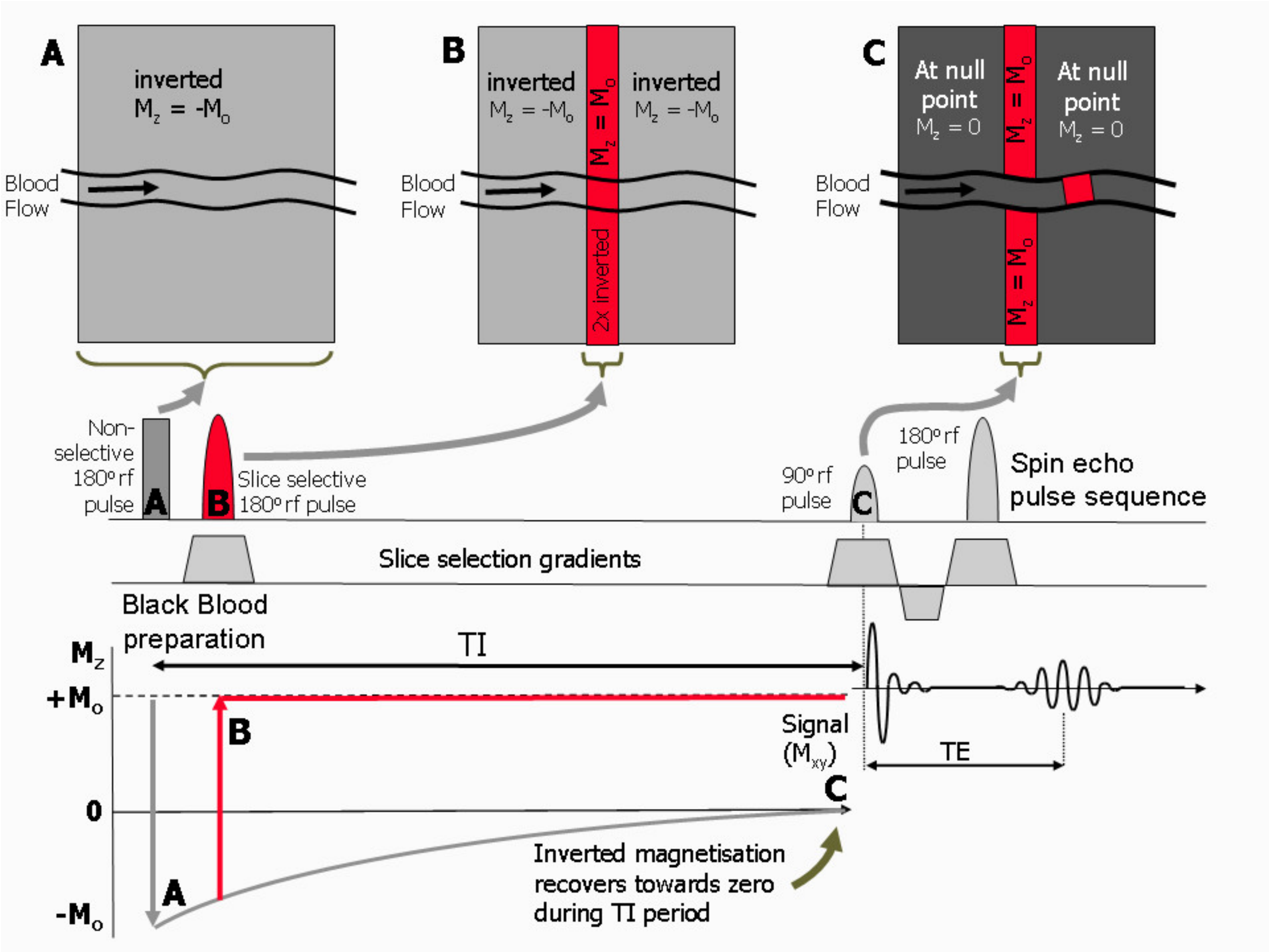
- Use T1 shortening contrast agent (Gadolinium based chelates, or Gd) to reduce blood T1
- Flow independent, i.e. non TOF effects
- Consideration
  - Dosage: safety, T1 shortening effects
  - Shorter TR and higher flip angle can be used than TOF
  - Faster scans, or higher resolution
  - No TONE pulse needed
  - Venous signal



(a) (b)

