Arterial Spin Labelling

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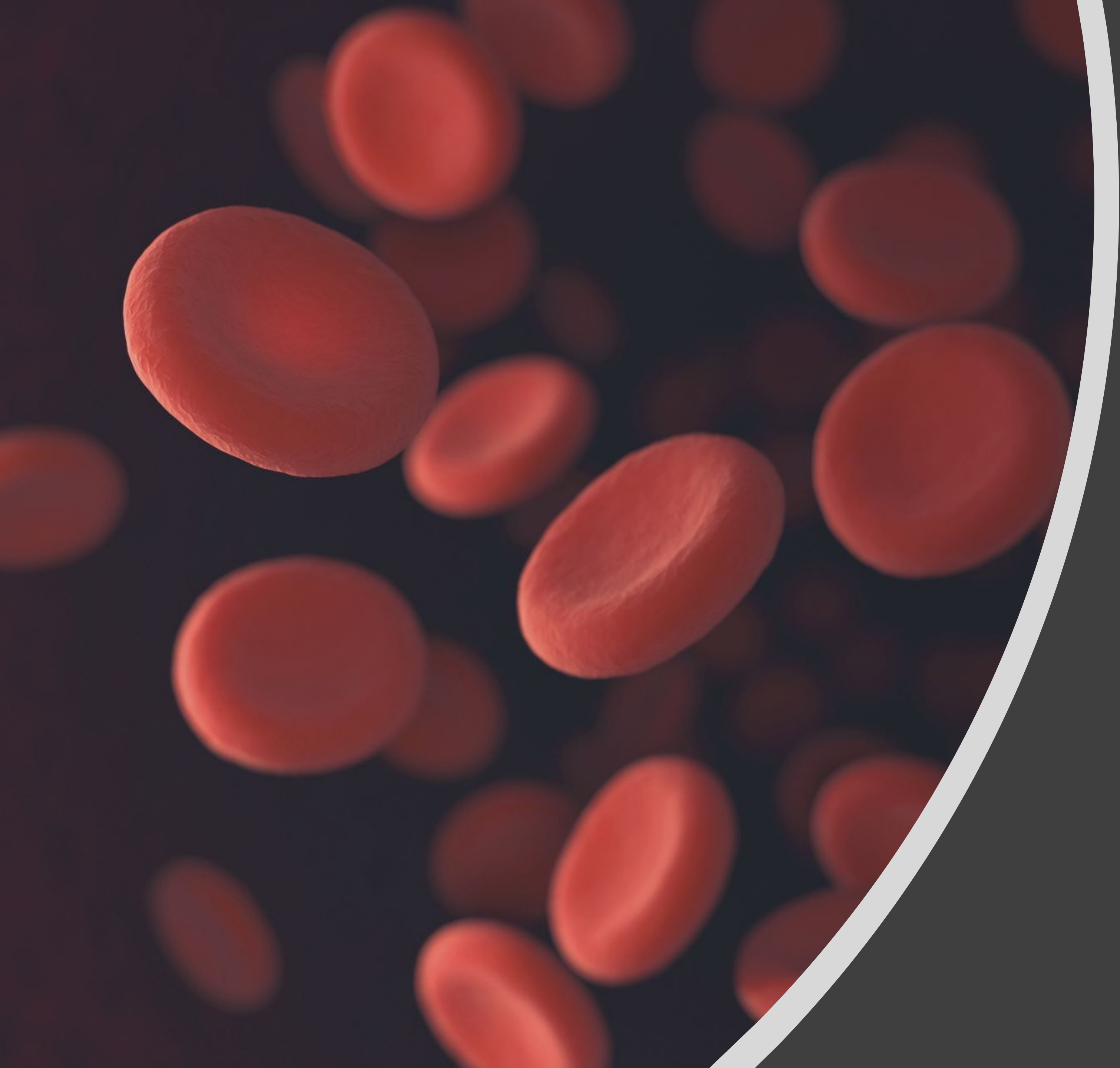
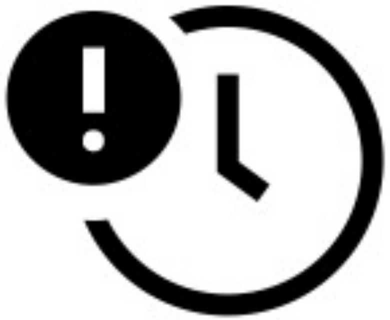


