National Undergraduate Neuroanatomy Competition

Neuroimaging

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Row Fogo Centre for Research into Ageing and the Brain
Small Vessel Diseases Research

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Outline

- Brain MRI scans and sequences
- Types of MR images
- White matter tracts
- CT vs. MRI
- Healthy and unhealthy brains
- Common image processing procedures
- Practical applications

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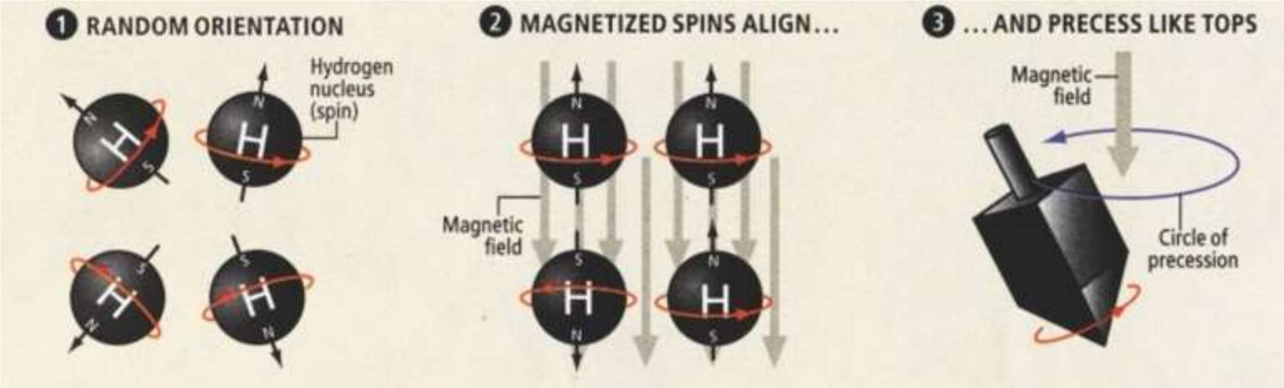
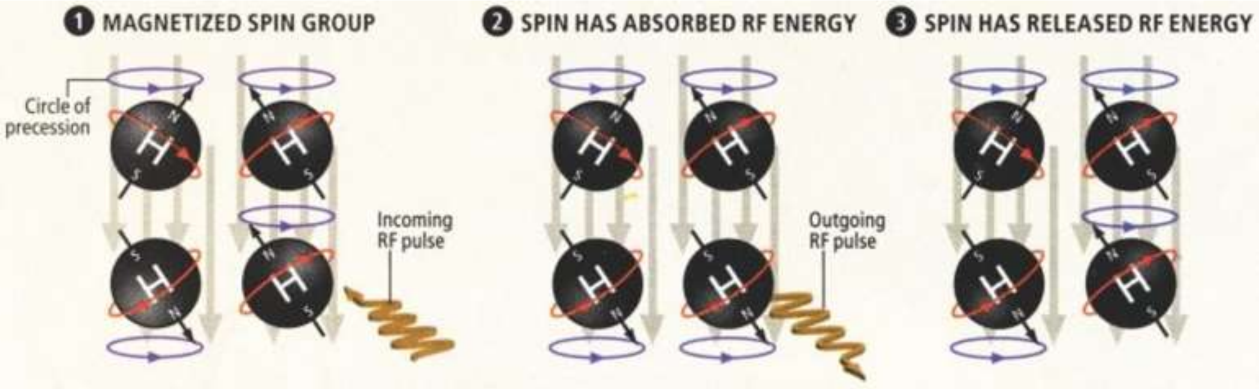
Principle





http://en.wikipedia.org/wiki/Magnetic_resonance_imaging

The contrast between different tissues is determined by the rate at which excited atoms return to the equilibrium state.

In MRI, there are more than 180 out from 20 known basic types of pulse sequences

Spin Echo Sequence
- Dual Echo Sequence
- Modified Spin Echo
- Multi Echo Multiplanar
- Partial Saturation Spin Echo
- Variable Echo Multiplanar

Fast Spin Echo
- Carr Purcell Sequence
- Carr Purcell Meiboom Gill Sequence
- Double Fast Spin Echo
- Double Turbo Spin Echo
- Dual Echo Fast Acquisition Interleaved Spin Echo
- Half Fourier Acquisition Single Shot Turbo Spin Echo
- Multiple Echo Single Shot
- Rapid Acquisition with Refocused Echoes
- Turbo Spin Echo
- Ultrashort Turbo Spin Echo

Inversion Recovery Sequence
- Flow Sensitive Alternating Inversion Recovery
- Fluid Attenuation Inversion Recovery
- Inversion Recovery Spin Echo
- Short T1 Inversion Recovery
- Turbo Inversion Recovery

Usual to describe pulse sequences are: the repetition time (TR), the echo time (TE), if using inversion recovery the inversion time (TI), and in case of a gradient echo sequence, the flip angle.

Specific pulse sequence weightings are dependent on the field strength, the manufacturer and the pathology.

http://www.mr-tip.com/serv1.php?type=seq

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MRI sequences vs. modalities

Sequences: Different contrasts depending on echo time (TE), repetition time (TR), presence or not of inversion pulse (TI)

Modalities: Acquisition procedure

- Dynamic → More than 1 acquisition in time, sequential. e.g. Perfusion MRI, Dynamic contrast enhanced (DCE-MRI), fMRI
- Static → 1 acquisition e.g. structural
- Metabolic → measures the concentration of specific chemicals, e.g. MR spectroscopy images neurotransmitters

Principle: many nuclei have spin and all nuclei are electrically charged. If an external magnetic field is applied, an energy transfer is possible between the base energy to a higher energy level.

Basic types of structural MRI

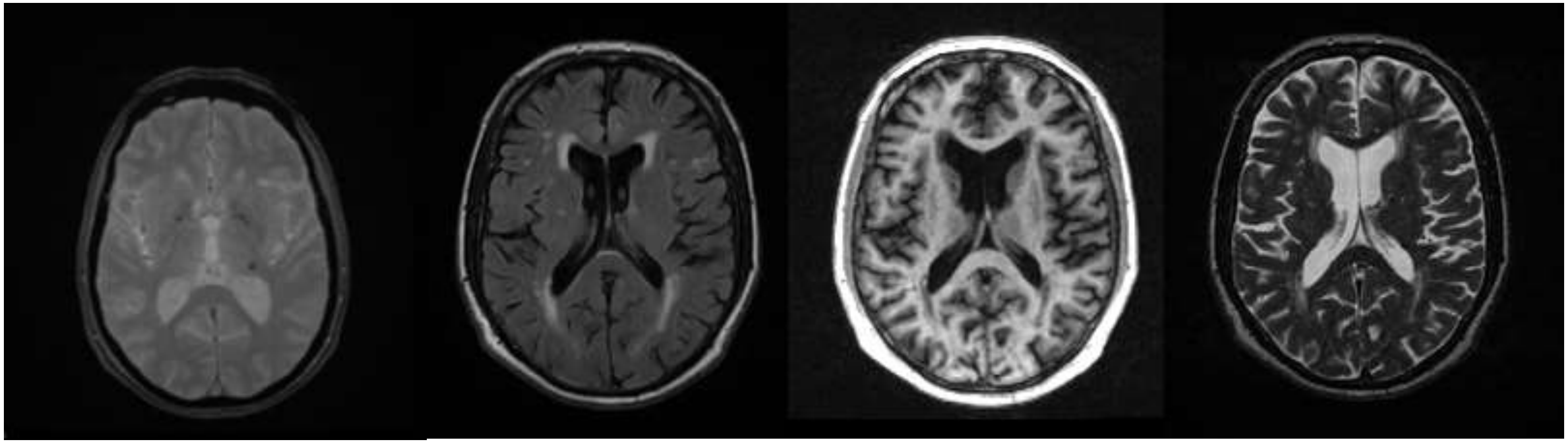
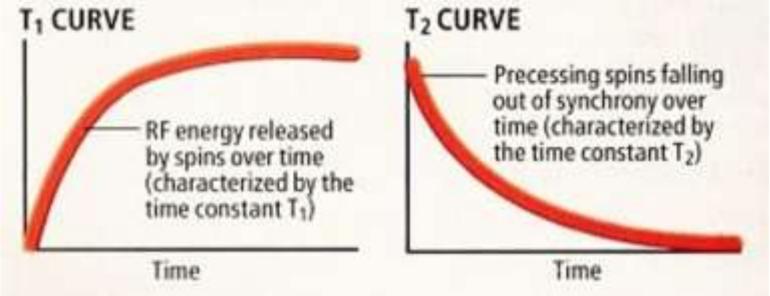


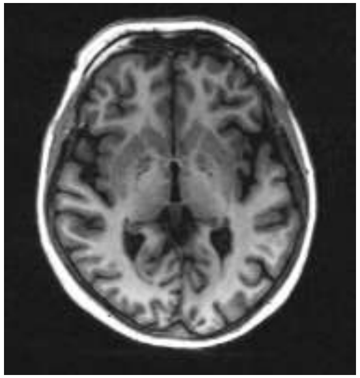
Image contrast may be weighted to demonstrate different anatomical structures or pathologies. Each tissue returns to its equilibrium state after excitation by the independent processes of T1 (spin-lattice) and T2 (spin-spin) relaxation.

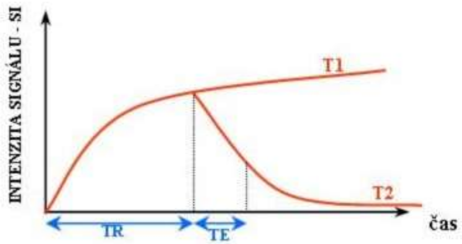


http://en.wikipedia.org/wiki/Magnetic_resonance_imaging

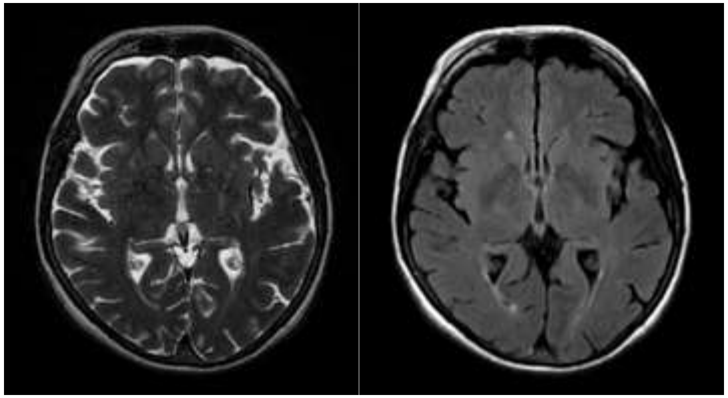
Basic types of structural MRI

To create a T1-weighted image, we wait for different amounts of magnetization to recover before measuring the MR signal by changing the repetition time (TR). This image weighting is useful for assessing the cerebral cortex, identifying fatty tissue and for post-contrast imaging.





To create a T2-weighted image, we wait for different amounts of magnetization to decay before measuring the MR signal by changing the echo time (TE). This image weighting is useful for detecting oedema, revealing white matter lesions and perivascular spaces.



http://en.wikipedia.org/wiki/Magnetic_resonance_imaging

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Parametric images

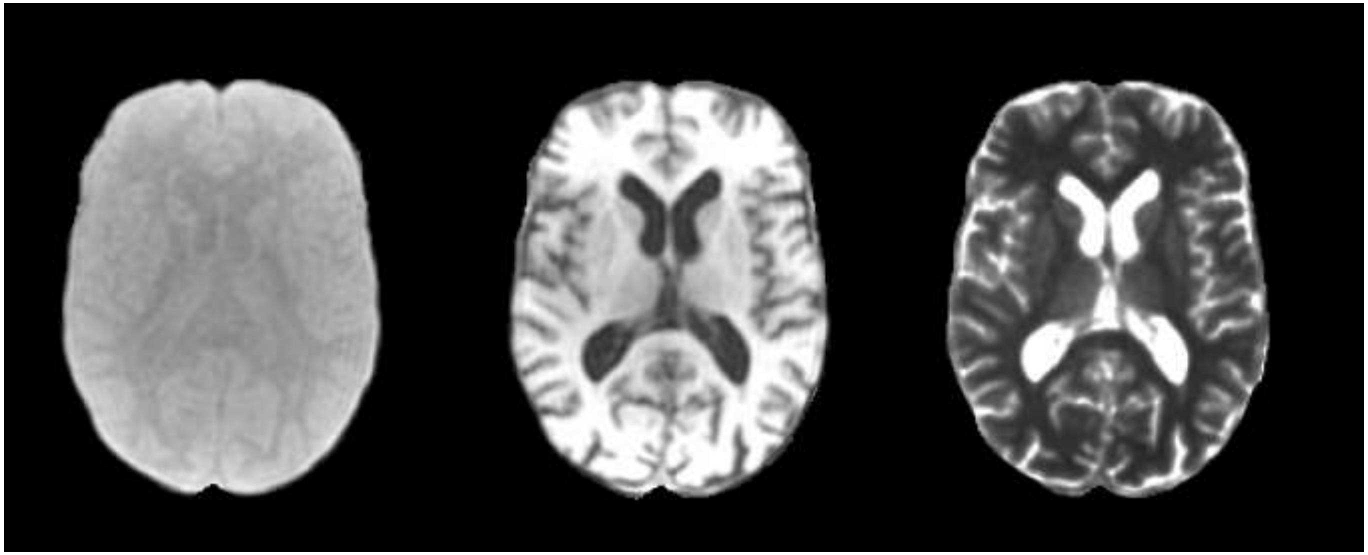
T1 map

It is calculated from the following formula:

