Advanced MRI in the Clinic : Functional MRI (*f*MRI)

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MD Anderson Cancer Center
Making Cancer History®

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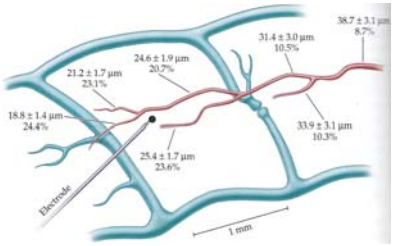
Declaration of Financial Interests or Relationships

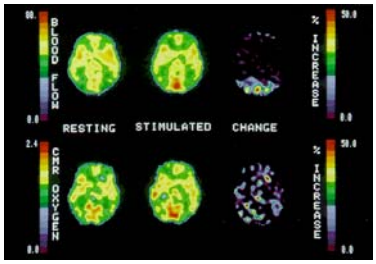
I have no financial interests or relationships to disclose with regard to the subject matter of this presentation.

Neuronal activity → Vascular response → Blood oxygenation increase

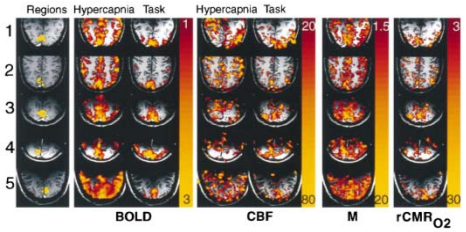
- Energy required by neuronal activity is generated from cerebral metabolism of glucose and oxygen.
- Metabolic demand requires increase in blood flow.
- Blood flow brings more oxygen than needed.



Huettel, Song and MacCarthy, Functional MRI, 2nd Ed.

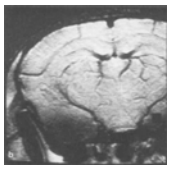


Fox et al., Science, 1988

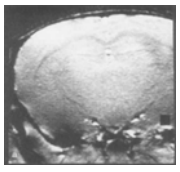


Davis et al., PNAS, 1998

Blood Oxygenation Level-Dependent (BOLD) *f*MRI



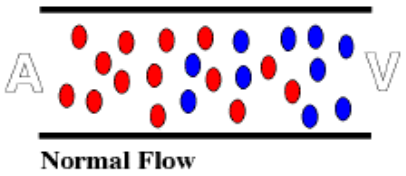
Inhalation of normal air



Inhalation of pure O_2

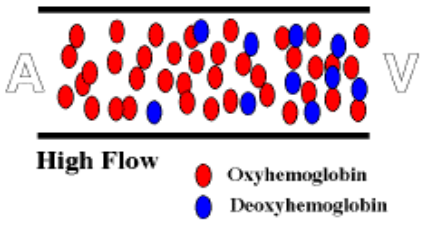
Ogawa et al., PNAS, 1990
Ogawa et al., MRM, 1990

Baseline



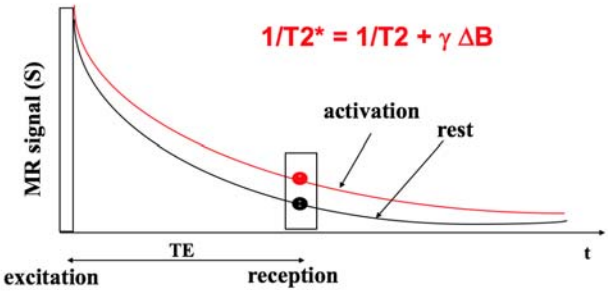
Low BOLD signal

Activation



High BOLD signal

BOLD *f*MRI w/ T2*-weighted GRE-EPI



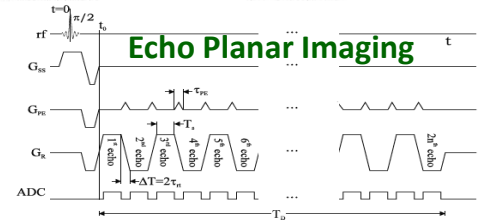
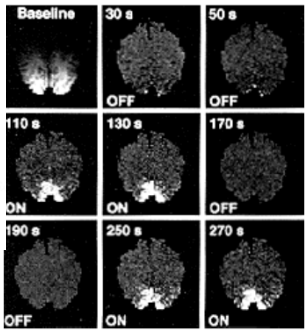
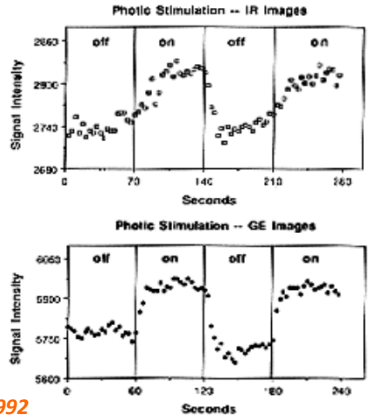


