Functional Imaging: A review of fMRI, DTI and Non-invasive Perfusion Imaging

Kristine Mosier DMD, Ph.D.
Neuroradiology & Imaging Science
Department of Radiology
Clinical fMRI, Chief Head & Neck Imaging
Associate Professor of Radiology, Neuroscience and Biomedical Engineering
Indiana University School of Medicine & IUPUI

---

Overview

- Functional Brain Mapping
  - Neurophysiology and hemodynamic basis of BOLD / CBF.
  - fMRI paradigms, data acquisition and processing.
  - Clinical case examples.
- Diffusion Tensor Imaging (DTI) & Fiber-tracking.
- Non-invasive Perfusion Imaging (Arterial Spin Labeling).
- Cases

---

BOLD-fMRI
Functional Imaging: fMRI

- Brain activity can be mapped using either BOLD technique (Blood Oxygen Level Dependent) or rCBF.
- Both BOLD and CBF changes dependent on neurovascular coupling.
- BOLD signal most closely correlated with LFP (local field potentials).
- fMRI performed in the neurosurgical setting to map eloquent cortex.
Slide 7

**BOLD mechanism: summary**

- Neuronal activity → focal net increase in blood flow and oxygenation.
- Increase in focal oxygenated blood → decrease in deoxyhemoglobin → less T2* effect → increase in signal intensity.

Slide 8

![Diagram](image)

Slide 9

![Diagram](image)
Slide 10

**BOLD fMRI: contrast mechanism**

- Relative mismatch between $O_2$ delivery and $O_2$ extraction during activation period
- Blood flow is increased to activated regions of brain
- $O_2$ extraction also increased, but less than increase in $O_2$ delivery

Slide 11

**BOLD fMRI: contrast mechanism**

- Thus increased oxyHb at post-capillary level $\rightarrow$ decreased deoxyHb
- DeoxyHb is paramagnetic
  $\rightarrow$ decreases $T_2^*$ (decreases signal)
- Decrease in local deoxyHb results in increased signal intensity on $T_2^*$-wtd images (+1-5%)
Slide 13

Basis of BOLD fMRI


Slide 14

Raw Image Time Series

visual stim vs no stim

Slide 15

Difference Image Time Series

visual stim vs no stim
• Peak BOLD signal arises at the level of the post-capillary venule.
• Problem: contribution to signal from draining veins spatial, temporal artifact.
• Animal expt. at high field (e.g. 7-9T) within 200 µm of LFP.
• Humans: several studies BOLD accurate to within 1cm of electrode.
Slide 19

**fMRI Data acquisition**

- Acquire time-series of fast images while subject performs sensorimotor, language or cognitive task.
- Process time-series data using statistical methods & compare signal change during task performance with signal during rest / baseline.
- **Accurate processing**: need to remove drift, motion, physiological noise.

Slide 20

**fMRI: Study Overview**

1. Patient Preparation
2. Paradigm Design
3. Data Acquisition
4. Image Reconstruction and Processing
5. Statistical Maps Computation
6. Visualization of Maps and Analysis
7. Workstation
8. Data Transfer

Slide 21

[Image of brain scan with text: Blood Oxygenation Level-Dependent (BOLD) 2D]

- Acquired Image
- Dynamic BOLD
- Blood Flow-Time Curve
Slide 22

Slide 23

Slide 24
Slide 25

Slide 26

Slide 27
Slide 28

Slide 29

Slide 30
Slide 31

fMRI Post-Processing: FT paradigm

Mean + T-map

Slide 32

fMRI Post-Processing: FT paradigm

GLM

Slide 33

fMRI: Typical Tasks

- Sensorimotor
  - Gross motor: Finger-tapping, tongue tapping
  - Fine motor: object manipulation (Mosier)
  - Sensory: Visual field / retinotopic mapping
- Language: expressive & receptive speech
  - Expressive speech: Word generation, Object naming, Rhyming
  - Receptive speech: Passive Listening, Rhyming
- Memory: Working memory
- Other: Swallowing / articulated speech (Mosier)
- Not yet standardized: ASFNR working on that!
Slide 34

**fMRI: Choice of Tasks**

<table>
<thead>
<tr>
<th>Location</th>
<th>Gross Motor</th>
<th>Fine Motor</th>
<th>Language</th>
<th>Visual Field</th>
<th>Working Memory</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frontal</td>
<td>+</td>
<td>+/-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parietal</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temporal</td>
<td>+/-</td>
<td>+</td>
<td>+/-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Occipital</td>
<td>+</td>
<td>O/Nect</td>
<td>Naming</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Insular</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td>+</td>
</tr>
</tbody>
</table>

Slide 35

**fMRI: Patient Selection**

- Intracranial lesion requiring eloquent cortex mapping.
- Patient able to undergo MR imaging at 1.5T or 3T (only 3T at IUPUI).
- AVM patients: specific clips not safe @ 3T.
- Stents: not all safe @ 3T
- Body habitus
- Claustrophobia
- Able to speak & understand English
- Able to read @ 6th grade level.
- Peds +/-

Slide 36

**Clinical fMRI: Neurosurgical Mapping**
Case 1: Oligodendroglioma; Bilateral Finger tapping

Central sulcus

Pre-central gyrus

Case 1: Oligodendroglioma; Object manipulation - right hand: fine motor, sensory - tactile, proprioception

Case 1: Oligodendroglioma Language: Word Generation: speech execution
Case 1: Oligodendroglioma Language: Naming; semantic language: speech reception and execution

Case 1: Oligodendroglioma Language: Rhyming; semantic language

Case 2: Finger-tapping
Slide 43

Case 2: Object Manipulation

Slide 44

Case 2: Working Memory

Slide 45

fMRI Brain Mapping

Advantages:
- Non-invasive mapping of eloquent cortex w/ maps co-registered to anatomical images.
- In many institutions, this has completely replaced WADA testing.

Disadvantages:
- Not all subjects are candidates: MRI safety, patient must be awake & cooperative, pediatrics.
- Requires a team with expertise: neuroradiology, neurosurgery, neuroradiologist, MRI physicists, image processing specialists, etc.
- Indirect measure of neuronal activity.
Case 4: Oligoastrocytoma < Gr III

Left Chkbd

Right Chkbd

Face Matching

DIFFUSION
Slide 58

- Anisotropic Diffusion
- Parallel Fibers

Slide 59

- Measuring the tissue of the diffusion tensor
- Measuring diffusion using a diagonal axis

Slide 60

**DTI**

Diffusion weighted gradients must be applied in multiple directions to obtain the information required to generate the Diffusion Tensor (D).

\[
D = \begin{bmatrix}
D_{xx} & D_{xy} & D_{xz} \\
D_{yx} & D_{yy} & D_{yz} \\
D_{zx} & D_{zy} & D_{zz}
\end{bmatrix}
\]

Eigenvectors

Eigenspectrum
Slide 61

Slide 62

Slide 63

Case 5 - DTI/FA
Case 6: 54 y.o. w/partial complex seizures & speech arrest

Case 6: Bilateral Finger-tapping

Case 6: Word Generation