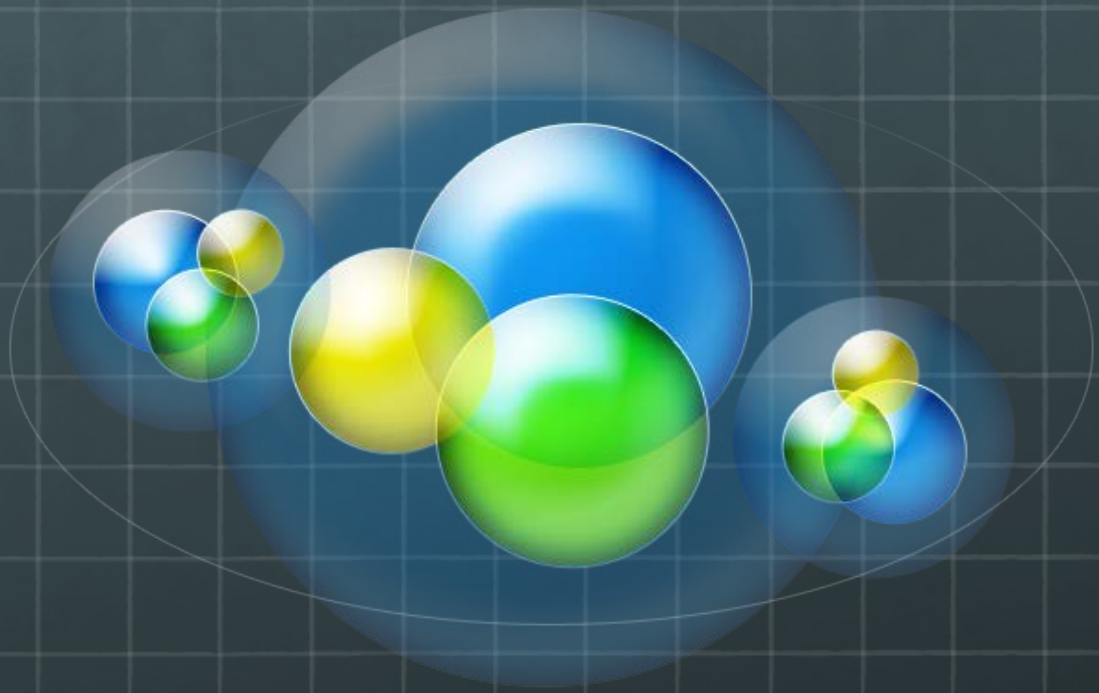


Perfusion MRI Toolbox

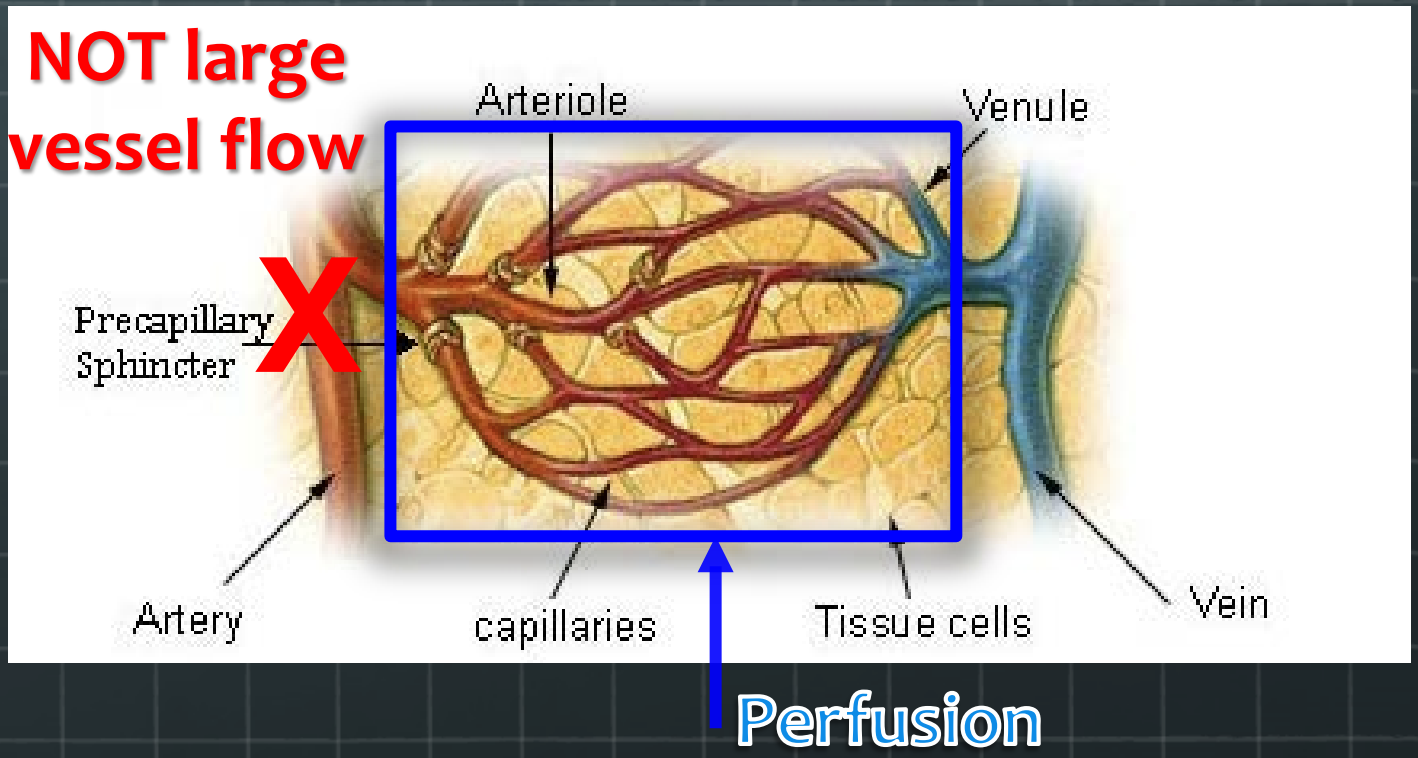
Kathleen M. Schmainda, PhD
Professor, Radiology & Biophysics
Vice-Chair, Radiology Research
Medical College of Wisconsin

Human Placenta Project

May 27-28th, 2014

Perfusion-MRI Definition

- Delivery of Blood Flow to tissue



Perfusion-MRI Methods

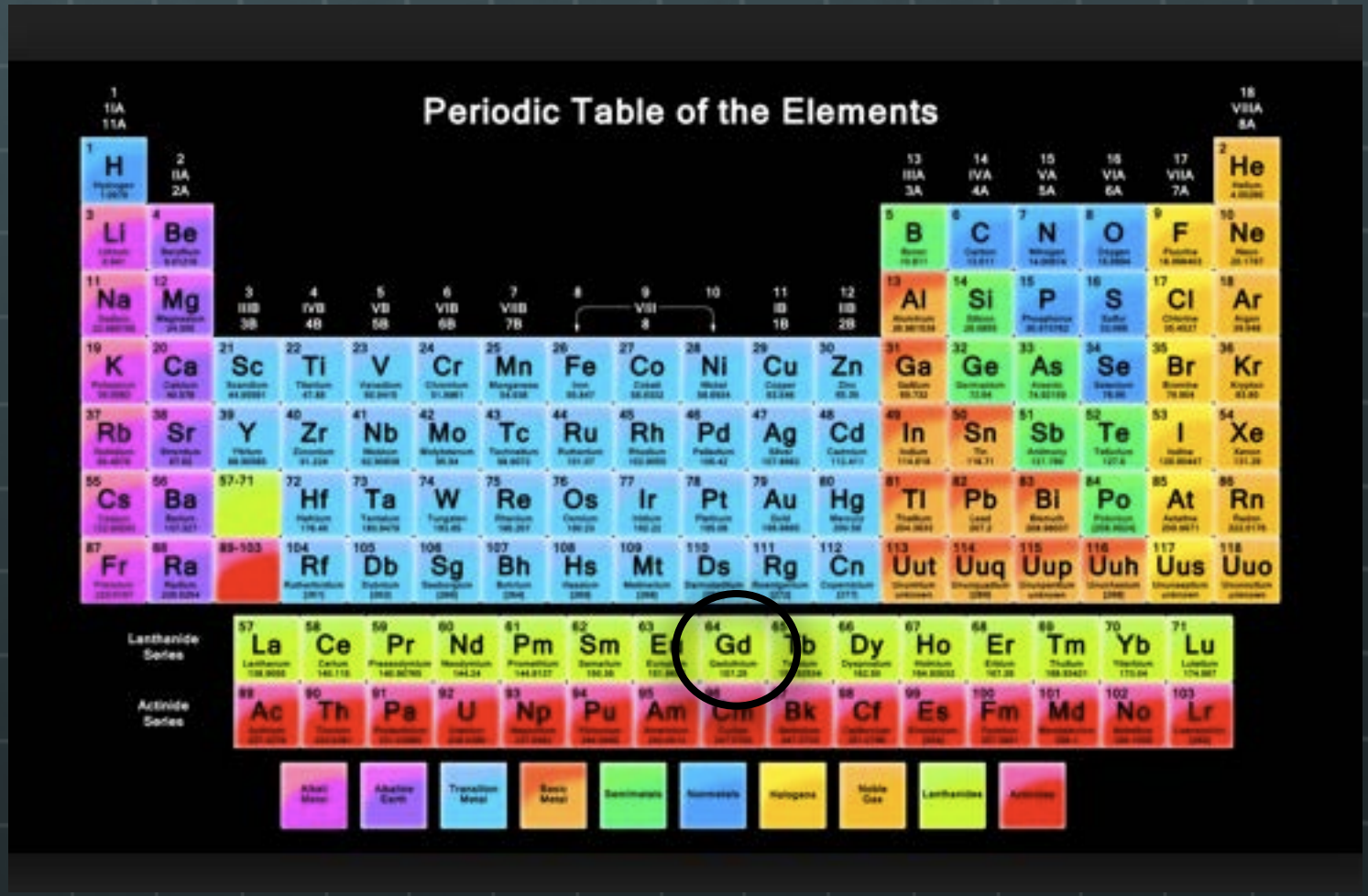
- Dynamic Contrast Enhanced (DCE-MRI)
- Dynamic Susceptibility Contrast (DSC-MRI)

Exogenous Contrast

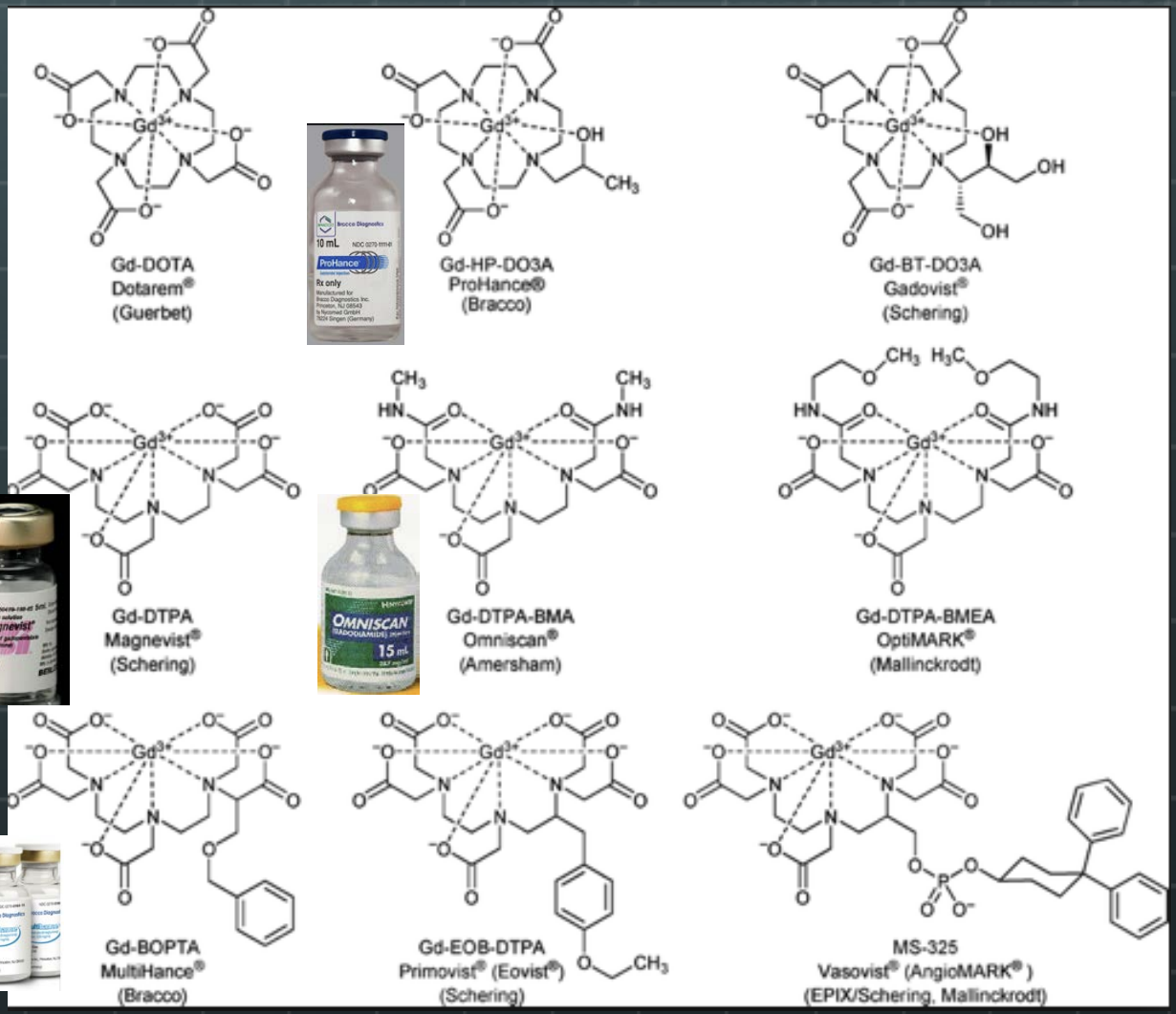
- ASL: Arterial Spin Labeling
- BOLD: Blood Oxygenation Level
- IVIM: Intravoxel Incoherent Motion

