Medical/Bio Research Topics Ⅰ: Week 03 (18 March 2025)

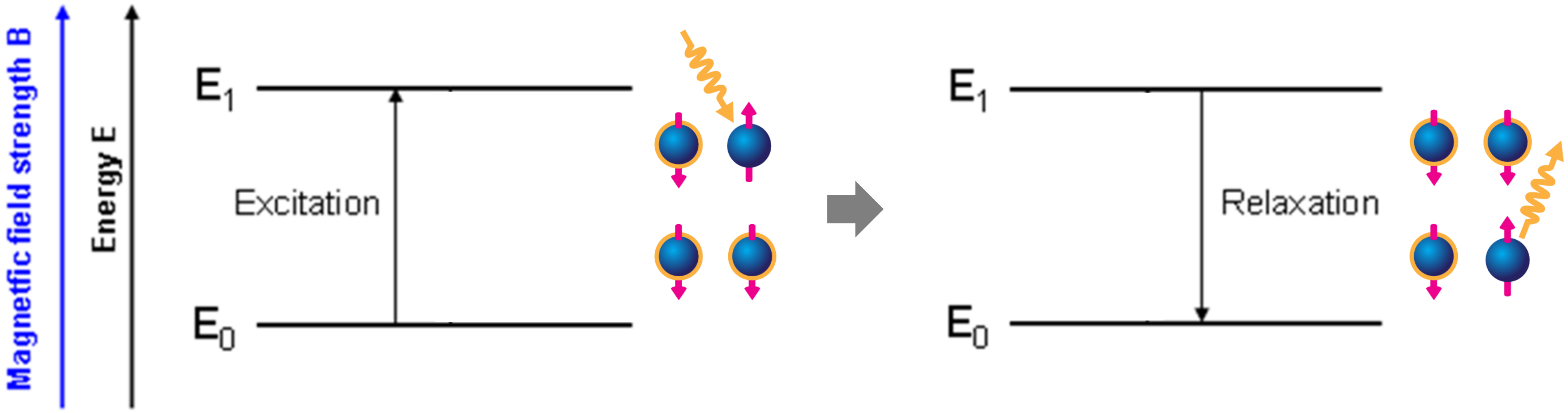
Structural MRI (1): Basic Principles

구조 자기공명영상 (1): 기본 원리

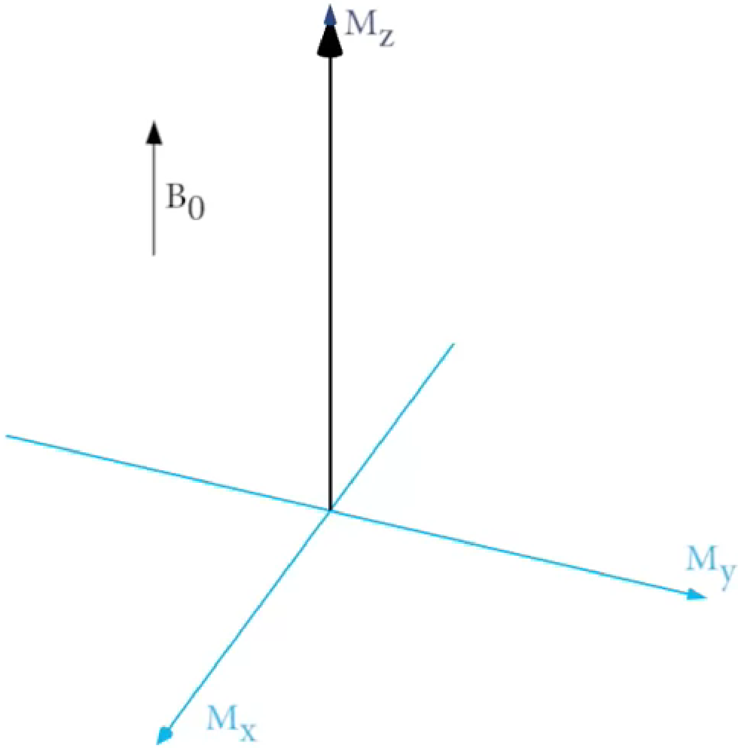
- MRI > CT
  (almost all disease)
  - infarct, tumor, inflammation, infection
  - degeneration, atrophy
  - hemorrhage, trauma
- CT = MRI
  - acute hemorrhage
- CT > MRI
  - calcification

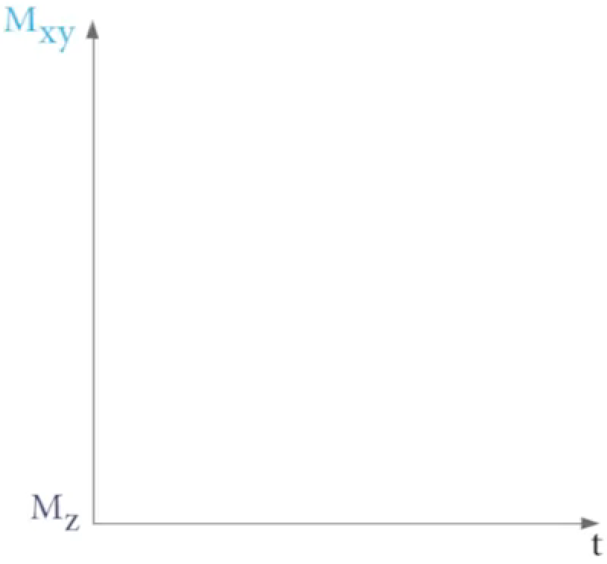
MRI Principles

- Medical application of nuclear magnetic resonance (NMR)
  - Generates different contrasts between tissues based on the relaxation properties of hydrogen nuclei therein



