Lecture 24 – MRI application

This lecture will cover: *(CH5.17-5.19)*

- MR angiography
- Functional MRI (fMRI)
- Diffusion Tensor Image (DTI).
- Clinical application

(*Supplementary reading: The Essential Physics of Medical Imaging CH13.3-13.4)*

Magnetic resonance angiography

- Not require the use of contrast agent;
- Most commonly used MRA is time-of-flight (TOF, 时间飞越法) angiography;
- Short T_1 ($T_{1,eff}$) due to blood flow;

$$\frac{1}{T_{1,\mathrm{eff}}} = \frac{1}{T_1} + \frac{v}{S_{\mathrm{th}}}$$

Where v: blood velocity

S_{th}: slice thickness

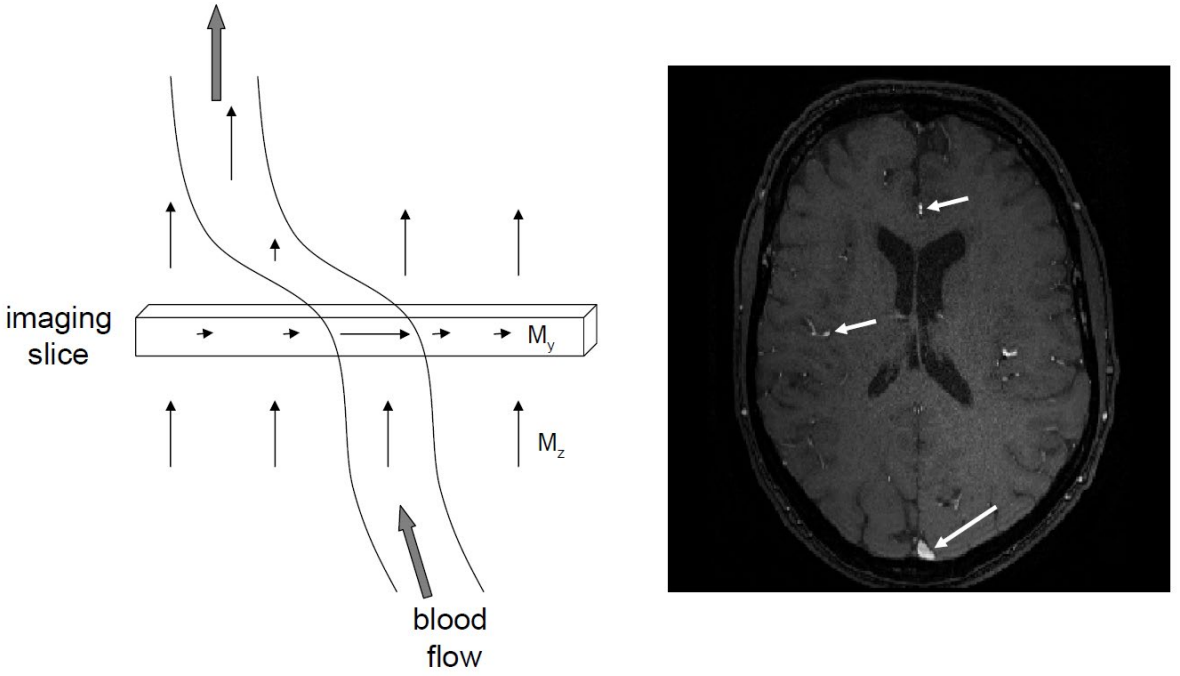
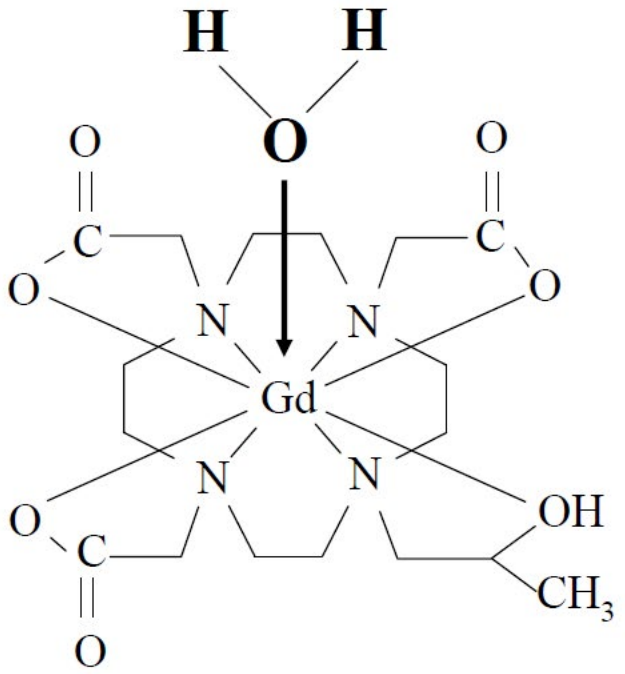


Fig. (left) The TOF MR angiographic technique. Blood flowing into the imaging slice has full M_z magnetization before the RF pulse, and so a 90° pulse creates maximum M_y magnetization. In contrast, stationary tissue within the slice experiences every RF pulse during the imaging sequence and since $TR \ll 3T_1$ is 'saturated', i.e. has an M_z magnetization which is much less than its thermal equilibrium value. Therefore, the 90° pulse creates a much lower M_y magnetization in the tissue than in the blood. (right) Image of a slice through the brain showing the vessels (arrows) with flow perpendicular to the image slice as bright spots.

MRI contrast agent

- Used to increase CNR between healthy and diseased tissue, especially small lesions;
- Positive contrast agent;
  - Paramagnetic;
  - Gd-based chemicals;
  - Increase MRI signal intensity on T_1 weighted scans by shortening the T_1 of tissue;
- Negative contrast agent:
  - Superparamagnetic;
  - Consisting of small magnetic particles containing iron oxides with diameter 30-100nm or less;
  - Reduce MRI signal intensity by causing very strong inhomogeneities in the local magnetic field (reduced T_2^*);