Figure adopted from Haacke et al., 1st Ed, 1999



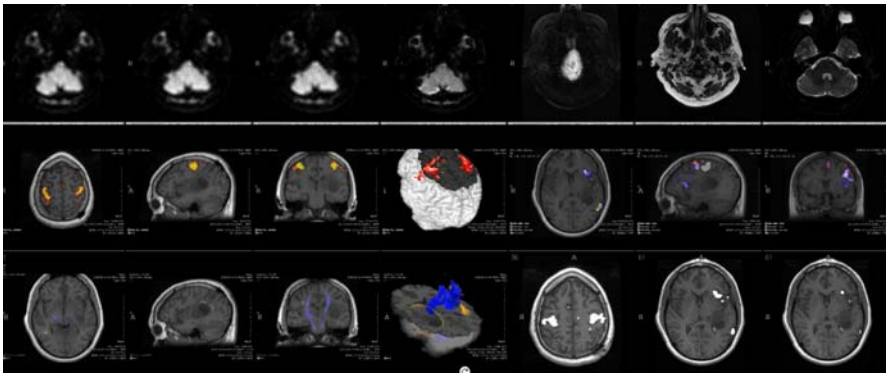


Kwong et al., PNAS, 1992

Introduction Implementation Limitations

CPT Codes

70554: Magnetic resonance imaging, brain, functional MRI; including test selection and administration of repetitive body part movement and/or visual stimulation, not requiring physician or psychologist administration
70555: Magnetic resonance imaging, brain, functional MRI; requiring physician or psychologist administration of entire neurofunctional testing
96020: Neurofunctional testing selection and administration during noninvasive imaging functional brain mapping, with test administered entirely by a physician or psychologist, with review of test results and report.



https://www.asfnr.org/cpt-codes/

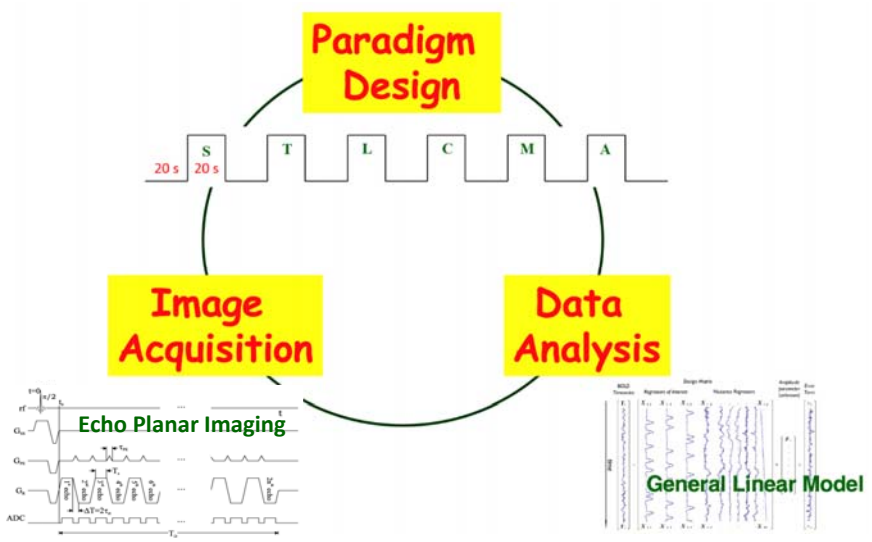
A presurgical fMRI/DTI example from MDACC