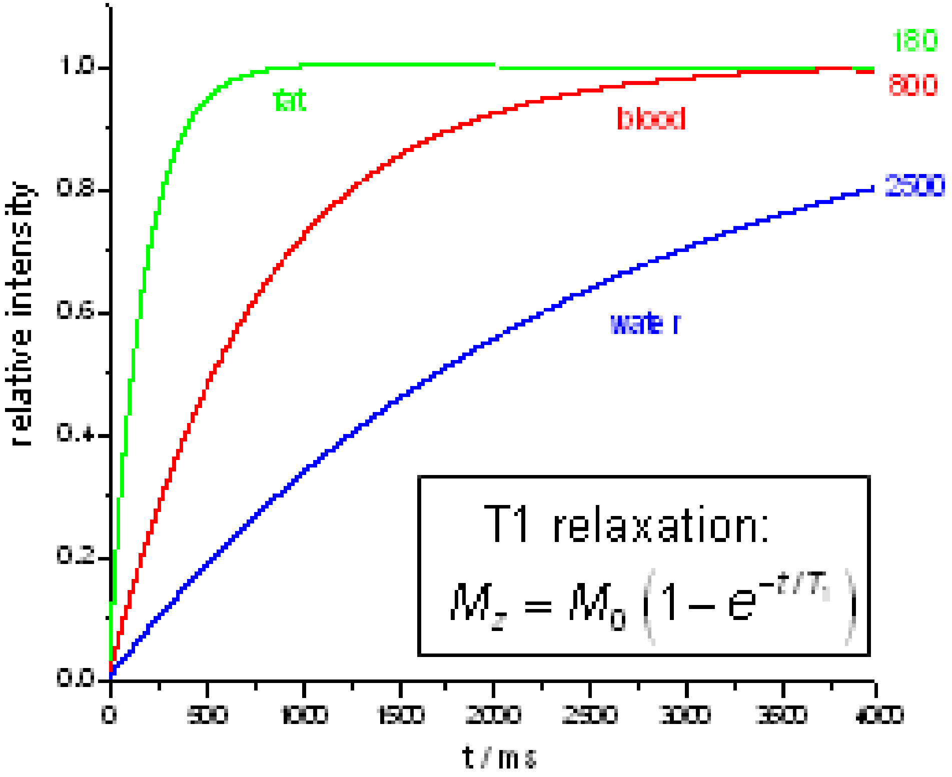
- Two different relaxation times
  - T1 (longitudinal relaxation time)
    - Time taken for hydrogen nuclei to realign with the external magnetic field
    - Spin-lattice relaxation time: time taken for the longitudinal magnetization to recover 63% (1-(1/*e*)) of its initial value
    - Water-based tissues in the 400-1200 ms range; fat-based tissues in the 100-150 ms range
  - T2 (transverse relaxation time)
    - Time taken for hydrogen nuclei to lose phase coherence among the nuclei
    - Spin-spin relaxation time: time taken for the transverse magnetization to irreversibly decay to 37% (1/*e*) of its initial value
    - Water-based tissues in the 40-200 ms range; fat-based tissues in the 10-100 ms range

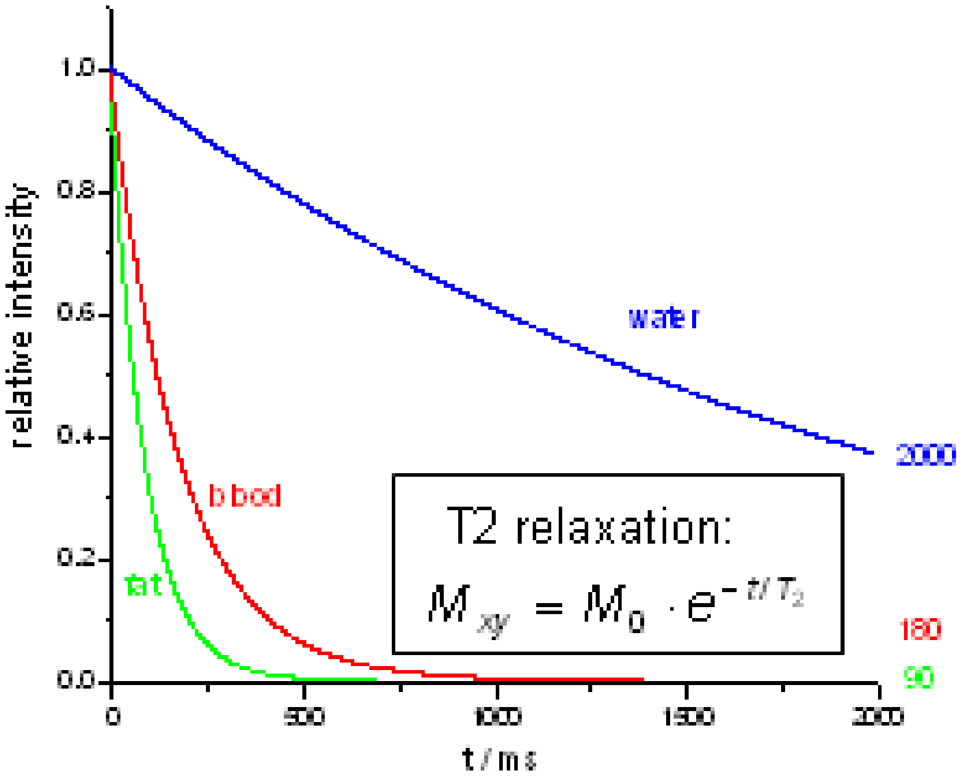




[https://en.wikipedia.org/wiki/Spin-spin_relaxation]

Exponential Decay of Magnetization Towards Its Equilibrium Value

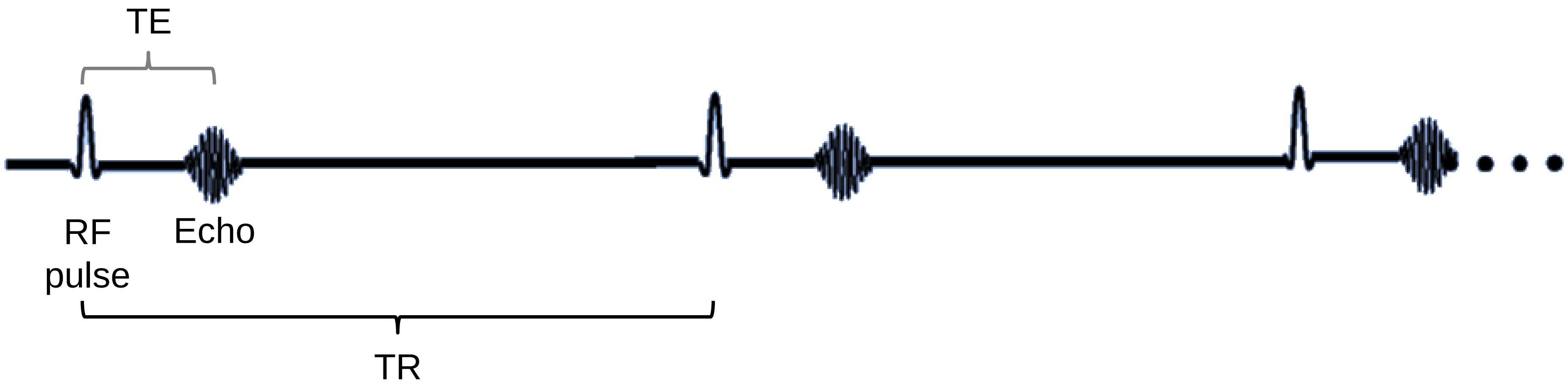




[Pollacco, 2016]

Differences in T1 and T2 Relaxation Times between Tissues

- By varying the sequence of radio frequency electromagnetic waves (RF pulses) applied and collected
  - Repetition time (TR): Time between successive pulse sequences applied to the same slice
  - Echo time (TE): Time between the delivery of the RF pulse and the receipt of the echo signal



[https://mriquestions.com/tr-and-te.html]