Endogenous Contrast

Introduction: Gadolinium



Introduction: Gadolinium



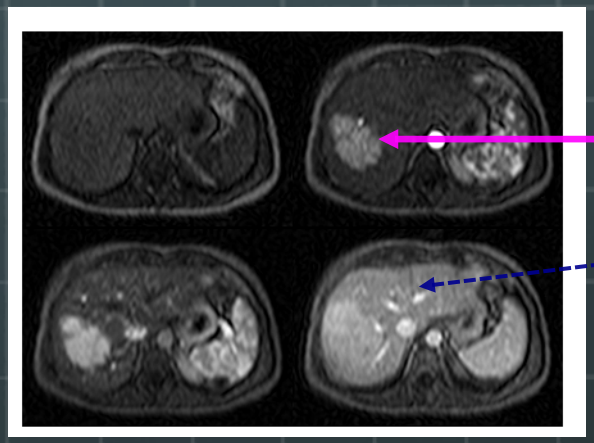
Gd-enhanced MRI

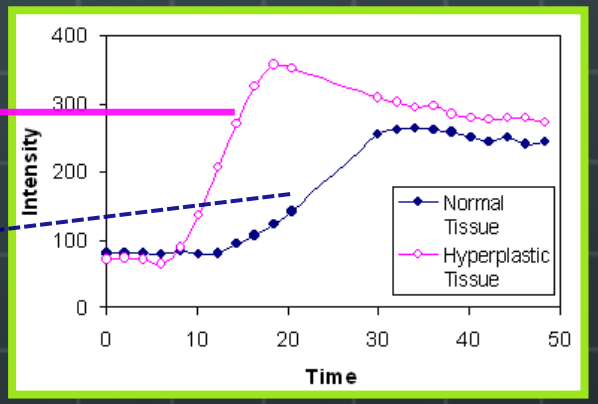
T1-weighted MRI

T1-weighted MRI with contrast agent

Dynamic Approaches

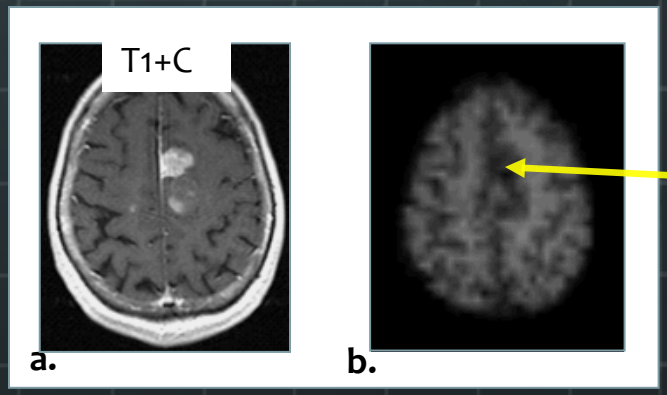
- Dynamic Contrast Enhanced (DCE-MRI)

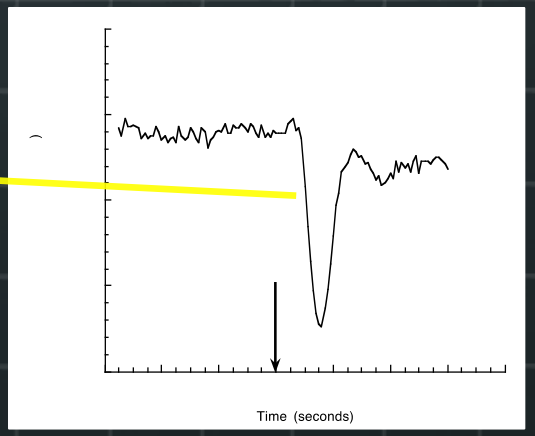




"T1" Brighter

- Dynamic Susceptibility Contrast (DSC-MRI)



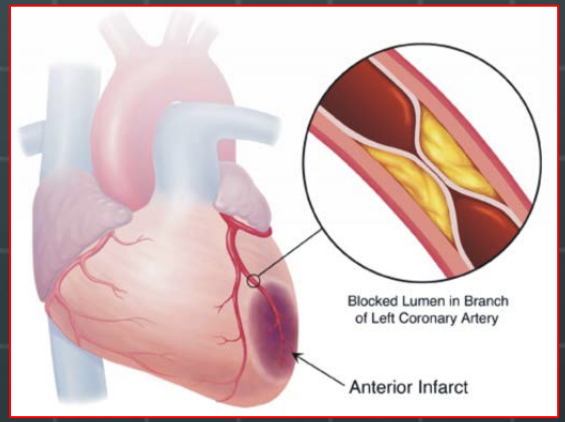


"T2" Darker

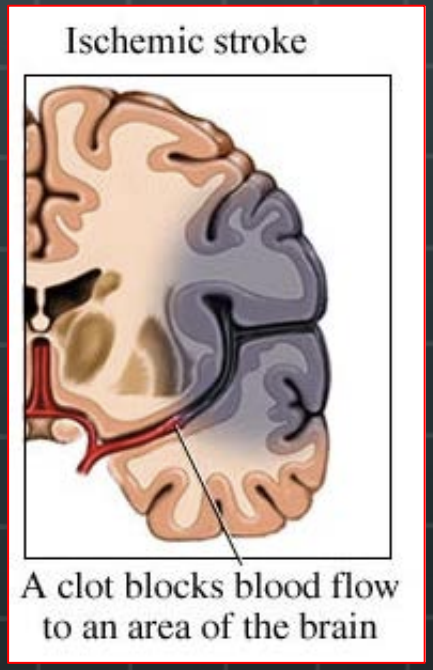
Two Primary Applications

- **Ischemia:**

Cardiac Ischemia

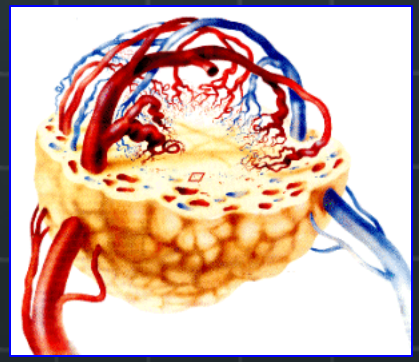


Cerebral Ischemia



- **Cancer:**

Tumor Angiogenesis



Perfusion-MRI Methods

- Dynamic Contrast Enhanced (DCE-MRI)
- Dynamic Susceptibility Contrast (DSC-MRI)

Exogenous Contrast

- ASL: Arterial Spin Labeling
- BOLD: Blood Oxygenation Level
- IVIM: Intravoxel Incoherent Motion

Endogenous Contrast

Perfusion-MRI Methods

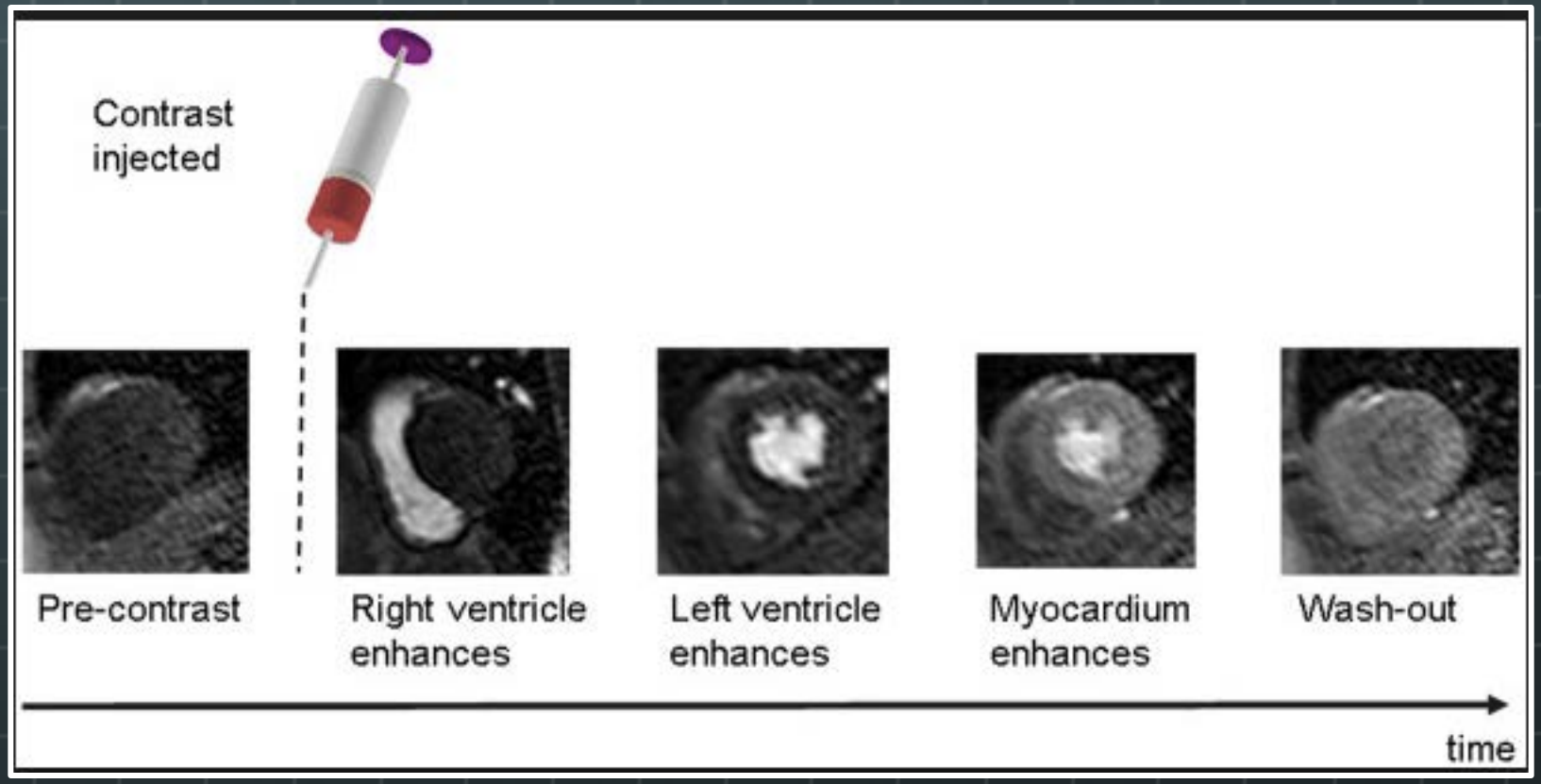
- Dynamic Contrast Enhanced (DCE-MRI)
- Dynamic Susceptibility Contrast (DSC-MRI)

Exogenous Contrast

- ASL: Arterial Spin Labeling
- BOLD: Blood Oxygenation Level
- IVIM: Intravoxel Incoherent Motion

Endogenous Contrast

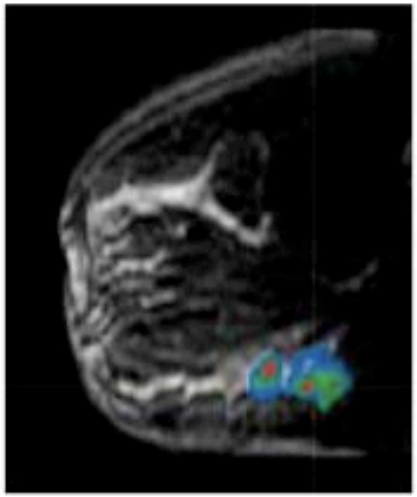
Cardiac DCE-MRI

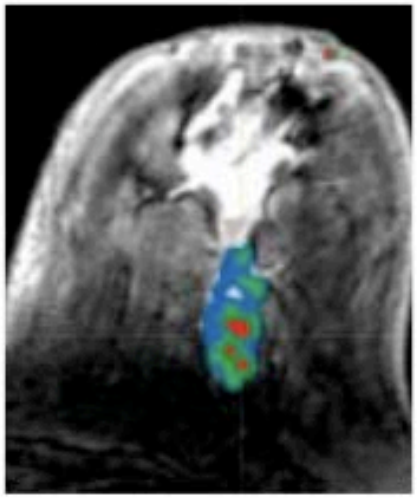


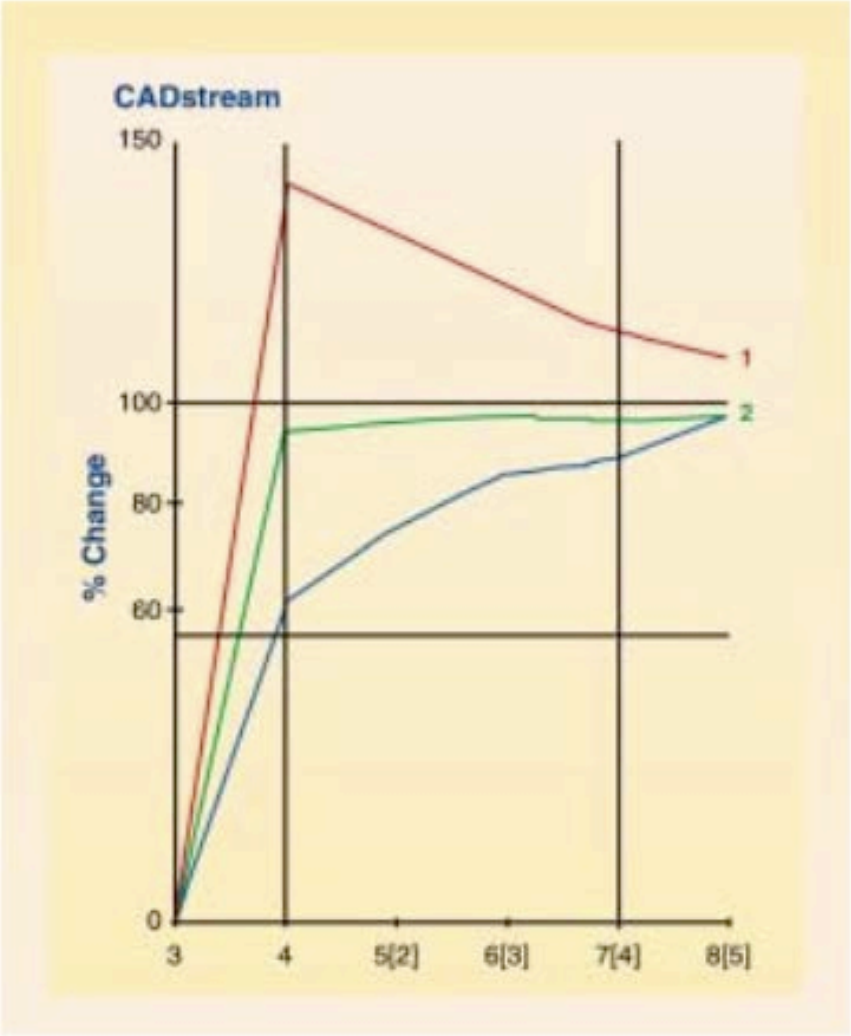
Journal of Cardiovascular Magnetic Resonance 2012 14:66