$1/T1 = 1/TR \ln [(S_R \sin\alpha_2 \cos\alpha_1 - \sin\alpha_1 \cos\alpha_2)/(S_R \sin\alpha_2 - \sin\alpha_1)]$

where $S_R = S1/S2$, being S1 the signal acquired at α_1 and S2 the signal acquired at α_2

α_1 α_2 T1 map



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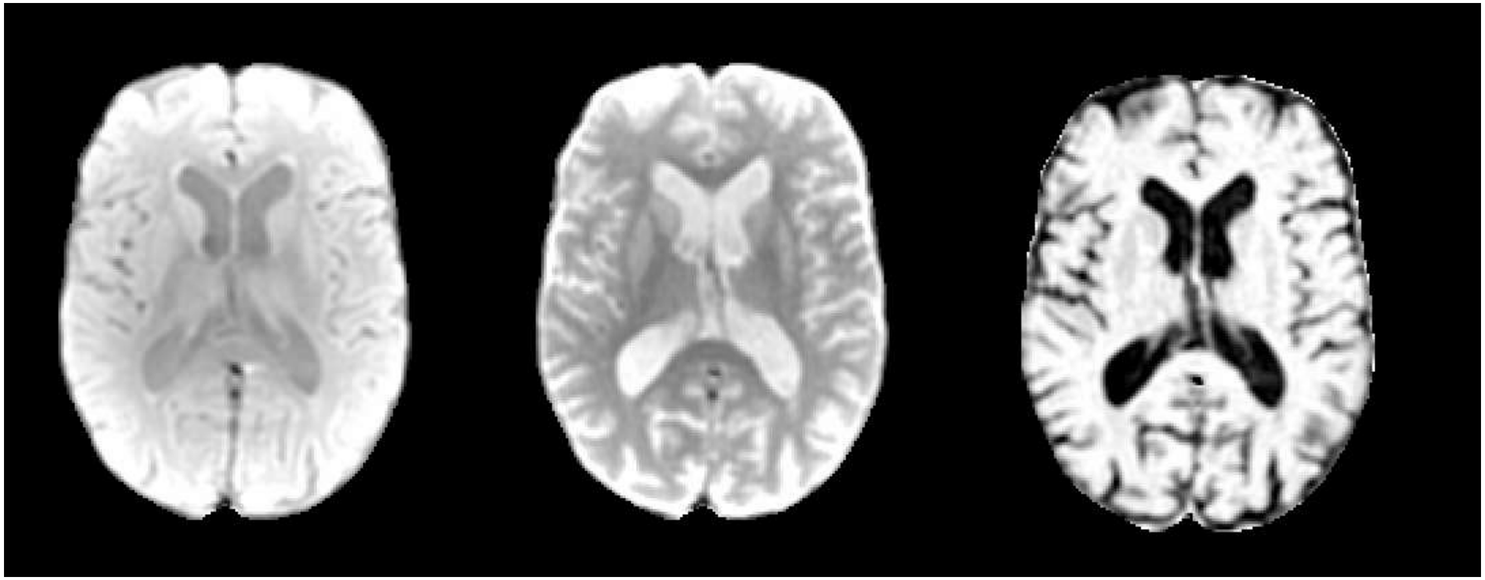
MTR: Magnetisation Transfer Ratio (in tumours, it is approx. 30% and in healthy tissue it is approx. 50%)

It is calculated as: MTR = (M0-Ms)/M0

where M0 is a spin echo clinical sequence with TR/TE ≈ 3500/10 ms at a bandwidth of 15.6KHz and represents the signal obtained without the RF pulse. Conversely, Ms is the equivalent signal but obtained with the RF pulse at a bandwidth of 1000 KHz



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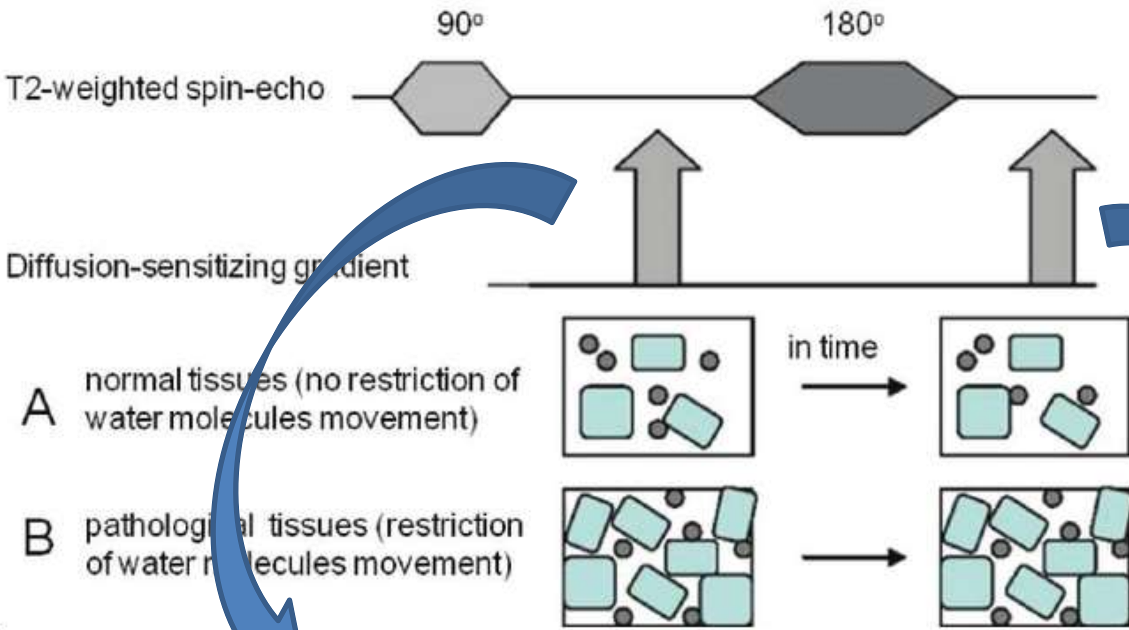
Diffusion



Two symmetric diffusion-sensitizing gradients applied around the 180 or refocusing pulse in the standard T2-weighted spin-echo sequence.

Resonance frequencies of effected tissues (in particular, water molecules) will be changed → dephasing of the transverse magnetization

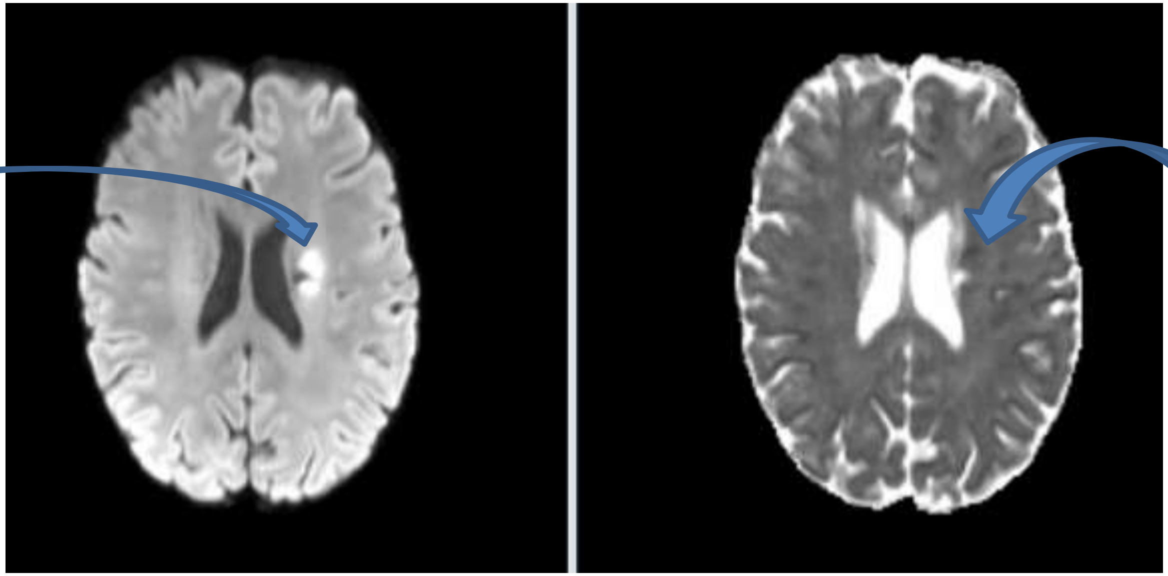
Re-applying the same gradient for the same duration but of opposite polarity "rephases" MT for stationary water molecules →no significant change in the measured signal intensity

(Adapted from Balyasnikova et al. (2012). Am J Nuclear Med Mol Imag. 2. 458-74.)

Diffusion

Vascular abnormalities with restricted diffusion: Infarcts (venous or arterial), diffuse hypoxic injury, posterior reversible encephalopathy

Bright in DWI (from approx. 30-120 mins to 10-14 days)



Restricted diffusion = Low Apparent Diffusion Coefficient (ADC)

Possible mechanisms:

1) Increase in cellular water
2) Reduction in extracellular space (consequence of cellular swelling → increased tortuosity in extracellular pathways
3) Fragmentation of cellular components

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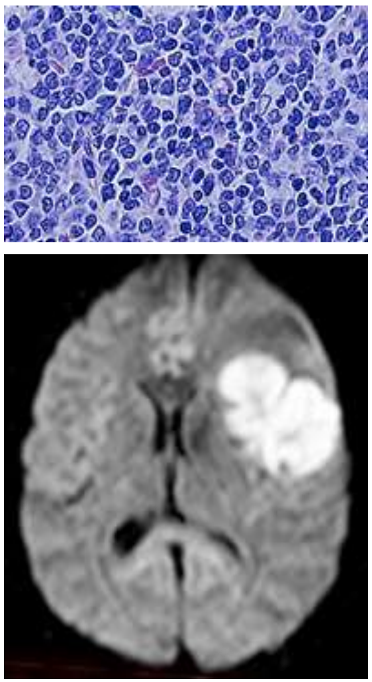
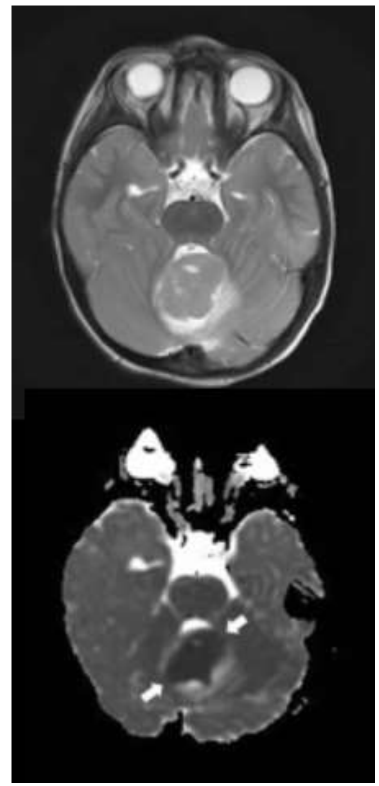
Diffusion

Neoplastic abnormalities with restricted diffusion: lymphoma, epidermoid, xanotogranuloma of choroid plexus, medulloblastoma, some meningiomas, metastases <u>(The majority of neoplasms do not restrict diffusion or change it only mildly)</u>



Lymphoma (from: https://mriquestions.com/dwi-bright-causes.html)



Posterior fossa medulloblastoma (from: https://doi.org/10.1007/s00381-016-3168-1)

Diffusion

Other pathologies with restricted diffusion:

Infectious abnormalities: Abscess, empyema, meningoencephalitis (herpes), Creutzfelt-Jacob disease (CJD)

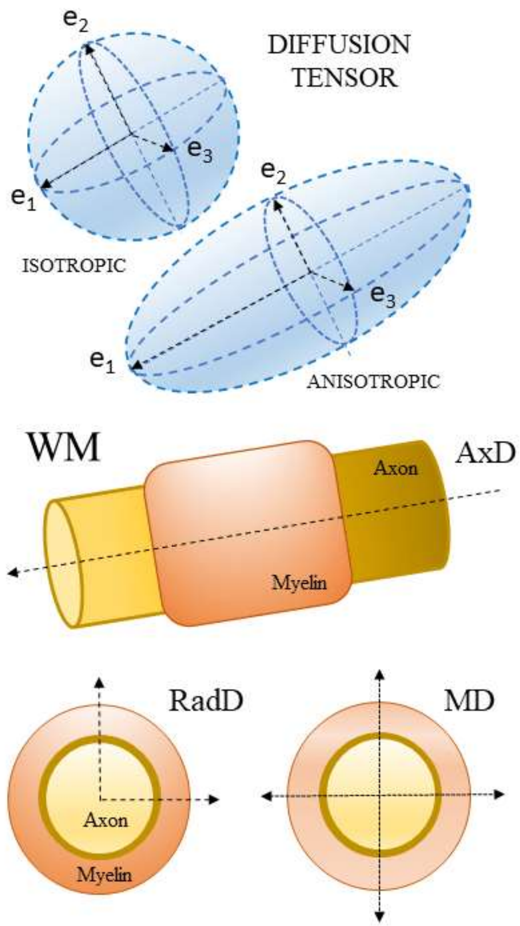
Traumatic abnormalities: hematoma, diffuse axonal injury, Wallerian degeneration, status epilepticus, contusion

Toxic/Metabolic abnormalities: CO poisoning, drugs (heroin,carbamazepine,…), hypo-/hyperglycaemia, and some congenital biochemical disorders)

Debate on confounds in terminology and radiological assessment in:

Diffusion-weighted imaging | Radiology Reference Article | Radiopaedia.org

Diffusion Tensor Imaging (DTI)



MRI technique that enables the **measurement of the restricted diffusion of water in tissue**

Parameters per voxel: a rate of diffusion and a preferred direction of diffusion—described in terms of three-dimensional space—for which that parameter is valid.