Positive contrast agent



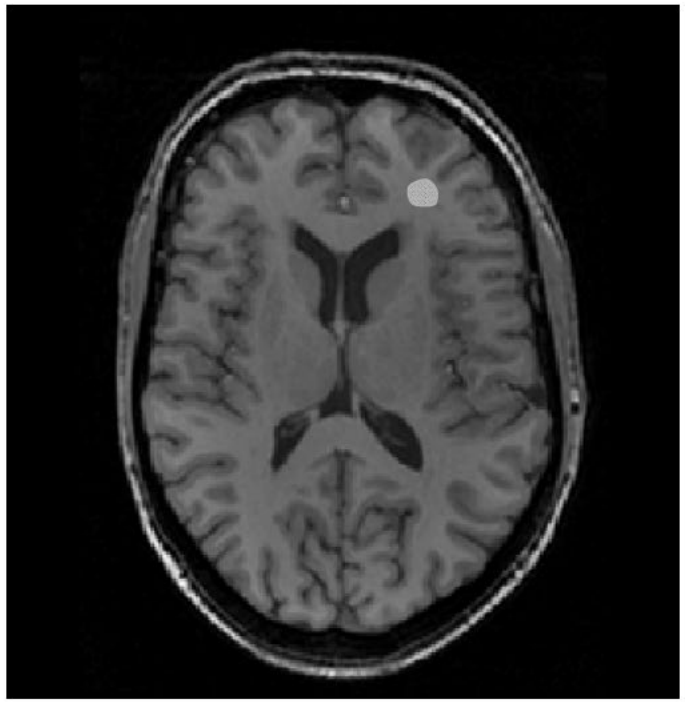


Fig. (left) The chemical structure of a positive MRI contrast agent (Prohance). One co-ordination position is free, which allows water to bind strongly but reversibly to the Gd-ion and undergo extremely fast T_1 relaxation. (right) One slice through the brain showing accumulation of the agent in a small lesion, which appears bright on a T_1-weighted sequence.

Negative contrast agent

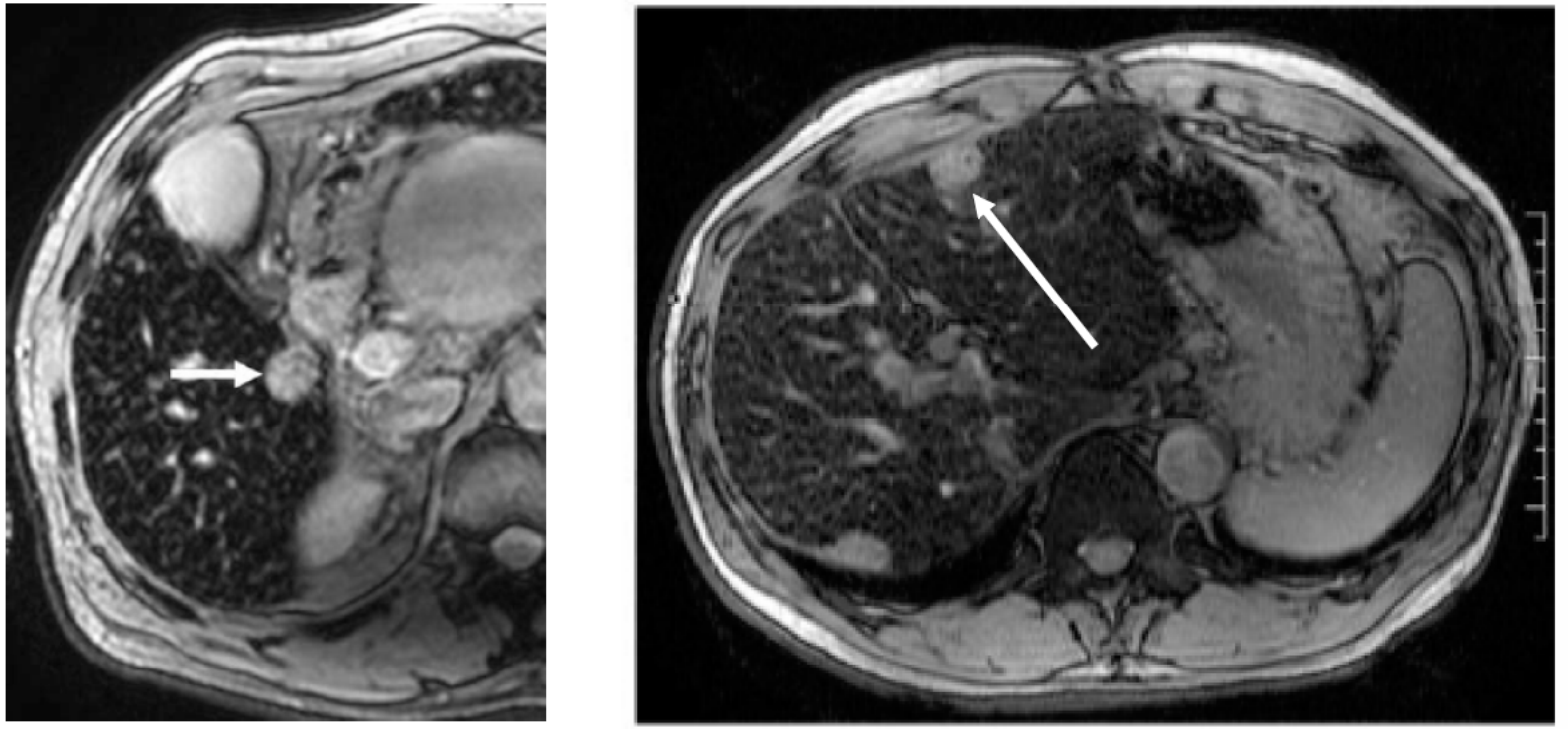
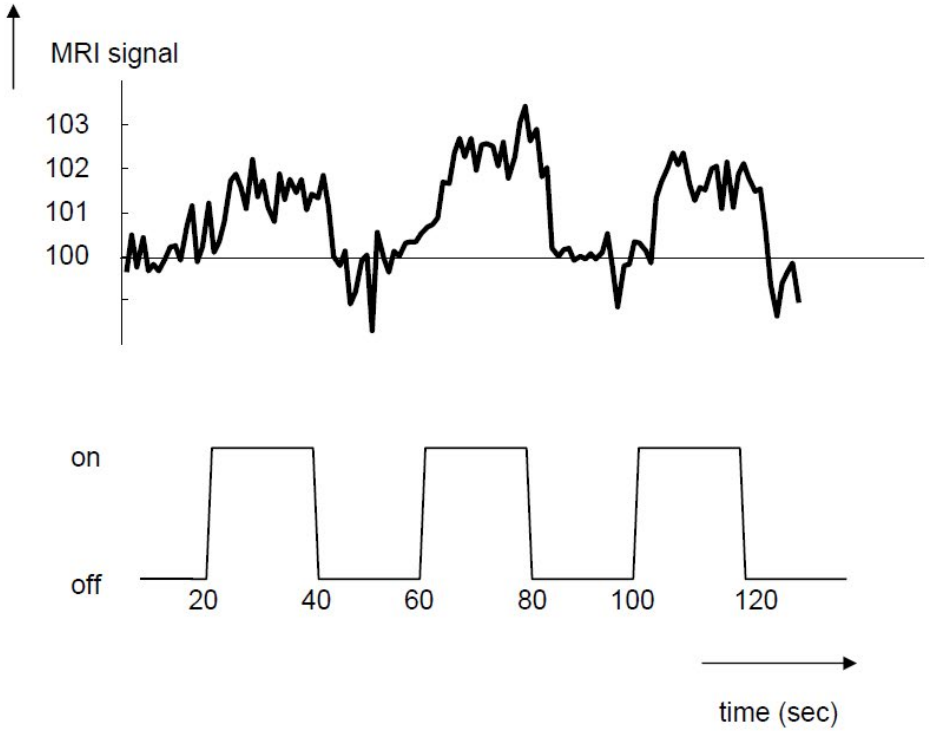