Breast DCE-MRI

Confirma™



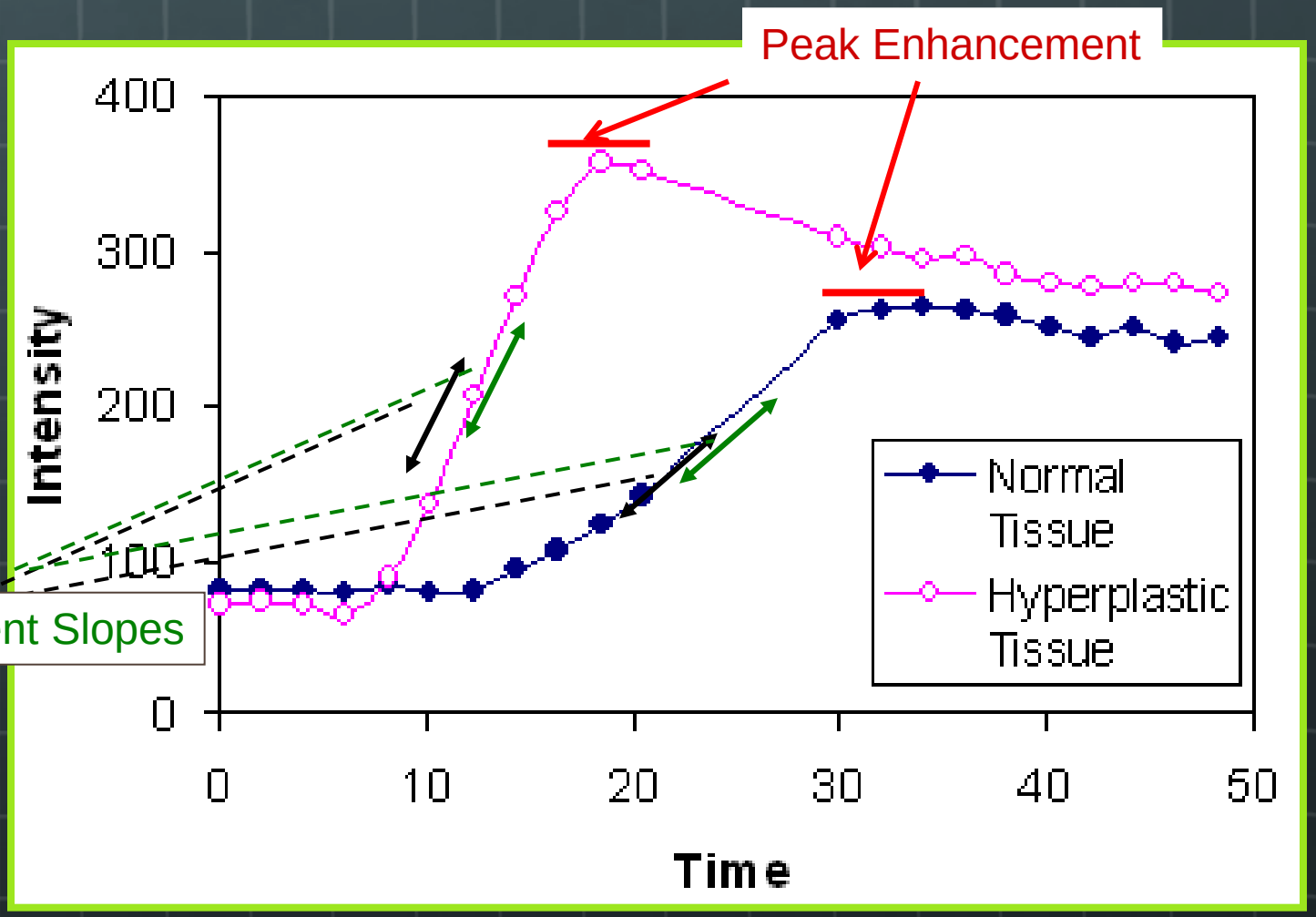




◄Figure 2. These CADstream real-time dynamic contrast curves of MRIs from the same patient as in Figure 1, interactively demonstrate contrast uptake and washout levels representative of the tissue demonstrating anolgenesis. Based on the work of Christiania K. Kuhl, MD, red washout type curves are more commonly seen with invasive neoplasms than are green curves, and green curves are more commonly associated with invasive neoplasms than are blue curves. Image courtesy of Fir Hill Diagnostic Imaging, Seattle, Washington.

▼ Figure 3. CADstream maximum intensity projection (MIP) image. This feature allows radiologists to view enhancing lesions in three dimensions. Clinical image courtesy of First Hill Diagnostic Imaging, Seattle, Washington.

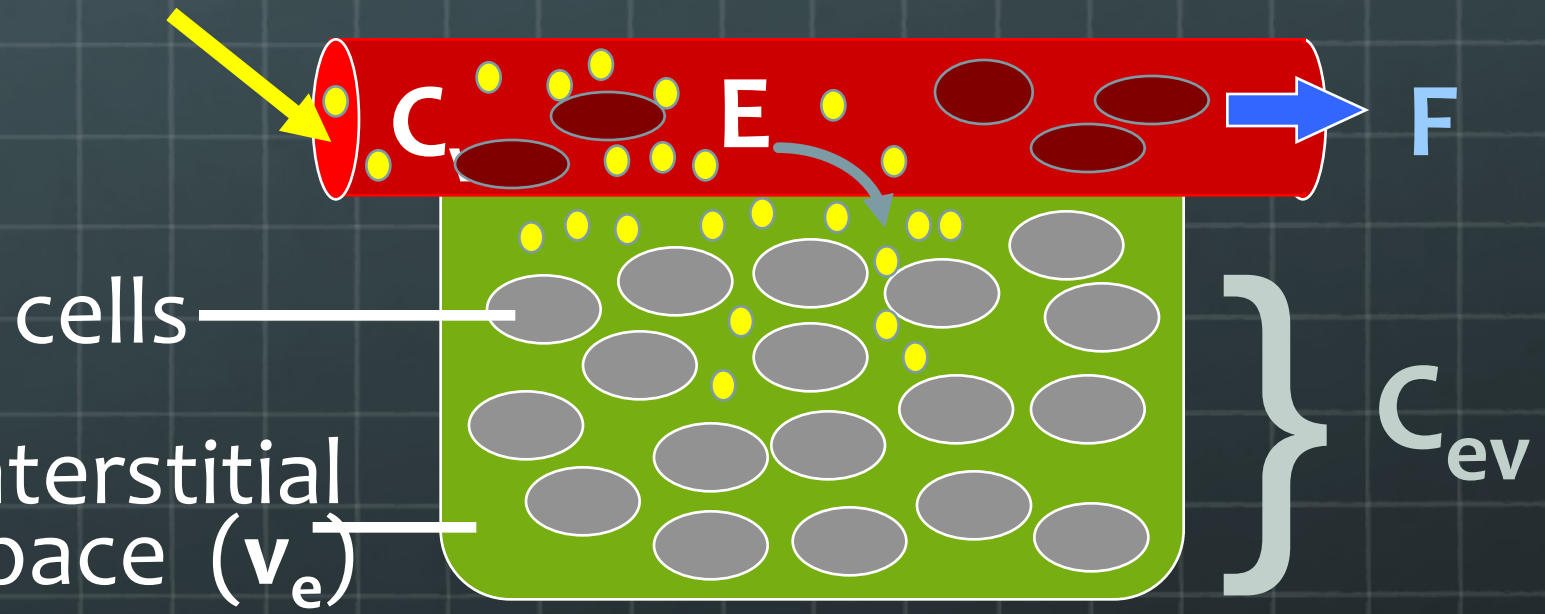
Liver DCE-MRI



Erasmus MC, Biomedical Imaging Group, Rotterdam

Contributions to Intensity Changes:

Gd-DTPA



Consensus *Tofts* Model:

JOURNAL OF MAGNETIC RESONANCE IMAGING 10:223–232 (1999)

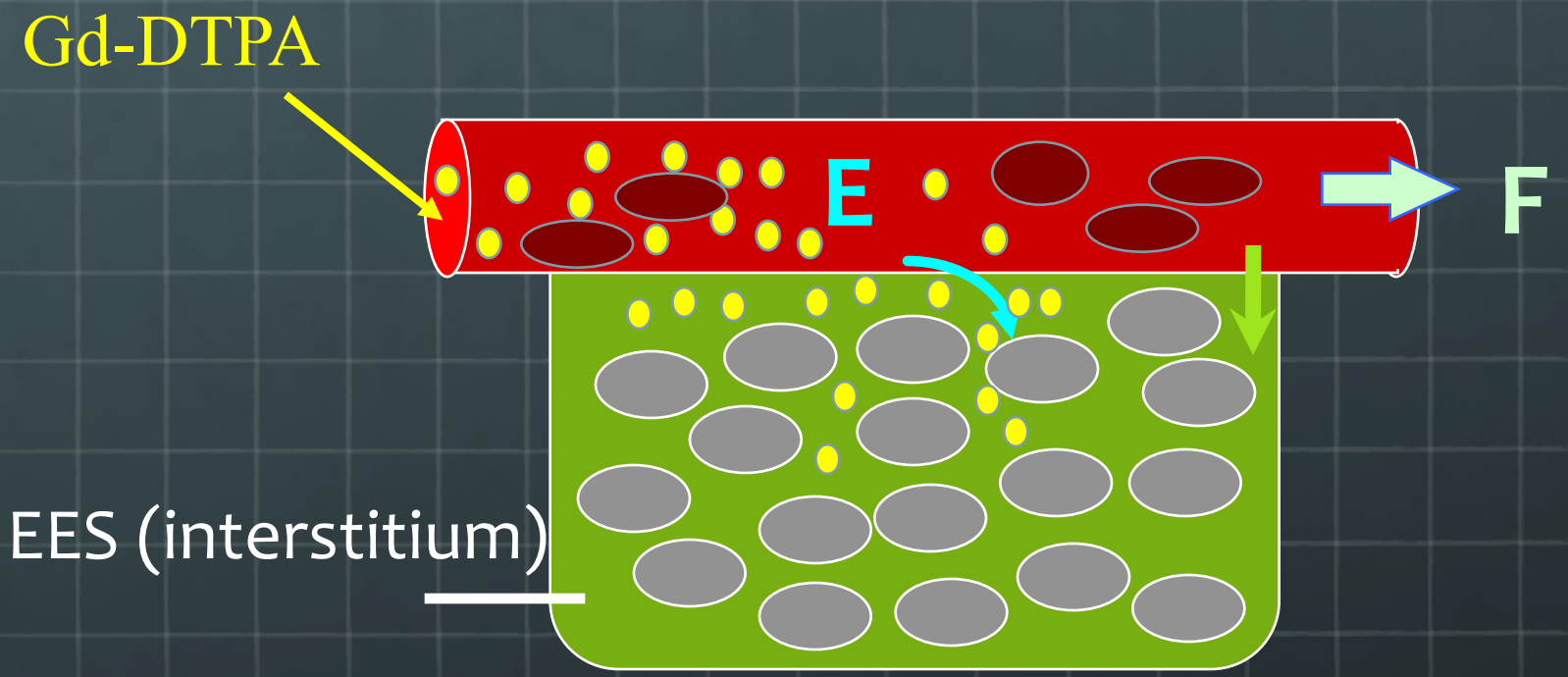
Review

Estimating Kinetic Parameters From Dynamic Contrast-Enhanced T_1-Weighted MRI of a Diffusable Tracer: Standardized Quantities and Symbols