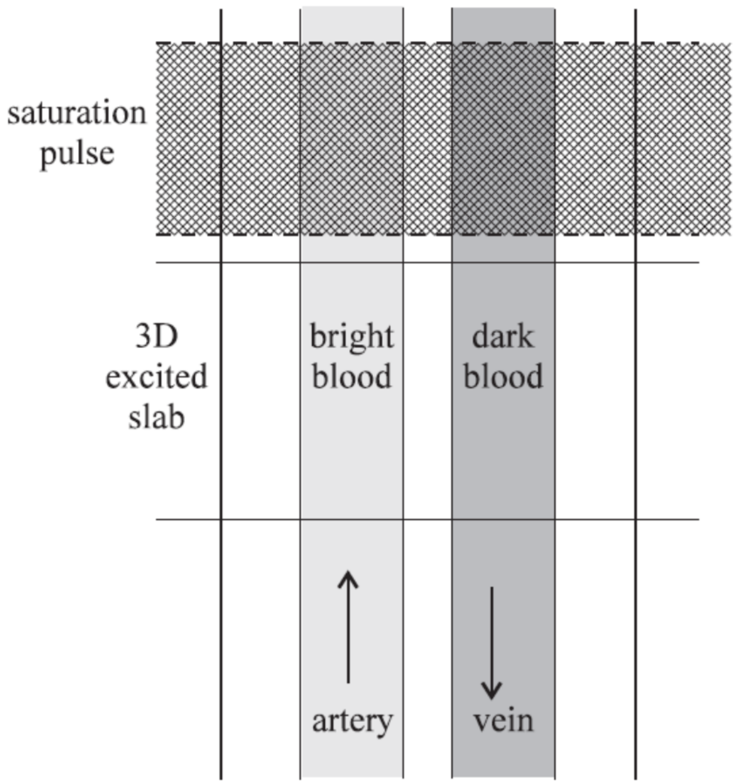
Black blood MRA

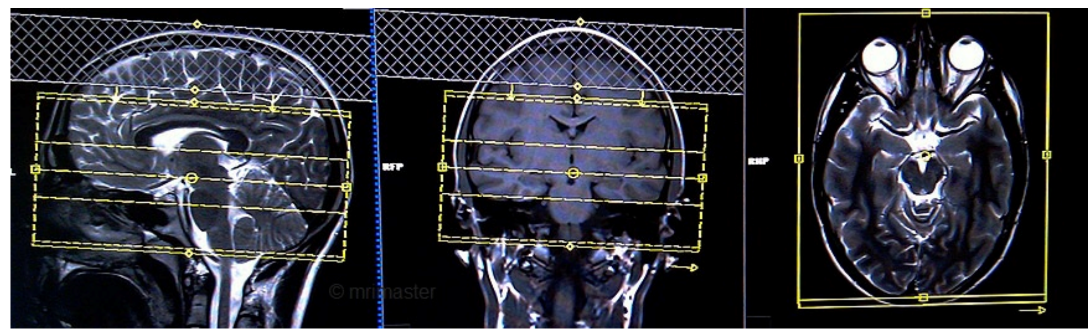
- Suppress inflow signal using DIR

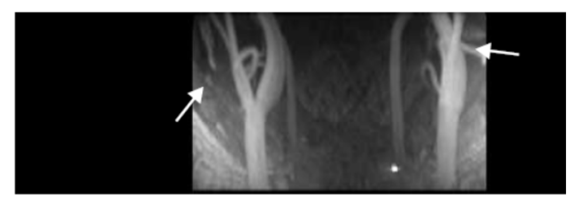


Black blood MRA

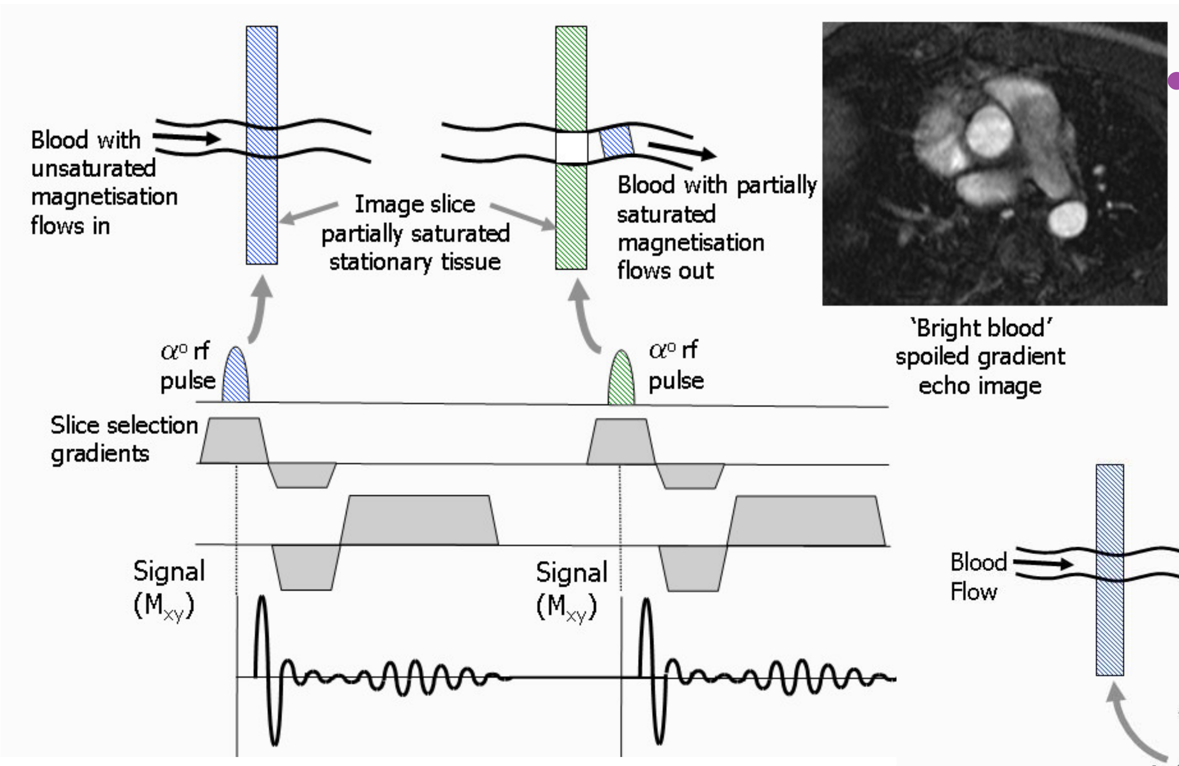
- Suppress inflow signal using Saturation band