Fig. Two examples of hepatocellular carcinomas (indicated by the white arrows) imaged after injection of USPIO negative contrast agents. The surrounding liver tissue is dark in the T_2^*-weighted gradient echo imaging sequences, but the carcinomas do not take up the agent and so appear bright relative to the healthy tissue.

Functional MRI (fMRI)

- Signal intensity changes depending on the level of oxygenation of the blood in brain (Increased T_2).
- T_2-weighted imaging
- Multiple-slicing echo planar imaging;



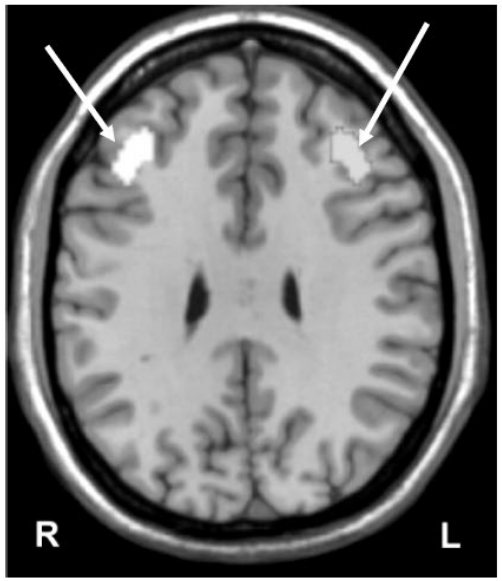
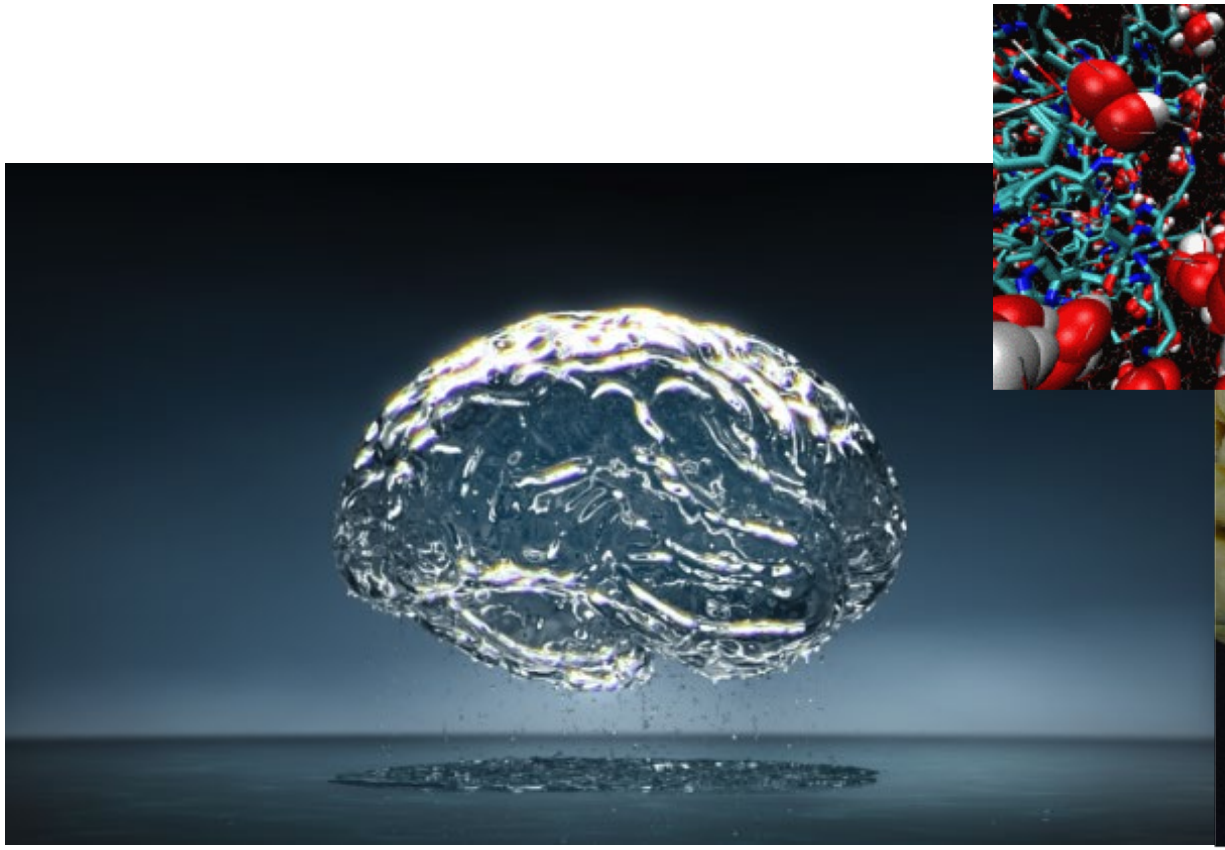
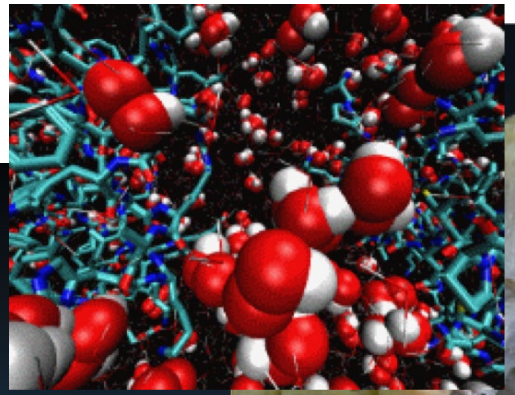


Fig. (left) Plot of the MR signal intensity within an activated voxel as a function of time, and below the time-course of the particular stimulus being presented. The MRI signal increase is delayed by approximately 6 s with respect to the stimulus due to the finite hemodynamic response time. Signal changes are of the order of a few percent. Correlation of the MRI signal intensity with the stimulus pattern on a pixel-by-pixel basis produces the voxels (right) which show a statistically significant correlation in two areas outlined by the arrows.

