Arterial Spin Labeling in Body MRI

Neil M. Rofsky, MD
FACR, FISMRM, FSCBTMR

Department of Radiology and Advanced Imaging Research Center

UT Southwestern Medical Center
Disclosures

• None

Acknowledgements

• Ananth J. Madhuranthakam, Ph.D.
• David Alsop, Ph.D.
• Ivan Pedrosa, M.D.
Why Perfusion?

• Perfusion = the delivery of $O_2$ and nutrients to tissue by means of blood flow

• Classically measured using a diffusible tracer that can exchange between the vascular compartment and tissue and is quantified in tissue-specific units of $mL/g/min$
Perfusion is ‘tracer’ determined
Pharmacokinetic modeling

- With contrast we can only measure the mean value of tumor components. Assumptions of exchanges are used to derive ‘Quantitative Results’.

\[ K_{ep} = \frac{K_{trans}}{V_e} \]
Pharmacokinetic modeling

• With contrast we can only measure the mean value of tumor components
  assumptions of exchanges are used to derive ‘Quantitative Results’

• Microvessels of cancer
  – High density
  – Hyperpermeability

\[ K_{ep} = \frac{K_{trans}}{V_e} \]
Background: DCE

- Long history of utilization
- Based on firm theories & models
- Uses basic pulse sequences
- Used in a variety of cancers
DCE MRI: Pitfalls

- Safety/tolerance
  - NSF, allergy
- Protocol Harmonization
  - Sequences: not =
  - Gd agents are not =
    - Ionic, non-ionic
- Blood Hct/ Arterial input
  - Broad applicability of model assumptions?
- Tumor heterogeneity
  - Kinetics best assessed w/ high temp/low spatial resolution
Arterial Spin Labeling

- No contrast media; no tracer accumulation
- Blood H$_2$O is magnetically labeled
- Labeled blood ‘flows’ to tissue of interest
- Quantitative method for assessing perfusion
ASL Schematic

At 3T: slower decay rate of labeled blood
ASL Subtraction Experiment

Control Image

Labeled Image

Imaged Slice

Inversion Labeling
(a negative signal)
ASL in Neurological Applications

- Robust
- Validated in animals & humans
- Commercially available

* 60 yo w/ bx proven glioblastoma, 3 Tesla, 5 min

* Dai W et al. MRM 2008; 60: 1488-1497
Blood Flow Monitoring of Experimental Antiangiogenic Tx in Glioma
(Grade III Oligodendroglioma)

Pre  4 wks  10 wks  16 wks  24 wks  30 wks

c/o David Alsop, PhD, BIDMC
ASL outside Neurological Applications

• Best for high flow physiology/pathophysiology

• Measures tissue perfusion w/o exogenous contrast material

• Advantageous for pts with compromised renal fxn

Fenchel M et. al. Radiology 2006; 238: 1013-1021
Wu WC et. al. Radiology 2011; 261: 845-853
Pulsed ASL (PASL)

- Flow Alternating Inversion Recovery (FAIR)*
- Combined with True-FISP (or b-FFE) acquisition#

*Kim SG MRM 1995; 34: 293-301
#Martirosian P MRM 2004; 51: 353-361
Fenchel M et. al. Radiology 2006; 238: 1013
Pseudo Continuous ASL (pCASL)

- pCASL has relatively high labeling efficiency*
- pCASL is amenable to background suppression#, and readily quantifiable
- Unique resp triggering strategies have been developed for prolonged data acquisitions

Pulse Sequence

- 4.1 seconds labeling
- 3.0 seconds post-label delay
- TR = 6 s

- 1.5 seconds long labeling
- 1.5 seconds long post-label delay

Saturation pulses (imaging region)
FOCI Inversion Pulse

Non-selective Inversion Pulses

Superior Saturation Pulses

pseudo-CASL

SShTSE

2D Perfusion in Normal Volunteer

Perfusion difference image shows clear *cortico-medullary* differentiation.
Background Suppression

Robson PM et al. MRM 2009; 61: 1374
ASL Renal BF
Test-Retest Results (Repeatability)

- Renal blood flow (w/in slice)
  - Mean 355 (128 intersubj SD) ml/min/100g
  - Within scan test retest SD 5.03%
  - One week test retest SD 13.3%