Introduction Implementation Limitations

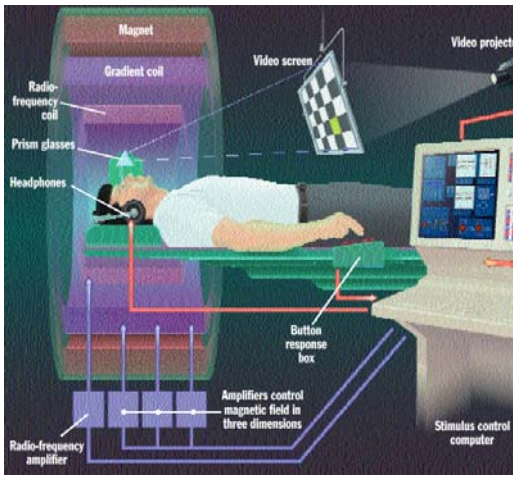
Implement a clinical *f*MRI program

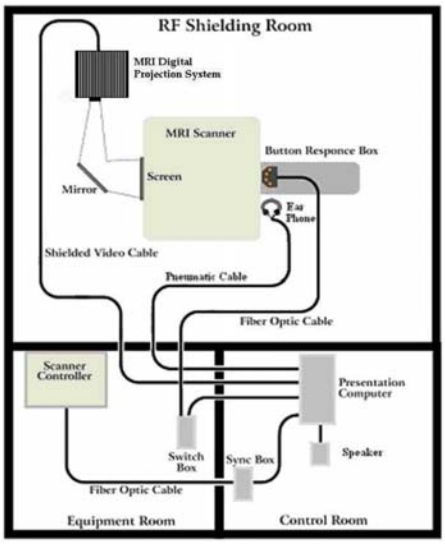
It's a Team work:

- **Neuropsychologist**
- **Neuroradiologist**
- **Neurosurgeon**
- **Physicist**
- **Specialized Technologist**



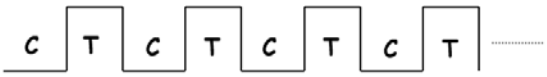
Need special hardware/software





- **Real-time fMRI**
- **Post-processing:**
  - **Vendor software**
  - **FDA-cleared 3rd party software**
  - **Research software (AFNI, FSL, SPM etc.)**

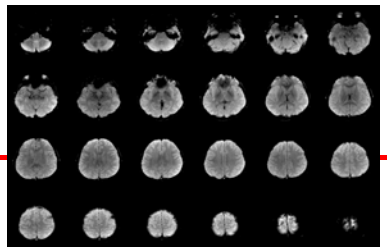
Paradigm design



- Blocked design: more common for clinical *f*MRI
- Block duration: 10 - 30 s
- Number of cycles: 3 - 6
- Task block:
  - Motor: hand, toe, tongue …
  - Visual: checkerboard stimulation …
  - Speech: word generation, letter fluency, sentence completion …
- Control block:
  - fixation, visual, motor …

Image Acquisition

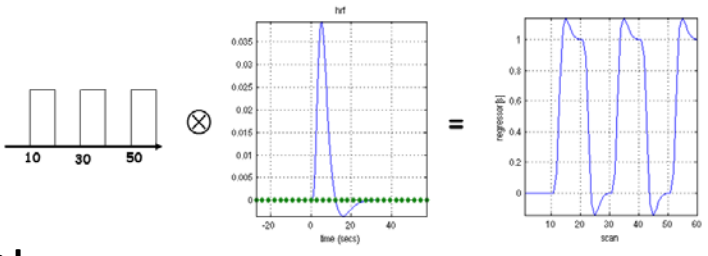
- Typical *f*MRI protocol at 3T:
  - Single-shot GRE-EPI
  - TR = 2-3 s (<=2s for er- and rs-)
  - TE = 25-35 ms
  - FA = 70-90^0
  - matrix size = 64-128 (w/ PI)
  - in-plane resolution = 2-4 mm
  - slice thickness = 3 - 5 mm
  - 25-45 slices
  - dynamics = 60-150
  - scan time = 3-5 min

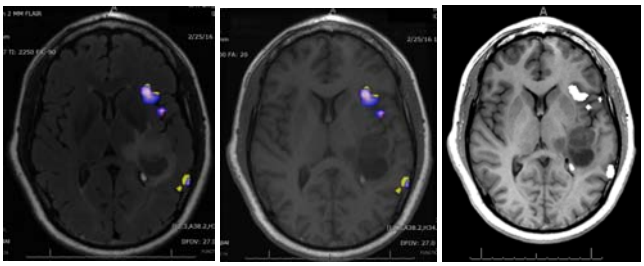


Introduction Implementation Limitations

*f*MRI data analysis

- **Data pre-processing**
  - **Motion correction**
  - **(Slice timing correction)**
  - **(Spatial normalization)**
  - **Spatial smoothing**
  - **(Temporal filtering)**
- **Activation maps: statistical analysis I**
  - **Correlation/GLM analysis**
  - **Thresholding (intensity / cluster size)**
- **Group analysis: statistical analysis II**
  - **Voxel-based analysis**
  - **ROI analysis**
- **Data reporting and visualization**





Introduction Implementation Limitations

Agreement with intraoperative stimulation /Specification to eloquent areas

- Task-*f*MRI performs well for motor mapping
- For speech-*f*MRI, agreement with direct cortical stimulation is moderate.
- Task in general will activate more areas than eloquent cortices.