Paul S. Tofts, DPhil,[1]* Gunnar Brix, PhD,[2] David L. Buckley, PhD,[3] Jeffrey L
Elizabeth Henderson,[5] Michael V. Knopp, MD,[6] Henrik B.W. Larsson, MD,[7]
Ting-Yim Lee, PhD,[5] Nina A. Mayr, MD,[8] Geoffrey J.M. Parker, PhD,[1]
Ruediger E. Port, MD,[6] June Taylor, PhD,[9] and Robert M. Weisskoff, PhD[10]

$$C_t(t) = K^{trans} \int C_p(\tau) e^{\left(-K^{trans}/v_e\right)(t-\tau)} d\tau$$

Delivery of Gd-based contrast agent to tissue:

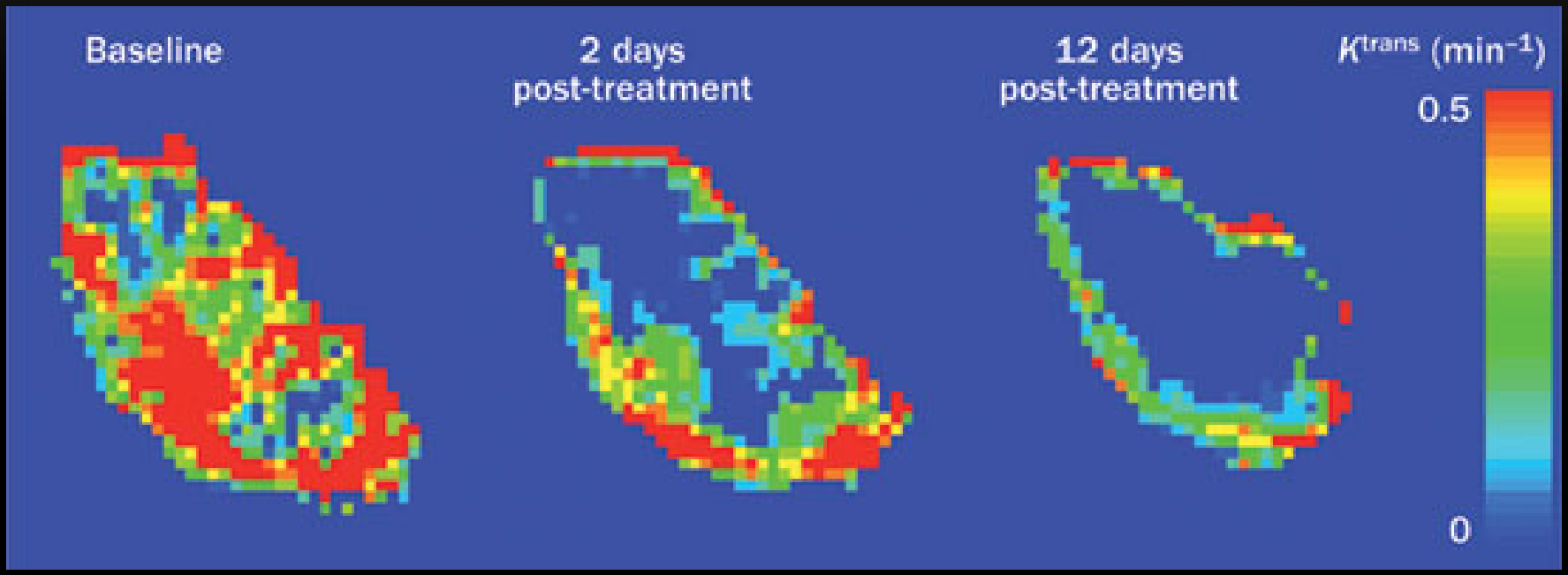


K^{trans} (min^{-1}): volume transfer constant = EF

EES: the volume of extravascular extracelluar space per unit volume of tissue (v_e; $0 < v_e < 1$).

k_{sp} (min^{-1}): the flux rate constant between EES and plasma

Figure 2 Example of three K^{trans} parameter maps



O'Connor, J. P. B. *et al.* (2012) Dynamic contrast-enhanced MRI in clinical trials of antivascular therapies
Nat. Rev. Clin. Oncol. doi:10.1038/nrclinonc.2012.2

nature REVIEWS CLINICAL ONCOLOGY

Perfusion-MRI Methods

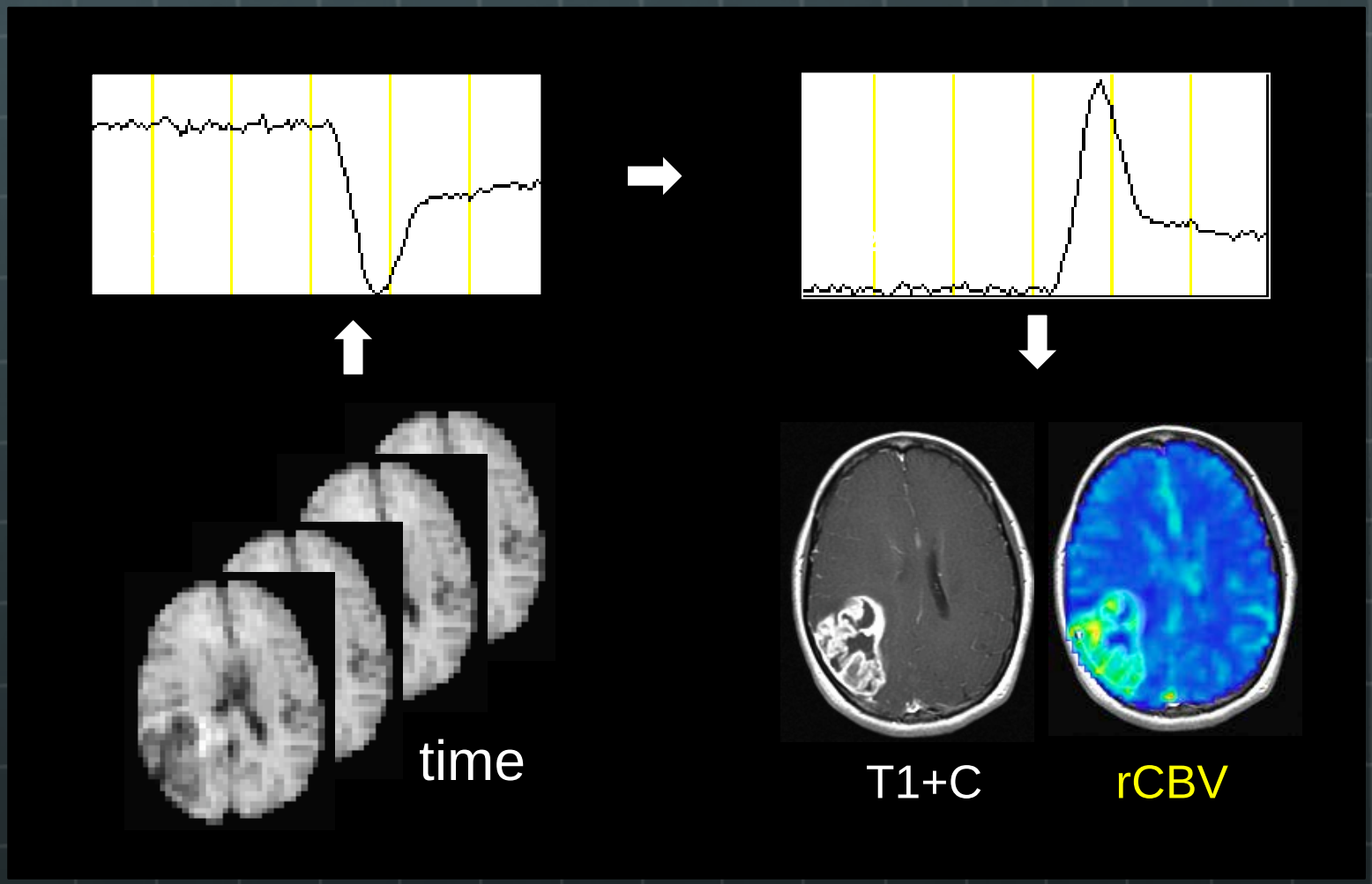
- Dynamic Contrast Enhanced (DCE-MRI)
- Dynamic Susceptibility Contrast (DSC-MRI)

Exogenous Contrast

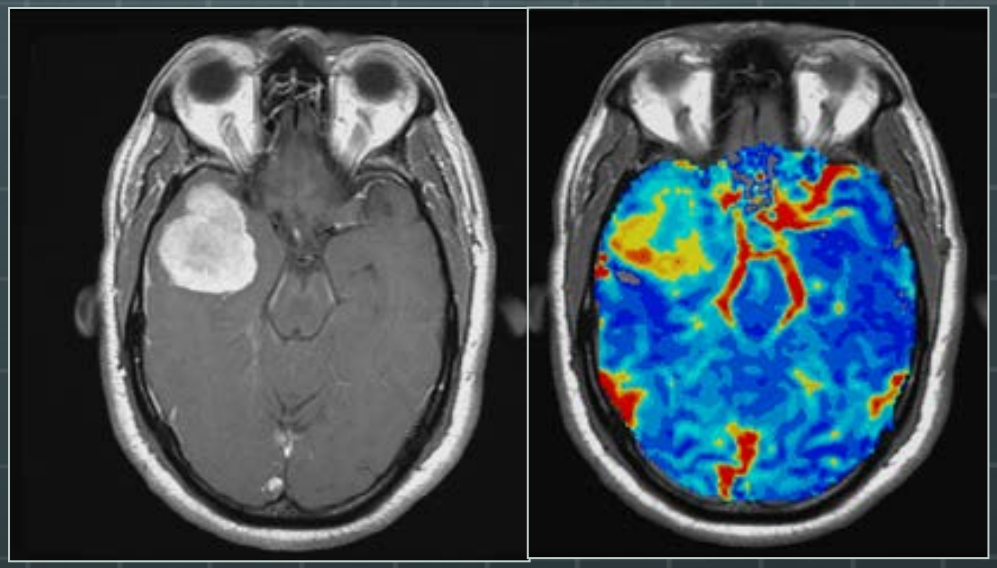
- ASL: Arterial Spin Labeling
- BOLD: Blood Oxygenation Level
- IVIM: Intravoxel Incoherent Motion

Endogenous Contrast

DSC-MRI in *Brain Tumor*



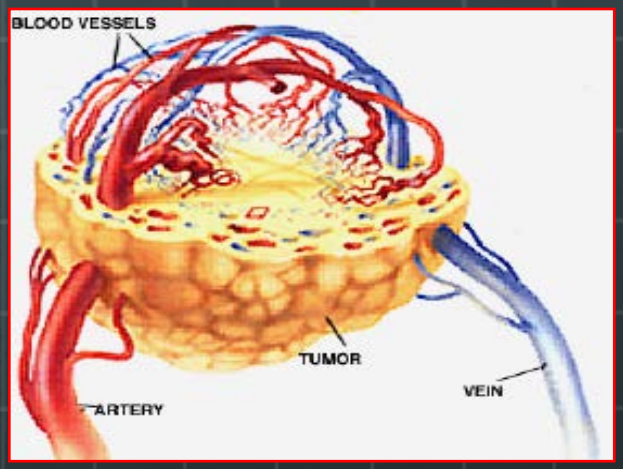
DSC-MRI in *Brain Tumor*



Standard MRI

Perfusion MRI
"rCBV"

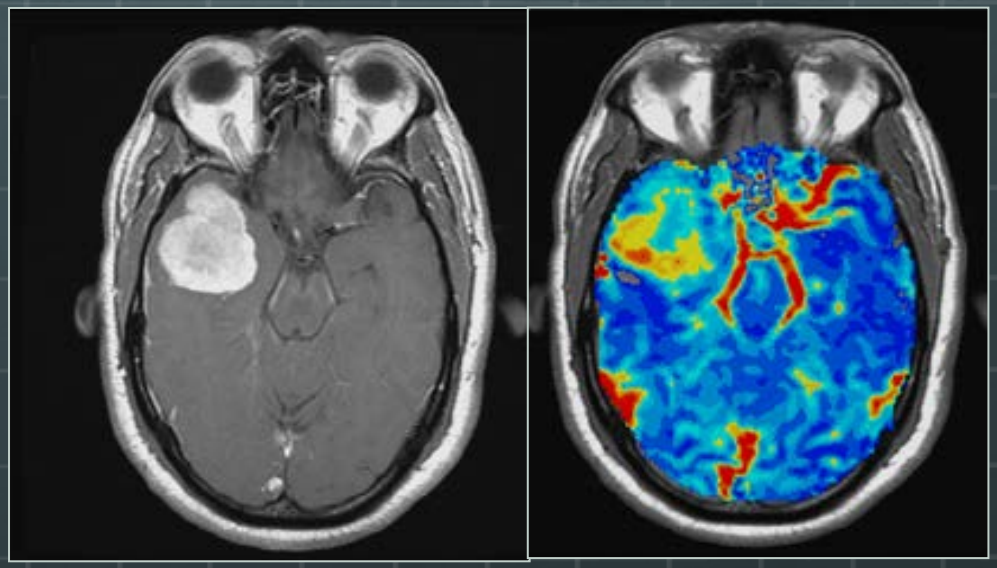
Angiogenesis



From: RK Jain, Sci. Am. 271(1):58 (1994)

…provides information on tumor angiogenesis (new vessel growth)