These parameters are calculated by vector or tensor math from six or more different DWI acquisitions, each obtained with a different orientation of the diffusion sensitizing gradients.

(Figure adapted from Gatto 2020. J Integrative Neurosci. 19. 571-592. DOI: 10.31083/j.jin.2020.03.165)

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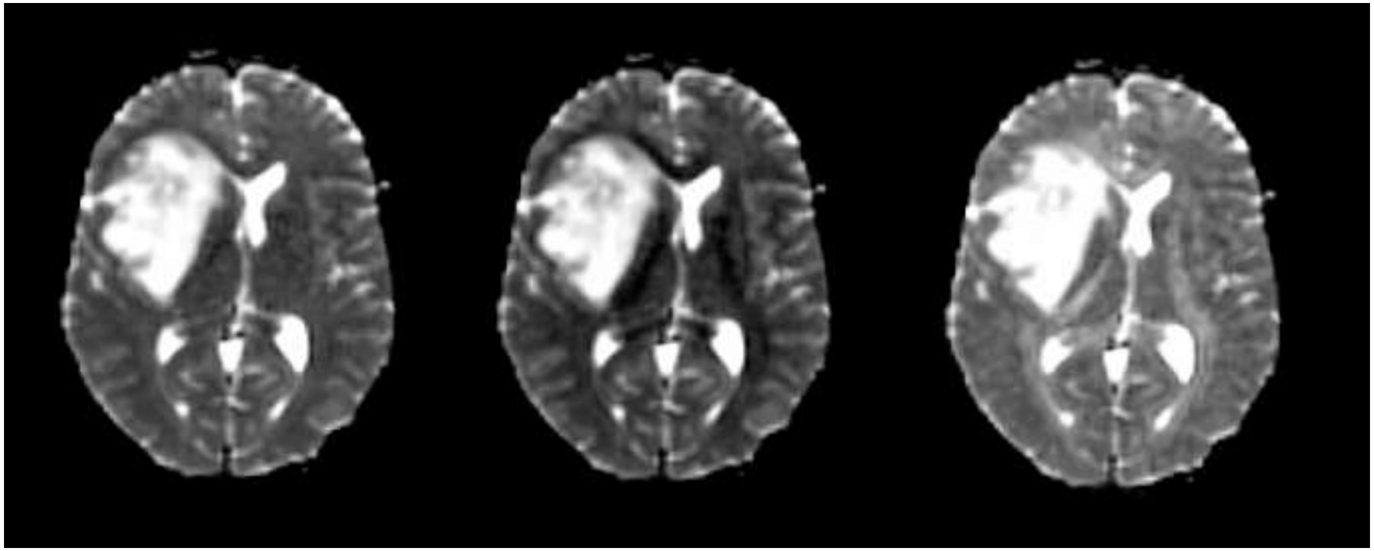
MD: Mean diffusivity

It is calculated as the average of the eigenvalues of the ellipsoid tensor for each voxel, measuring the diffusivity of the water molecules along each of the three primary axes:

MD = (L1+L2+L3)/3

Lrad: Radial diffusivity, calculated as Lrad=(L2+L3)/2

Lax: Axial diffusivity, equal to L1



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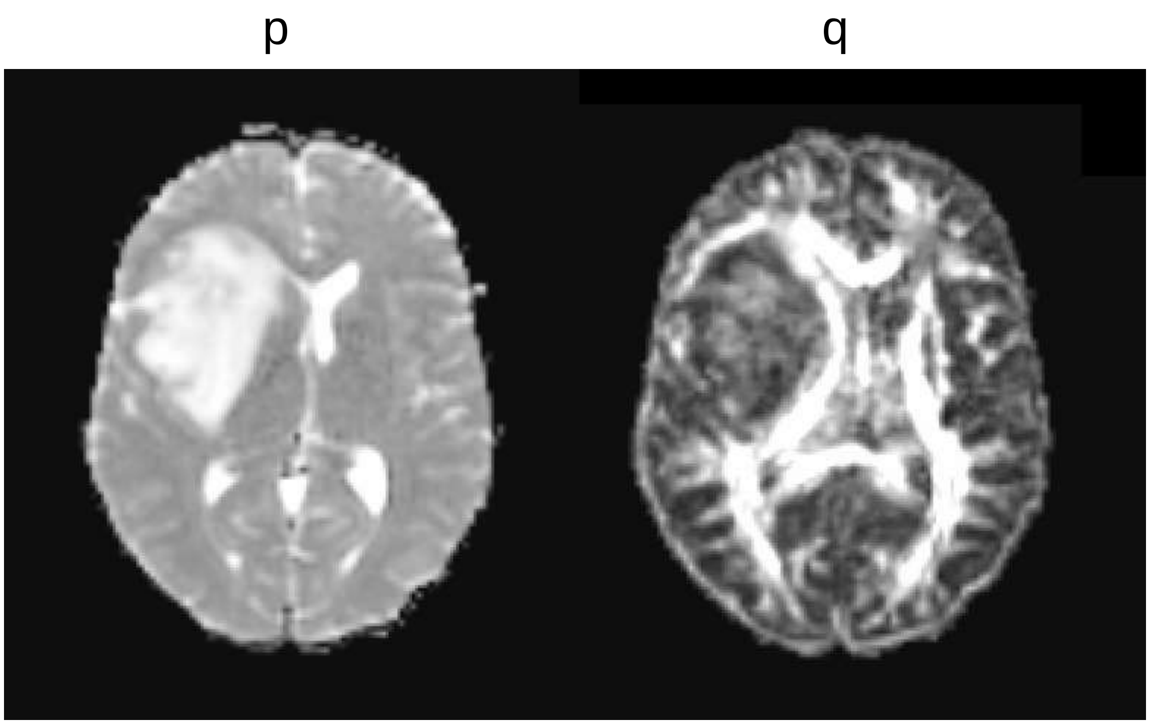
p: Map of isotropic diffusion

It is calculated as: $p = \sqrt{(3MD)}$

q: Map of anisotropic diffusion

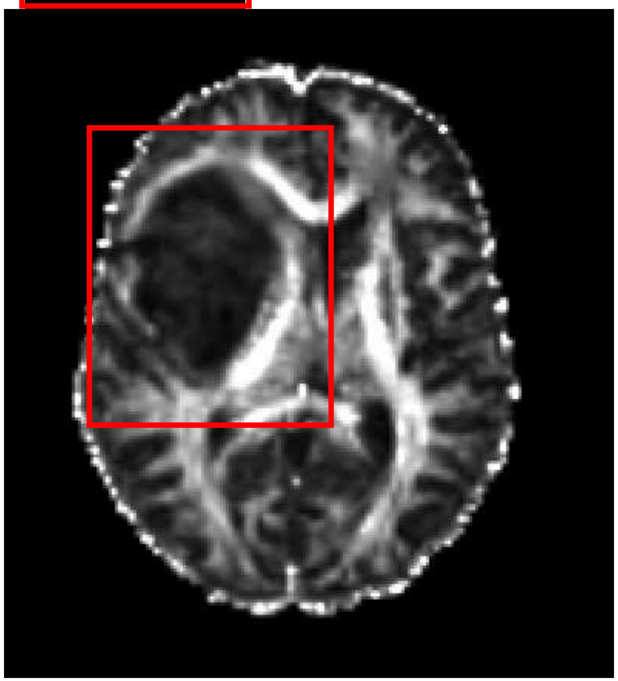
It is calculated as: $q = \sqrt{((L1-MD)^2+(L2-MD)^2+(L3-MD)^2)}$



8) FA: Fractional anisotropy

Describes the degree of anisotropy of the diffusion in each voxel, from 0 isotropic to 1 for fully anisotropic. It is calculated as:

$$FA = \sqrt{\frac{3}{2}}\sqrt{\frac{(L1-MD)^2+(L2-MD)^2+(L3-MD)^2}{\sqrt{(L1^2+L2^2+L3^2)}}}$$



Example from a study on 18 patients with brain tumours

Area segmen-ted	Gross tumour (LWC)		Gross tumour (HWC)		Oedema / infiltration	
Type of tumour	Gliomas	Meningio-mas	Gliomas	Meningio-mas	Gliomas	Meningio-mas
FA	0.120	0.202	0.0886	0.0894	0.0881	0.230
MD	1.34×10^{-3}	7.89×10^{-4}	1.65×10^{-3}	1.65×10^{-3}	1.55×10^{-3}	1.15×10^{-3}
MTR	40.47	45.18	29.89	28.49	38.44	47.45
T1 map	1.855	1.585	2.410	2.652	2.583	1.383

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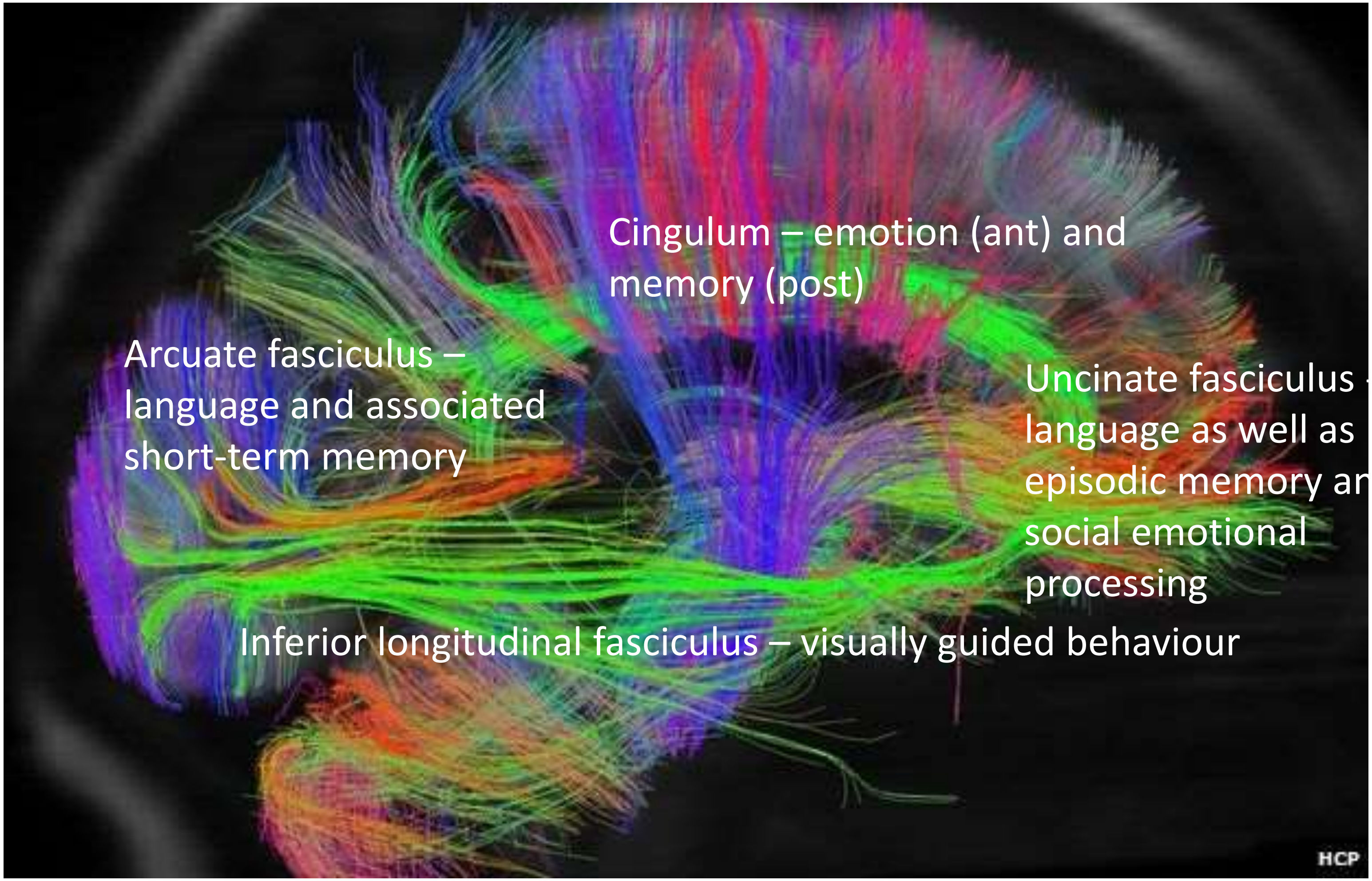
Human brain networks