Arterial Spin Labelling

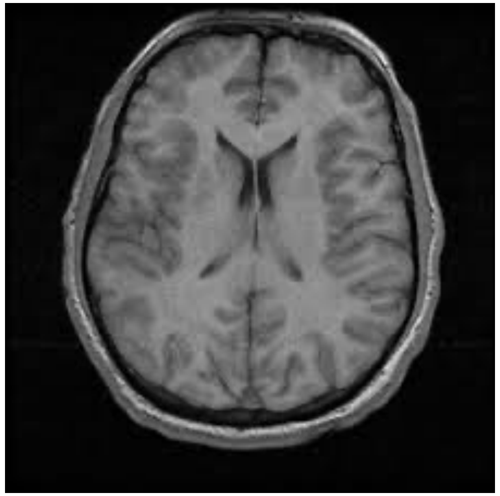
"Labelled" spins in arterial blood water act as an endogenous tracer

Arterial Spin Labelling

Production of tracer
(labelling)



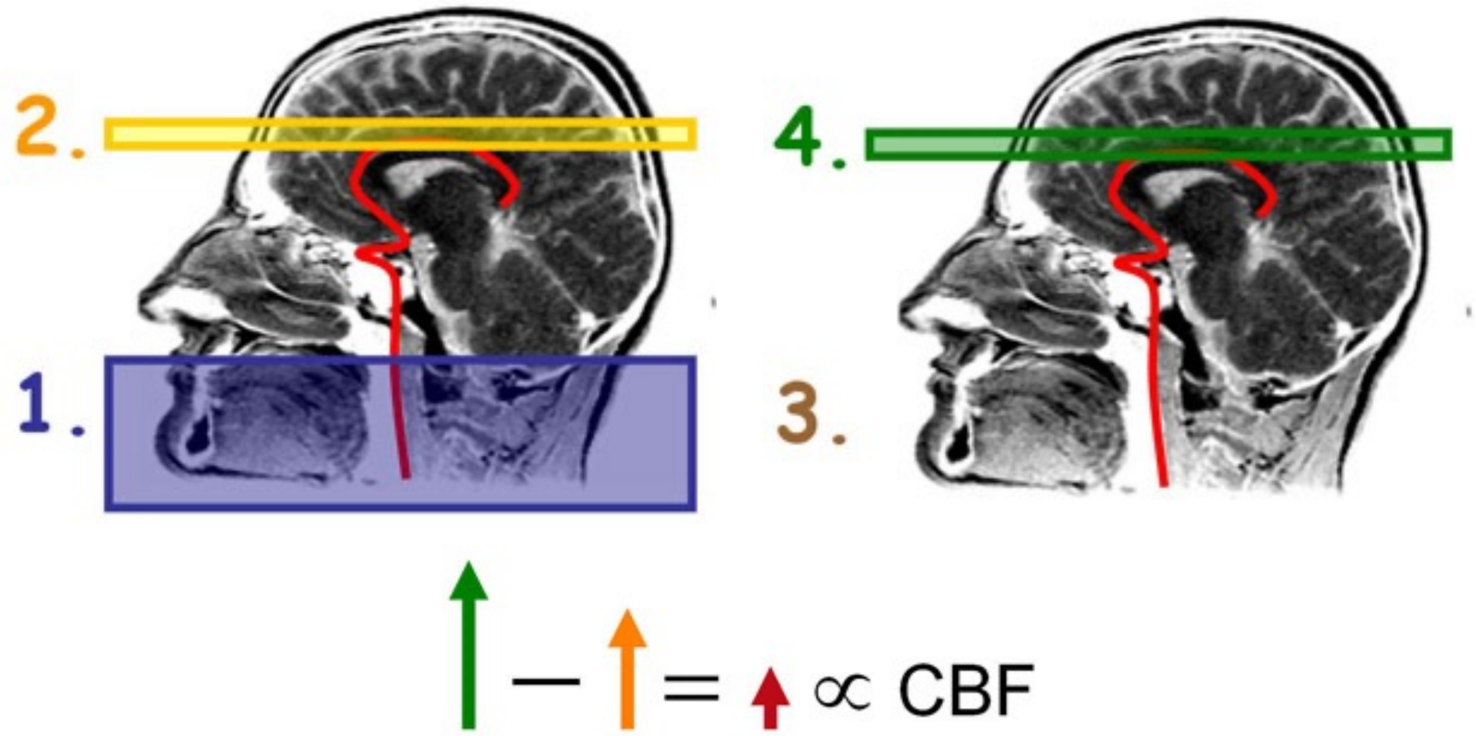
Wait for tracer to reach target organ
(post labelling delay)