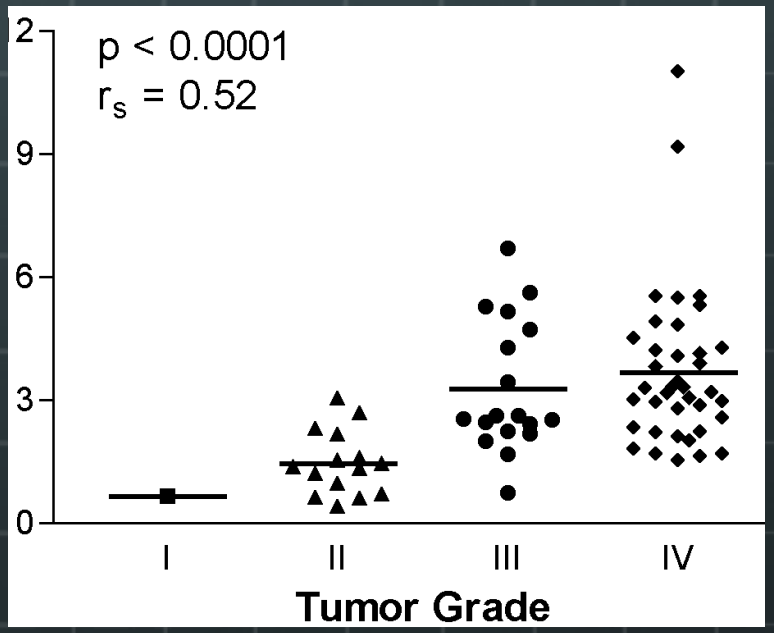
DSC-MRI in *Brain Tumor*



Standard MRI

Perfusion MRI
"rCBV"

- **rCBV Predicts Tumor Grade**



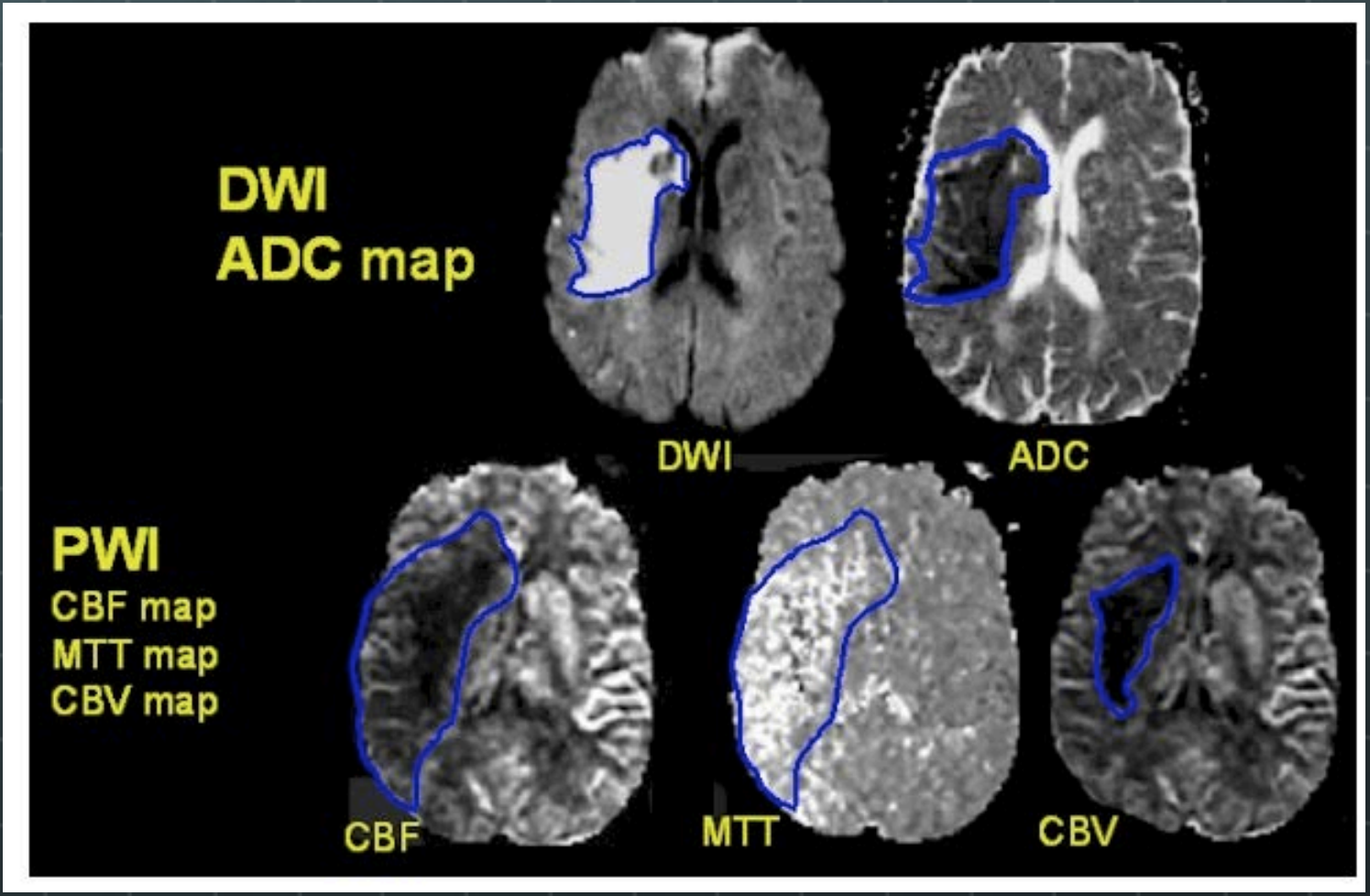
DSC-MRI in *Stroke*

$$C_{VOI}(t) = CBF \int_0^t C_a(t)\, R(t-\tau)\, d\tau$$

CBF:

- requires measurement of arterial input function (AIF)
- deconvolve tissue function with arterial input function to get a residue function
- peak of residue function = CBF
- CBV = integration of c(t)
- MTT = “CBV / CBF”; integration of residue function

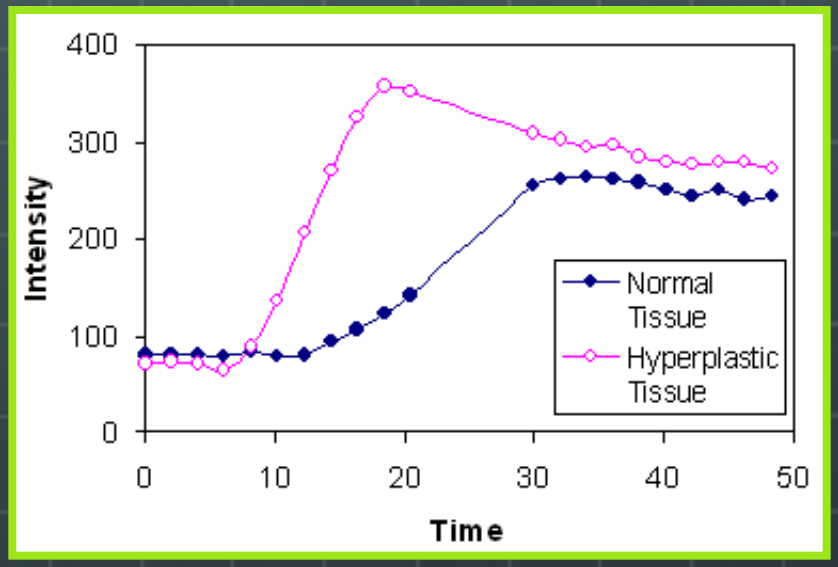
DSC-MRI in *Stroke*



http://www.asnr.org/neurographics/2/2/1/11.shtml

Summary

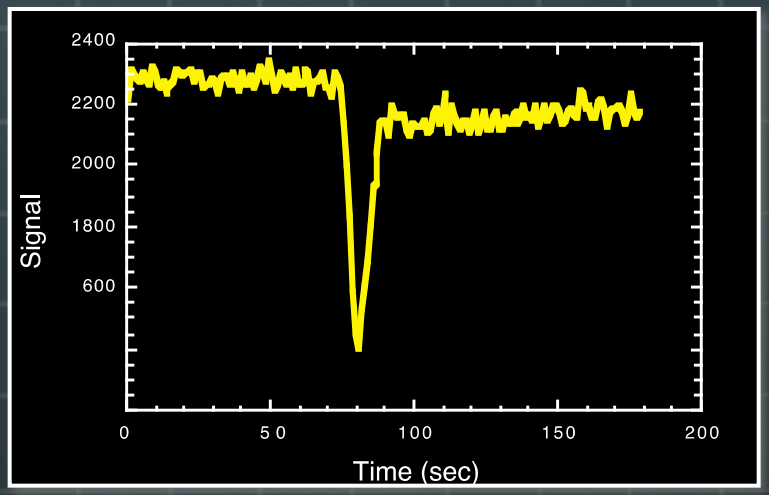
DCE:



- Temporal Resolution: many seconds; better image quality
- T1-weighted sequence (min TE)

Body

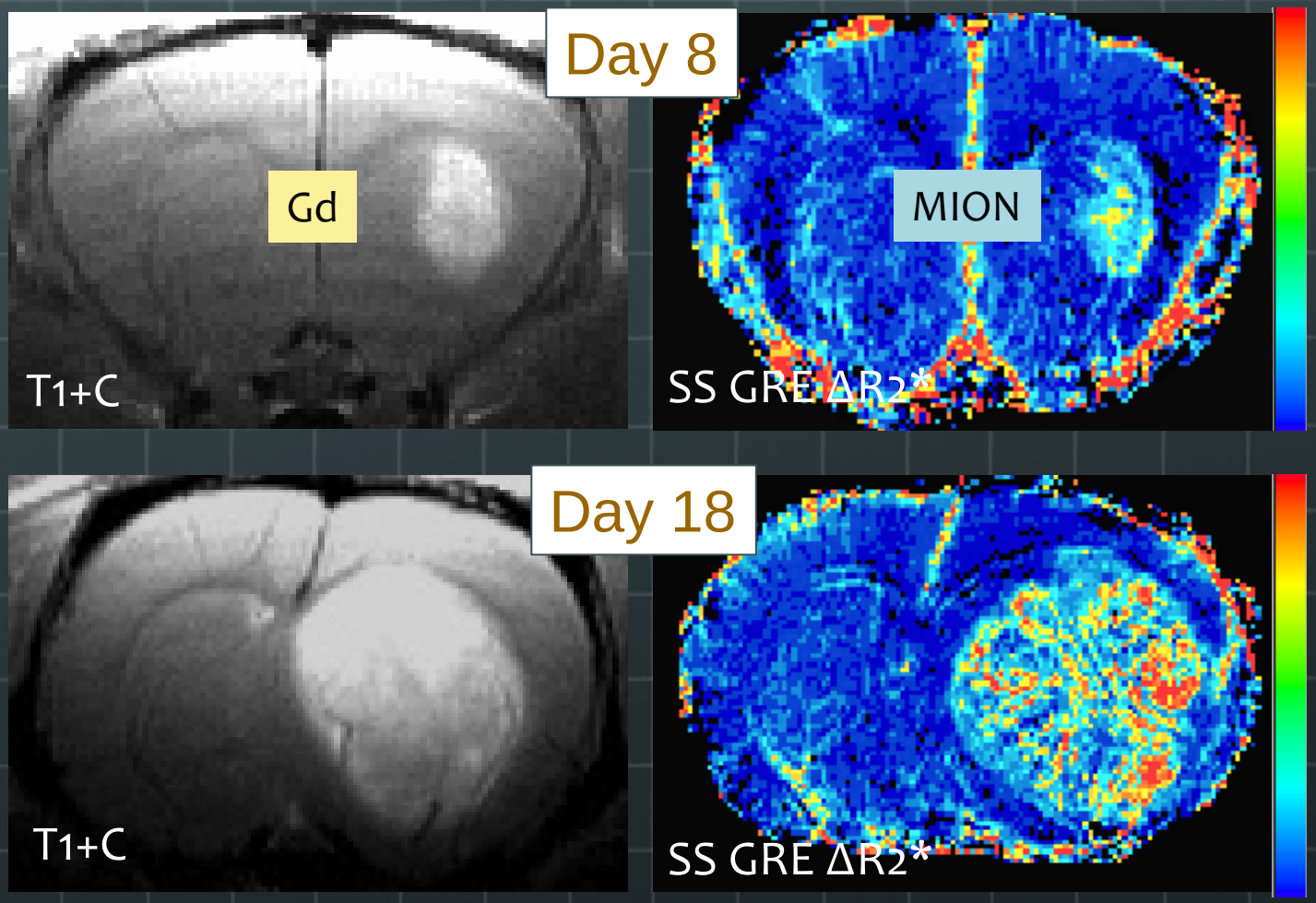
DSC:



- Temporal Resolution: ≈ 1 sec; spatial/temporal trade-off
- T2/T2*-weighted sequence (longer TE)