Diffusion Tensor Image (DTI)

- Water in Brain and Muscle





75% in skeletal muscle
78% in brain

Water molecules are at constant random movement; described by a diffusion coefficient D.

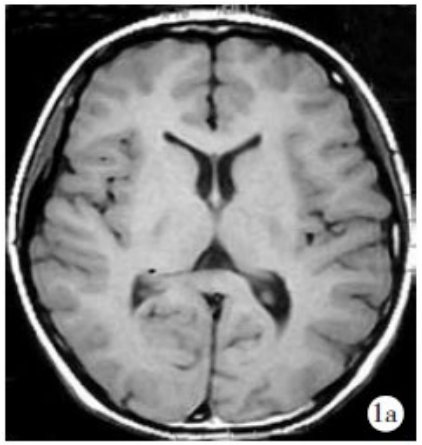
Basic principle

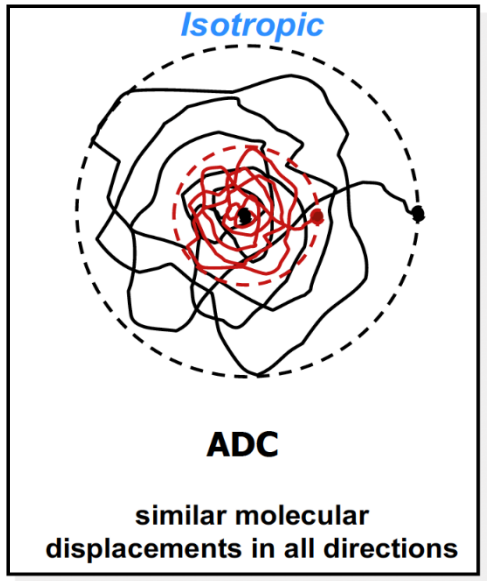
- Diffusion

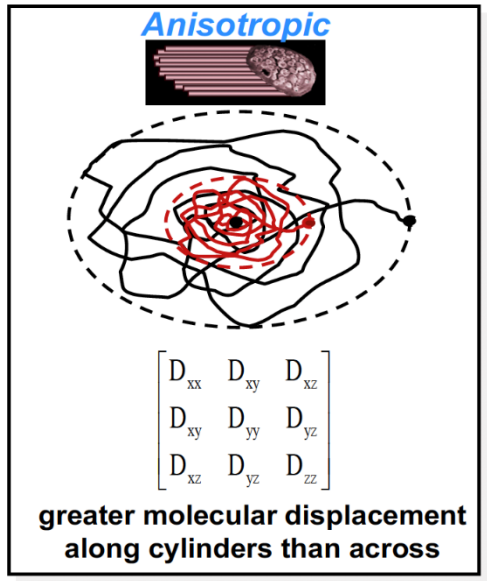
  isotropic

  anisotropic

- Diffusion coefficient, D

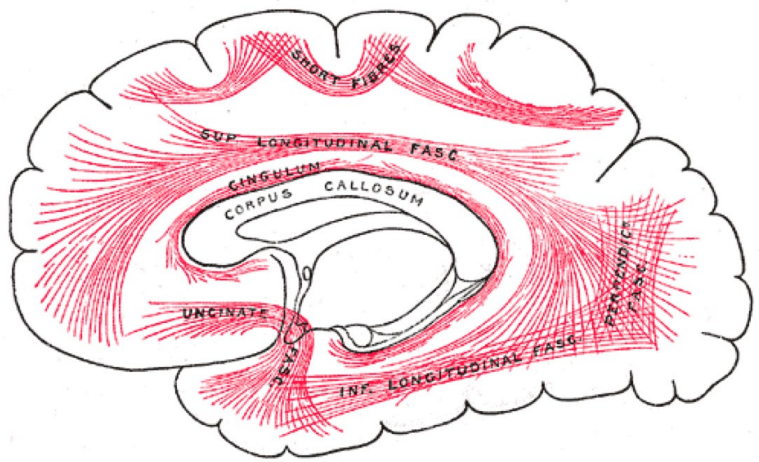




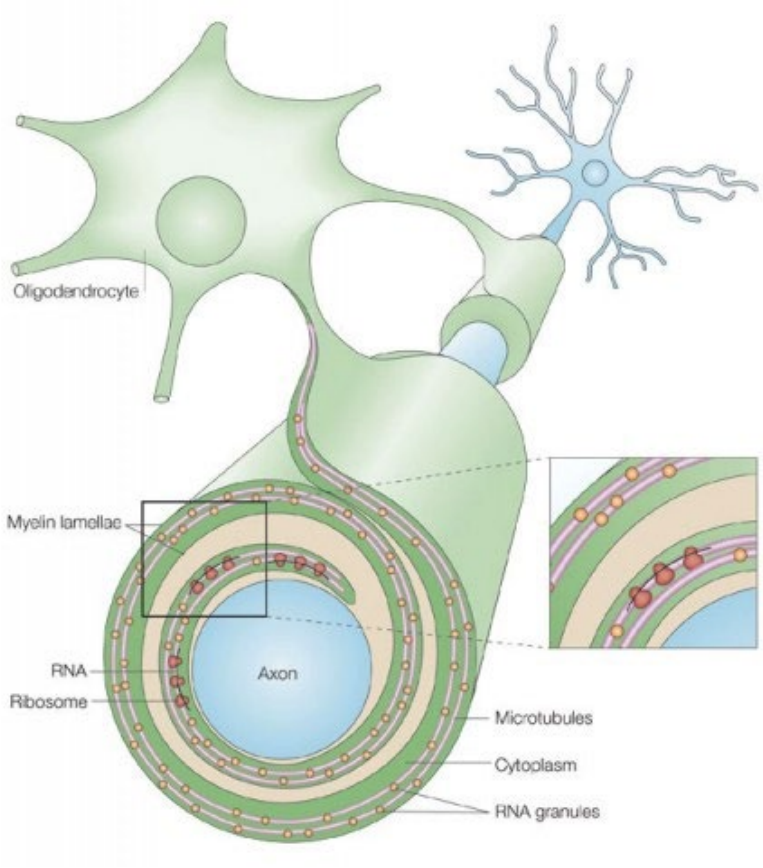


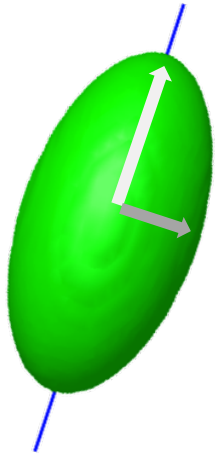