MRI Contrast Types

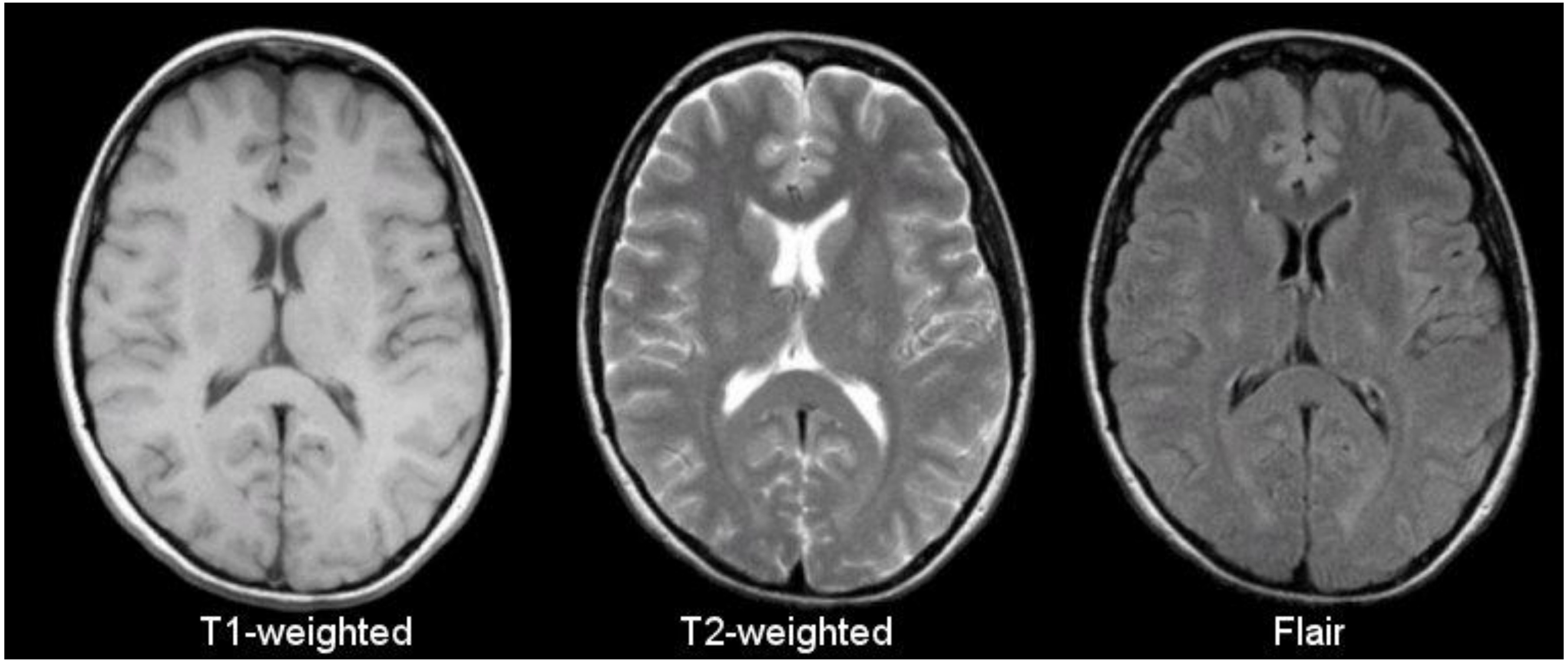
- T1-weighted
  - Contrast predominately determined by T1 differences between tissues
  - Produced by using shorter TE (decreasing the T2 effect) and shorter TR (enhancing the T1 effect by rapidly exposing hydrogen nuclei to RF pulses)
  - Tissues that return to alignment faster than other tissues are bright on a T1-weighted image

- T2-weighted
  - Contrast predominately determined by T2 differences between tissues
  - Produced by using longer TE (enhancing the T2 effect by allowing hydrogen nuclei to move away from each other) and longer TR (decreasing the T1 effect)
  - Tissues that remain in phase longer than other tissues are bright on a T2-weighted image

- Fluid attenuated inversion recovery (FLAIR)
  - Heavily T2-weighted in that TE and TR are very long
  - Dampens ventricular cerebrospinal fluid signals, causing the highest signals from certain brain parenchymal abnormalities

	TR (msec)	TE (msec)
T1-Weighted (short TR and TE)	**500**	**14**
T2-Weighted (long TR and TE)	**4000**	**90**
Flair (very long TR and TE	**9000**	**114**

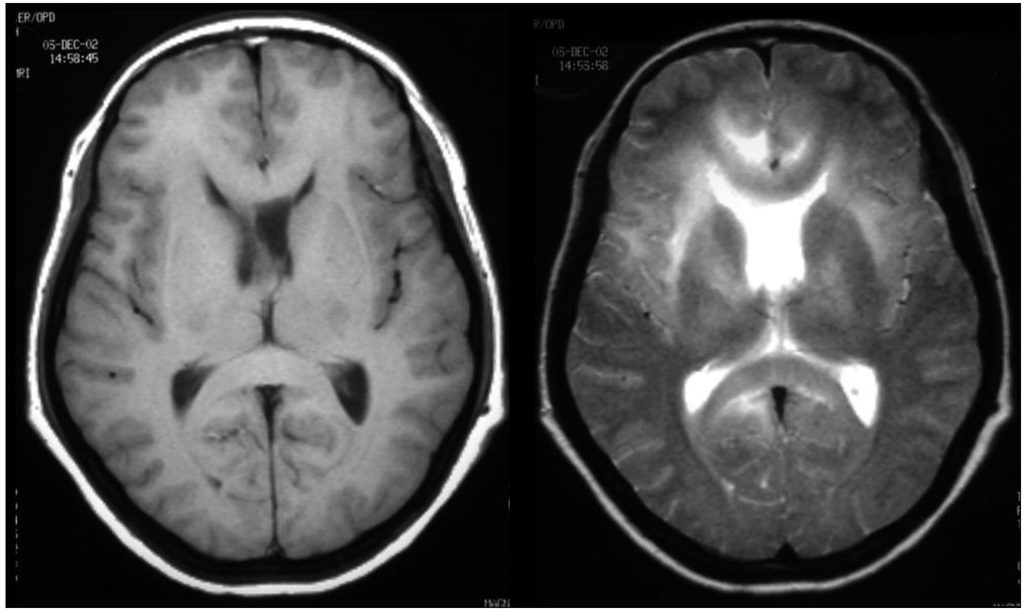
[https://case.edu/med/neurology/NR/MRI Basics.htm]



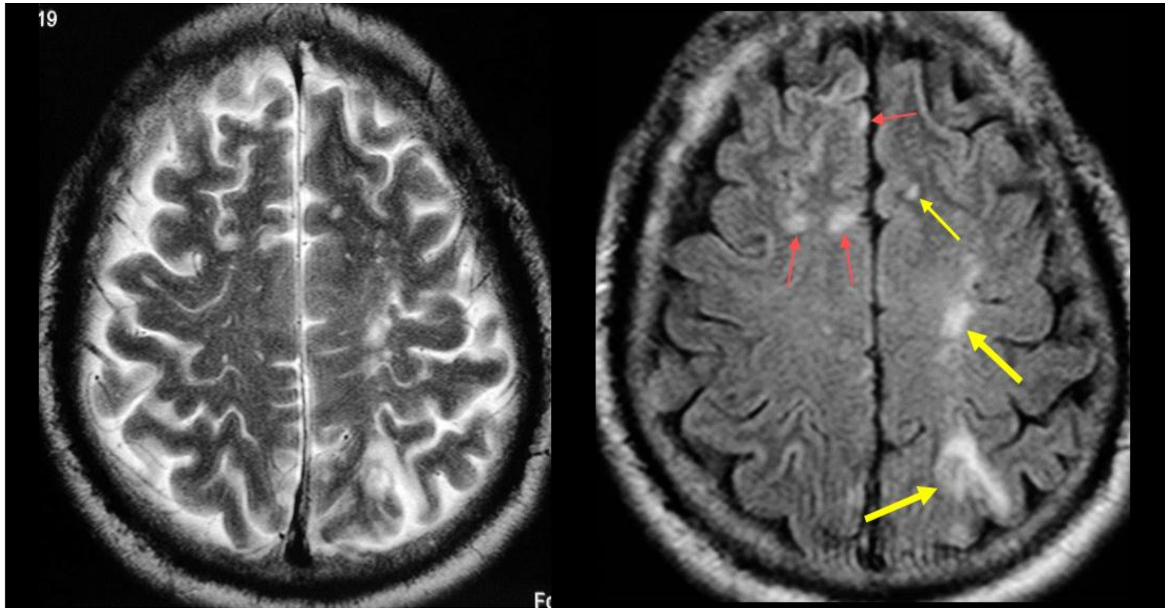
[https://case.edu/med/neurology/NR/MRI Basics.htm]