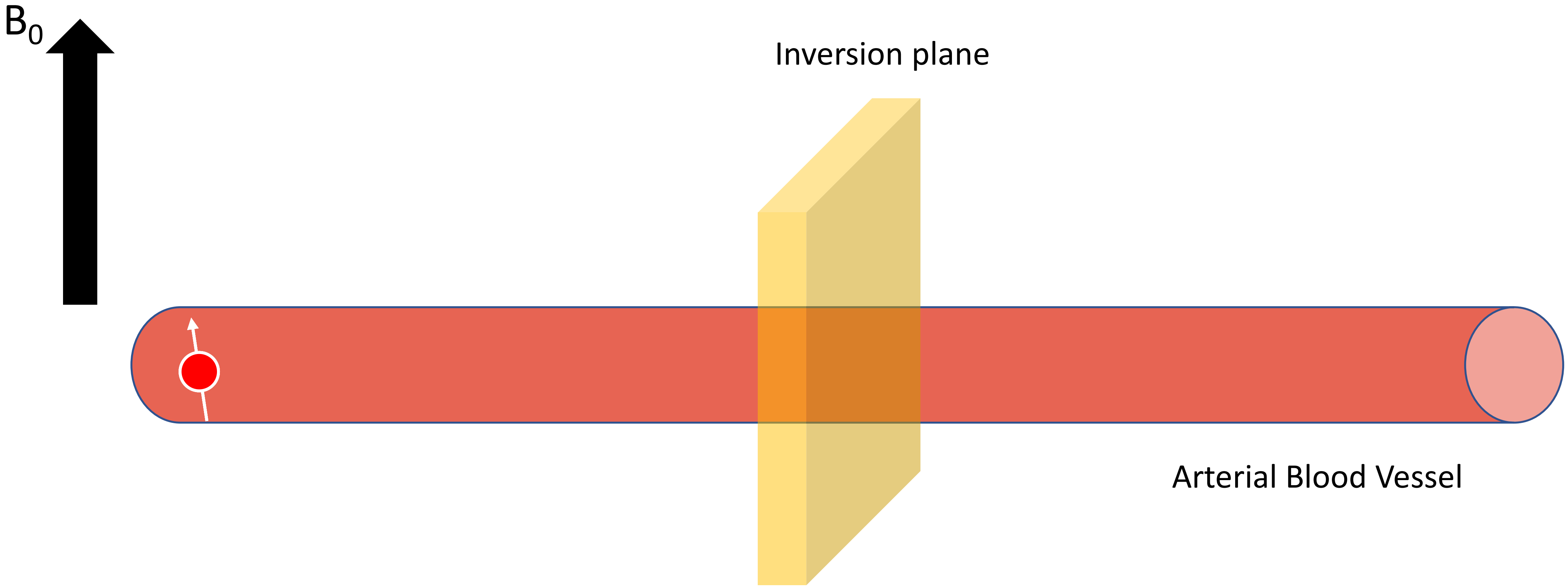
Aquire images

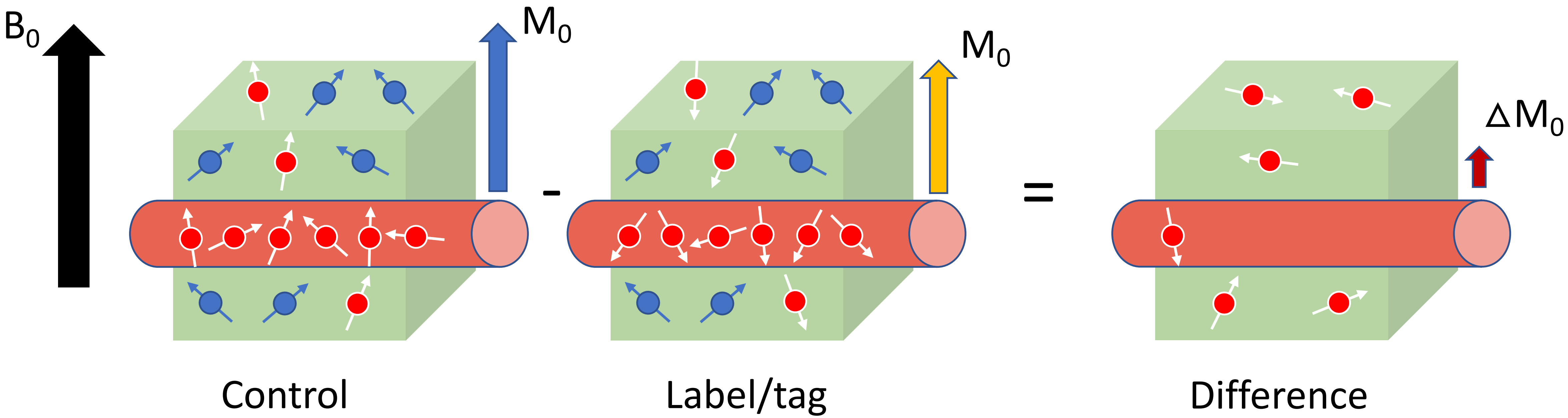