http://www.humanconnectomeproject.org/

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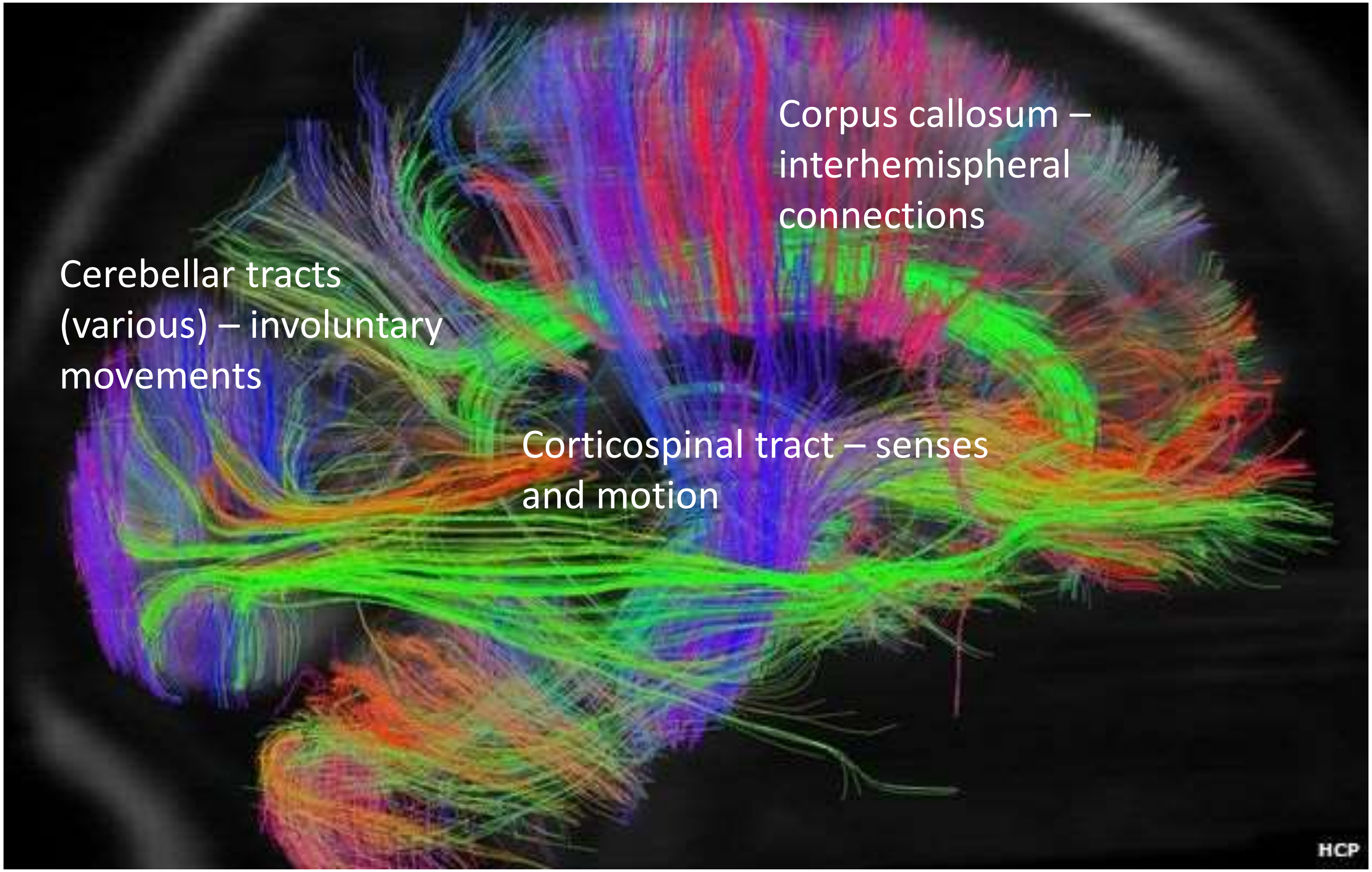
Human brain networks



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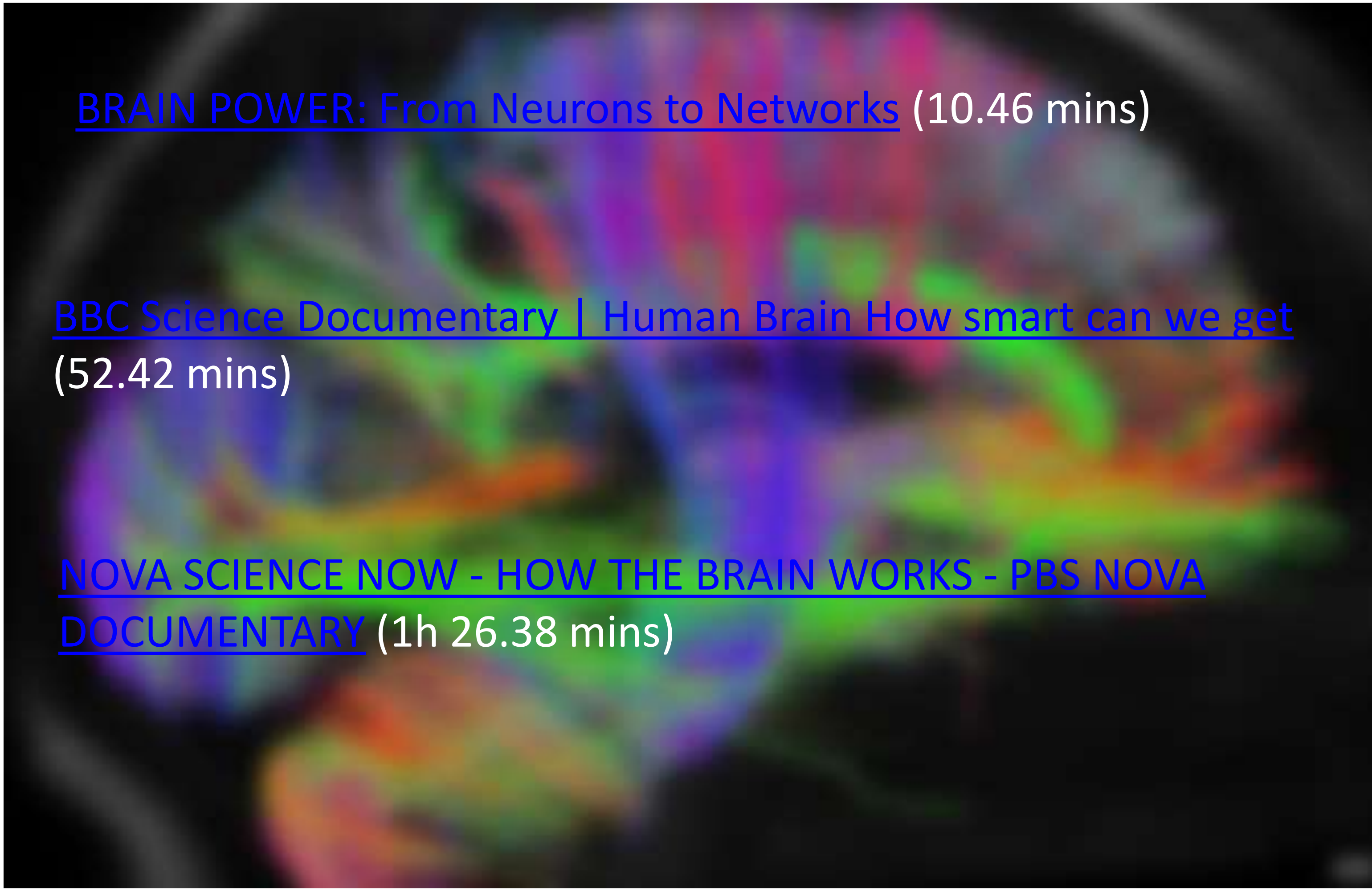
Human brain networks



BRAIN POWER: From Neurons to Networks (10.46 mins)

BBC Science Documentary | Human Brain How smart can we get (52.42 mins)

NOVA SCIENCE NOW - HOW THE BRAIN WORKS - PBS NOVA DOCUMENTARY (1h 26.38 mins)

http://www.humanconnectomeproject.org/

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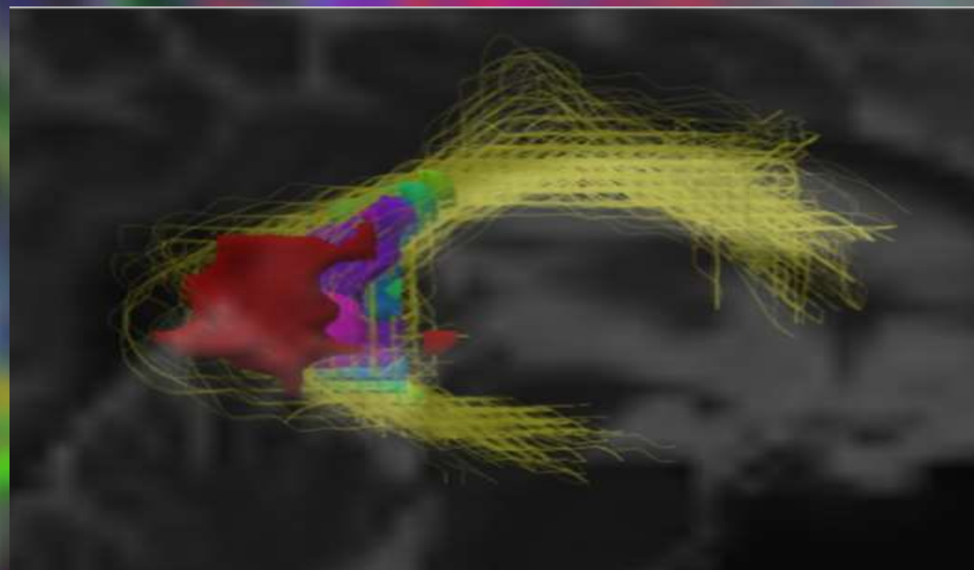
Human brain networks