Comparison between T1-weighted, T2-weighted, and FLAIR Images

T1-weighted vs T2-weighted

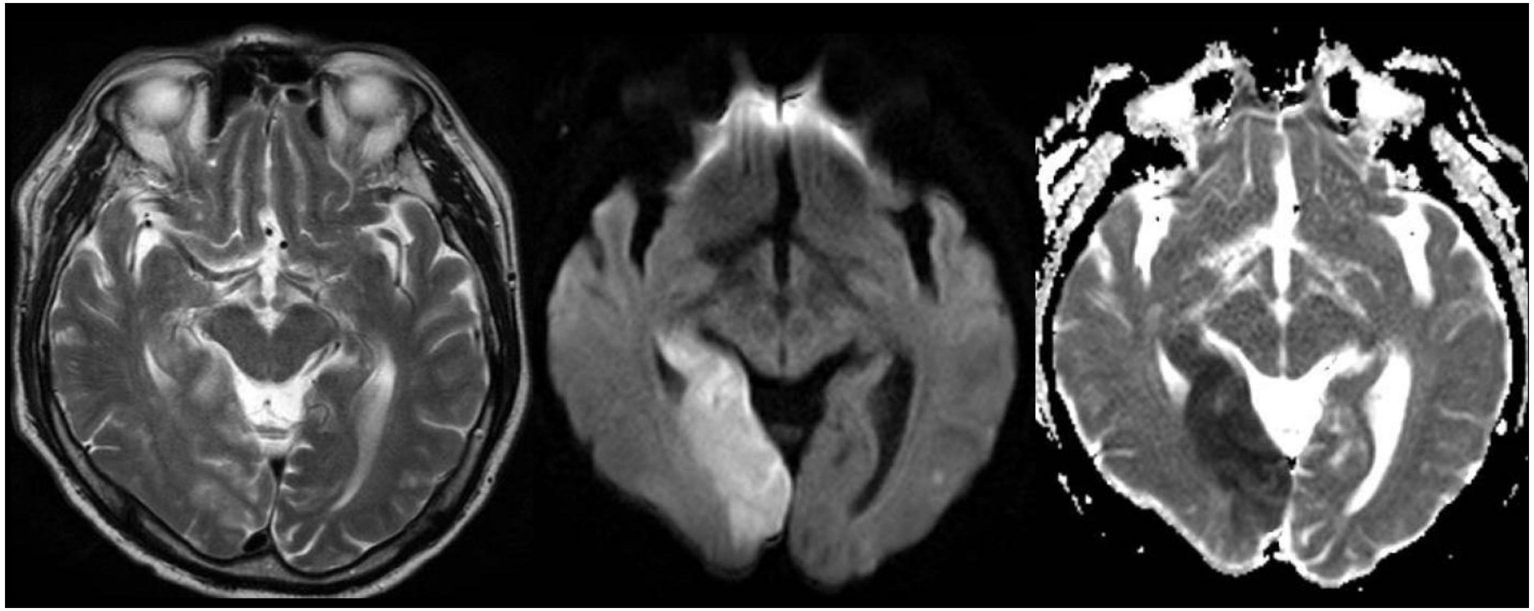


T2-weighted vs FLAIR



- Diffusion-weighted
  - Designed to detect the random movement (diffusion) of hydrogen nuclei
  - The restricted diffusion of hydrogen nuclei in the ischemic brain tissue results in an extremely bright signal
  - Sensitive for detecting acute stroke

T2-weighted vs diffusion-weighted

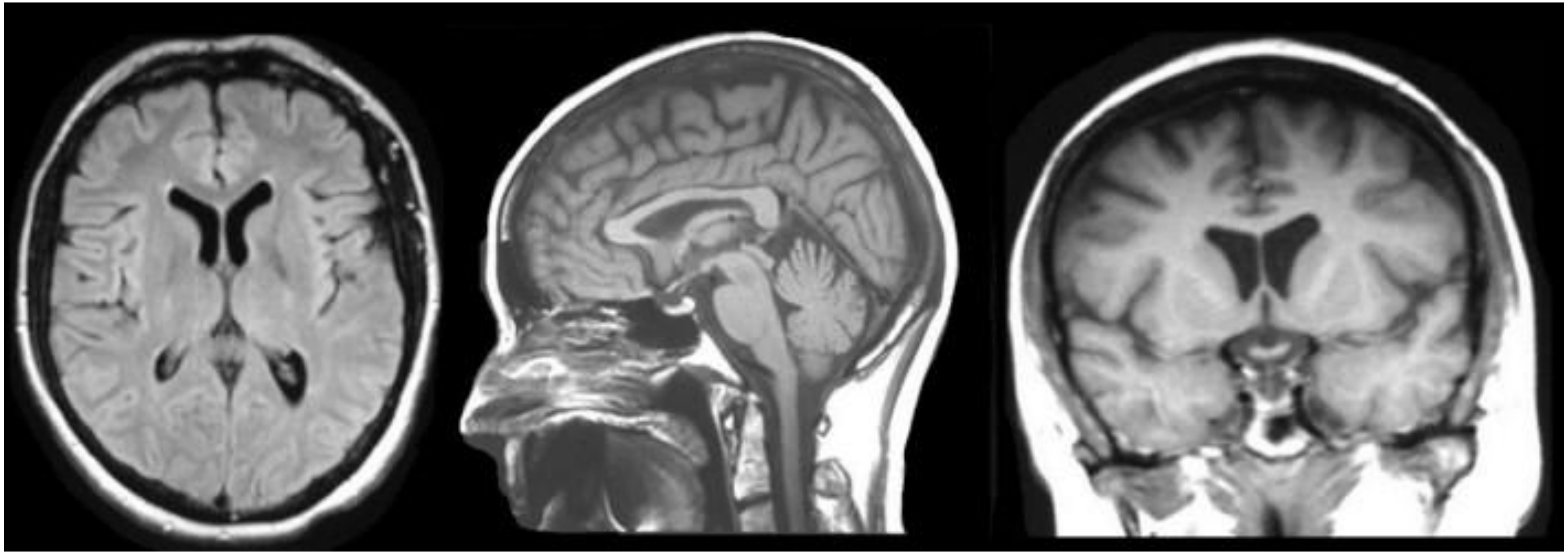


T1-weighted Contrast

- White matter (nerve fibres) has a very short T1 and relaxes rapidly
- Cerebrospinal fluid has a long T1 and relaxes slowly
- Grey matter (neuron congregations) has an intermediate T1 and relaxes at an intermediate rate