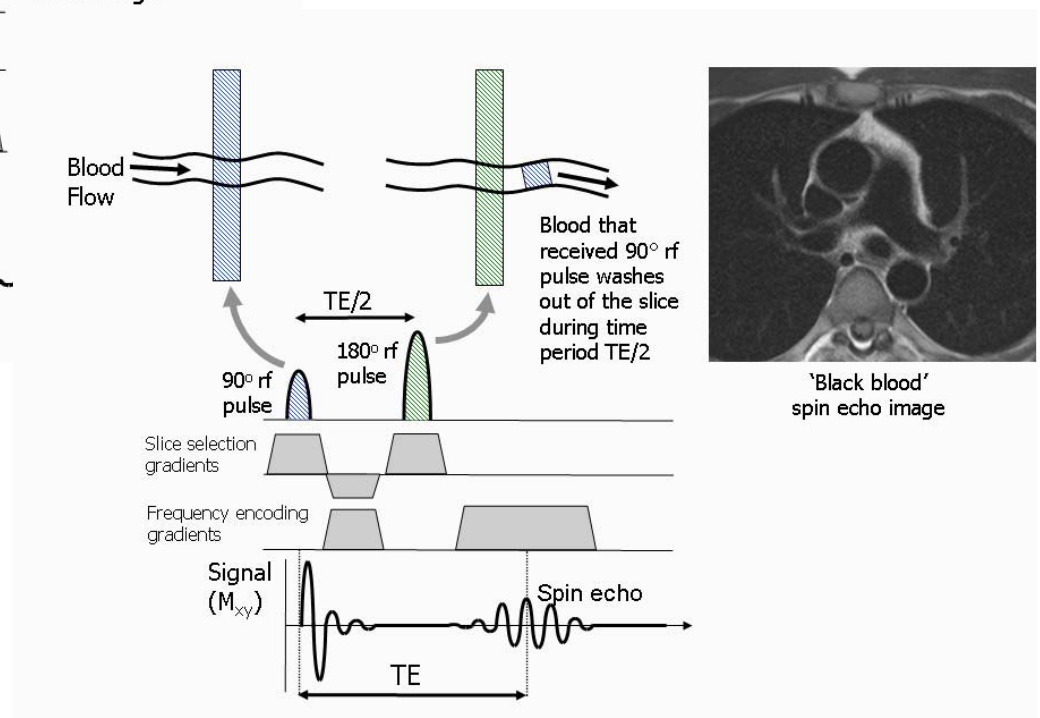




Black blood MRA



- Increased inflow signal using gradient echo



- Suppress inflow signal using Spin Echo

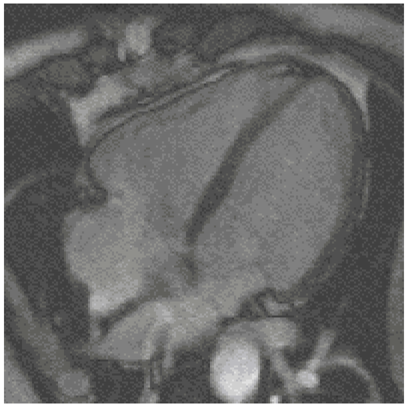
SSFP MRA

- TR<<T2, T1

$$M_y^+(\infty) = \frac{M_0(1-E_1)\sin\theta}{(1-E_1\cos\theta)-E_2(E_1-\cos\theta)}$$