Tracer Kinetic Modelling

Arterial Spin Labelling



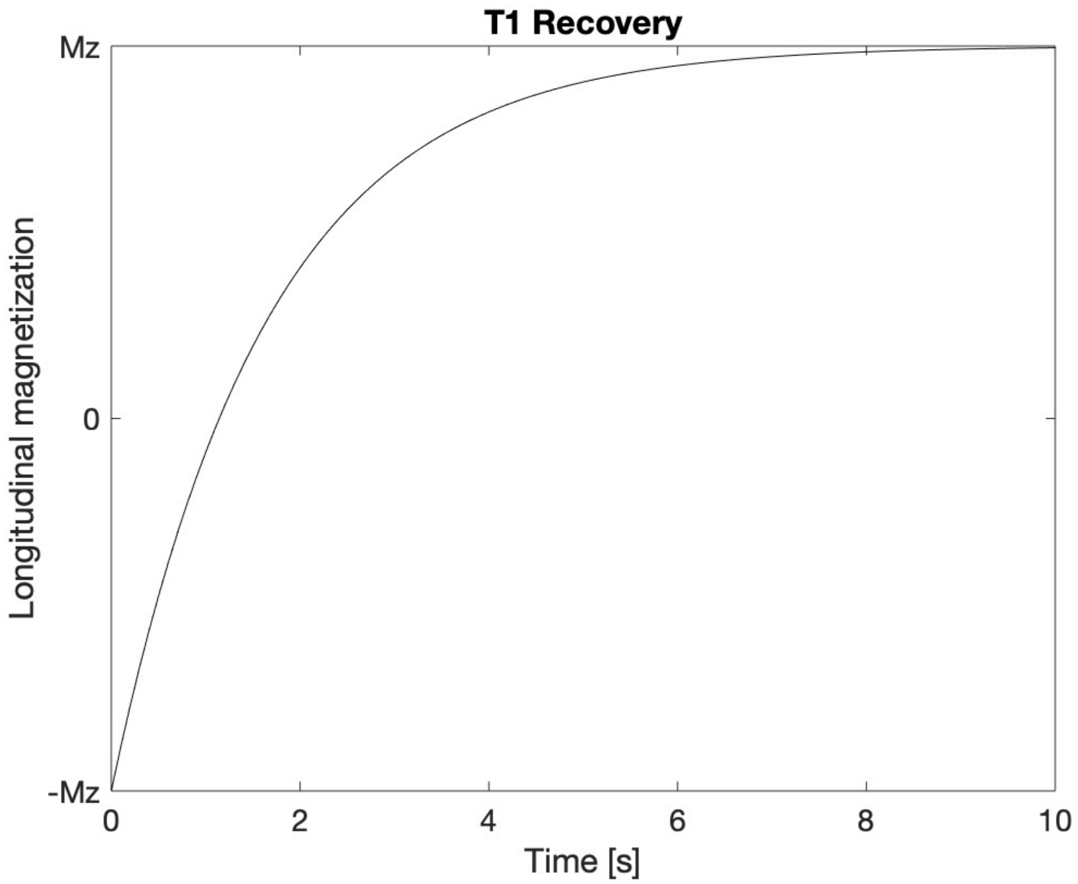
Labelling