Producing an image
at a time when the curves are widely separated
between the tissues

- White matter contributes to lighter voxels
- Cerebrospinal fluid contributes to darker voxels
- Grey matter contributes to voxels with intermediate shades of grey



[https://case.edu/med/neurology/NR/MRI Basics.htm]

T1-weighted Contrast of the Brain

Tissue	T1-Weighted	T2-Weighted	Flair
CSF	Dark	Bright	Dark
White Matter	Light	Dark Gray	Dark Gray
Cortex	Gray	Light Gray	Light Gray
Fat (within bone marrow)	Bright	Light	Light
Inflammation (infection, demyelination)	Dark	Bright	Bright

[https://case.edu/med/neurology/NR/MRI Basics.htm]

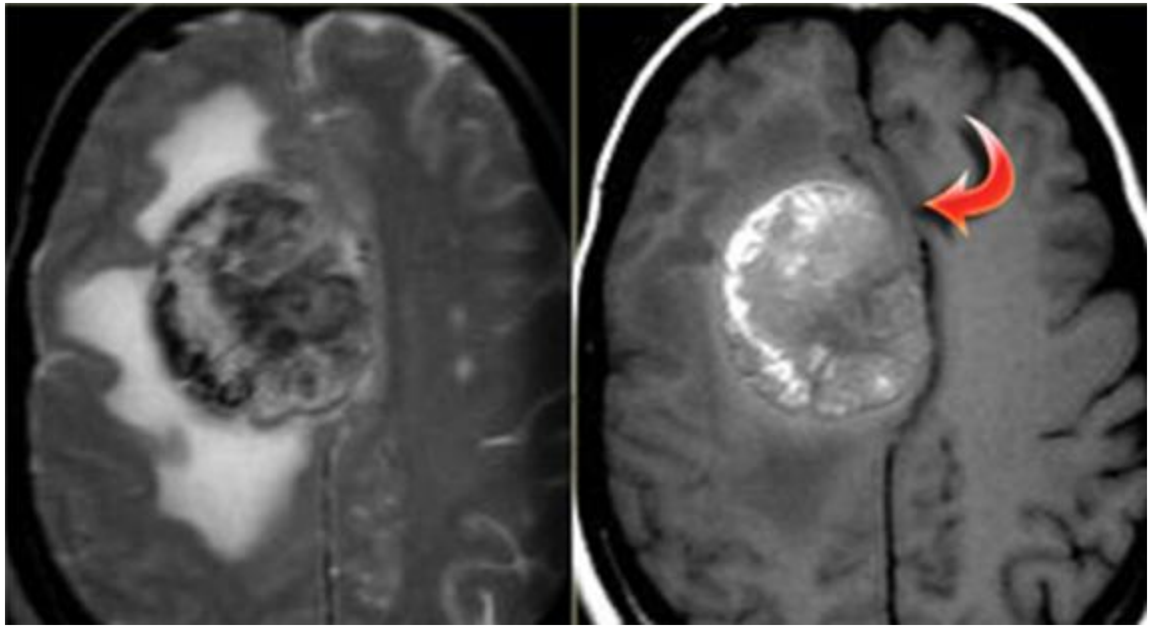
Different Contrasts of the Brain

Structural MRI (sMRI)

- MRI technique primarily for examining the macroscopic anatomy and tissue composition (grey matter, white matter, and cerebrospinal fluid) of the brain
- Applications of sMRI
  - Clinical diagnosis and abnormality detection
  - Quantitative brain morphometry
  - Anatomical reference for co-registration

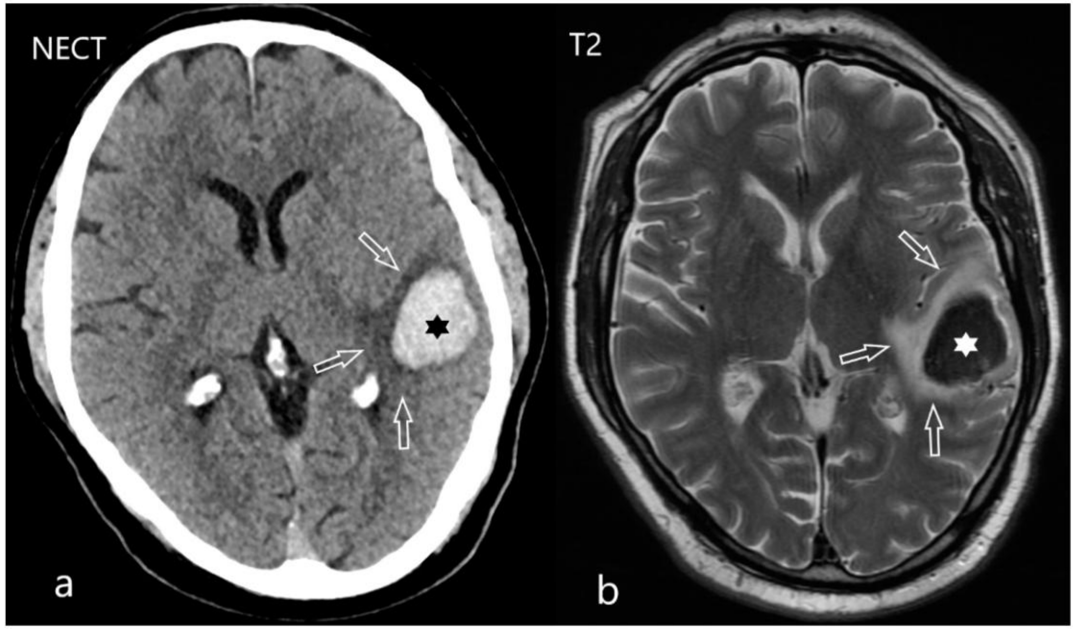
Abnormality Detection with sMRI

- Brain lesion
  - Area of damaged or abnormal tissue in the brain caused by injury, disease, or developmental abnormality
    - Brain tumor
    - Stroke
    - Epilepsy
    - Multiple sclerosis
  - Disrupts the way the brain works, causing a wide range of symptoms



[https://radiologyassistant.nl/neuroradiology/brain-tumor/systematic-approach]