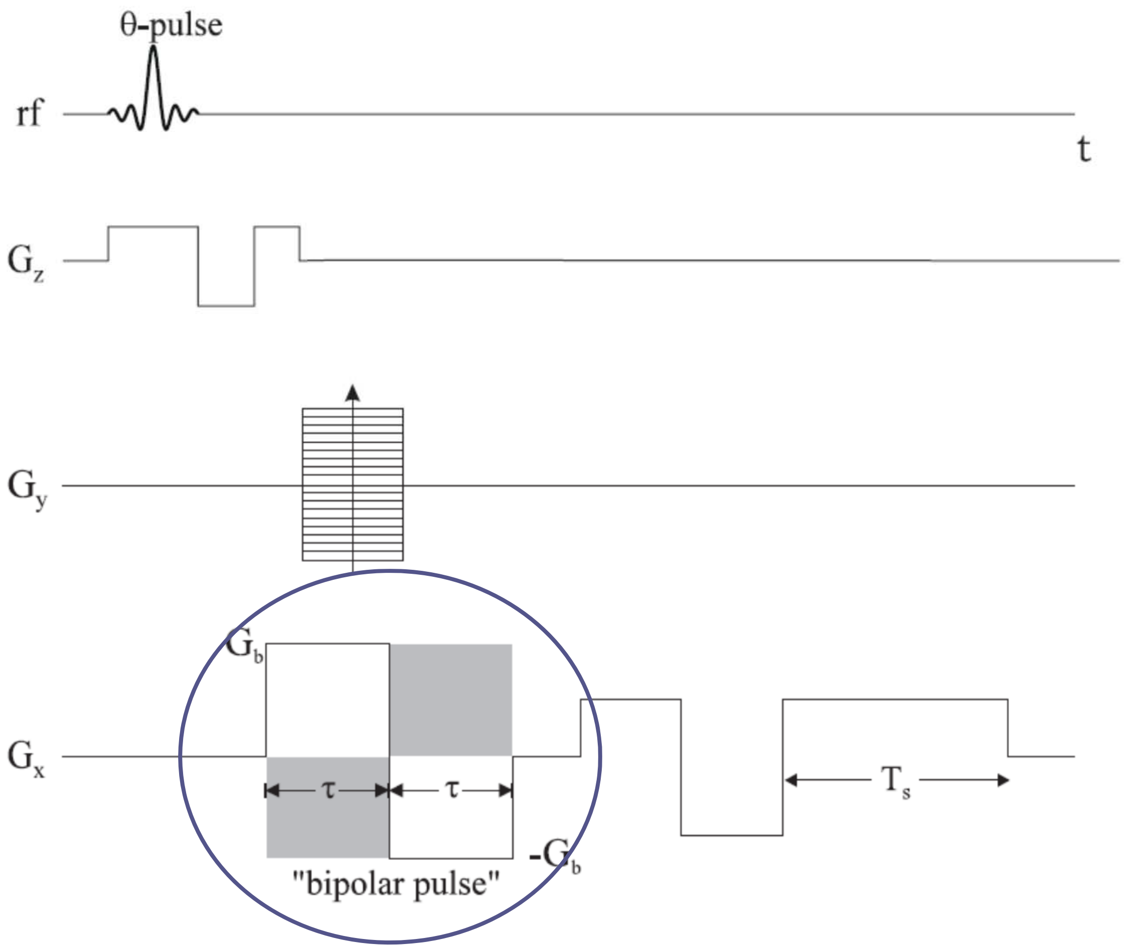
$$\simeq \frac{M_0\sin\theta}{\left(\frac{T_1}{T_2}+1\right)-\cos\theta\left(\frac{T_1}{T_2}-1\right)}$$

$$M_y^+(\infty)|_{\theta=\theta_{opt}} \simeq \frac{1}{2}M_0\sqrt{\frac{T_2}{T_1}}$$



CSF and blood have high T2/T1 ratio:
Flow independent MRA

Phase contrast



VENC: velocity encoding
or
VENC value = $\pi/(\gamma G\tau^2)$

Why bipolar gradient?

Why flow compensation after flow encoding?

$$\phi_v(t) = -\gamma \int G(\tau) v \tau d\tau \quad \Rightarrow \quad \phi_{v\pm} \equiv \phi_{v_x}(T_E) = \mp \gamma G v_x \tau^2$$

Phase contrast

$$\phi_{v\pm} \equiv \phi_{v_x}(T_E) = \mp\gamma G v_x \tau^2$$

- Error source
  - Field inhomogeneity lead to phase variation
  - RF penetration effects (B1 field inhomogeneity)
  - Unknown phase baseline
  - Phase aliasing due to fast flow + low VENC
  - Low phase CNR due to slow flow + high VENC
- Solutions
  - Subtraction on phase images or complex division between two image sets with opposite VENC values
  - Set VENC value according to $\pi/(\gamma G\tau^2)$ to avoid aliasing