When something goes wrong somewhere



Damage may either propagate along the tracts or accumulate prompting re-routing of the signal transmission reflecting in different patterns of cortical activation

doi: 10.3389/fneur.2019.00784/full

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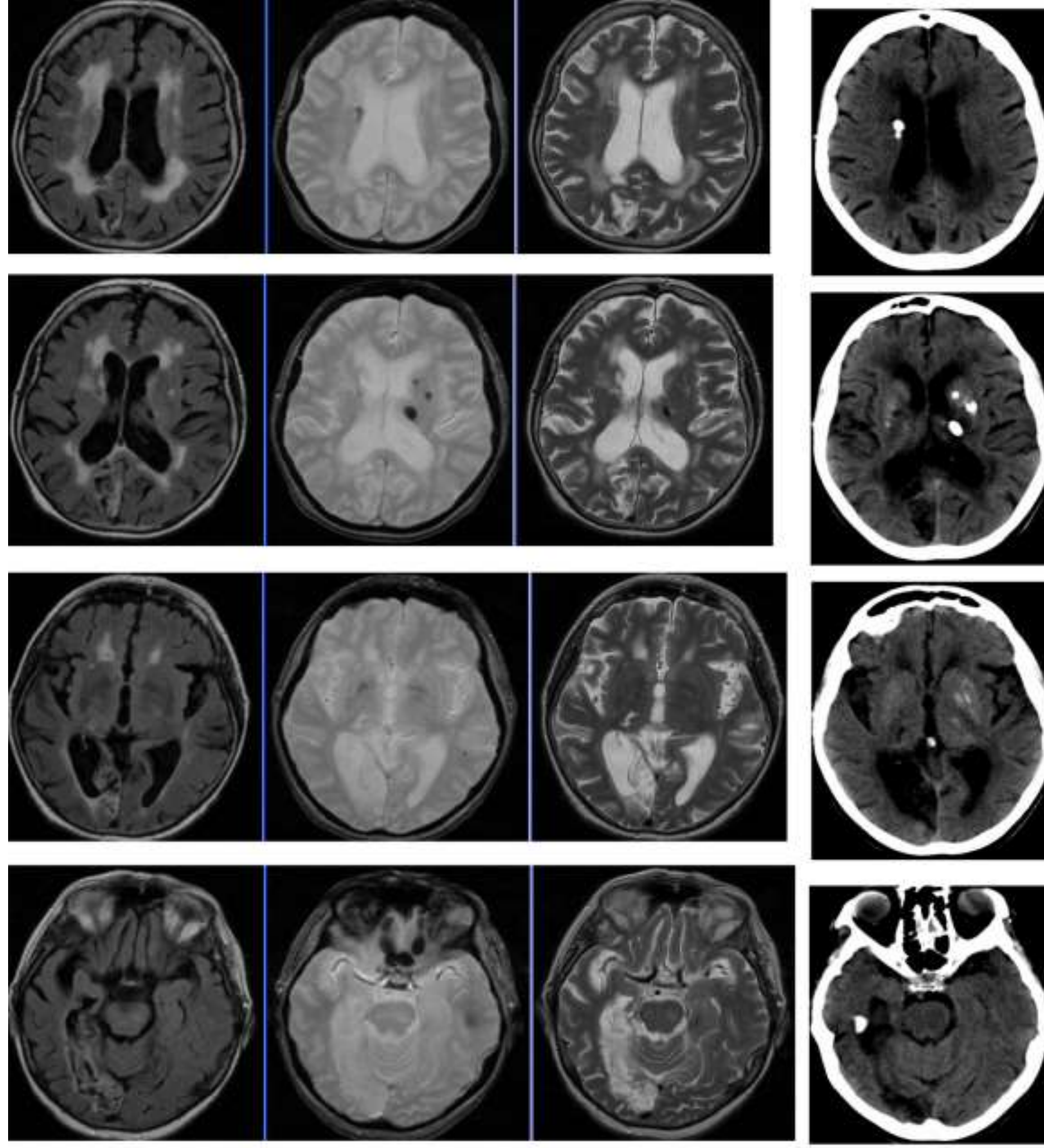
CT vs. MRI

faster acquisition
(usually < 5 mins)



basal ganglia
Flair - hypointense
T2* - hypointense
T2 - hypointense
CT- hypointense

Choroid plexus
Flair - hyperintense
T2* - hypointense
T2 - hypointense
CT - hyperintense

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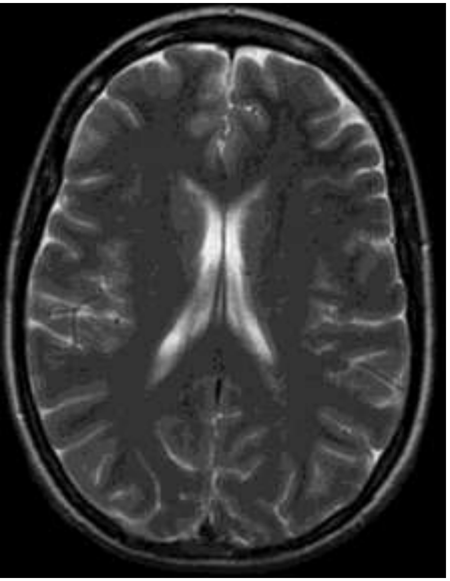
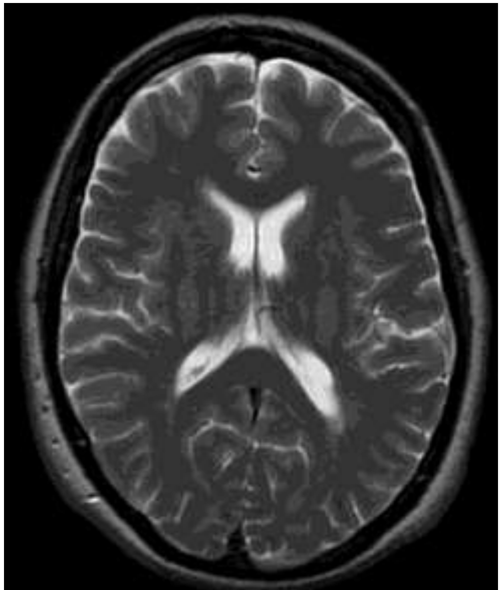
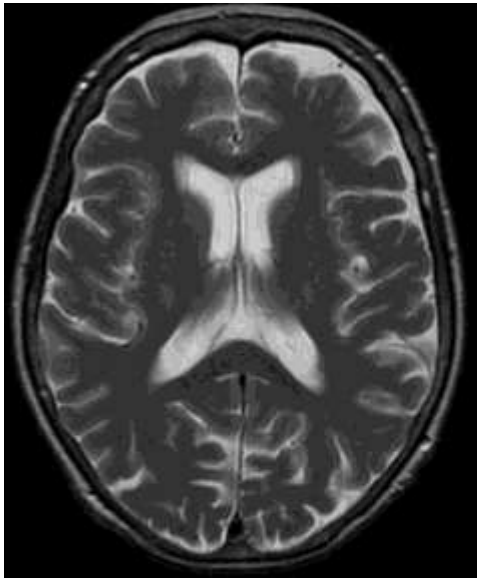
Outline

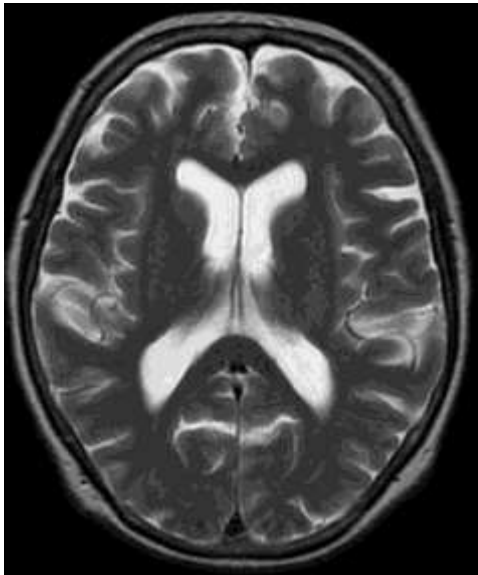
- ✓ Brain MRI scans and sequences
- ✓ Types of MR images
- ✓ White matter tracts
- ✓ CT vs. MRI
- Healthy and unhealthy brains
- Common image processing procedures
- Practical applications

The healthy adult brain



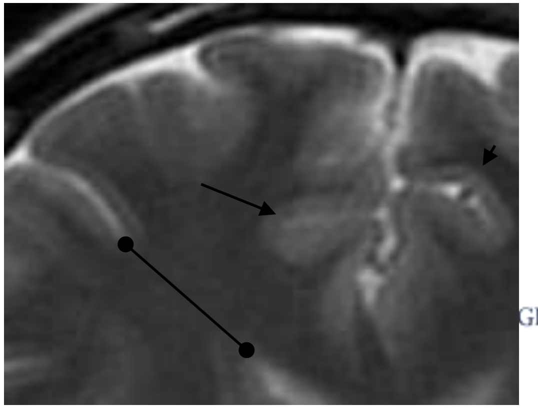


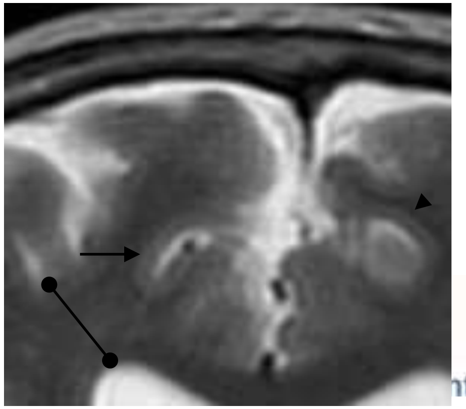




20s-30s

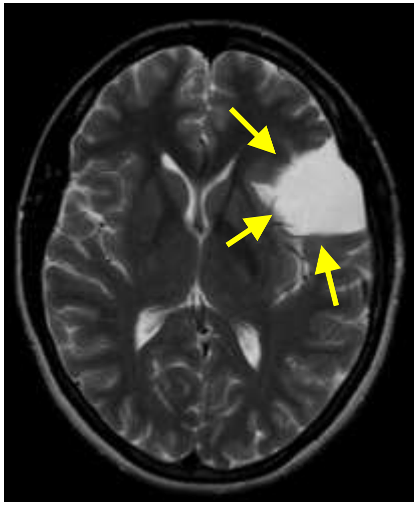
60s, 70s, 80s





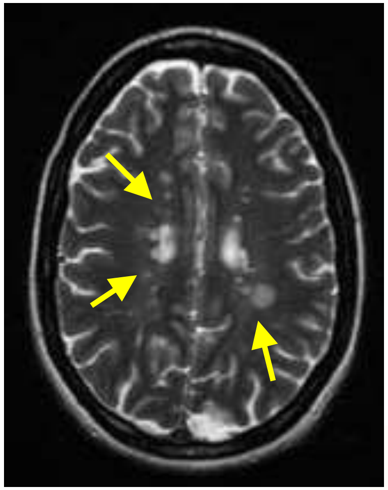
What can be wrong in our brains ?

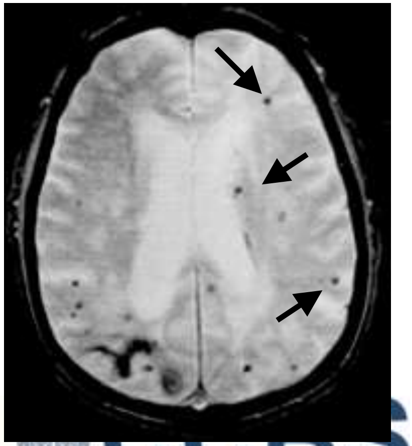
- Neoplasms
- Cysts
- Structural vascular abnormalities
- Inflammatory lesions



Cerebrovascular disease markers

- White matter hyperintensities
- Silent brain infarcts
- Brain microbleeds





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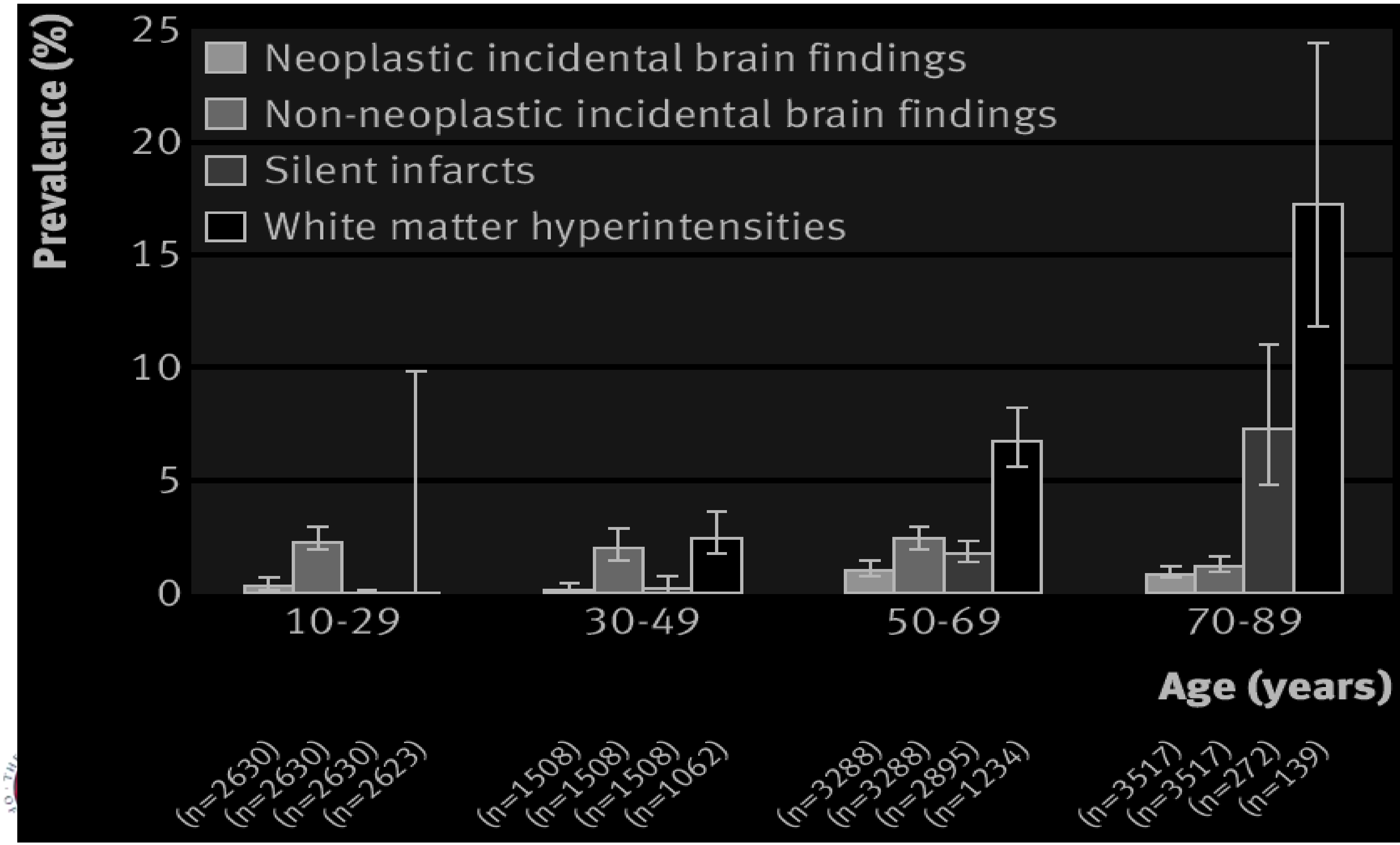
How common is it ?
Incidental findings Systematic Review