2D Perfusion in Patient
Scan time: 3min, 18 sec

Clear cell RCC shows heterogeneous tumor perfusion
Hx: Rt nephrectomy, New LT RC; eGFR = 27

8-2007

ASL MRI


RT 4/08 & 6/08
Metastatic RCC treated with PTK 787, targets VEGF tyrosine kinase receptor.
ASL Monitoring of Anti VEGF Receptor Therapy in RCC

Size changes not meaningful
Early Δ’s at 1 mo in blood flow and tumor size vs. delay of dz progression after tx initiation

3D ASL

- 2D acq = single slice, in ~ 3 min; 16 pairs of label/control
- 3D acq = 16-24 slices of 3 mm in ~ 4 min
3D Perfusion Diff Image in NI Volunteer

Coronal 2D

Coronal 3D

Sagittal Reformat

Axial Reformat
3D Perfusion in Patient Volunteer

Perfusion difference image in the native sagittal orientation

Clear cell renal cell carcinoma showing high perfusion in the superior location of the kidney (outline)

Sagittal 3D Acquisition

Coronal Reformat

T₂-Weighted Image

Surgical Excision

Low perfusion

High perfusion

Invasive

R01 CA154475-01
High Flow #1 → Classic clear cell

More trabeculated ← Invasive

Low Flow → More hyalinized

Ivan Pedrosa M.D., UTSW
NIH RO1 (1R01CA154475-01)
Heterogeneous Perfusion in High Grade ccRCC

Zhang et al. Clin Genitourin Cancer. 2015
Conclusions

• ASL provides absolute perfusion quantification
  – non-invasive assessment of tumors
  – high accuracy & reproducibility

• Can be used repeatedly
  – no exogenous contrast agent
  – no ionizing radiation

• Can be extended to other tumors
  – Fibroids, Lung Ca, Sarcomas
Results: Dynamic Inflow Visualization

- MIP views of 8-slice image for each time point (total 12 min scan time)

- Symmetric filling – Healthy volunteer
- ~1 sec to fill ACA/MCA branches above CoW and basilar artery below CoW
- ~2 sec to fill the extra-cranial arteries
Quantitative MRI vascular measures vs MVD

MVD = Microvessel density on CD31 IHC

Zhang et al. Clin Genitourin Cancer. 2015
THANK YOU
Results: 3D Imaging – Cerebral Vasculature

• MIP of 64 slice-encode 10-min scan
• Labeling in the common carotid artery
• Excellent depiction of vessels
Results: 3D Imaging – Cerebral Vasculature

- Multiple view planes of vasculature
- Single projection acquisition
- Flexibility afforded by subtraction and BGS

MIP views of multiple 8 slice-encode images in 2-min scan

Single projection image acquired in less than 10 seconds
Results: Dynamic Inflow Visualization

- MIP views of 8-slice image for each time point (2 min per time point)
- Labeling in the common carotid artery
  - Labeling duration before imaging: between 200 ms and 3000 ms

- Symmetric Filling
  - Healthy volunteer
- ~1 sec to fill ACA/MCA branches above CoW and basilar artery below CoW
- ~2 sec to fill the extra-cranial arteries
Results: Vessel Selectivity

- MIP views of 8-slice image (2 min scan time)
- Labeling in left and right ICAs

Excellent contra-lateral suppression
Results: Vessel Selectivity

- MIP views of 8-slice image (2 min scan time)
- Labeling in right ECA, vertebral artery
  ECA and cerebellar branches separated
- Residual labeling in ICA

![MIP images showing vessel selectivity](image-url)
Results: Dynamic Inflow Visualization

• MIP views of 8-slice image for each time point (total 12 min scan time)

• Labeling Duration before imaging: between 200 ms and 3000 ms

• Symmetric filling – Healthy volunteer

• ~1 sec to fill ACA/MCA branches above CoW and basilar artery below CoW
New Slides for Neil

Full refocusing (180deg) suppresses ghosting

8-slice encodes, 1.5 min scan, 180 flip angle, 2 sec labelling duration
New Slides for Neil

Normal variation – left ICA feeds both ACA branches

8-slice encodes, ~2 min scan, 180 flip angle, 2 sec labelling duration
New Slides for Neil

8-slice encodes, ~2 min scan, 180° flip angle, 2 sec labelling duration

Nl variation – LT ICA feeds both ACA branches