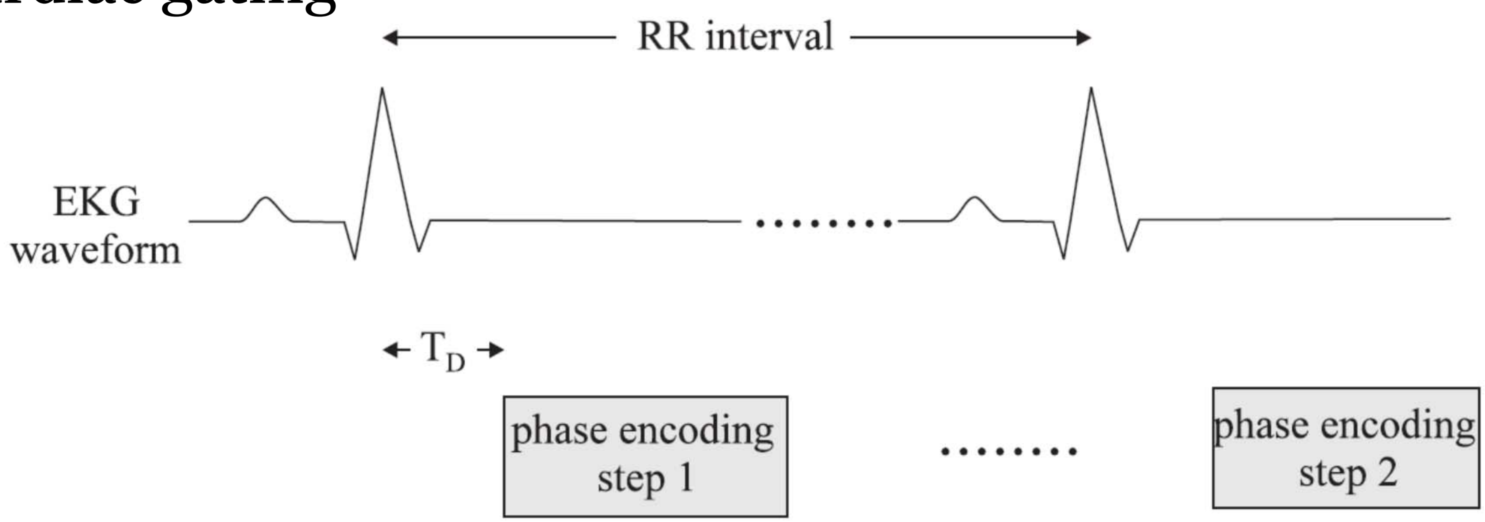
Flow quantification

- Definition

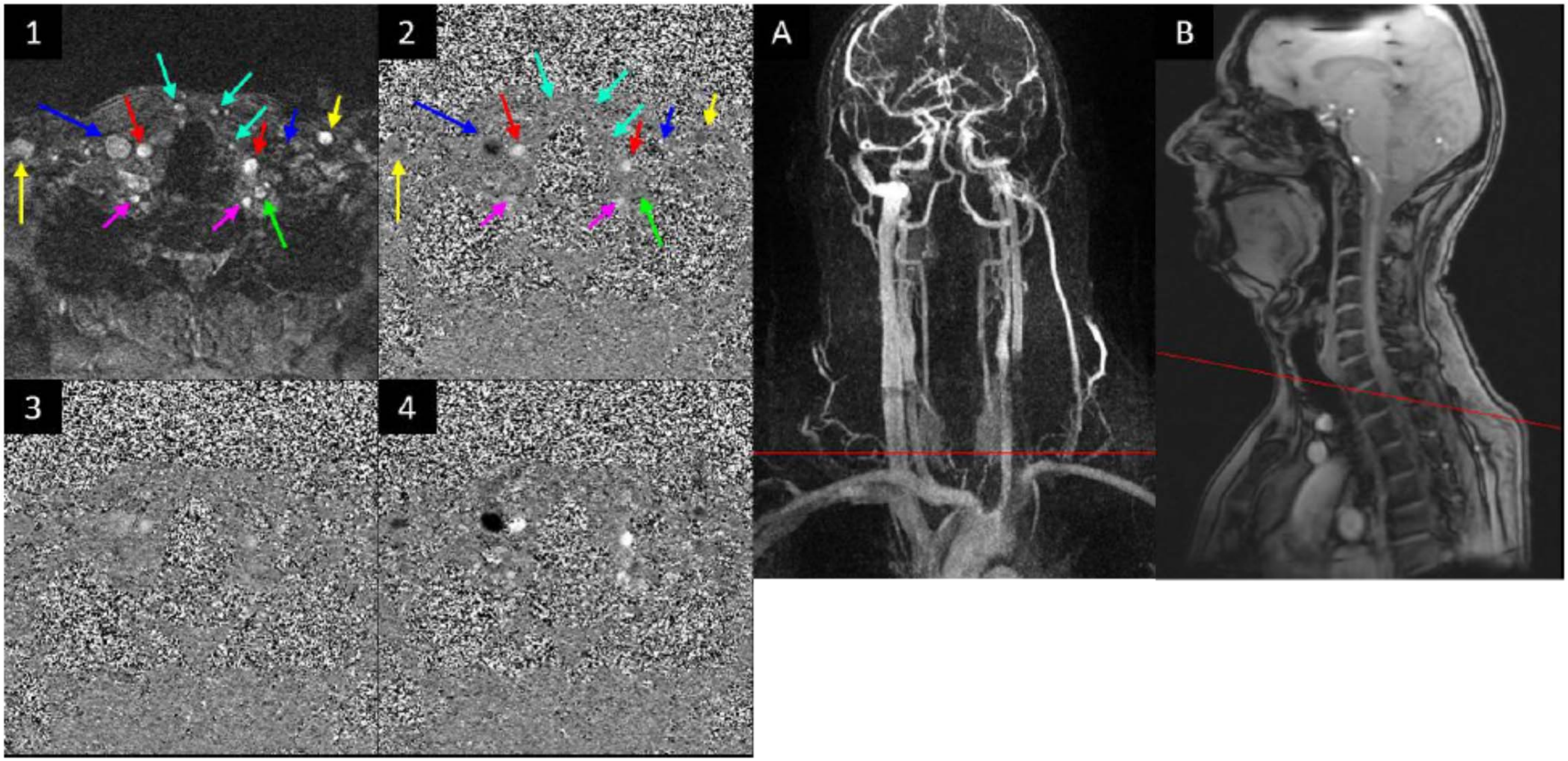
$$F = \int v_z \, dA$$

- Practically, flow refers to the blood volume that passes through a vessel in a give duration such as a cardiac cycle