BMJ 2009 339:b3016

(16 studies, involving 19,559 people)



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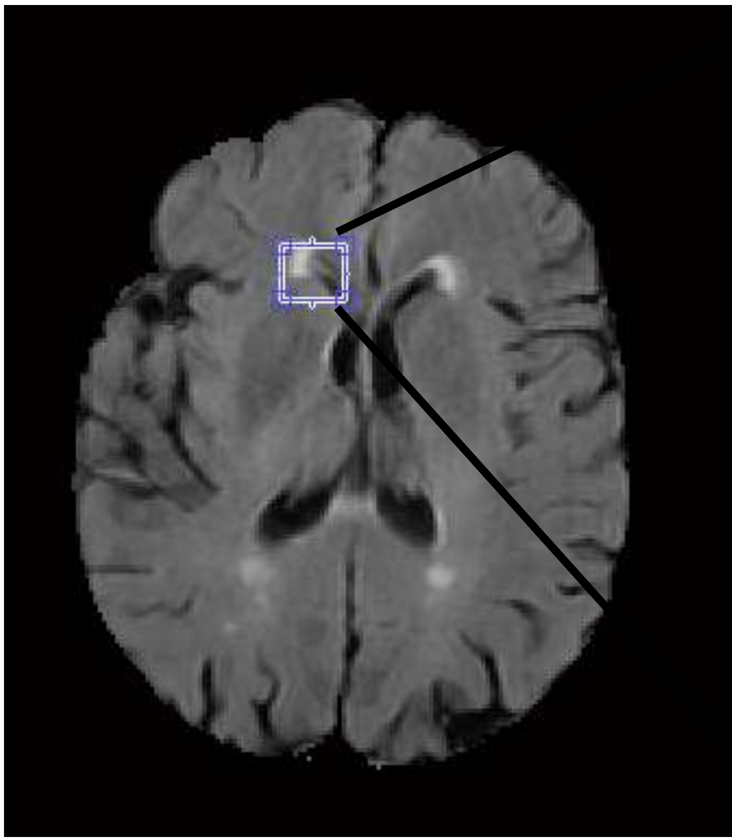
MRI - Digital images



55	60	73	87	98	100	87	71	60	52	50	49	53	58
57	60	78	96	105	104	91	70	57	52	54	53	52	53
58	63	83	102	110	103	82	65	52	45	51	56	54	52
58	69	87	101	107	96	75	70	65	48	41	48	54	54
57	69	89	102	105	92	73	66	67	62	49	39	46	53
57	71	92	106	107	97	79	62	56	63	62	50	42	45
57	68	83	92	93	87	77	62	50	47	47	48	49	43
58	59	63	68	67	62	61	62	55	39	27	31	41	44
58	59	61	62	63	61	61	64	63	52	32	22	33	44
59	59	57	56	61	63	64	64	66	69	51	24	25	36
55	55	52	54	61	63	63	62	62	69	68	42	22	27
54	53	50	53	60	62	60	61	62	62	65	59	41	33

A grid of pixels – each of which contains a single value…

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Common image processing procedures

- Registration

  - Inter-modalities → for feature assessment

  - Inter-subjects → for generating distributional maps
- Feature extraction

  - manual, semi-automatic, automatic
- Use of feature-shape or physical models
- Statistical analyses

  - feature characteristics
  - association with clinical parameters

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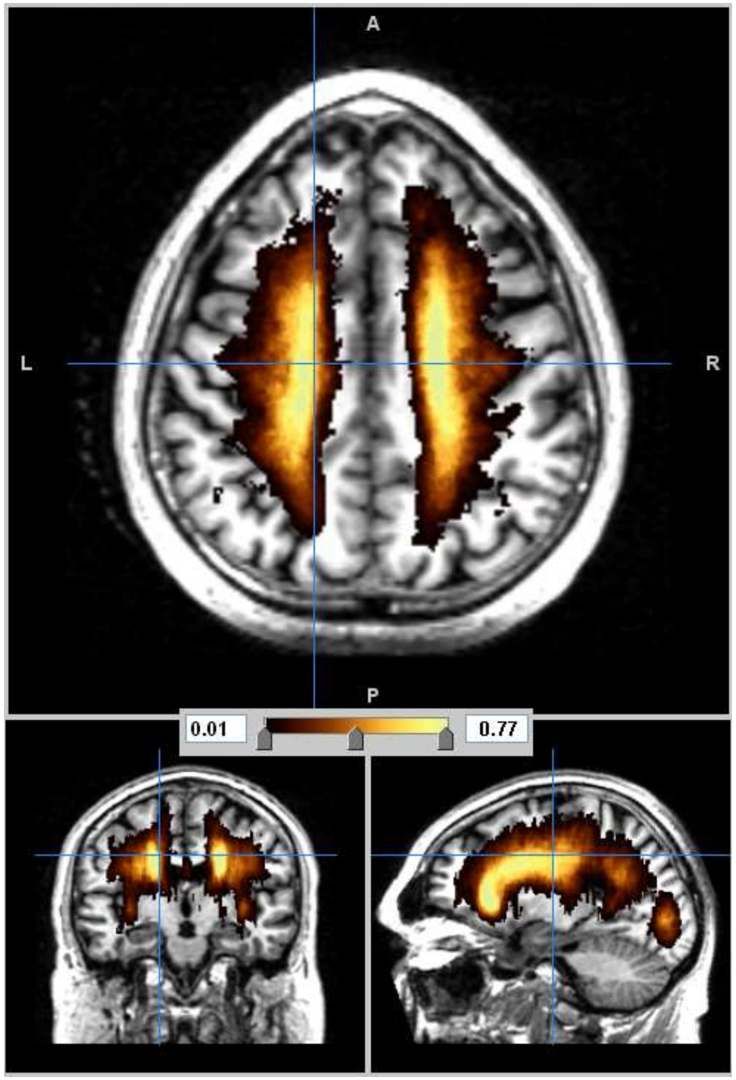
Inter-subject registration

Probability distribution map of the white matter hyperintensities of presumably vascular origin on 89 stroke patients



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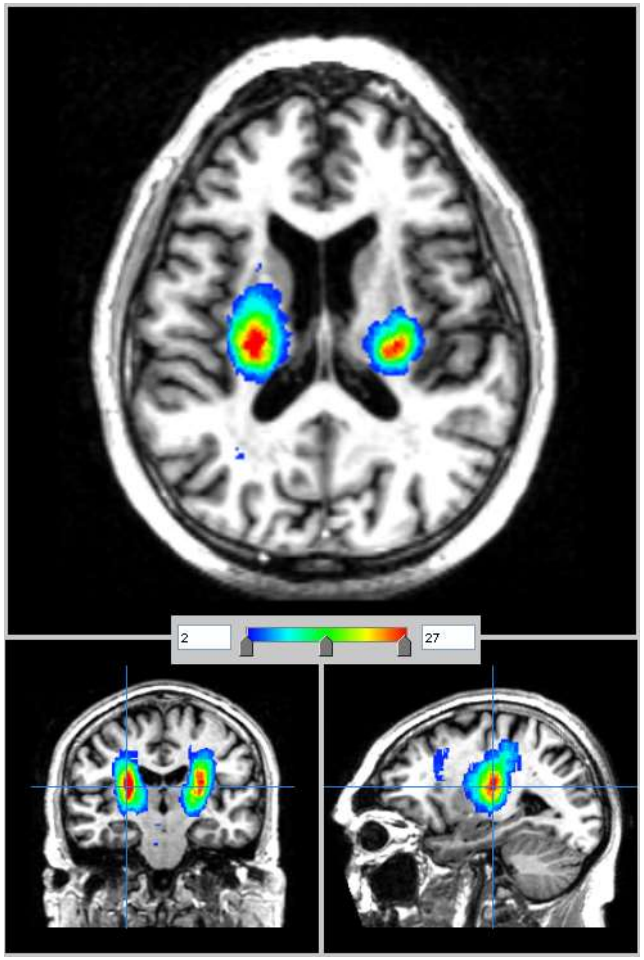
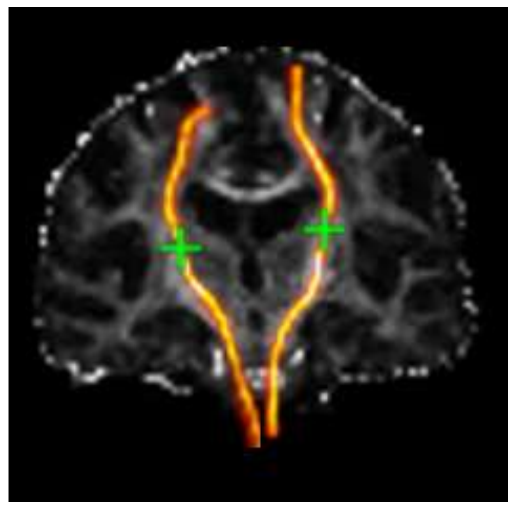
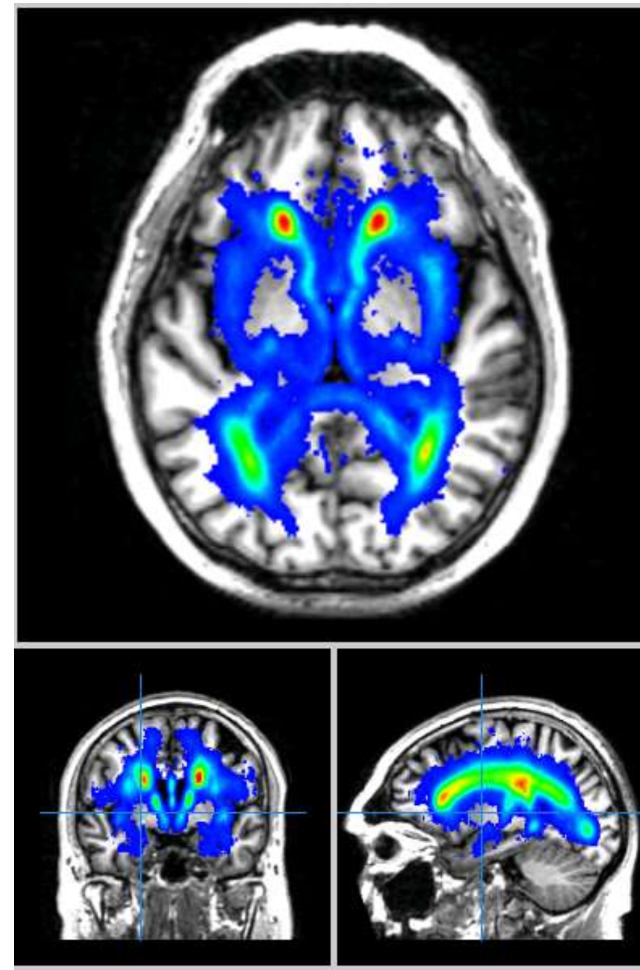
Why one causes symptoms and not the other ?