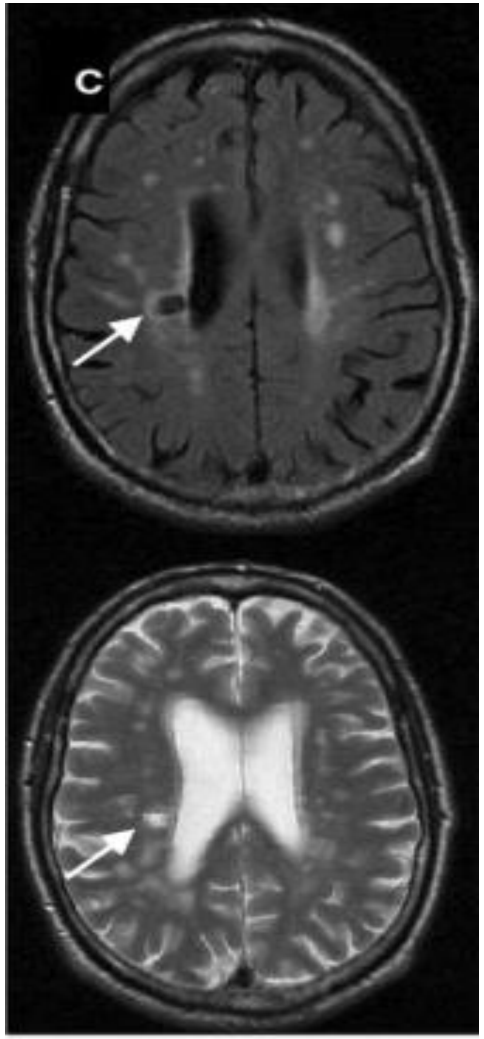
Brain Tumor (Melanoma Metastasis) on T2-weighted and T1-weighted Images



[Malikova and Weichet, 2022]

Stroke Lesion (Acute Intracerebral Hemorrhage) on CT and T2-weighted Images

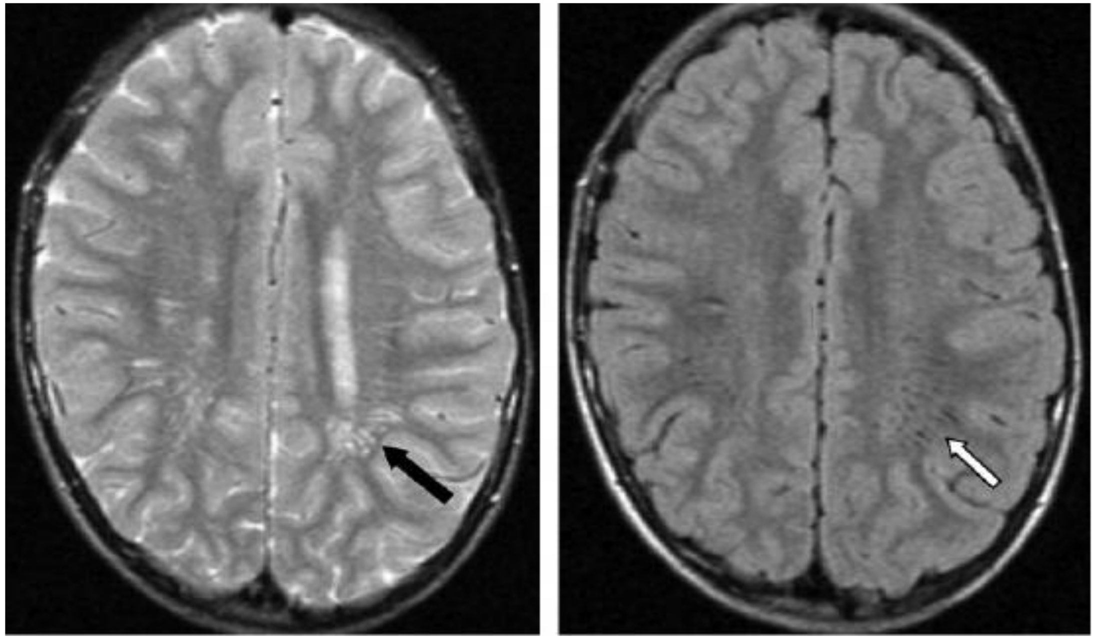
- White matter hyperintensity
  - Area of high intensity (increased brightness) within the cerebral white matter on a T2-weighted image
  - Reflects a lesion produced largely by demyelination and axonal loss
  - Frequently seen in older people and possibly associated with increased risk for some brain diseases



[Wardlaw et al., 2015]

White Matter Hyperintensity on FLAIR and T2-weighted Images

- Perivascular space (Virchow–Robin space)
  - Fluid-filled space surrounding certain blood vessels
  - Typically located in the basal ganglia and white matter of the brain
  - Can become enlarged or dilated, in a close association with aging or signaling abnormalities

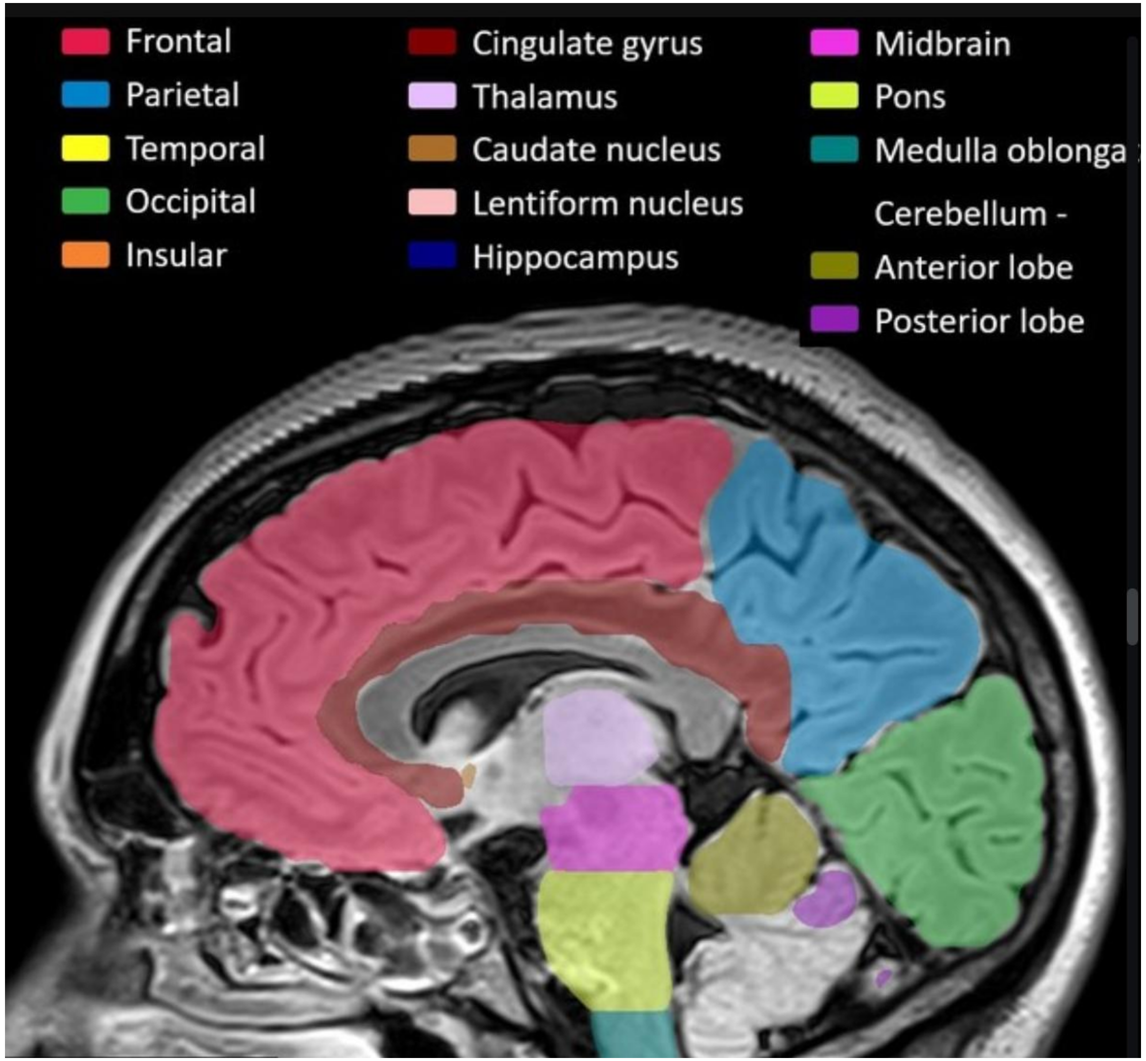


[Kwee and Kwee, 2007]