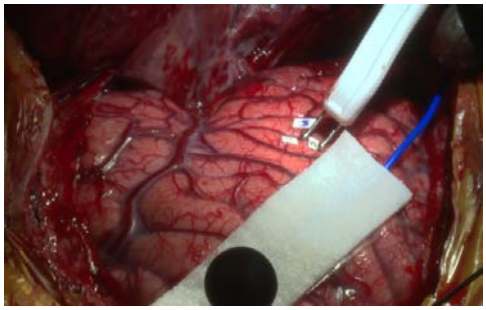
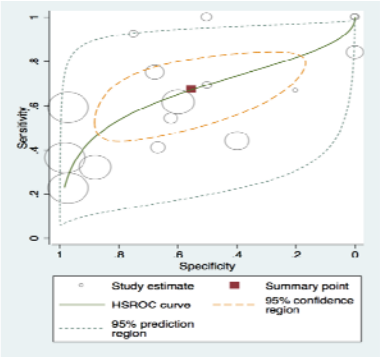


Photo from Sujit Prabhu, MD

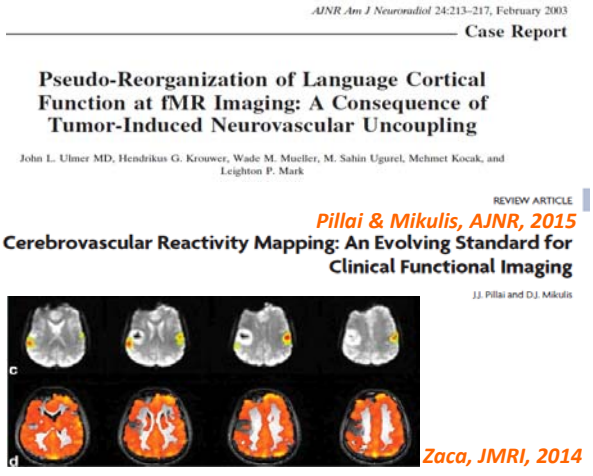
Accuracy of Presurgical Functional MR Imaging for Language Mapping of Brain Tumors: A Systematic Review and Meta-Analysis[1]

Sensitivity = 67%
Specificity = 55%

Weng, Radiology, 2018



Patient related (Performance/Impaired neurovascular coupling)



AJNR Am J Neuroradiol 24:213–217, February 2003

Case Report

Pseudo-Reorganization of Language Cortical Function at fMR Imaging: A Consequence of Tumor-Induced Neurovascular Uncoupling

John L. Ulmer MD, Hendrikus G. Krouwer, Wade M. Mueller, M. Sahin Ugurel, Mehmet Kocak, and Leighton P. Mark

Pillai & Mikulis, AJNR, 2015

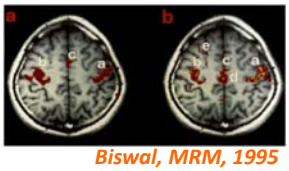
REVIEW ARTICLE

Cerebrovascular Reactivity Mapping: An Evolving Standard for Clinical Functional Imaging

