Diffusion Tensor Imaging
in brain tumours

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why presurgical DTI?
Overall high-grade gliomas (WHO grade III and IV)

- With DTI survival: 21 months
- Without DTI survival: 14 months

Wu et al. Neurosurgery 2007;61:935
Outline

- **Technique.**
- **Anatomy of white matter tracts**
  - corticospinal tract (CST)
  - arcuate fasciculus (AF)
  - optic radiation (OR).
- **Presurgical assessment**
  - localisation and infiltration of white matter tracts.
- **Considerations**
  - limitations and pitfalls.
- **Conclusions**.
Diffusion weighted imaging (DWI)

Diffusion tensor imaging

= Diffusion weighted imaging

(not vice versa)

Brownian (1827) motion of molecules
⇒ DWI measures the microscopic motion of water molecules.
Diffusion weighted imaging (DWI)

Einstein: \[ <r^2> = 6D_t \]

DWI: T2-weighted SE sequence

Gx  Gy  Gz
Diffusion tensor imaging (DTI)

- Application of diffusion gradients in multiple (>6) directions.
- Measure anisotropy of Brownian motion of water molecules.
- High degree of organisation (white matter) → high degree of anisotropy.

\[ FA = 0 \quad \text{and} \quad FA > 0 \]
Common DTI parameters

ADC
apparent diffusion coefficient

FA
fractional anisotropy

Directional map
1. (green) = A-P
2. (red) = L-R
3. (blue) = S-I
Fiber Track Reconstruction
WHITE MATTER TRACTS
Anatomy

- White matter tract assessment requires anatomical knowledge
  - placement of seed/target ROIs for fibre tracking
  - presumed location of ‘eloquent’ white matter tract.
- Attempts to standardise ROI placement, no consensus
  - use of single versus multiple ROIs
  - ROI size
  - thresholds (angular, FA)
  - order of ROI placement.
Corticospinal tract (CST)

corona radiata

internal capsule

cerebral peduncle

source: Grey’s Anatomy
Tracking the CST

cerebral peduncle

internal capsule

posterior limb
Tracking the CST using fMRI
Tracking the CST using fMRI
Arcuate fasciculus (AF)

“Broca’s” area

Arcuate fasciculus

“Wernicke’s” area
Arcuate fasciculus (AF)
Tracking the AF

seed ROI
Tracking the AF

seed ROI

target ROI
Tracking the AF

seed ROI

target ROI
Optic radiation (OR)
Optic radiation (OR)

seed ROI: (near) lateral geniculate nucleus
target ROI: calcarine sulcus
Brain tumour and white matter tracts

PRESURGICAL ASSESSMENT
Tumour proximity to white matter tracts

48 y.o. male: glioma
Validation with electrical stimulation (ES)

  - Mean distance between subcortical stimulation sites and CST tractography: $8.7 \pm 3.1\text{mm}$.

- Mikuni et al. J Neurosurg 2007;106:593
  - 40 patients
  - 18/20 ES+ if CST < 1 cm on DTI
  - 3/20 ES+ if CST >1 cm on DTI.
Combine with fMRI

- fMRI to localise eloquent cortex
  - comprehensive overview for the neurosurgeon.
- fMRI for ROI placement
  - primary motor cortex (hand, foot, mouth): CST
  - language areas: AF
  - particularly in presence of oedema (↓ FA).

Smits et al. AJNR 2007;28:1354
Tract integrity

- Normal FA displacement only
- FA, normal orientation
- FA, disorientation
- Tumour infiltration
- Tract disruption

Field et al. JMRM 2004;20:555
Tumour infiltration

- Tumour infiltration
  - may be undetectable on conventional MRI
  - indistinguishable from oedema.
- Fractional anisotropy (FA)
  - strong inverse correlation between FA and degree of tumour infiltration on histology.
  - progressive decrease remote > peritumoural white matter > tumour border > tumour core.
- Findings are very inconsistent.
Improved Delineation of Glioma Margins and Regions of Infiltration with the Use of Diffusion Tensor Imaging: An Image-Guided Biopsy Study

tensor decomposition

⇒ p (isotropic)
⇒ q (anisotropic)

reduced anisotropy
(↑↑ p and ↓↓ q)
⇒ tumour core

increased isotropy
(↑↑ p and ↓ q)
⇒ tumour invasion

Image courtesy of Stephen Price
predicting patterns of recurrence

diffuse p/q abnormality
diffuse recurrence (12/12)
time to recurrence: 261 ± 75 days

localised p/q abnormality
localised recurrence (8/8)
time to recurrence: 287 ± 62 days

limited p/q abnormality
limited recurrence (after > 2.5 y)
no recurrence in 3/5 patients

Price et al. Eur Radiol 2007;17:1675
Non-Invasive Assessment of the Invasive Microenvironment of Glioblastomas: A Multi-modal Imaging Study

SJ. Price, AMH. Young, OM. Thomas, LA. Mohsen, AJ. Frary, VC. Lupson and MA. McLean,

Depts of Clinical Neurosciences, Radiology and Wolfson Brain Imaging Centre, University of Cambridge, UK.
Selection of Regions of Interest

DTI

p

q

rCBV

MRS
Changes in Invasive Margins vs Non-Invasive

-40% -20% 0% 20% 40% 60% 80%

Glx ml NAA Cho Cr rCBV

N.S.

* * *

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Slide courtesy of Stephen Price
Considerations

LIMITATIONS

“You always complain that I don’t know how to show my emotions, so I made these signs.”

source: www.glasbergen.com
Oedema $\Rightarrow$ reduced FA
Fiber-tracking does not accurately estimate size of fiber bundle in pathological condition: initial neurosurgical experience using neuronavigation and subcortical white matter stimulation

Manabu Kinoshita, Kei Yamada, Naoya Hashimoto, Amami Kato, Shuichi Izumoto, Takahito Baba, Motohiko Maruno, Tsunehiko Nishimura, and Toshiki Yoshimine

[Images of MRI scans with annotations]
**Objective:** To investigate the intraoperative displacement of major white matter tracts during glioma resection by comparing preoperative and intraoperative diffusion tensor imaging-based fiber tracking.

**Methods:** In 37 patients undergoing glioma surgery, preoperative and intraoperative
Atlasing location, asymmetry and inter-subject variability of white matter tracts in the human brain with MR diffusion tractography

Michel Thiebaut de Schotten a,b,c,*, Dominic H. ffytche a,b, Alberto Bizzi d, Flavio Dell’Acqua a,b,g, Matthew Allin e, Muriel Walshe e,f, Robin Murray f, Steven C. Williams b, Declan G.M. Murphy a, Marco Catani a,b
CONCLUSIONS

Take Home Messages
Conclusions

- Glioma surgery: **maximum** resection for optimal survival
  - both sensitivity and specificity are important
  - ⇒ beware false negative tracts with oedema
  - ⇒ no need to spare destroyed tracts.
- Combine DTI (-tractography) with fMRI
  - ⇒ comprehensive overview for the neurosurgeon.
- Tractography and electrocortical mapping are complementary
  - better outcome than with either technique alone
  - used to identify initial sites for stimulation
    - → more rapid localisation of eloquent cortex during surgery.
- DTI may also provide information on tumour infiltration.
Thank you for your attention
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The European Forum for MR research and clinical practice
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