$$\ln\left(\frac{S}{S_0}\right) = -bD$$

$$b = \gamma^2 G^2 \delta^2 \left(\Delta - \frac{\delta}{3}\right)$$



Radial Diffusivity and Axial Diffusivity





Axial

$D_{\parallel}=\lambda_1$

Radial

$$D_{\perp}=\frac{\lambda_2+\lambda_3}{2}$$

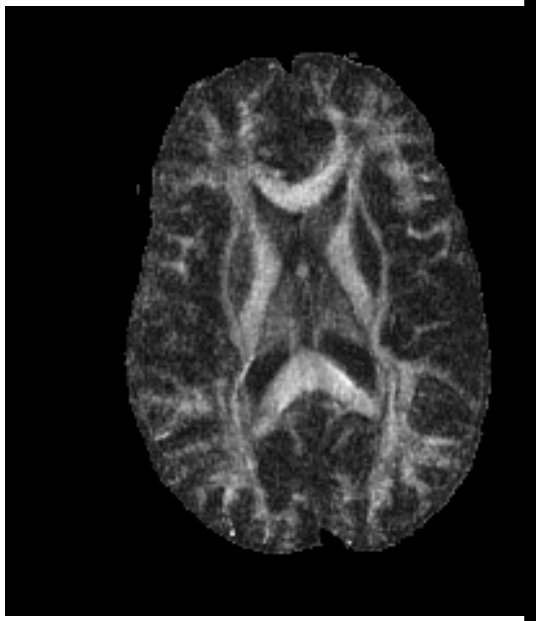
$$\begin{bmatrix} D_{xx} & D_{xy} & D_{xz} \\ D_{yx} & D_{yy} & D_{yz} \\ D_{zx} & D_{zy} & D_{zz} \end{bmatrix}$$

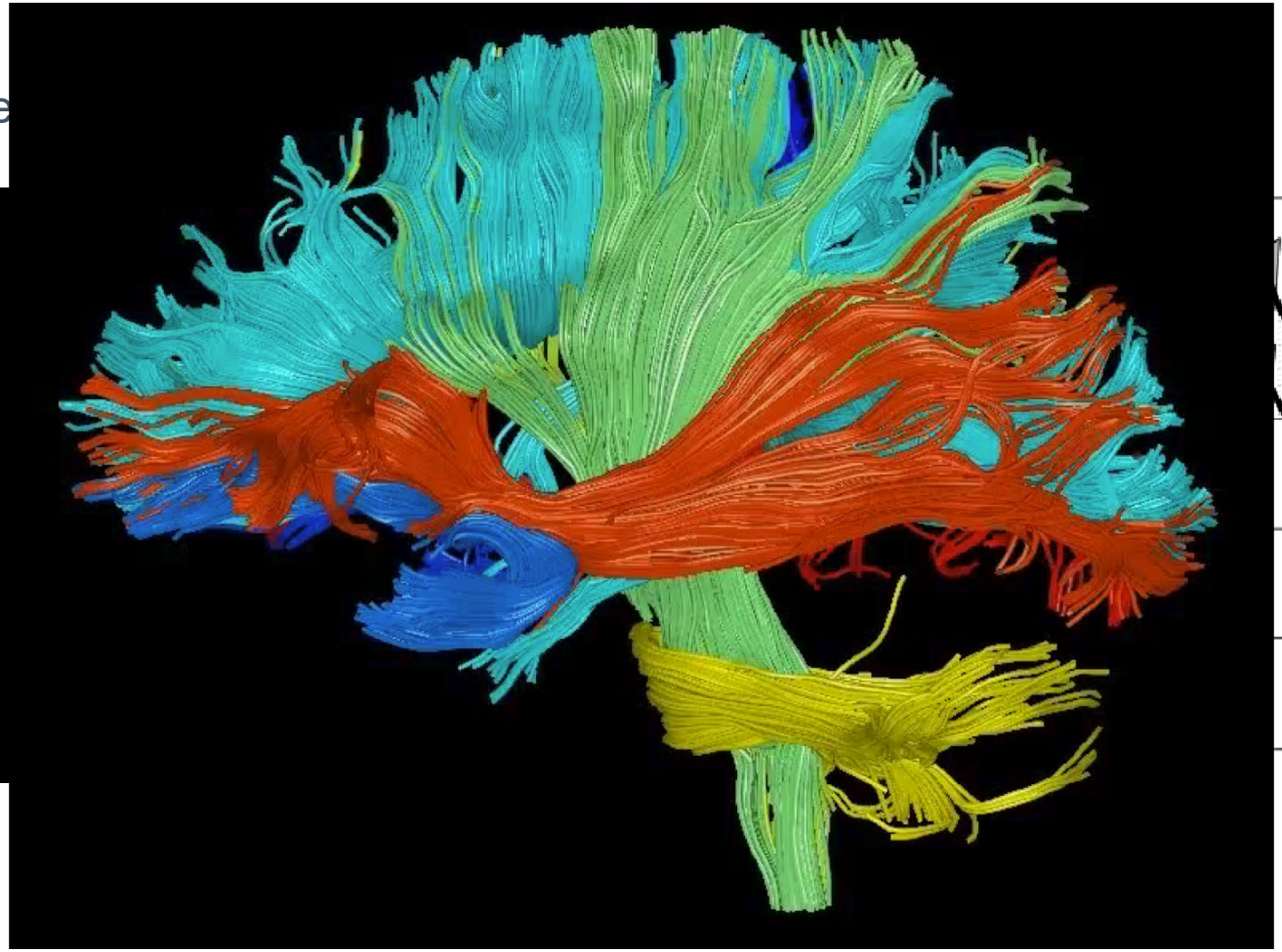
$$\begin{bmatrix} \lambda_1 & 0 & 0 \\ 0 & \lambda_2 & 0 \\ 0 & 0 & \lambda_3 \end{bmatrix}$$