Brain

Use Intravascular (Iron) Agent



From: Pechman et al., Poster #430

Perfusion-MRI Methods

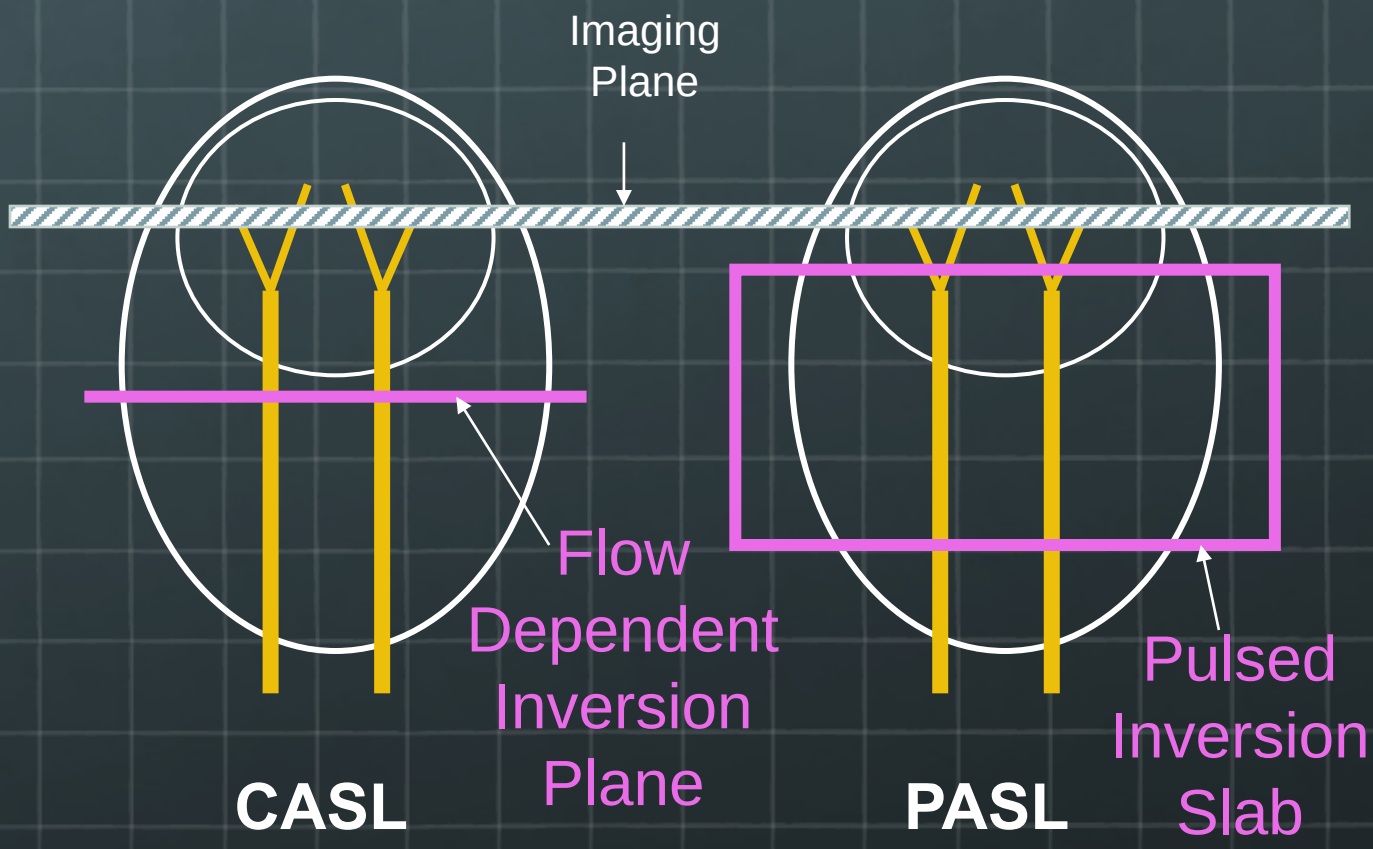
- Dynamic Contrast Enhanced (DCE-MRI)
- Dynamic Susceptibility Contrast (DSC-MRI)

Exogenous Contrast

- ASL: Arterial Spin Labeling
- BOLD: Blood Oxygenation Level
- IVIM: Intravoxel Incoherent Motion

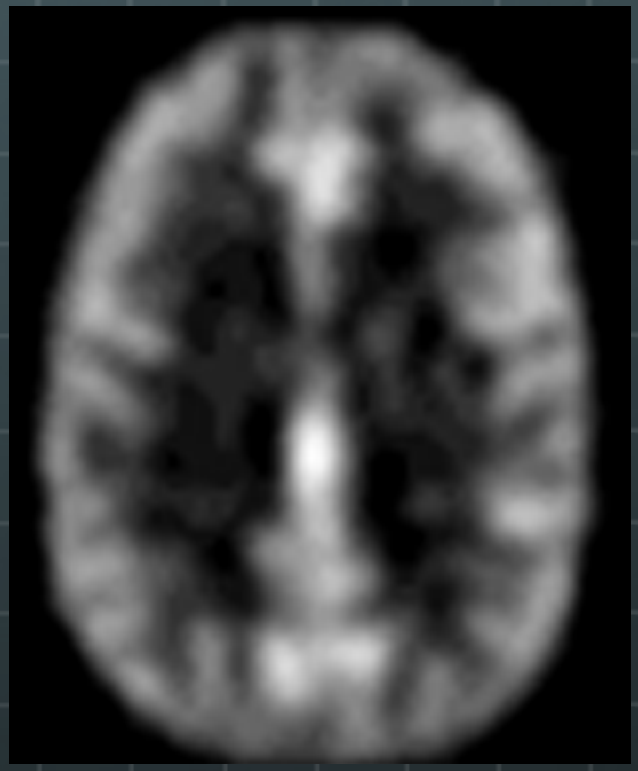
Endogenous Contrast

Arterial Spin Labeling

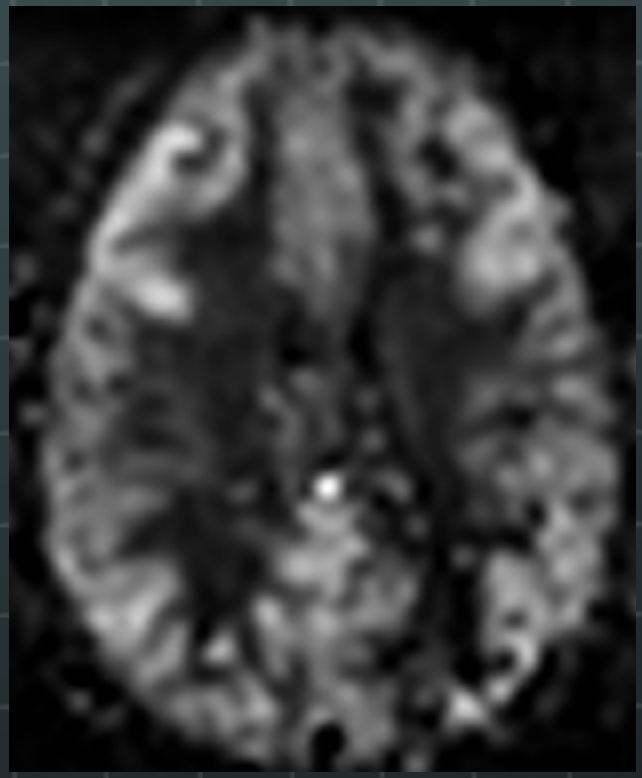


……"Label" Arterial Blood Water with RF Pulses

Arterial Spin Labeling (ASL)



PET: $H_2{}^{15}O$



MRI: ASL

Perfusion-MRI Methods

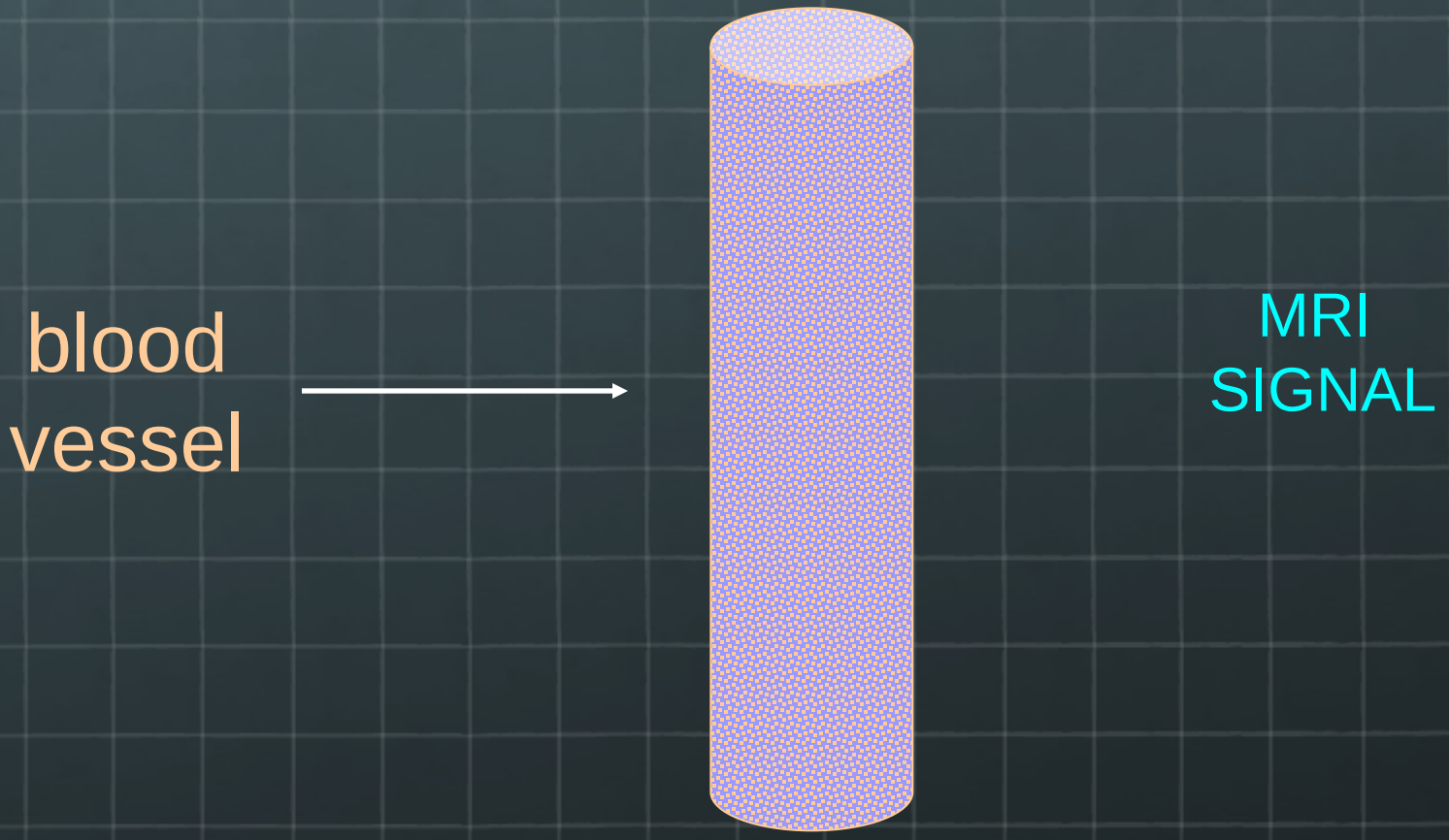
- Dynamic Contrast Enhanced (DCE-MRI)
- Dynamic Susceptibility Contrast (DSC-MRI)

Exogenous Contrast

- ASL: Arterial Spin Labeling
- BOLD: Blood Oxygenation Level
- IVIM: Intravoxel Incoherent Motion