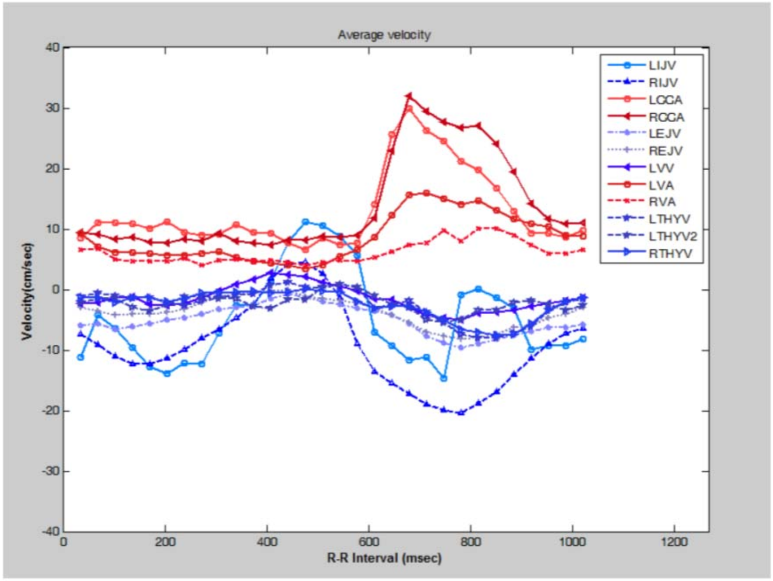
- Cardiac gating



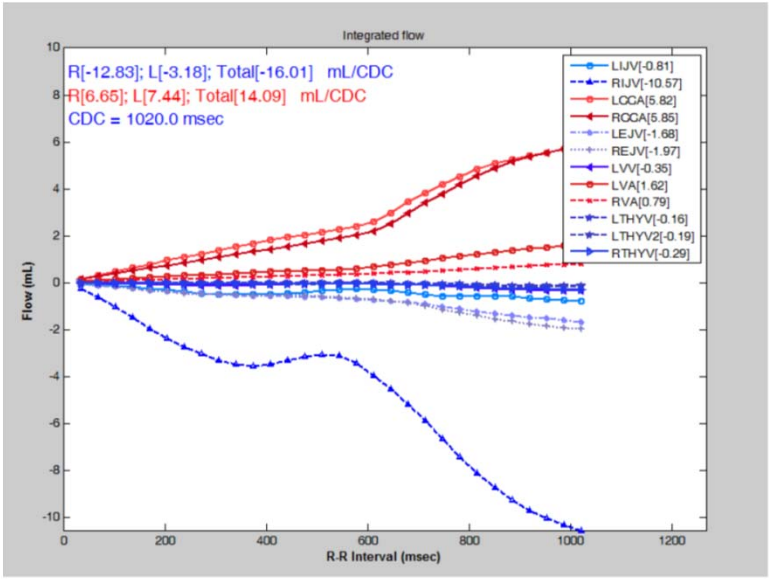
Flow quantification



Flow quantification

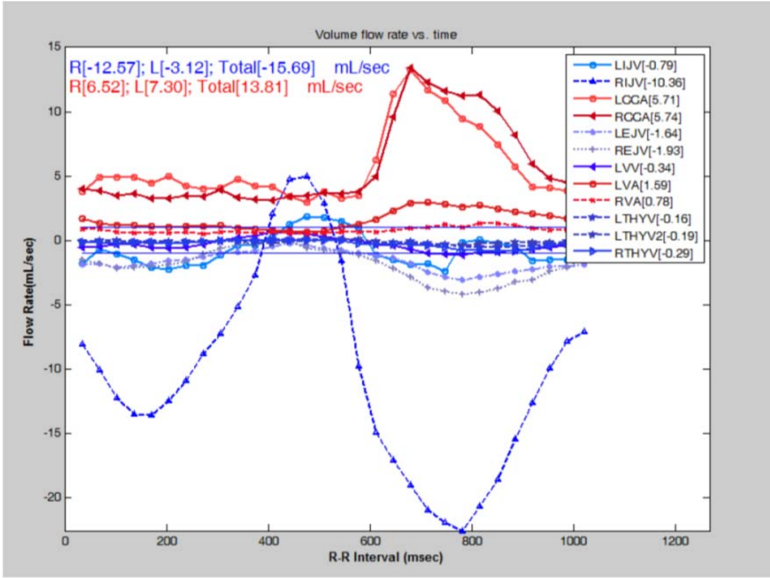


Average flow (cm/s)



Integrated flow (ml)