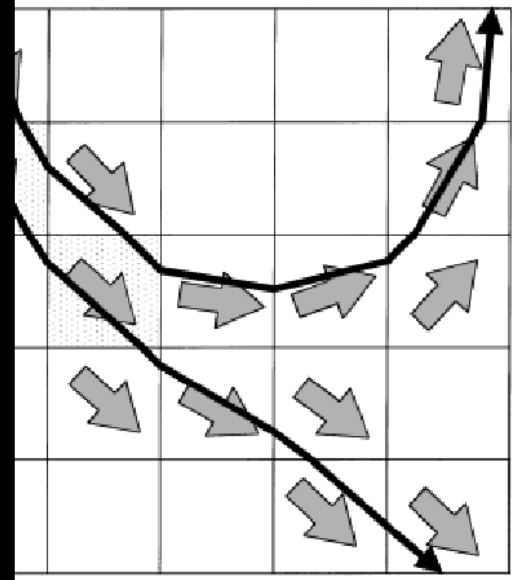
$$\lambda_1 > \lambda_2 > \lambda_3$$

Connecting Vectors

Largest e







Application: WM evolution across life-span

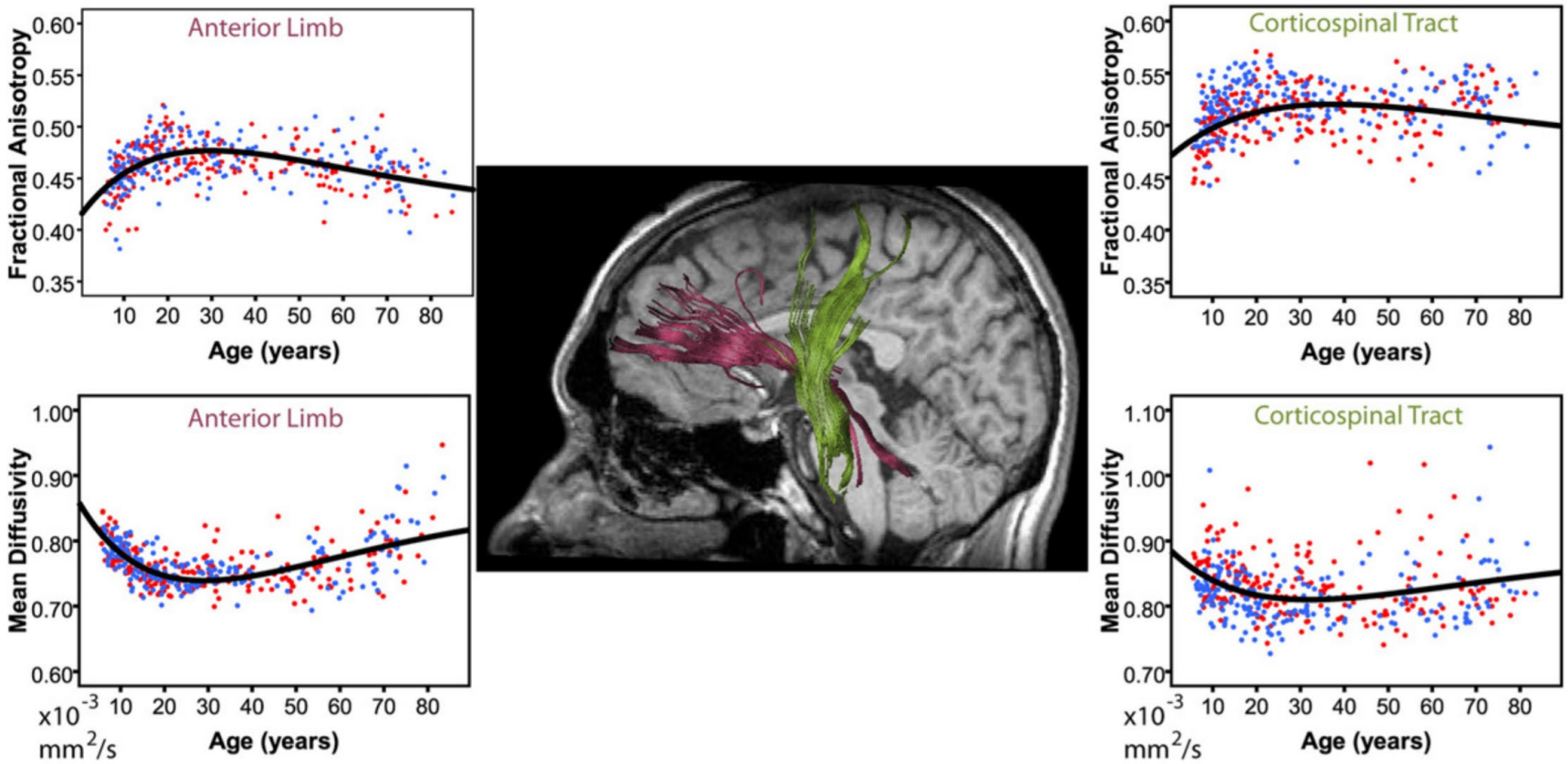


Fig. 3. Plots of fractional anisotropy and mean diffusivity within projection fibers across the lifespan. The peak/minimum ages for the corticospinal tracts occur approximately 5 years later than those for the anterior limb, but the age of peak FA and the age of minimum MD occur at approximately the same time within each tract. Males and females are shown separately as blue and red dots, respectively. *Lebel C, et al.(2012): Diffusion tensor imaging of white matter tract evolution over the lifespan. NeuroImage 60:340–352.*