Perivascular Space on T2-weighted and FLAIR Images

Brain Morphometry with sMRI

- Brain structure
  - Preserved macroscopic organization with individual variability
    - Consistent anatomical landmarks
    - Bilateral organization
    - Hierarchical arrangement

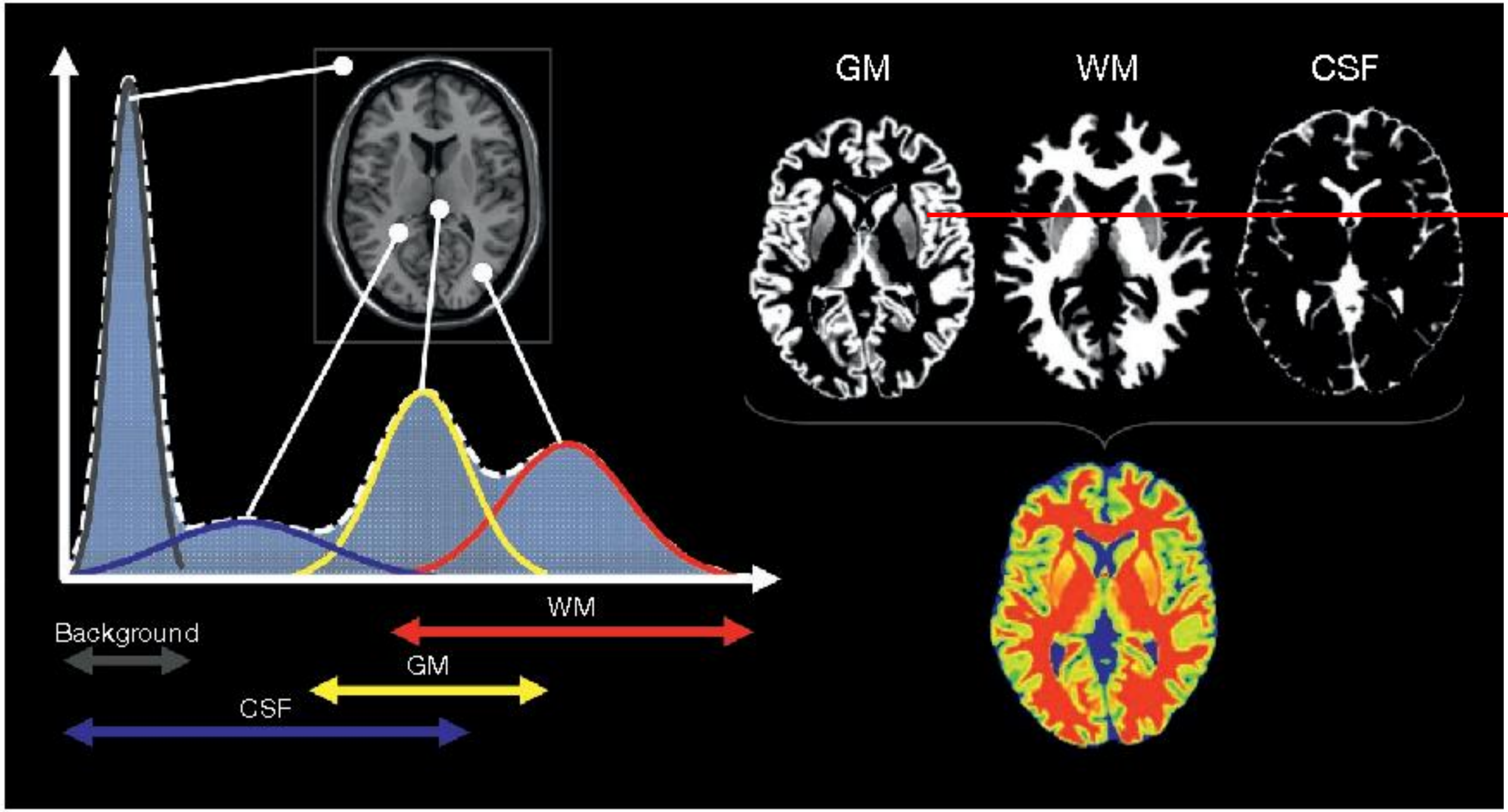


[https://radiopaedia.org/cases/brain-lobes-annotated-mri-1]

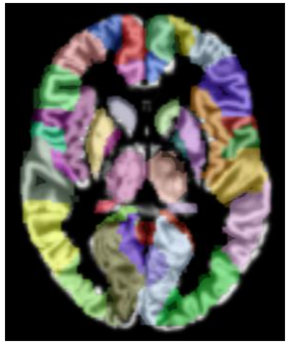
Anatomical Identification of Brain Structure

- Brain morphometry: Quantitative analysis of brain structure
  - Volume and density measurements
    - Global brain volume
    - Regional tissue volumes
  - Size and shape analysis
    - Cortical thickness
    - Surface area
    - Regional shape variations
  - Gyrification and folding patterns
    - Gyrification index
    - Sulcal depth and length
    - Folding complexity

- Voxel-based morphometry (VBM)
  - Local differences in density or volume
  - Given that, after the segmentation of an image, each voxel contains a measure of the probability according to which it belongs to a specific segmentation class
- Surface-based morphometry (SBM)
  - Local differences in thickness or gyrification
  - Given that, after the segmentation of an image, the boundary between different segmentation classes can be reconstructed as a surface

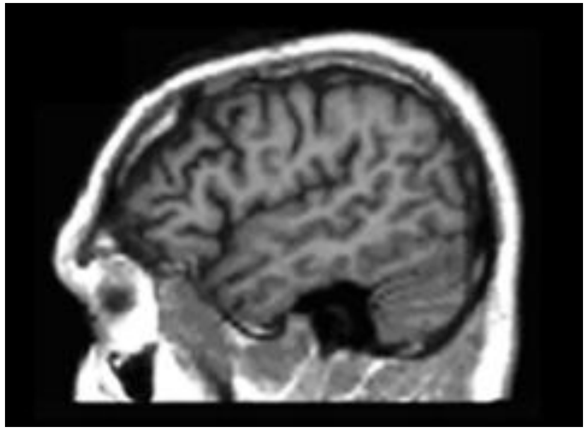


Grey matter volume

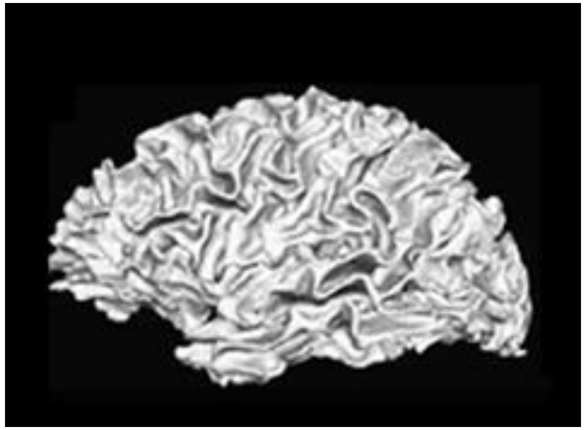


[Kurth et al., 2015]