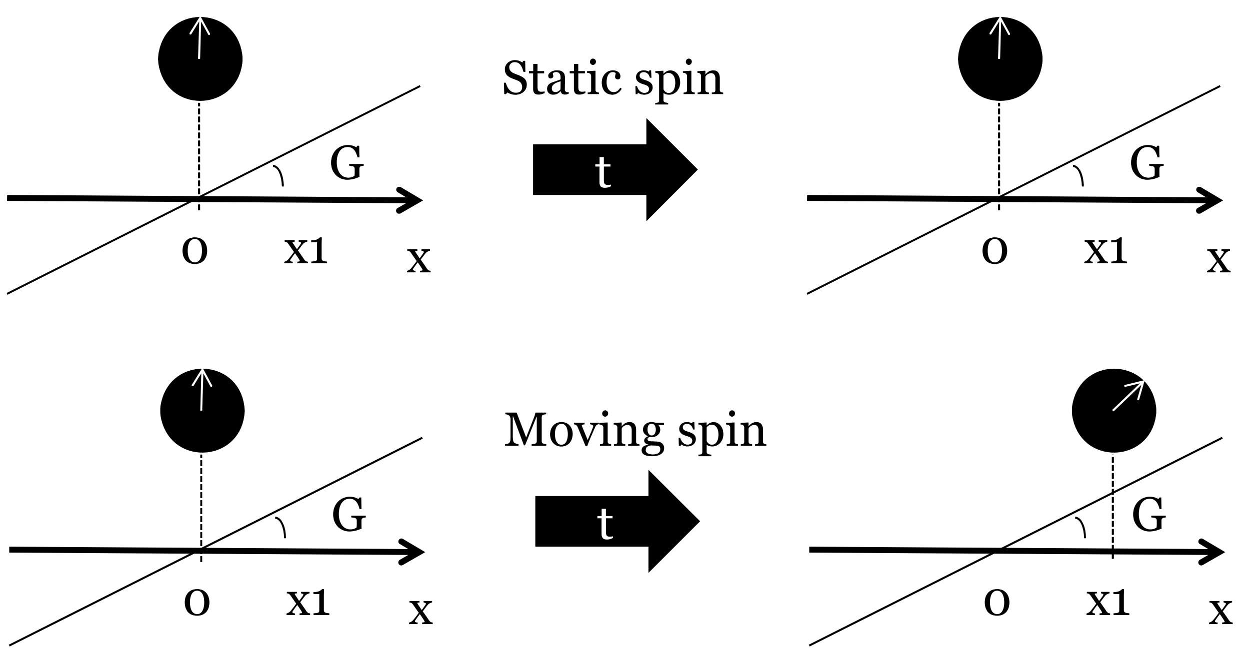
Example:
Reflux flow in Right Internal Jugular Vein

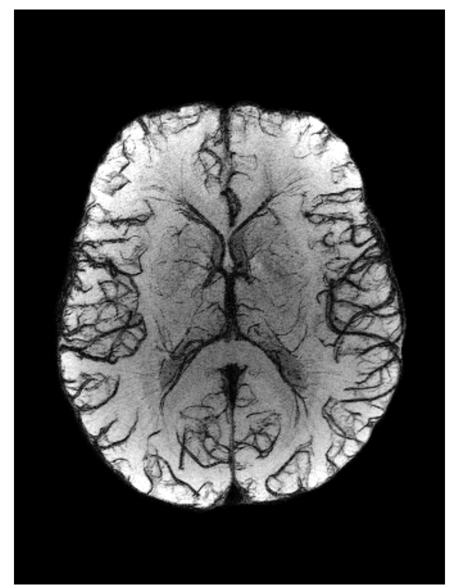


Volume flow rate (ml/s)

Imaging examples

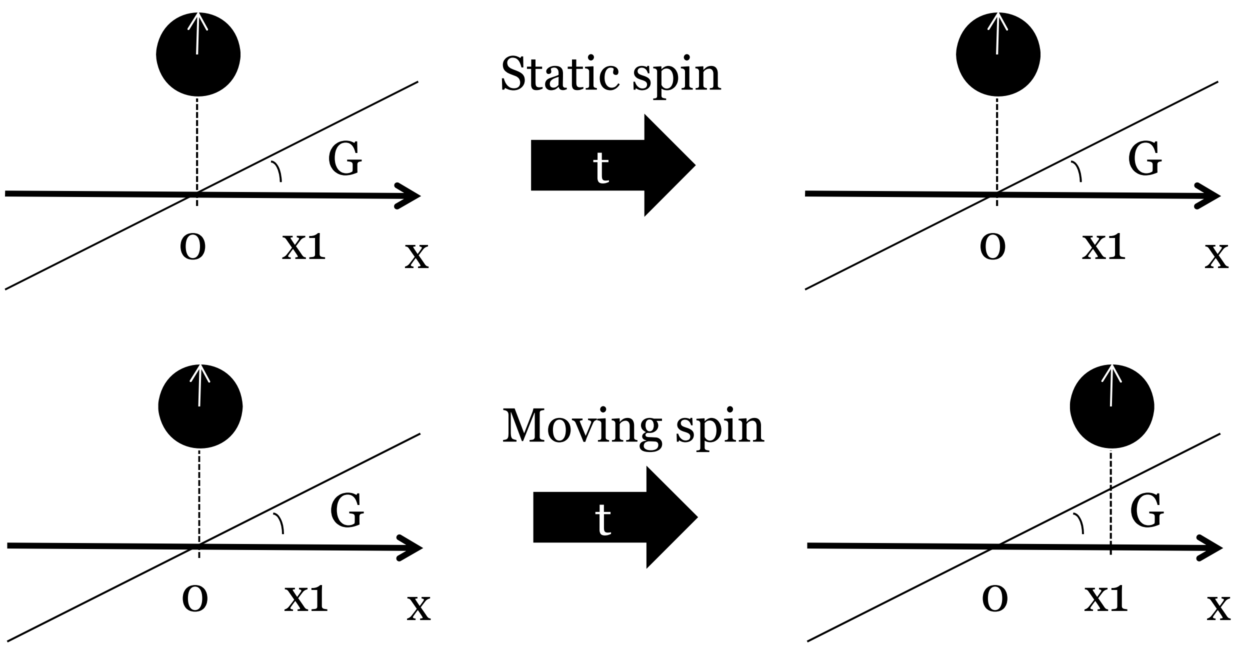
- Flow related contrast (Macroscopic)
  - Flow dephasing (BG/bipolar dephasing gradient)
  - Flow compensation
  - Flow encoding