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Neurological application

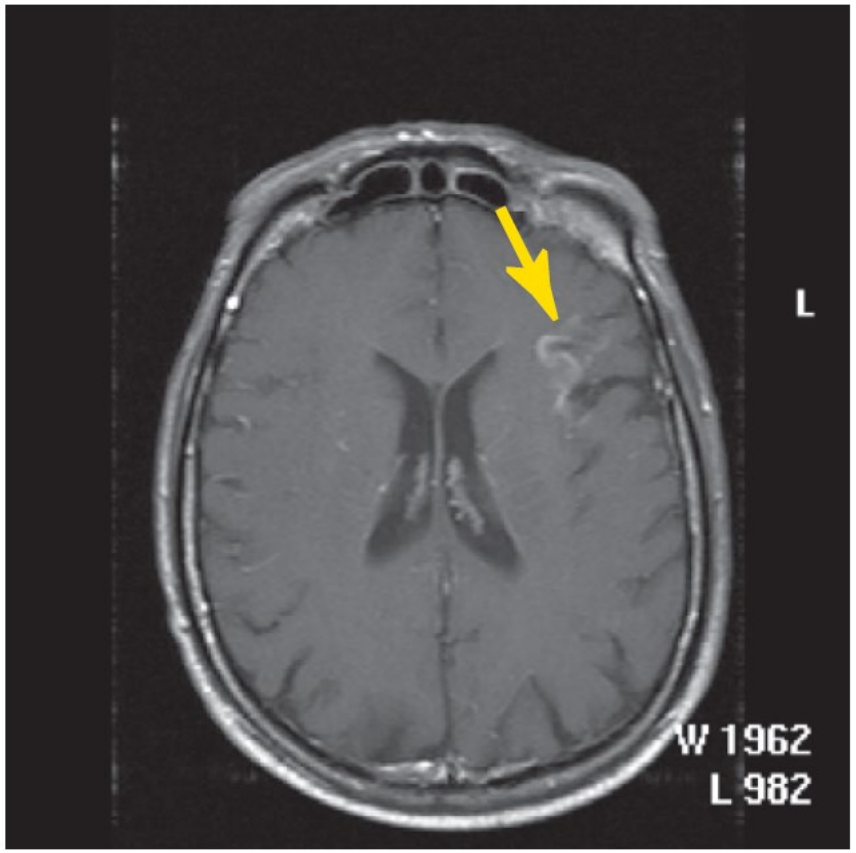
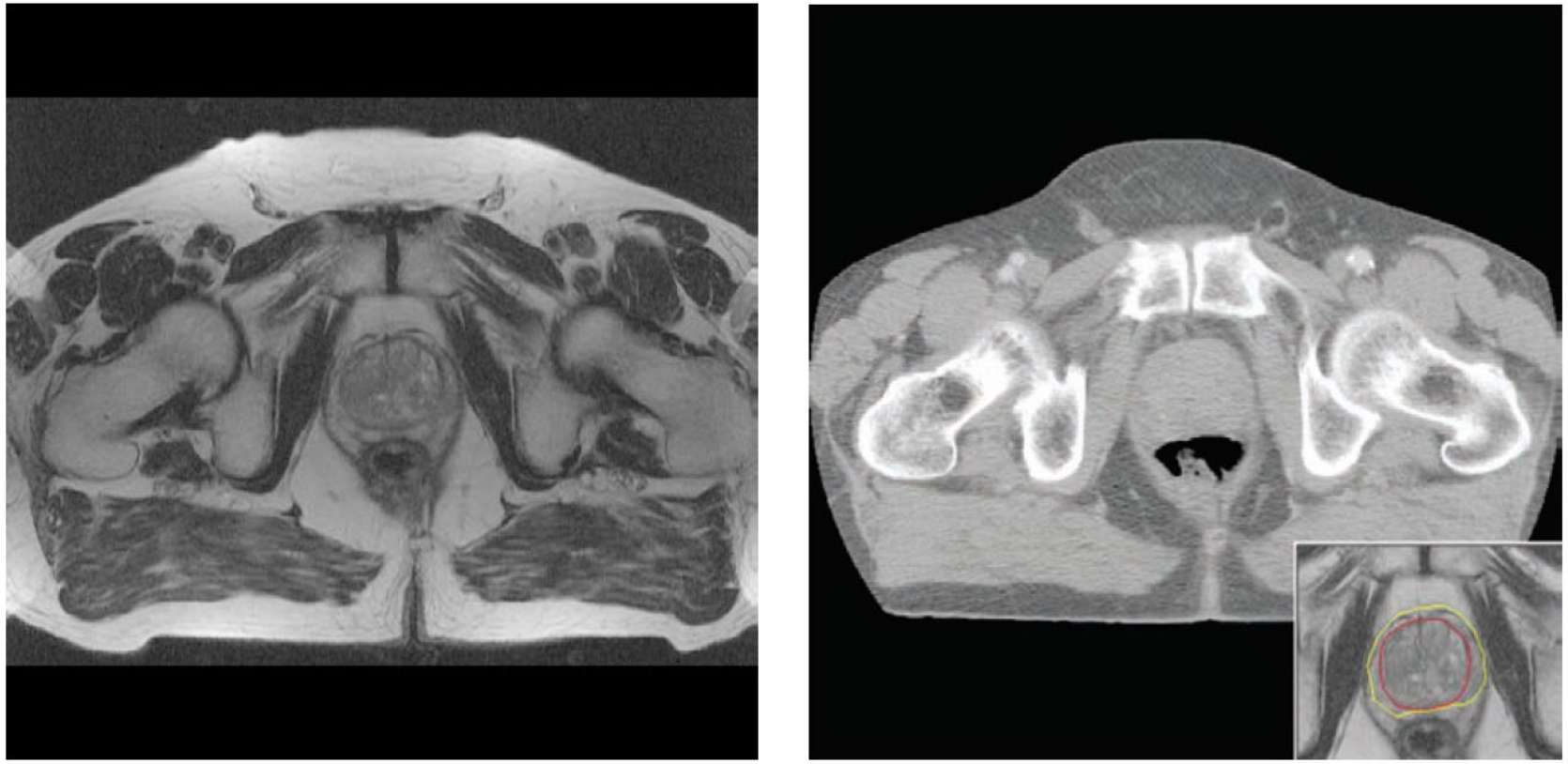


Fig. T_1-weighted 2D SE image after contrast injection (Gd–DTPA) shows a hyperintense area (arrow) in the left frontal cortical region because of abnormality of the blood–brain barrier after stroke.

Body applications



(a) (b)

Fig. (a) MR image obtained with a T_2-weighted TurboSE sequence (TE = 120 ms, TR = 6 s) through the prostate. (b) CT image of the same cross-section. The images of both modalities were geometrically registered with image fusion software. The contour of the prostate was manually outlined in both images (see lower right corner; MRI red contour, CT yellow contour). CT systematically overestimates the prostate volume because of the low contrast between prostate tissue and adjacent periprostatic structures, which can only be differentiated in the MR image.