Segmentation of the Brain into Different Tissues



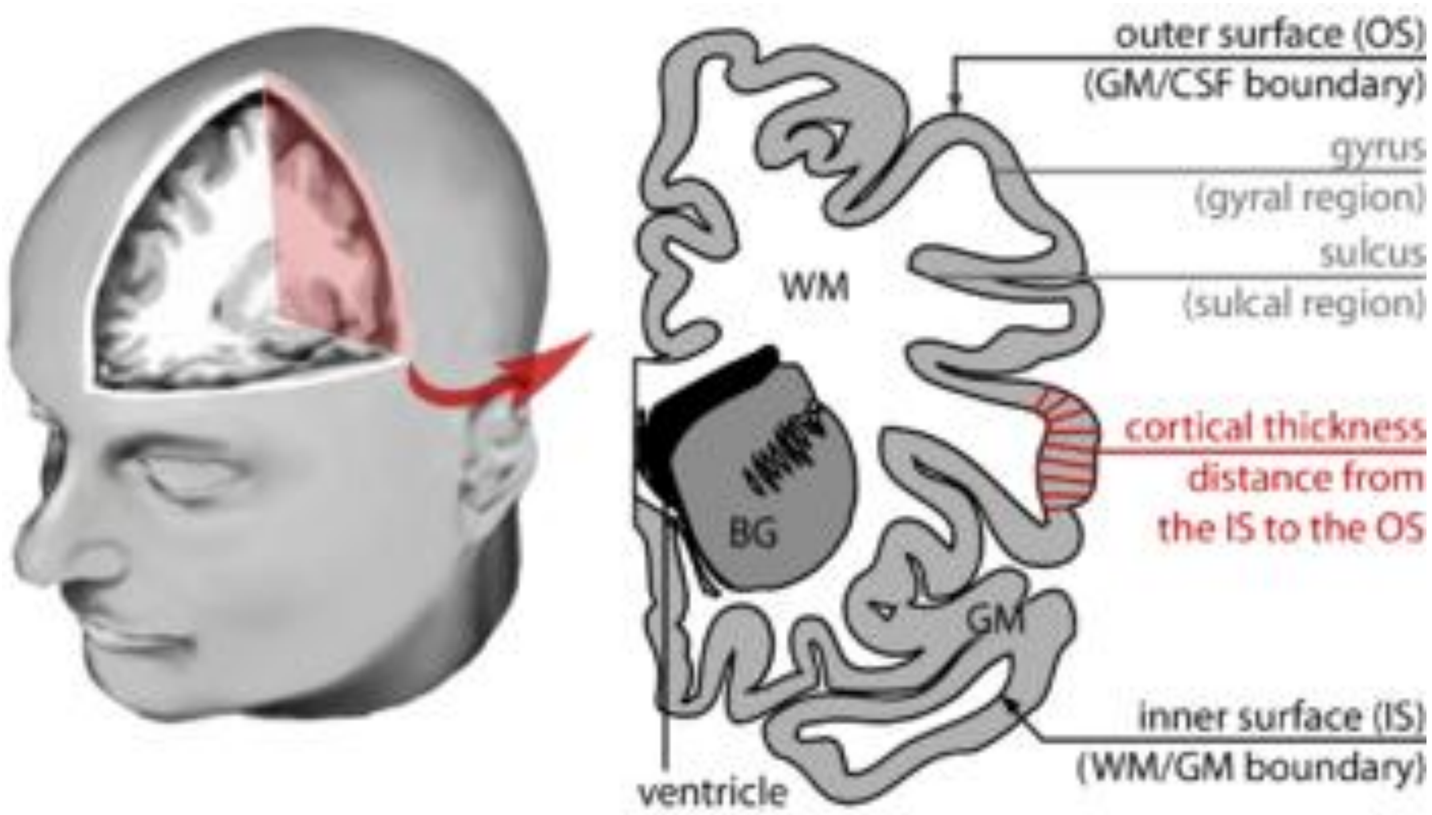
T1-weighted sMRI



Brain surface

[https://en.citizendium.org/wiki/Surface-based_morphometry]

Reconstruction of Brain Surfaces from T1-weighted sMRI



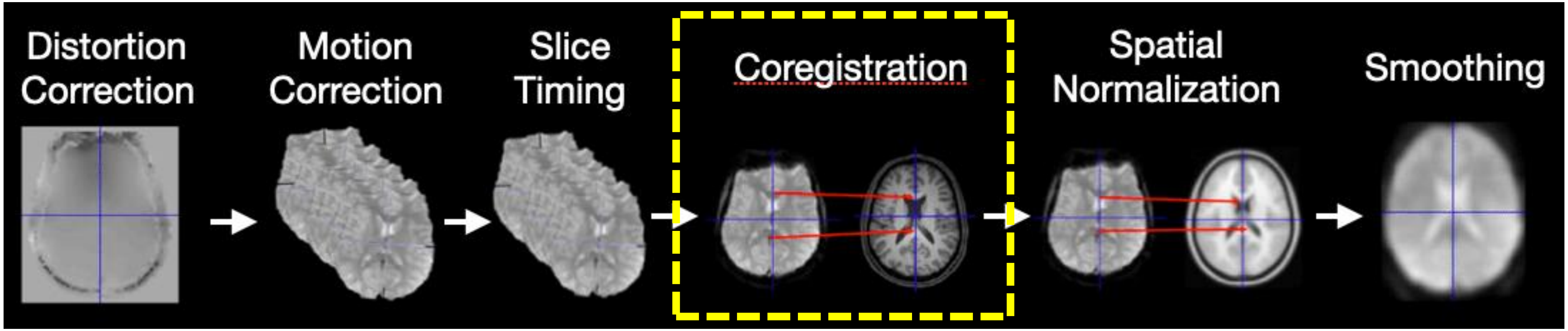
[https://en.citizendium.org/wiki/Brain_morphometry]

Measurement of Cortical Thickness based on a Surface Representation of the Brain

sMRI as Anatomical Reference

- Co-registration between sMRI and functional/diffusion-weighted MRI
  - Within-subject between-modality registration
  - Spatial alignment of sMRI with functional and diffusion-weighted MRI
  - Integration framework for multimodal brain imaging

Between sMRI and functional MRI



[https://dartbrains.org/content/Preprocessing.html]

Co-registration as a Step of the Functional MRI Data Prerprocessing Pipeline