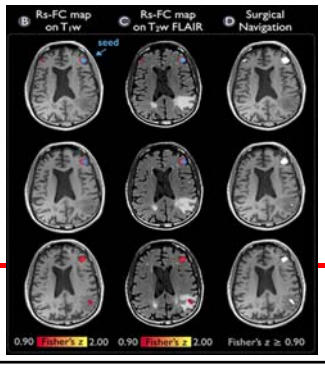
JJ. Pillai and DJ. Mikulis

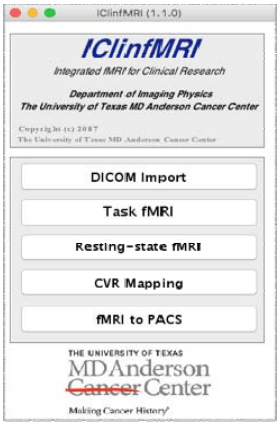
Zaca, JMRI, 2014

Resting-state *f*MRI



Biswal, MRM, 1995

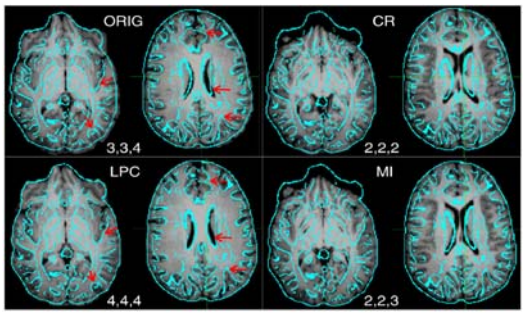




Hsu, Front Neuroinform, 2018

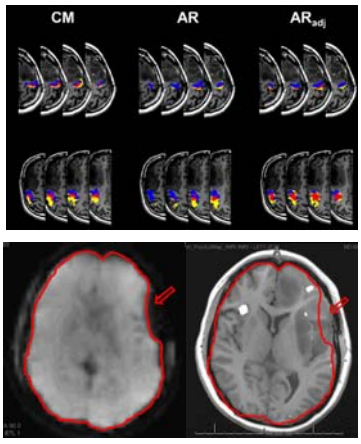
Image registration

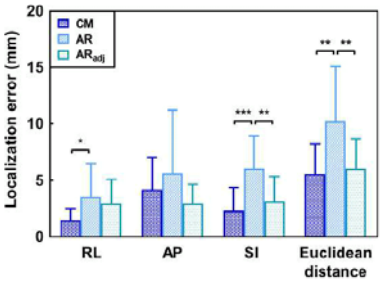
- Low-resolution EPI to high-resolution 3DT1
- EPI distortion is often worsened by previous surgery



1 - very poor alignments
2 - errors ~ > 5 mm
3 - errors 2-5 mm
4 - ~ 2 mm

Zaad, NeuroImage, 2009



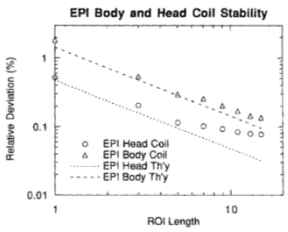


CM: coordinate matching
AR: Automated registration
AR$_{adj}$: AR with manual adjustment

Jen, Med Phys, 2018

Instability and noise

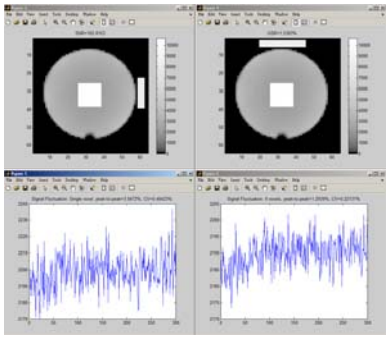
- Random noise: False negative
- Task-correlated noise: False positive

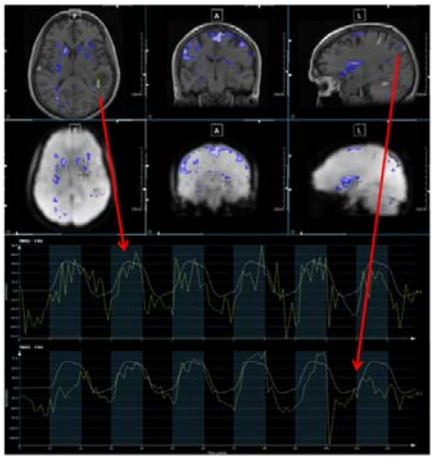


Weisskoff, MRM, 1996

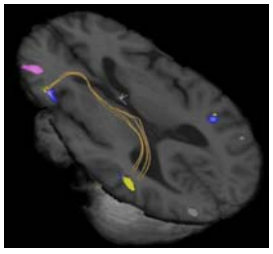
Signal stability testing

AAPM Report #100





Statistical thresholding remains a challenge!



LETT P<10^{-4}
CAT P<10^{-3}
SENT P<10^{-3}

Summary

- BOLD-*f*MRI using T2*-weighted GRE-EPI can reliably detect brain activations.
- Presurgical *f*MRI has become a routine clinical procedure.
- Presurgical *f*MRI is a team work and requires additional hardware and software.
- Understand limitations of clinical *f*MRI is important:
  - Difference with direct cortical stimulation
  - Patient performance of the task
  - Impaired neurovascular coupling
  - Image distortion and registration
  - Noise and signal instability

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Acknowledgement

Thank you for your attention!!

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