Musculoskeletal application

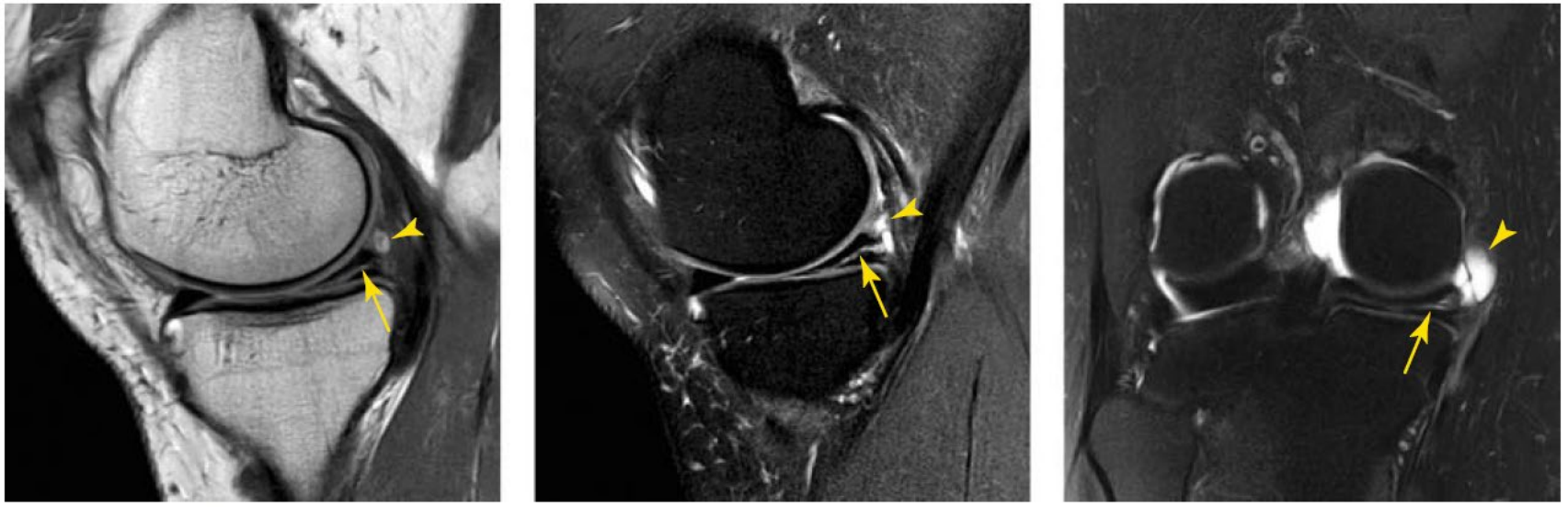


Fig. Sagittal proton density image (a), and sagittal (b) and coronal (c) T_2 fat-suppressed images of the knee joint, showing a tear in the posterior horn of the medial meniscus (arrow) and a parameniscal cyst (arrowhead).

Cardiology application

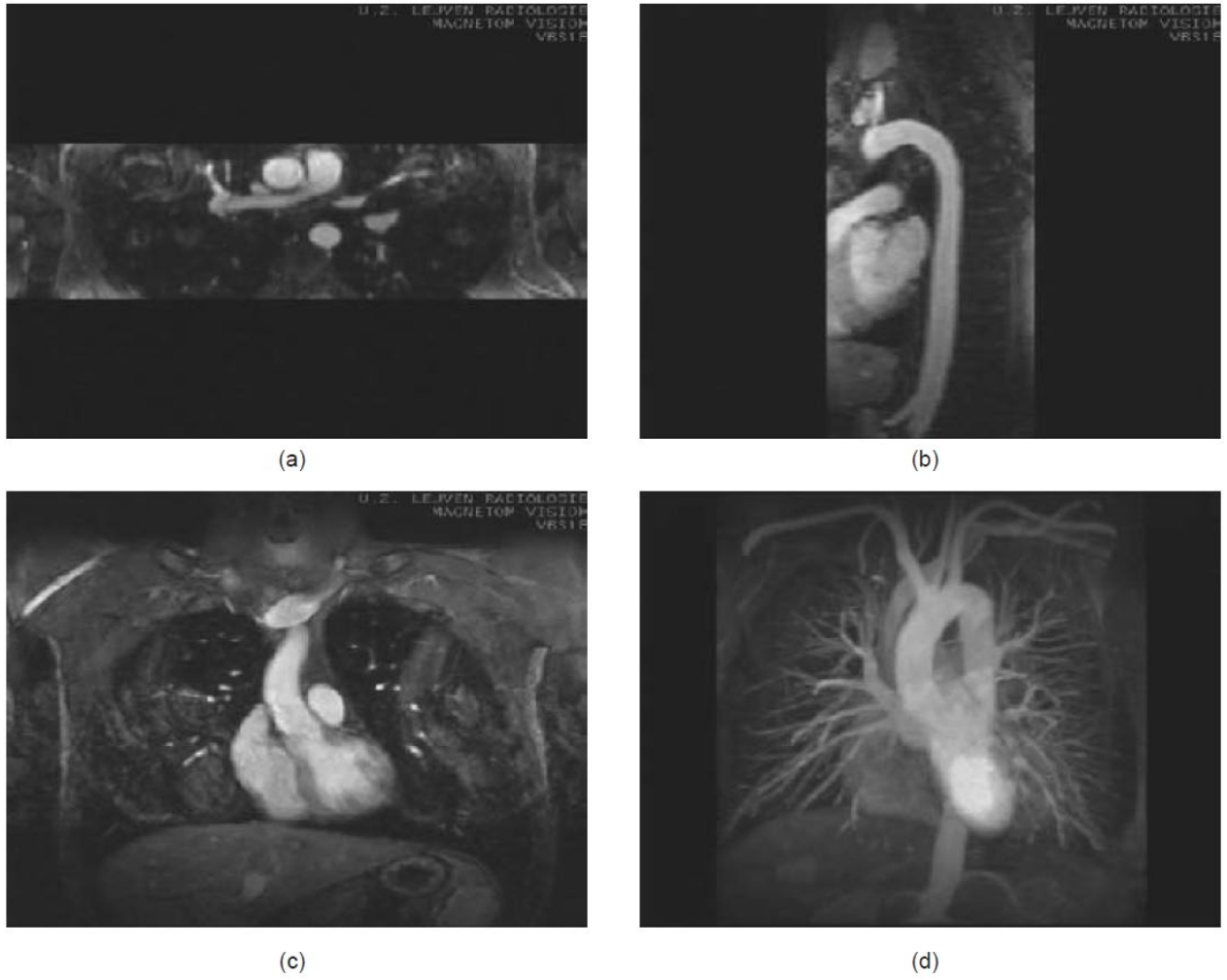


Fig. Contrast-enhanced 3D MR angiography of the thoracic vessels: (a) axial, (b) sagittal, (c) coronal view, and (d) maximum intensity projection.