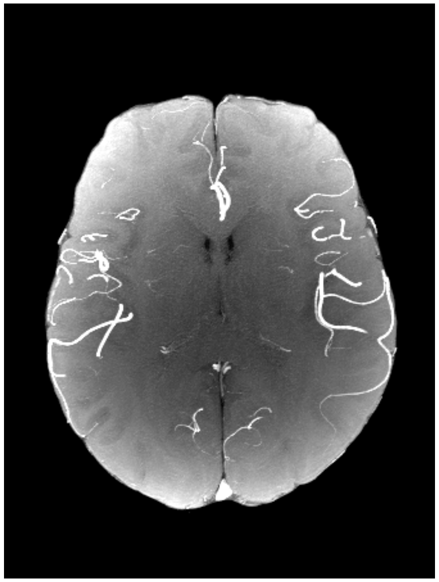




Imaging examples

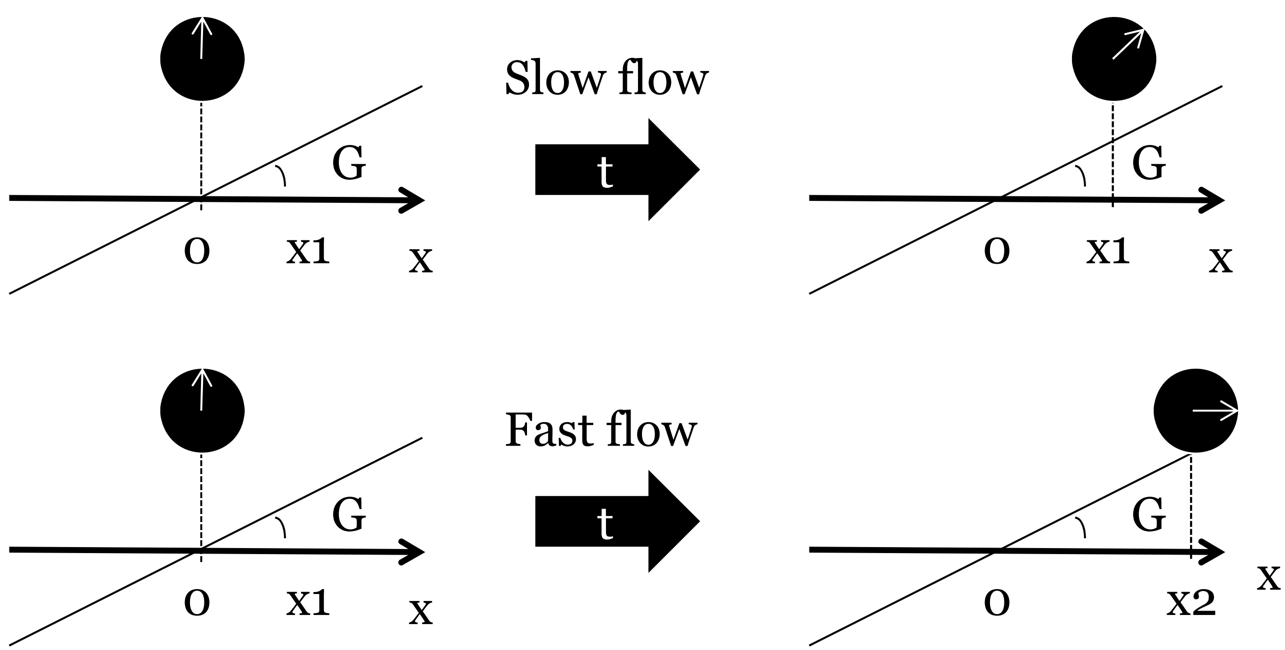
- Flow related contrast
  - Flow dephasing
  - Flow compensation (1st moment nulling gradient)
  - Flow encoding

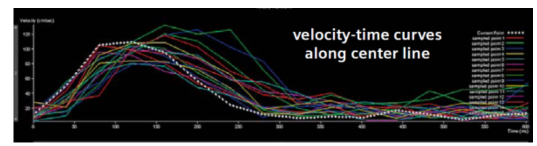


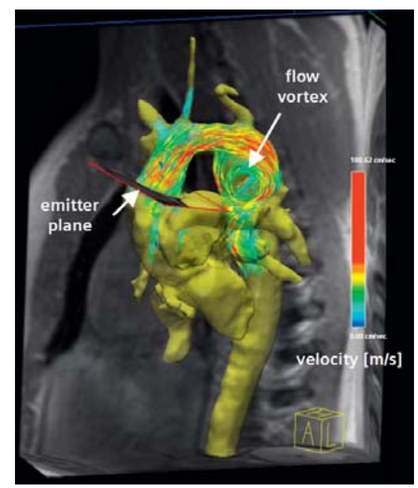


Imaging examples

- Flow related contrast
  - Flow dephasing
  - Flow compensation
  - Flow encoding (quantification)







4D flow, Michael Markl

Homework

- *Prob 24.2, 24.3, 24.4, 24.12, 24.18*

Next Session

Review & discussion

Ready to hand in your presentation essay