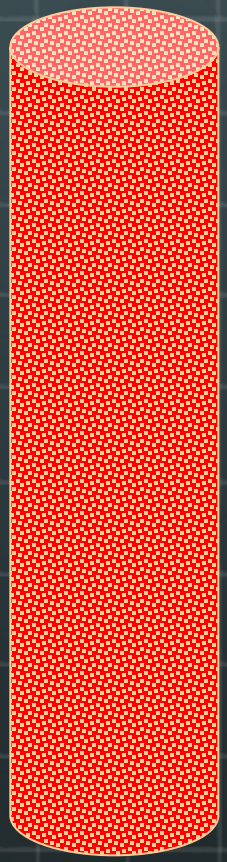
Endogenous Contrast

BOLD: Blood Oxygenation Level Dependent



BOLD: Blood Oxygenation Level Dependent

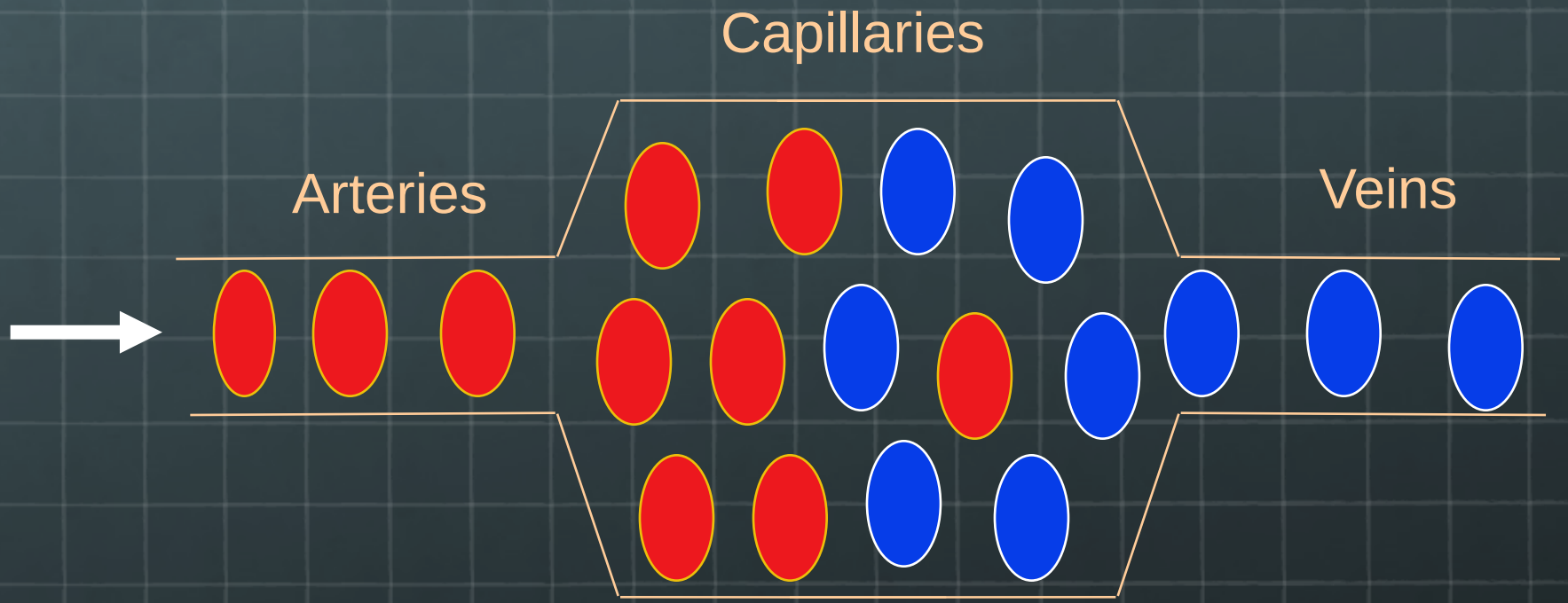
blood vessel



MRI SIGNAL

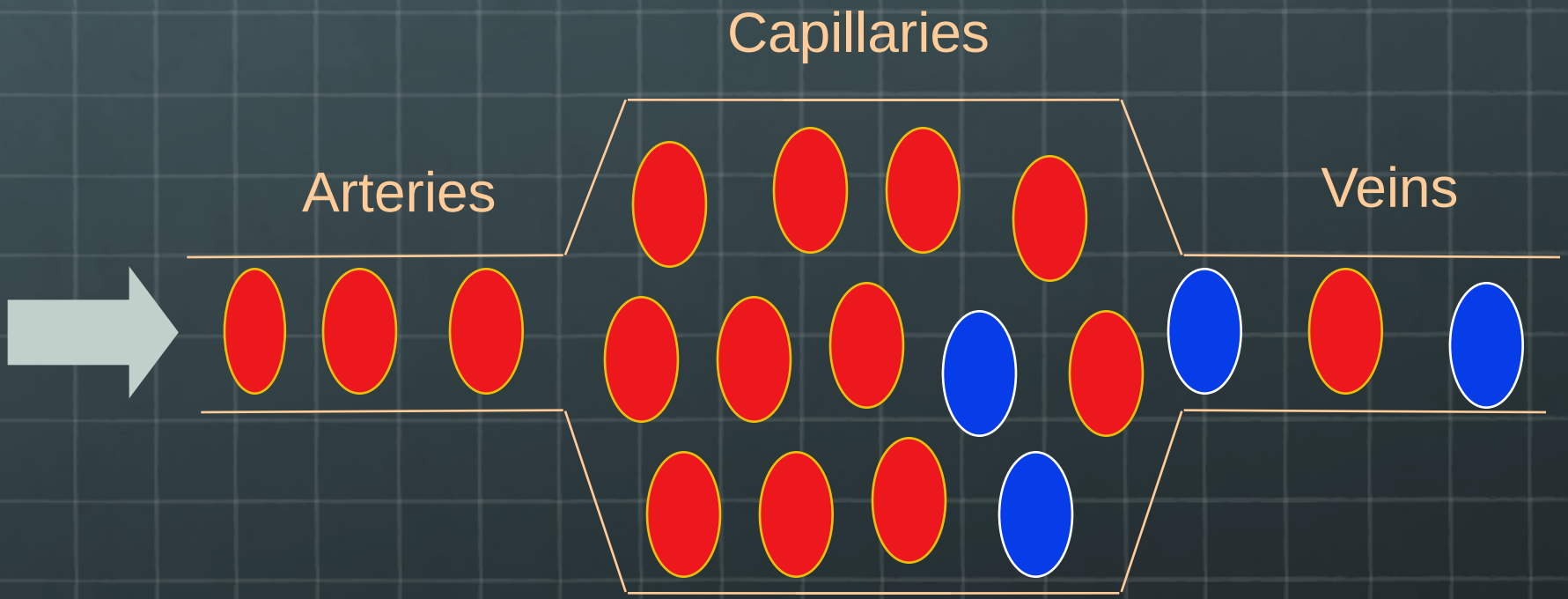
oxygenated blood

BOLD: *Resting*



SIGNAL

BOLD: *ACTIVATION*



SIGNAL

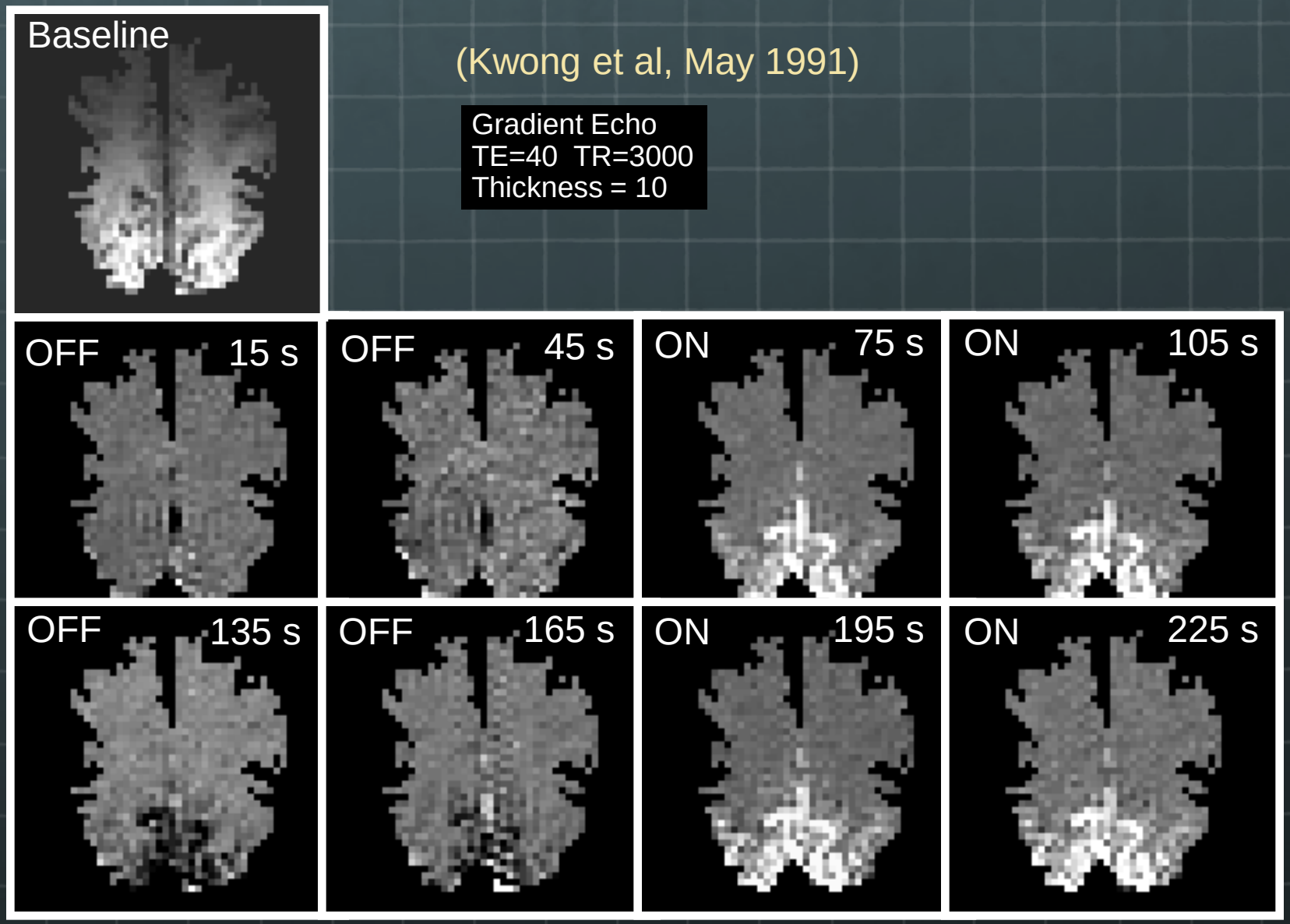
BOLD
(blood oxygenation level dependence)

blood flow ↑

oxygenated-blood ↑

MR signal ↑

BOLD: *Visual Activation*

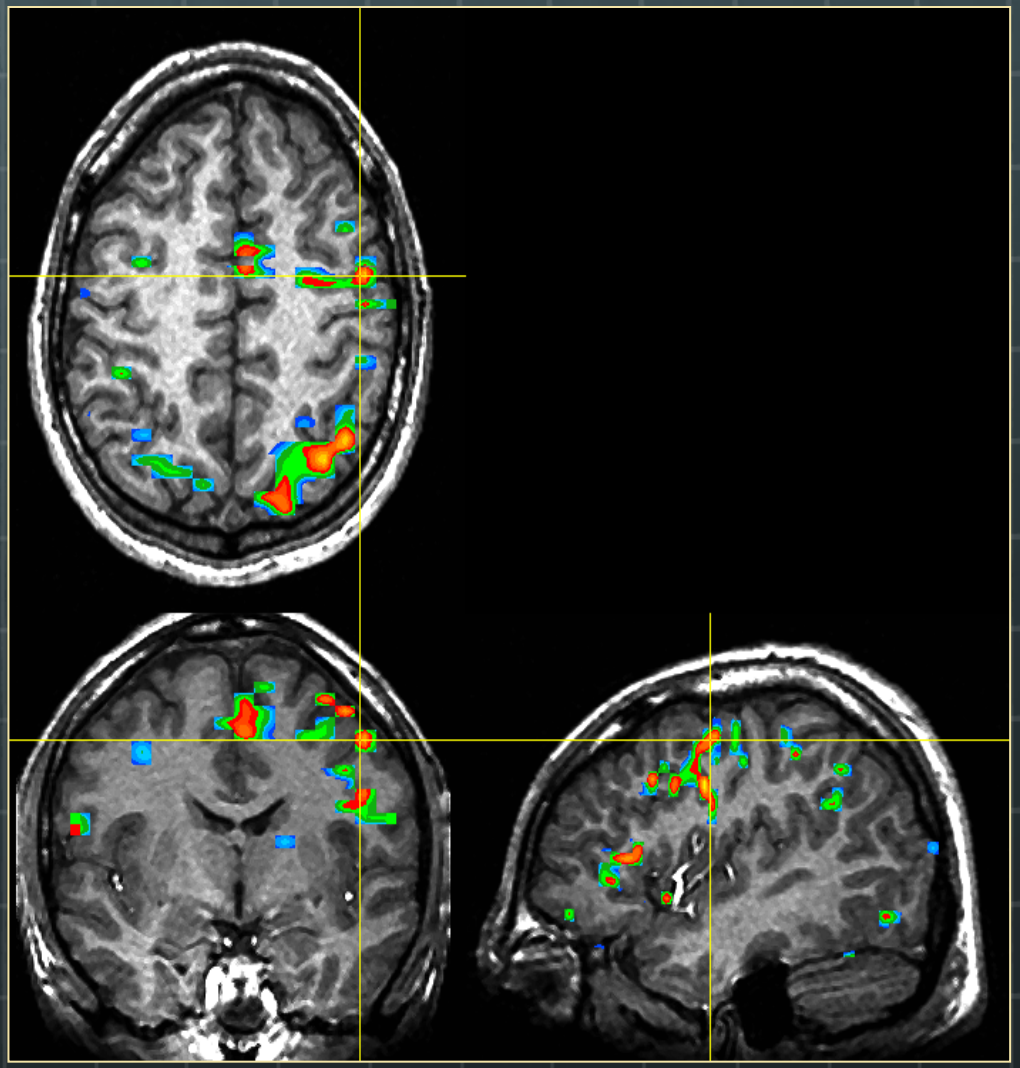


(Kwong et al, May 1991)

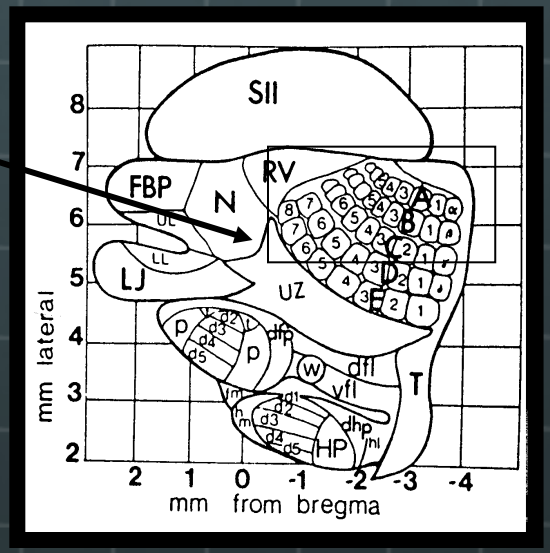
Gradient Echo
TE=40 TR=3000
Thickness = 10

(Proc. Natl. Acad. Sci. USA. 90(12):5675-9, 1992)