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Intra-subject registration

Image obtained soon after presenting acute stroke symptoms

Image obtained a year after

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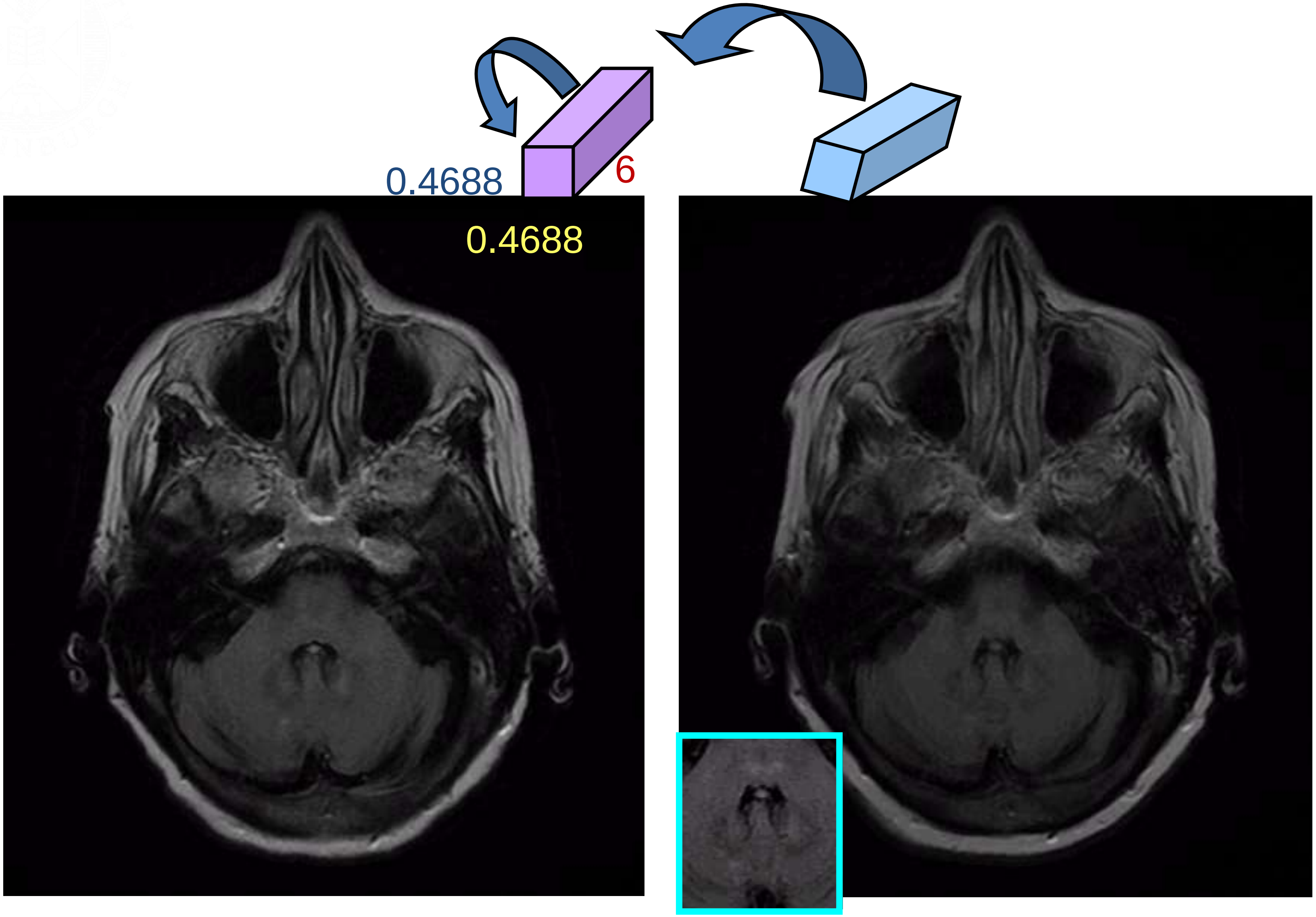
Follow-up image registered to baseline



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Diversity needed to be accounted for in feature detection

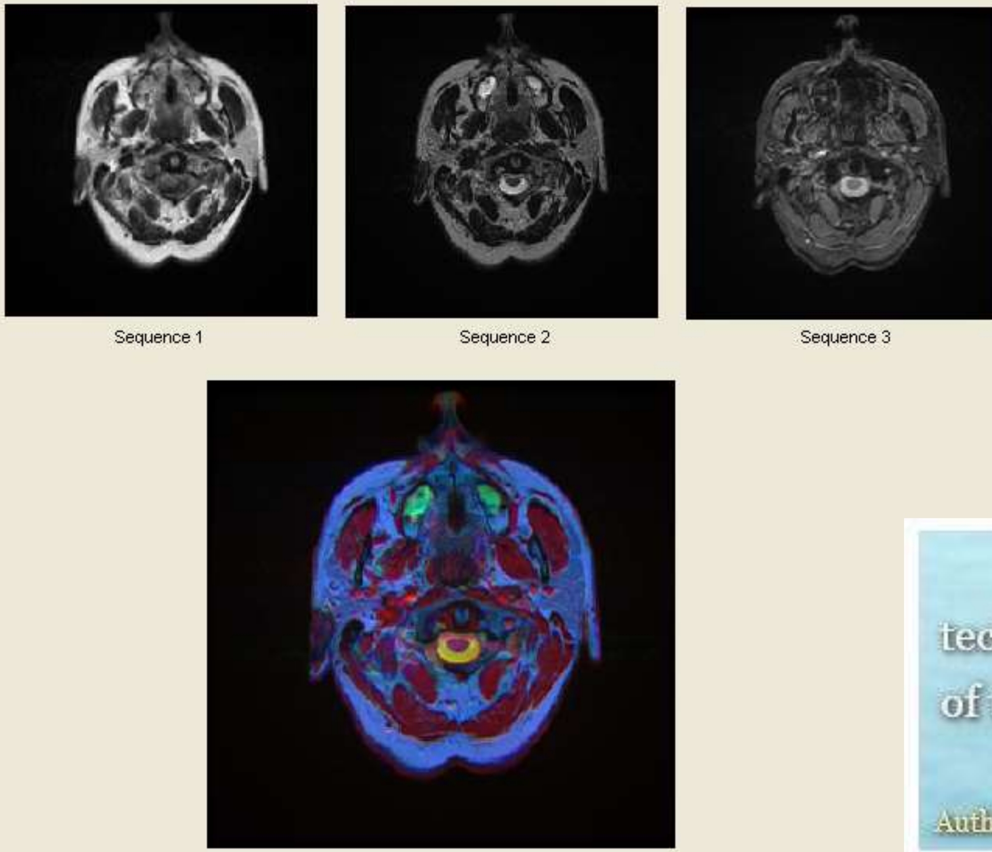
Sequence	Elscint	Fonar	GE	Hitachi	Philips	Picker	Shimadzu	Siemens	Toshiba
Spin Echo	SE	SE	SE, MEMP, VEMP	SE	SE	SE		SE	SE
Turbo Spin Echo / Fast Spin Echo		FSE	FSE	FSE	TSE	FSE		TSE	FSE
Single Shot Technique			SSFSE	Single Shot FSE	Single Shot TSE	EXPRESS		HASTE	FASE
FSE/TSE with 90Â° Flip-Back Pulse			FRFSE	Driven Equilibrium FSE	DRIVE			RESTORE	FSE T2 puls
Gradient Echo		Field Echo	GRE	GE	FFE	FAST		GRE	Field Echo
Coherent Gradient Echo	F SHORT	Field Echo	GRASS, FGR, FMPGR	Rephased SARGE, GFEC	FFE	FAST		FISP	Field Echo
Incoherent Gradient Echo (RF spoiled)		Field Echo	SPGR, FSPGR	GE/GFE	T1 FFE	RF spoiled FAST			Field Ec
Incoherent Gradient Echo (Gradient spoiled)	SHORT	Field Echo	MPGR	GRE		T1-FAST, NOSE		FLASH	Field Ec
Steady State Free Precession	E Short	Field Echo	SSFP, DE FGR	Time Reversed SARGE	T2 FFE	CE FAST		PSIF	
Balanced Sequence / True Fisp			FIESTA	BASG	Balanced FFE			TrueFISP	True SS
True FISP / Dual Excitation			FIESTA-C					CISS	
Double Echo Steady State						FADE		DESS	
Multi-Echo Data Image Combination								MEDIC	

From 9 main manufacturers, the characteristics of the MRI sequences and devices all differ

Device Information		Open MRI	
AIRIS II	Altaire	ARTOSCAN - M	Aurora 1.5T Dedicated Breast MRI System
C-SCAN	CHORUS 1.5T	Device	Echelon 1.5T
ENCORE 0.5T	Excelart AG with Pianissimo	Excelart XG with Pianissimo	FLEXART
FORTE 3.0T	G-Scan	iMotion 1.5 Tesla Magnet	Infinion 1.5T
Intera 0.5T	Intera 1.0T	Intera 1.5T	Intera 3.0T
Intera Achieva 1.5T	Intera Achieva 3.0T	Intera Achieva CV	MAGNETOM Allegra
MAGNETOM Avanto	MAGNETOM C	MAGNETOM Concerto	MAGNETOM Espree
MAGNETOM Harmony	MAGNETOM Jazz	MAGNETOM Rhapsody	MAGNETOM Sonata
MAGNETOM Symphony	MAGNETOM Trio (TIM System)	MagneVu 1000	MRP-7000
MSK-Extreme	OPART	Open MRI	Opera (E-SCAN XQ)
Panorama 0.23T	Panorama 0.6T	Panorama 1.0T	PoleStar
RELAX 0.35T	S-SCAN	Signa 3.0T	Signa Contour/i 0.5T
Signa HDe 1.5T	Signa HDx 1.5T	Signa HDx 3.0T	Signa Infinity 1.0T
Signa Infinity 1.5T TwinSpeed with Excite	Signa Infinity 1.5T with Excite	Signa OpenSpeed	Signa Ovation
Signa Profile	TOMIKON	Ultra	Upright MRI
Vantage	Virgo	VISART	

http://www.mr-tip.com/serv1.php?type=seq

Multimodality data fusion in diagnostics



RESEARCH

Jan 22, 2014

Fused images ease cardiac diagnoses

Dutch researchers have developed 3D visualization software that fuses anatomical and functional data into a single image. They believe the fused images make it easier to diagnose cases of coronary artery disease (CAD), according to a paper in the January issue of the *Journal of Nuclear Medicine*.

IEEE transactions on information technology in biomedicine : a publication of the IEEE Engineering in Medicine and Biology Society

Author Manuscript

NIH Public Access

and research

Feature-Based Fusion of Medical Imaging Data

Vince D. Calhoun, Senior Member and Tulay Adalı, Fellow

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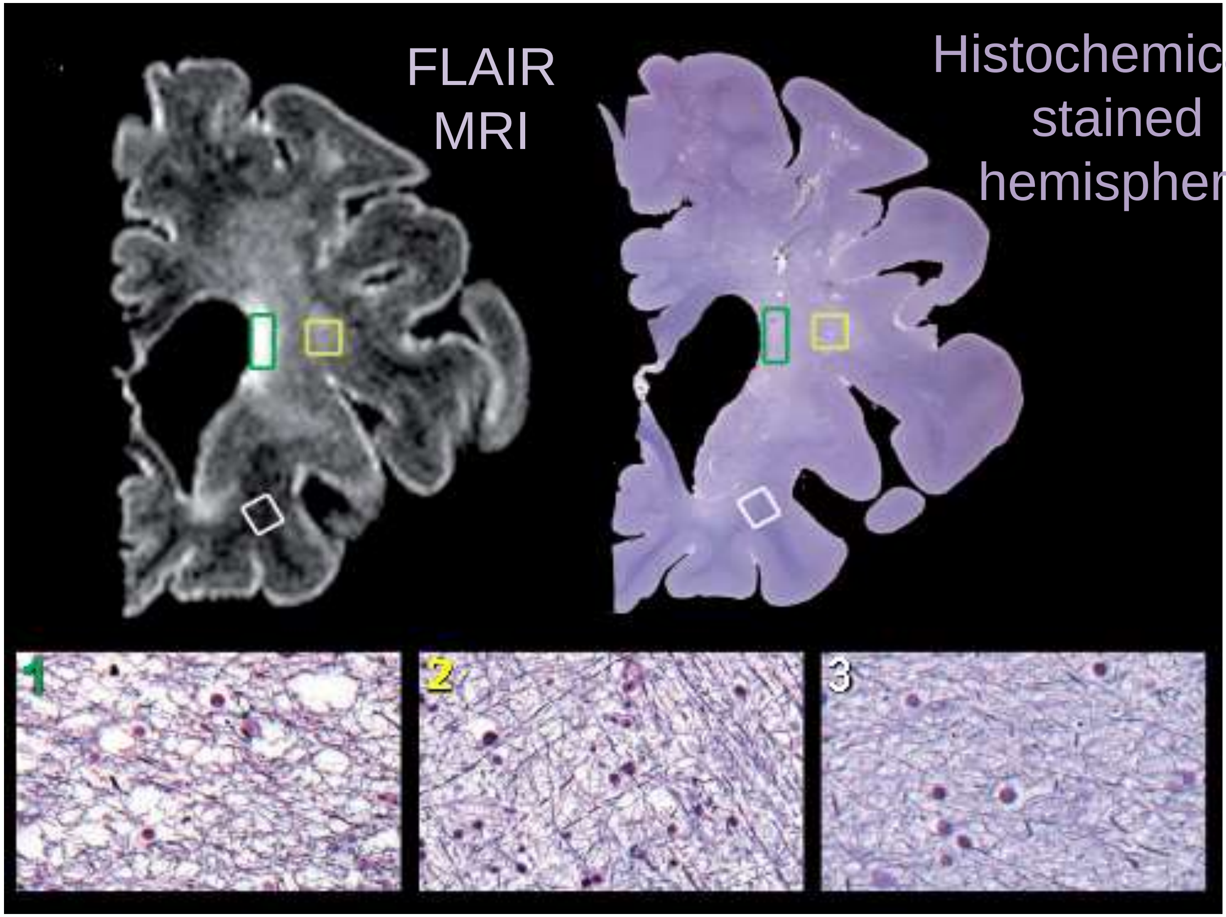
Edinburgh Neuroscience

