Pre-surgical planning for brain tumor resection using functional MRI

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Our patient: clinical history

85-year-old right-handed woman presents s/p fall with occipital head strike

Denies LOC or pre-syncopal symptoms. Endorses eight month history of falls secondary to progressive left-sided weakness and loss of balance.

PMHx: CAD, DM2, HTN, RCC s/p nephrectomy in 1999

Physical exam: notable for intact CN, diffuse left-sided weakness, unsteady gait. No sensory deficits. Labs unremarkable.
Our patient: Right parietal lesion on CT

- Central focus of hyper-attenuation
Our patient: Surrounding edema

- Central focus of hyper-attenuation
- Substantial surrounding edema
Our patient: Sulci effacement

- Central focus of hyper-attenuation
- Substantial surrounding edema
- Mass effect with sulci effacement
Our patient: Other findings

- Central focus of hyper-attenuation
- Substantial surrounding edema
- Mass effect with sulci effacement
- Minimal midline shift
- No fractures or other acute findings
Our patient: Differential diagnosis

- **Differential Dx:**
  1. Hemorrhagic infarct
  2. Hemorrhage into underlying mass lesion

- Well-circumscribed lesion, chronicity of symptoms => suspect hemorrhage into mass
Our patient: Intracranial hemorrhage on C- MRI

- Mild degree of T1 hyperintensity
Intracranial hemorrhage on C+ MRI

- Moderate degree of lesion enhancement
- Uncharacteristic of hemorrhagic infarct
- Consistent with contrast uptake by abnormal tumor vasculature

MRI head T1/ C+
Our patient: Approach to management

- Additional body imaging with CT:
  - Masses found in lung & breast
  - No masses found in remaining kidney or at prior surgical site

- Etiology of brain tumor unclear
  - Metastasis from occult RCC?
  - New primary brain tumor?
  - Metastasis from other site?

- Neurosurgical resection was recommended to decompress, reduce edema, improve local control, and biopsy
Frontoparietal tumors

- Neurosurgical resection often indicated, but carries risk of injury to:
  - Primary motor cortex in precentral gyrus and/or descending corticospinal tract
  - Frontal language regions if lesion is in dominant hemisphere (Broca’s area in orpeculum)

- Chief concern is paralysis and loss of speech and language

- Preoperative mapping of these areas could assist in surgical planning and reduce risk of injury
Pre-surgical planning:

*What does the neurosurgeon want to know?*

- Distance between tumor margin and essential functional areas
  - "Golden rule" says minimum distance 10 mm to preserve function
- Trajectory to tumor that avoids functional area (if one exists)
- With this information surgeon can:
  1. Determine if tumor is amenable for resection
  2. Decide if intraoperative cortical stimulation is needed
  3. Better navigate surgical procedure itself
- So-called "functional MRI" is a noninvasive approach that can safely identify essential functional areas in advance of surgical intervention
What is functional MRI (fMRI)?

“fMRI is a technique for determining which parts of the brain are activated by different types of physical sensation or activity, such as sight, sound or the movement of a subject's fingers.”

- Steve Smith, FMRI B, Oxford
Approach to fMRI

- Subjects are continuously imaged while performing specifically timed “tasks”

- Tasks are chosen based on neural system we wish to interrogate. Examples include:
  - Motor => Finger or foot-tapping
  - Visual => Viewing flashing checkerboards

- Analysis of images allows creation of statistical maps that localize task-based neural activity to corresponding brain regions
How is neural activity reflected in the MRI signal?

(i.e. how does fMRI work!!)
Contents of brain MRI voxel: *Parenchyma*

*Voxel = volumetric picture element*
Contents of brain MRI voxel: Microvasculature

Voxel = volumetric picture element

Van Zijl et al, Nat Med, 1998
From neural activity to MRI signal:
Microvasculature in brain voxel
From neural activity to MRI signal: Oxygen delivery via cerebral blood flow

- At baseline, cerebral blood flow (CBF) supplies oxygen-rich blood to capillary bed.
From neural activity to MRI signal: Oxygen delivery via cerebral blood flow II

- Chief oxygen-carrier is the macromolecule hemoglobin in red blood cell (RBC)
- Oxygenated hemoglobin is called oxyhemoglobin (HbO₂)
From neural activity to MRI signal: Oxygen extraction and consumption

- As blood traverses capillary bed, oxygen is extracted from HbO₂ into tissue and consumed.
From neural activity to MRI signal:
Venous deoxygenated hemoglobin (dHb)

- Deoxygenated hemoglobin (dHb) subsequently results on venous side.
From neural activity to MRI signal: Effects of dHb on MRI signal

- dHb is paramagnetic and perturbs the magnetic field
- Decreases baseline MR signal
From neural activity to MRI signal:
Stimulation increases neuronal activity

- During stimulation (e.g. from a task) **neuronal activity increases**
From neural activity to MRI signal:
Secondary increase in CBF flushes out dHb

- A secondary increase in CBF follows
- Increased CBF delivers more HbO₂ and *flushes out venous dHb*
From neural activity to MRI signal:
Reduction in dHb increases MR signal

- Decreased dHb results in a smaller field perturbation and an increase in MR signal
MR signal intensity: Baseline State

\[ [dHb] = 40\% \]
MR signal intensity: Activated State

This is the blood oxygen level dependent (BOLD) effect and is the basis for fMRI!
Sample “block-design” fMRI task:
Right handed finger-tapping

Acquire low-resolution MR images every two seconds

MR signal from left motor cortex
Generation of statistical map shows “activated voxels”
Central voxel with highly significant activation
Peripheral voxel with less significant activation
Our patient: fMRI protocol

- Use similar “block-design” fMRI paradigm
- Include:
  - Motor task: LH finger-tapping
  - Language: Verb repetition
Our patient:
Activation from *LH finger-tapping*
Our patient: *Primary motor cortex*
Our patient: **Supplementary motor cortex(?)**
Our patient: Activation from *Verb repetition*

- Activation seen in operculum frontale; location consistent with *Broca’s Area*
- *Suggests patient has left hemispheric dominance*
- Reduced risk of language impairment with resection of right-sided lesion.
Our patient: Surgical planning

- Tumor margin 5 mm away from motor activation strip
- Unobscured oblique trajectory available for direct approach
Our patient: Pre-post op comparison
Our patient: Post-operative changes

- T1 hyperintensity consistent with post-operative blood and proteinaceous material
- Thin rim of enhancement could be post-op change, but residual tumor cannot be excluded
Our patient: Outcome

- Patient initially had increased left-sided weakness post-operatively
- Not surprising given proximity of tumor to motor cortex
- Improved over time
- Preliminary pathology suggested metastasis from renal cell carcinoma
- She was discharged and will see oncology to discuss chemotherapy options
Summary

- Functional MRI can be useful tool for preoperative planning and assessment for brain tumor resection.
- fMRI creates “activation maps” which correlate to neural activity patterns.
- Link between neural activity and MRI signal arises from increased blood flow flushing out paramagnetic dHb during stimulation.
- Use of maps allow surgeons to:
  1. Assess resectability of tumors near essential functional areas.
  2. Decide if intraoperative cortical stimulation is needed.
References

- Sunaert S. Presurgical planning for tumor resectioning. JMRI. 2006; 23:887-095.
Acknowledgements

Thanks to:

- Rafael Rajos MD, Neuroradiology, BI DMC
- Ted Brewer MD, Neuroradiology, BI DMC
- Gillian Lieberman MD, Radiology, BI DMC
- Emily Hanson, Radiology, BI DMC