Clinical Aspects of Brain Imaging

Dafna Ben Bashat Ph.D.

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The role of brain imaging methods in the clinical practice

Clinical objectives:

- Diagnosis and prognosis
- Personalized Medicine - treatment decisions
- Therapy response assessment
The role of brain imaging methods in the clinical practice

Clinical needs:

- Structural information
- Functional information
- Metabolic information
- Tissue characterization
- Monitoring plasticity
- Neuro-feedback
- Guided biopsy
1.5T clinical system – Aera

1.5T clinical system – Avanto fit

3T clinical system - Skyra

3T Research system - Prisma
Brain Imaging Methods

- **X-Ray**
  - Uses computer-processed x-rays

- **Computed Tomography**
  - Uses computer-processed x-rays

- **Magnetic Resonance Imaging**
  - Uses strong magnetic fields and radiowaves

- **Positron Emission Tomography**
  - Detects gamma rays emitted indirectly by a tracer

- **Electroencephalography**
  - Records the brain voltage fluctuations

- **Magnetoencephalography**
  - Records the brain voltage fluctuations
Brain Imaging Methods
Spatial and temporal resolution

[Diagram showing the spatial and temporal resolution of different brain imaging methods, including EEG/ERP, NIRS, MEG, optical imaging (Hb), fMRI, PET, and SPECT.]
The Electromagnetic Spectrum

Mega Hz - No ionizing radiation!
**Structural information**
Conventional methods

**MRI**

**Functional MRI**
1990 – BOLD
Functional Imaging (fMRI)

**Structural and connectivity information**
1994- Diffusion Tensor Imaging (DTI)

**Vascular imaging**
DSC / DCE / ALS
MRA / MRV

**Metabolic information**
Spectroscopy

**Structural information**
MR Electrography
MRI parameters – microstructural properties of the tissue

Post contrast enhancement
Break down of the BBB

Diffusion
MD, Da, Dr, FA
Size of the cells - tissue compartment
Cell size, Myelination, Axonal injury, Fiber organization

Relaxometry
R1, R2, R2*
Direct physical characteristic of the tissue
Water content, maturation

Perfusion – DSC& DCE
CBV, CBF, BAT, MTT
Flow, Blood/plasma volume, Permeability
Bolus arrival time, vessel maturation, VMR
Principles of MRI

Energy – RF
Gradients are used to encode location
Structural information
Conventional methods

- T1 Contrast: Short T1 - High Signal
- T2 Contrast: Long T2 - High Signal
- Proton Density Contrast
- T2*
FLAIR

$T_1$ weighted image

$T_2$ weighted image

FLAIR
Clinical use:

Structural abnormalities
Lesions / Tumors
Diagnosis, therapy response assessment....

Brain tumors - diagnosis and grading
Brain lesion – diagnosis
Structural malformations
Development / aging
Brain Development

Newborn

6 months

2 years

7 years

12 years

22 years

T1 weighted
Normal development –
Regional maturation of cortical thickness: Ages 4-21 years

Volumetric measurements

Structural measurements

Lesion volume measurements

Weizman...Ben Bashat., Med Image Comput Assist Interv. 2010
Weizman...Ben Bashat., CARS 2011

Cystic, Solid– Enhancing, and Solid- Non Enhancing
Structural information Relaxometry methods

Longitudinal (T1) relaxation

MRI Measurement

WM GM CSF

Structural information

Relaxometry methods

40p.u. 100p.u. 0.2s⁻¹ 1.5s⁻¹ 0.2p.u. 2.2p.u. 0s⁻¹ 50s⁻¹

PD* R1 MT R2*
Structural information
Conventional methods

MRI

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Metabolic information
Spectroscopy

Structural information
MR Electrography
I. Conventional Diffusion Imaging
   ♦ Hypoxic Ischemic Injury
   ♦ Differentiation between lesions

II. Diffusion Tensor Imaging - DTI
    ♦ Structural anisotropy
    ♦ Structural connectivity

III. Advanced diffusion methods
    ♦ White Matter disorders
    ♦ Developmental delay
    ♦ Structural connectivity
Diffusion Imaging

In cellular tissue the diffusion is influenced by cellular compartments.
**Diffusion Imaging**

- The Measurement of mean displacement of water molecules
- Signal intensity in the image depends on displacement during the diffusion time

Slow diffusion
Restricted diffusion?

Fast diffusion
“Free” diffusion
Clinical applications: Ischemic stroke

Fast diffusion: Large Signal Decay
Hypointensity

Slow diffusion: Smaller Signal Decay
Hyperintensity
Ischemic stroke
Brain Lesions

Brain abscess

Brain metastatic lesion with necrotic core
Anisotropy of brain diffusivity

In the brain, diffusion is not isotropic.

Fractional Anisotropy (FA) (0-1)

\[
FA = \frac{\sqrt{3}}{\sqrt{2}} \frac{\sqrt{(\lambda_1 - \lambda)^2 + (\lambda_2 - \lambda)^2 + (\lambda_3 - \lambda)^2}}{\sqrt{\lambda_1^2 + \lambda_2^2 + \lambda_3^2}}
\]

Axial diffusivity (Da)

\[Da = \lambda_1\]

Mean diffusivity

\[
\frac{S(TE)}{S_0} = \exp \left[ -\gamma^2 G^2 \delta^2 \left( \Delta - \frac{\delta}{3} \right) D \right]
\]

\[MD = (\lambda_1 + \lambda_2 + \lambda_3)/3\]

Radial diffusivity (Dr)

\[Dr = (\lambda_2 + \lambda_3)/2\]
Diffusion Tensor Imaging - DTI
3D White Matter Directionality → Tractography

DTI - Tractography

Uncinate Fasciculus

Corpus Callosum & Cingulum

Corona Radiata

Superior Longitudinal Fasciculus

Inferior Longitudinal Fasciculus

Courtesy to Prof. Y. Assaf
DTI – Analysis methods

Volume / area of interest

Probabilistic Tractography

Streamline Tractography

Voxel based / TBSS - Tract-Based Spatial Statistics
DTI – Networks Analysis