BOLD: *Results Presentation*



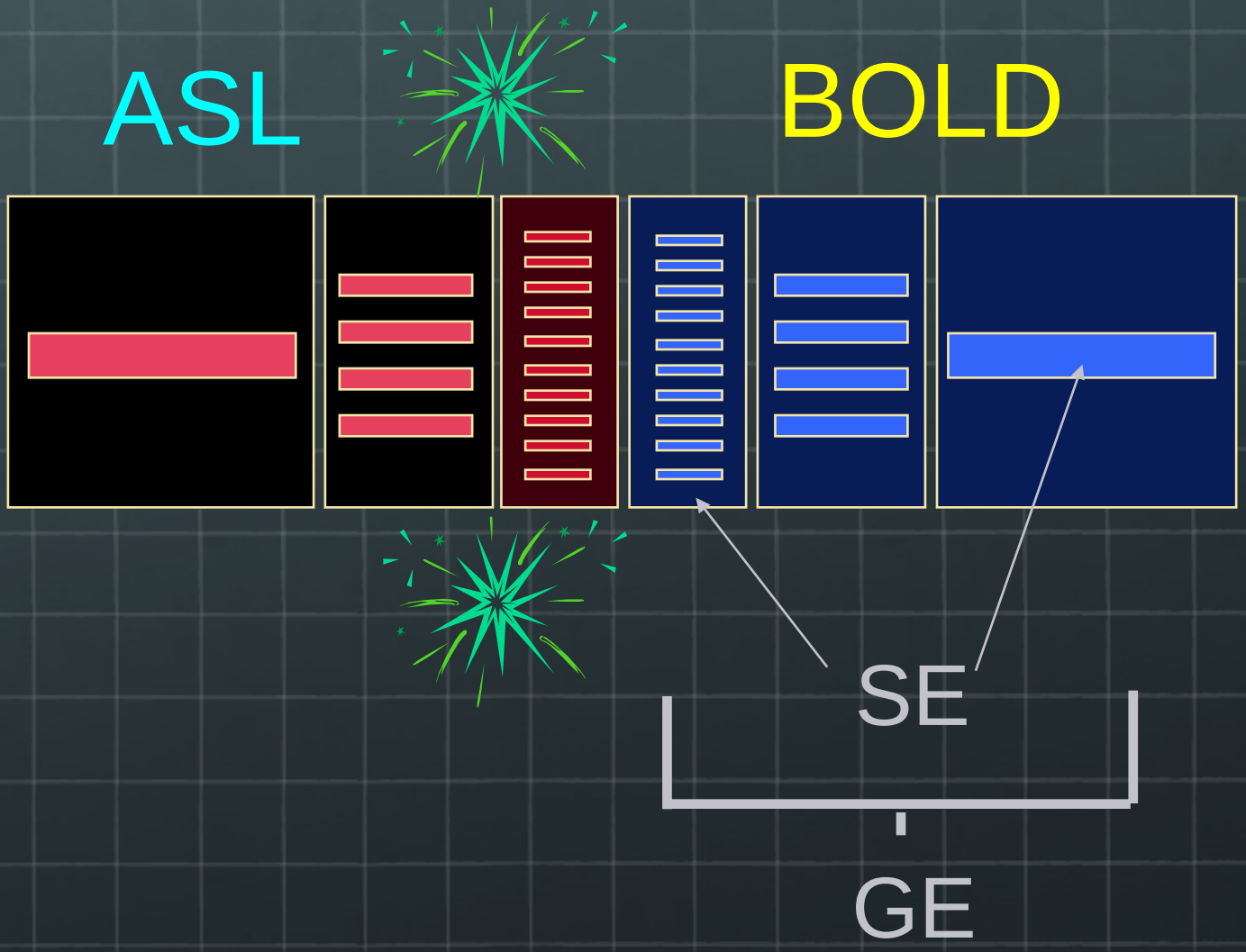
BOLD: *Rat Whisker Barrel*



- The large whiskers of the rat correspond in a one to one fashion with groups of cell bodies (barrels) in cortical layer IV of contralateral somatosensory cortex.

- Whiskers are cut to 3cm, and fitted through a comb and connected to a piezoelectric-driven actuator arm, which is run with a reproducible “on/off” cycle

ASL vs **BOLD:** *Vascular Specificity*



Perfusion-MRI Methods

- Dynamic Contrast Enhanced (DCE-MRI)
- Dynamic Susceptibility Contrast (DSC-MRI)

Exogenous Contrast

- ASL: Arterial Spin Labeling
- BOLD: Blood Oxygenation Level
- IVIM: Intravoxel Incoherent Motion

Endogenous Contrast

Diffusion-Weighted Imaging

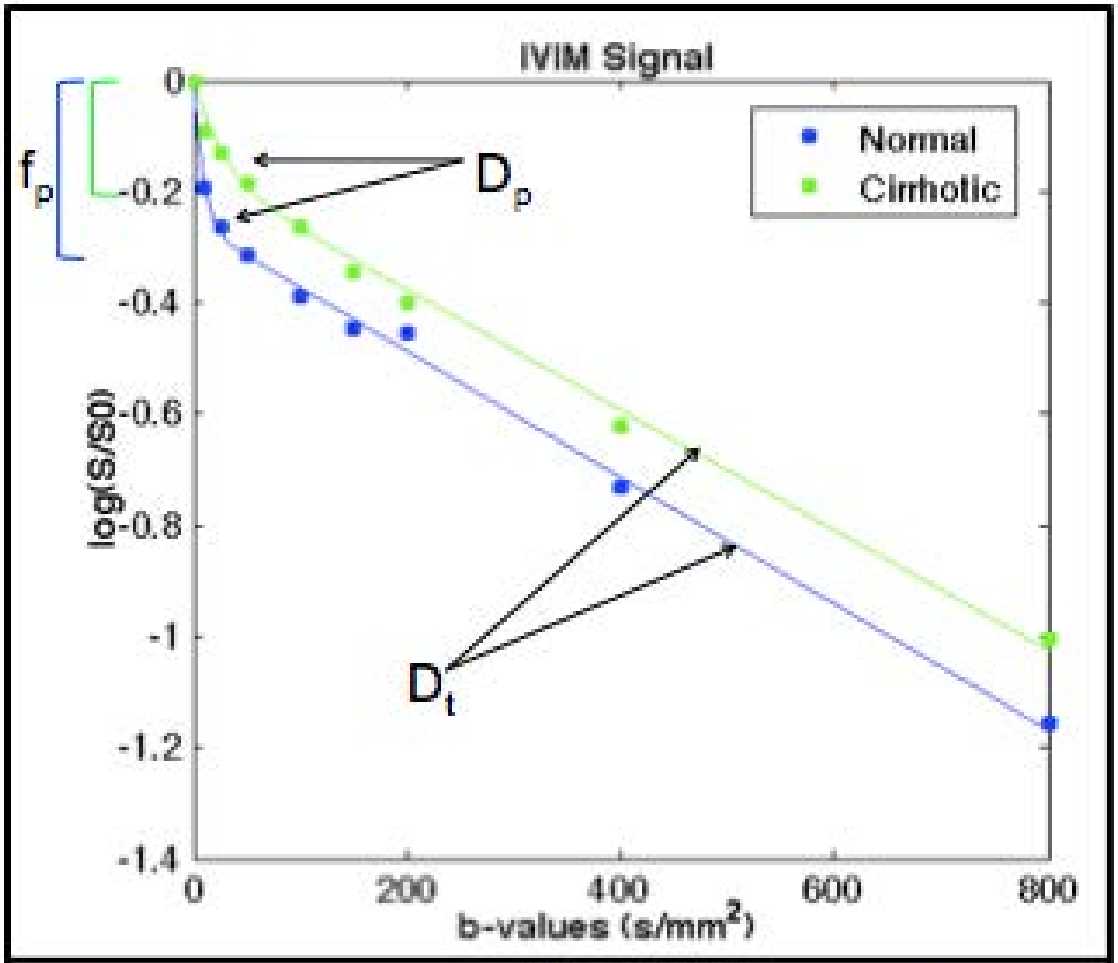
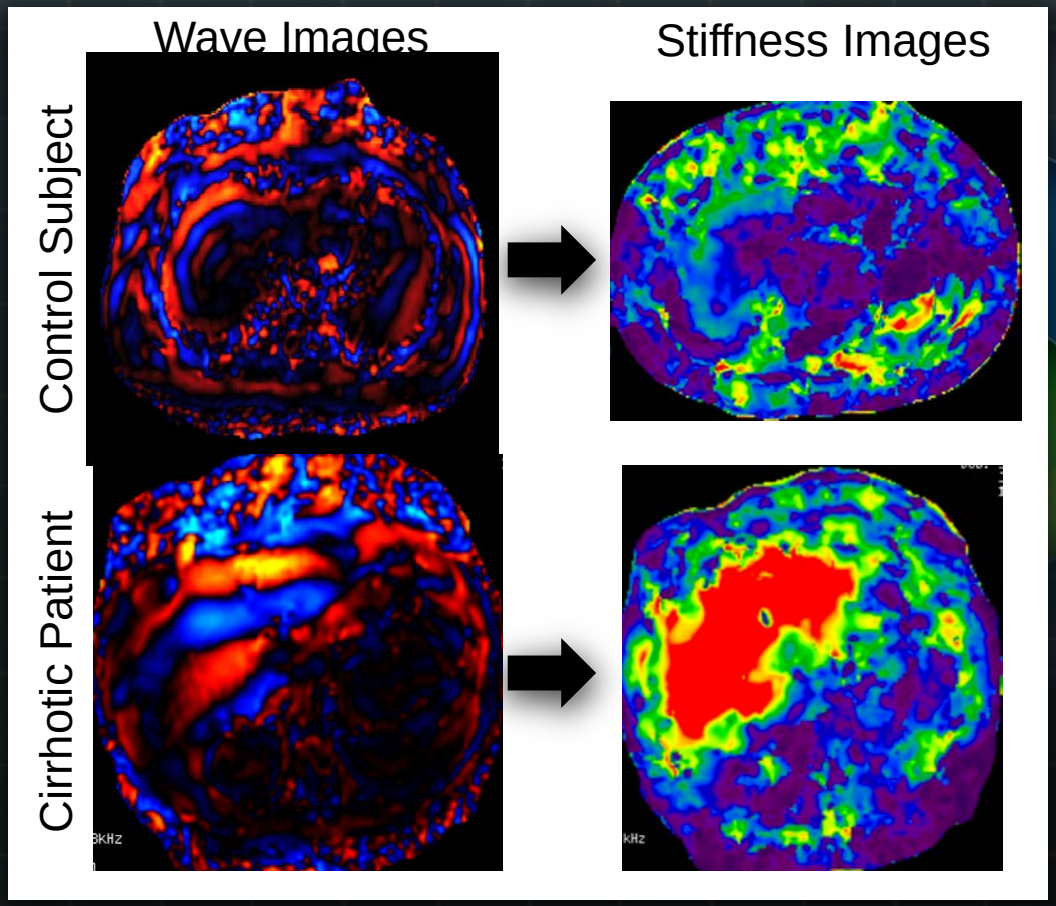


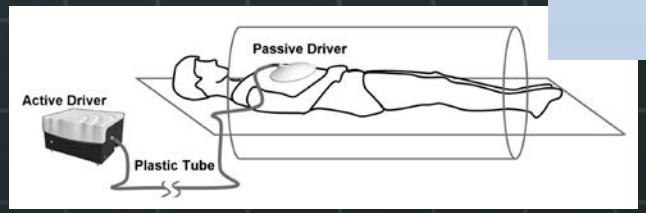
Figure 1. Example IVIM signal curves for a control (blue) and cirrhotic (green) patient.

Liver Imaging

Magnetic Resonance Elastography

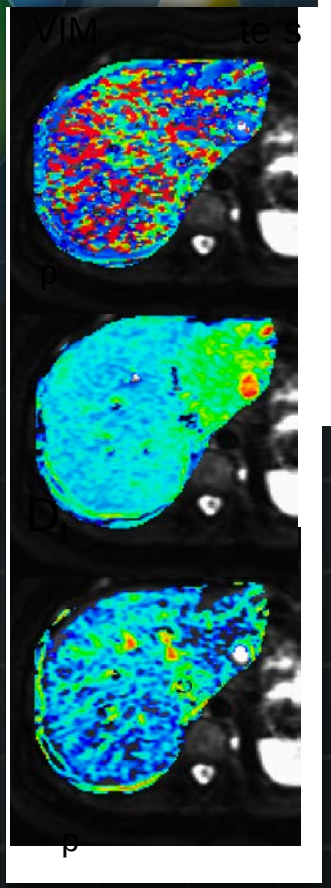


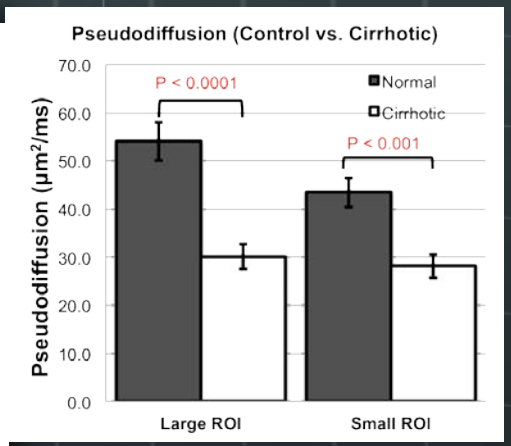
MRE allows for the extraction of tissue stiffness through the use of a vibrating driver



Diffusion Weighted Imaging

IVIM: The collection of multiple diffusion weightings (b-values) allows for the extraction of perfusion information from the diffusion signal





These parameters are different in cirrhotic patients vs. normal control subjects

SUMMARY

- Dynamic Contrast Enhanced (DCE-MRI)
- Dynamic Susceptibility Contrast (DSC-MRI)

Exogenous Contrast

- ASL: Arterial Spin Labeling
- BOLD: Blood Oxygenation Level
- IVIM: Intravoxel Incoherent Motion

Endogenous Contrast

Acknowledgements

1. **Funding**
   - NIH/NCI RO1 CA082500
   - NIH/NCI R43 CA134031, R44 CA134031
   - AHW - Translational Brain Tumor Research Program

2. **Lab Members / Collaborators**
   - Mona Al-Gizawy
   - Devyani Bedekar
   - Alex Cohen
   - Pete LaViolette
   - Eric Paulson
   - Kim Pechman
   - Melissa Prah
   - Jennifer Connelly
   - Elizabeth Cochran
   - Mark Malkin
   - Wade Mueller
   - Scott Rand