Histological evidence

Prefrontal brain slice of an 88-yrs old female with Alzheimer's disease



Bodian Silver stained sections

Figure adapted from Gouw AA et al. Brain (2008), 131:3286-3298

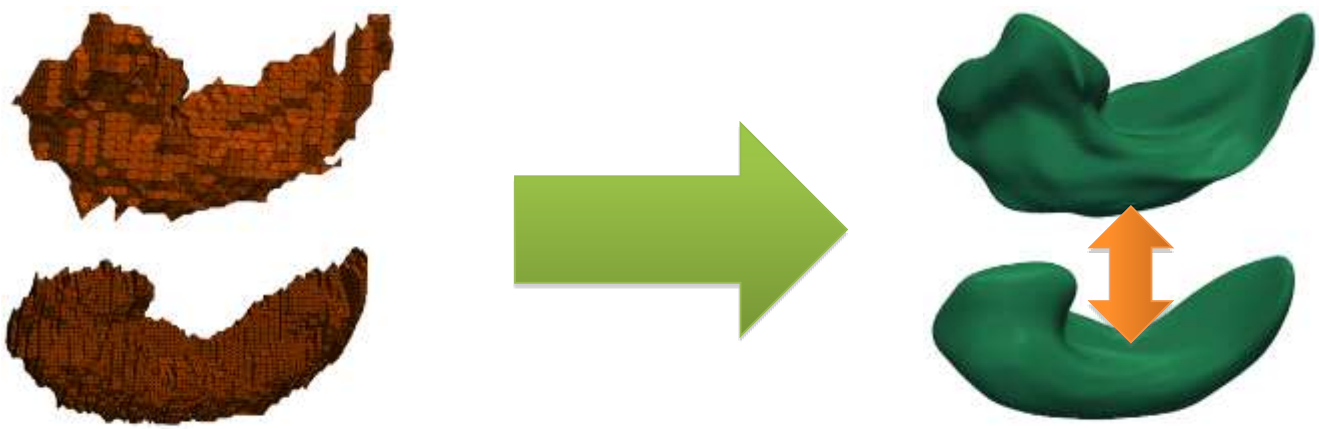
Surface modelling

Pre-requisites:

1) Smooth surface representing individual shape characteristics

2) Inter-subject point-to-point shape correspondence

3) Robust restoration of individual shape details across large variations of shape and size



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Surface modelling

4) Correct anatomical boundary delineation

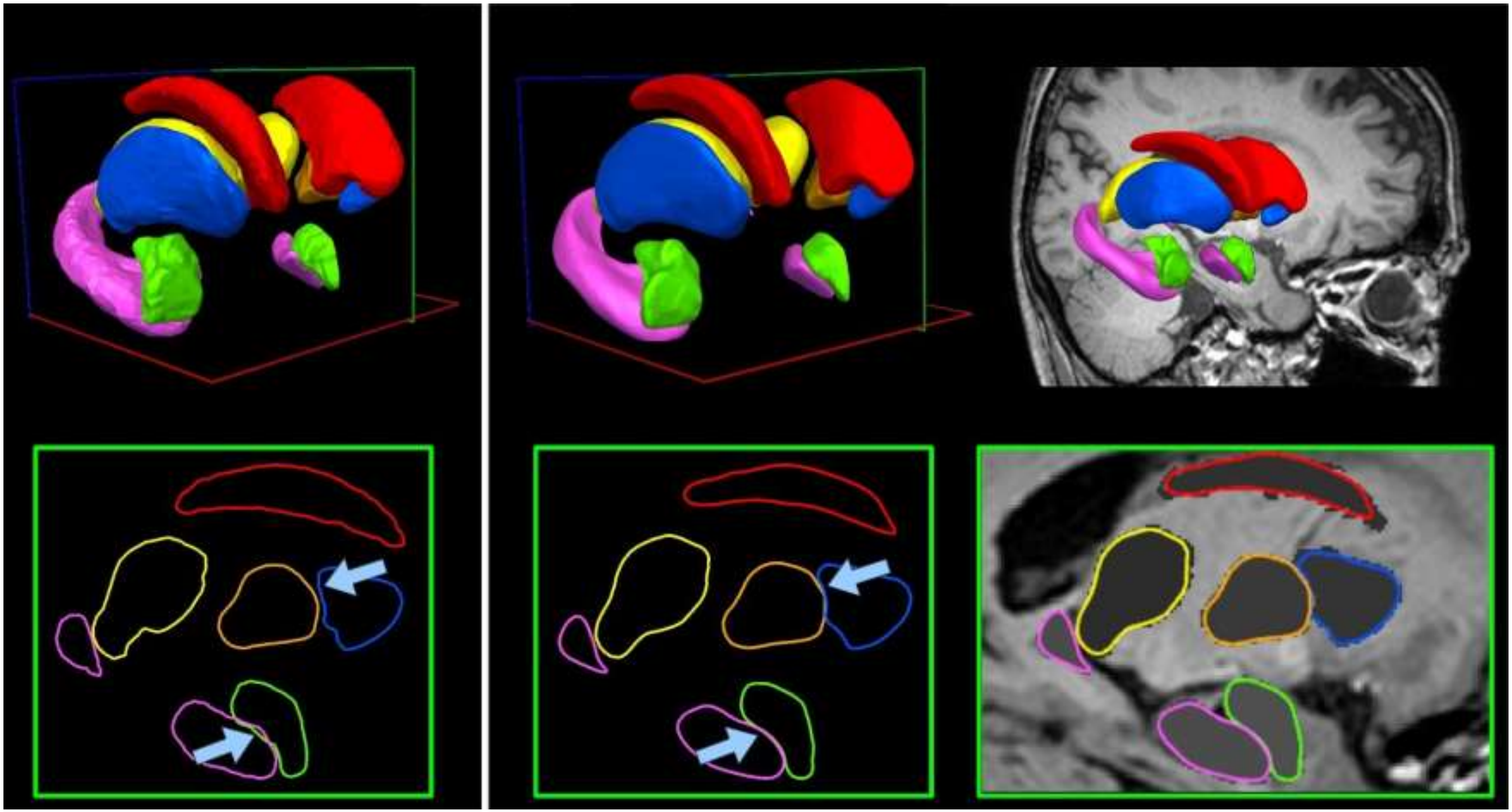

Image courtesy from Eng. Jaeil Kim

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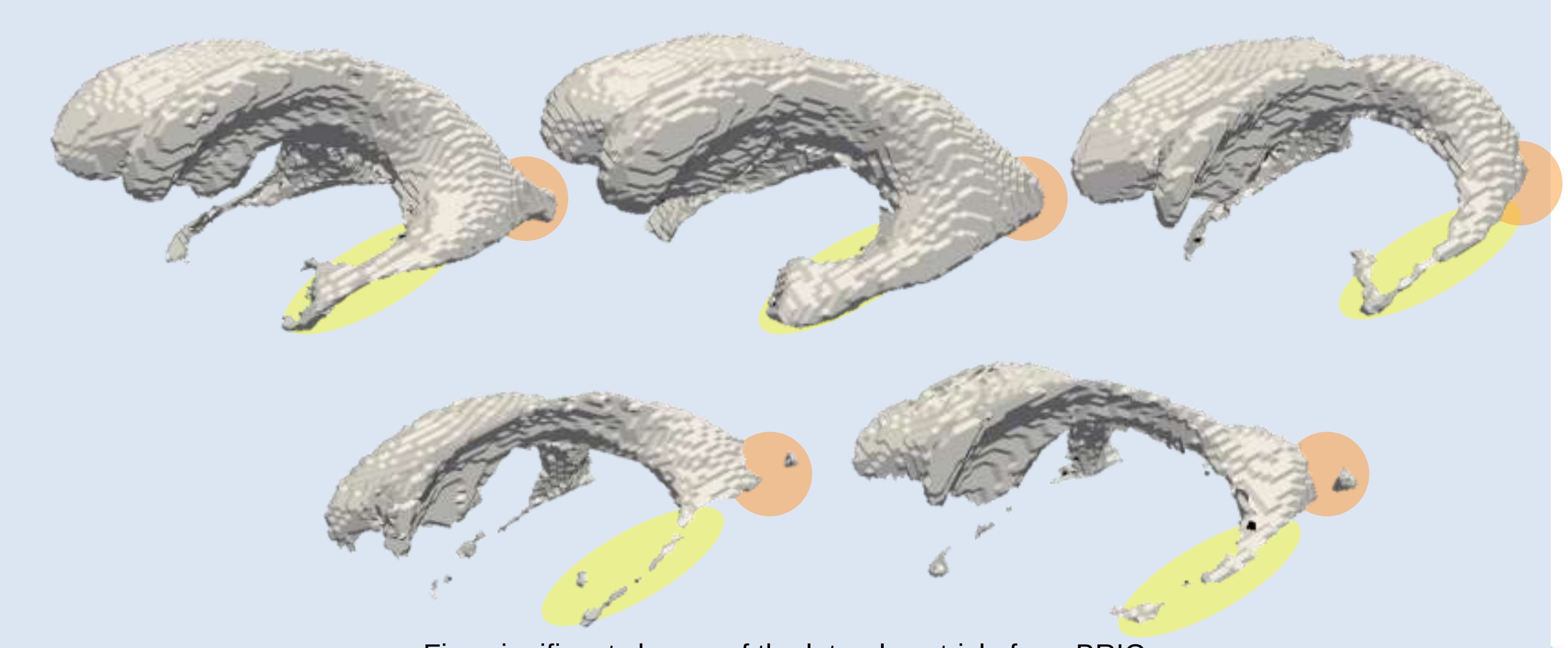
Complexity in the modelling

1) Surface's roughness can introduce errors in the inter-subject correspondence

2) Variability in ageing and disease cohorts



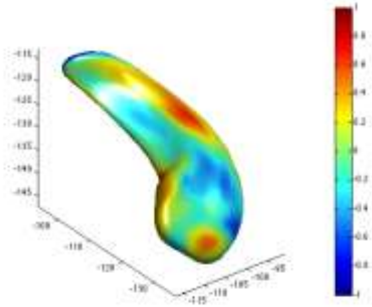
Five significant shapes of the lateral ventricle from BRIC

Image courtesy from Eng. Hojin Ryoo

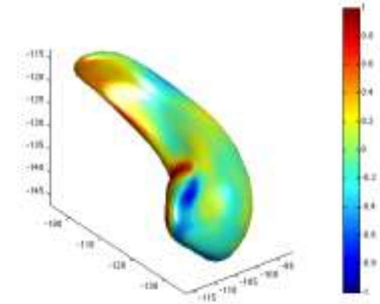
Example - Regional deformation pattern for general memory

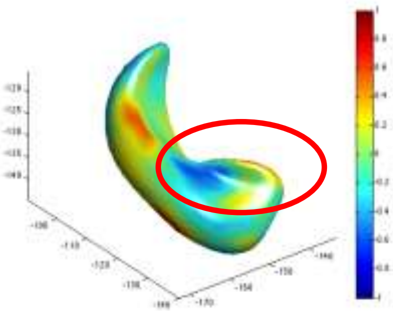
GM above mean+SD

GM below mean+SD

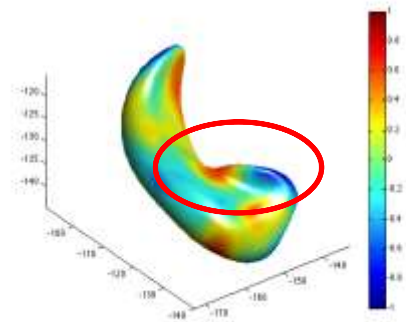


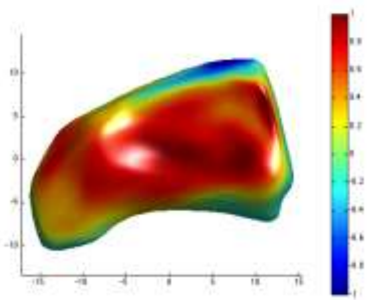
Left Hippocampus



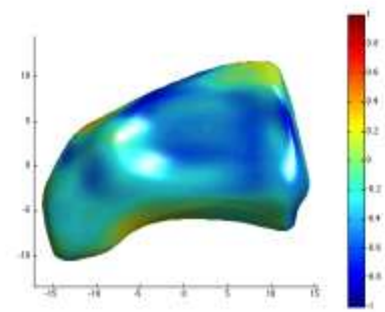


Right Hippocampus





3rd. ventricle



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Thanks!