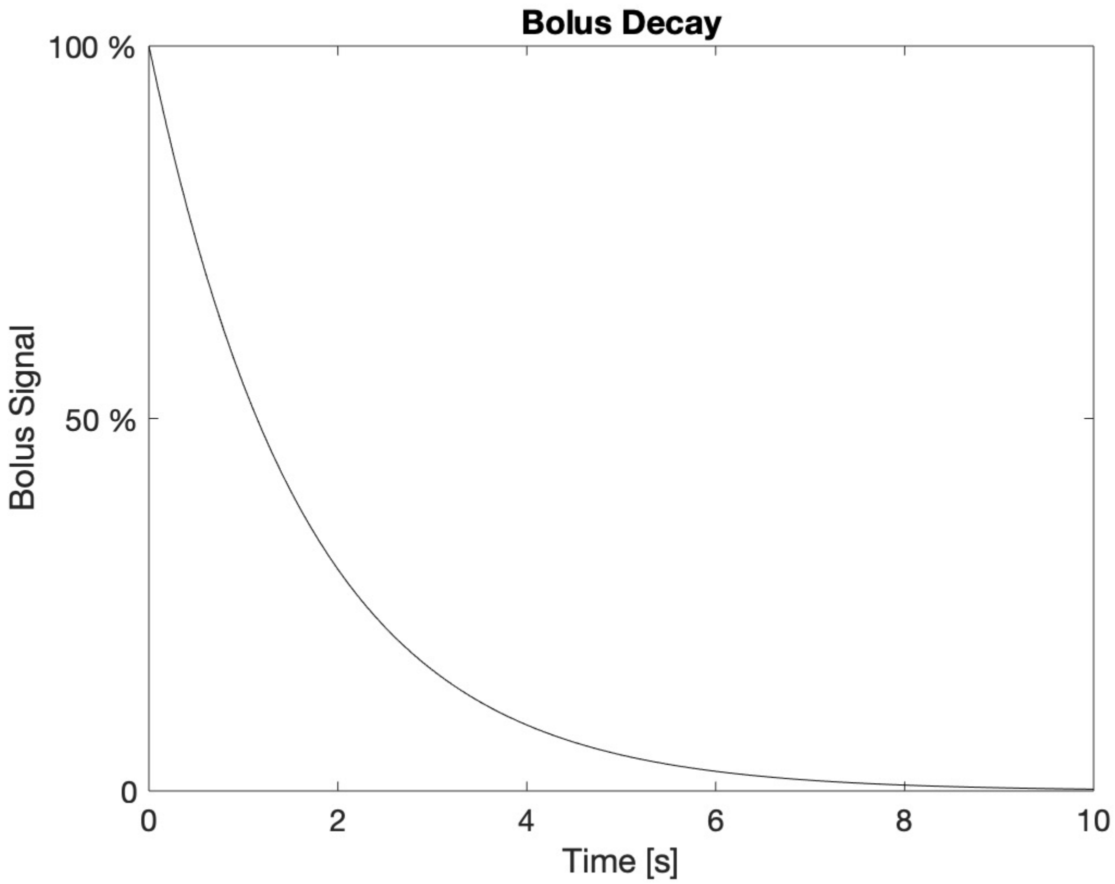




B_0
M_0
-
M_0
=
ΔM_0
Control
Label/tag
Difference

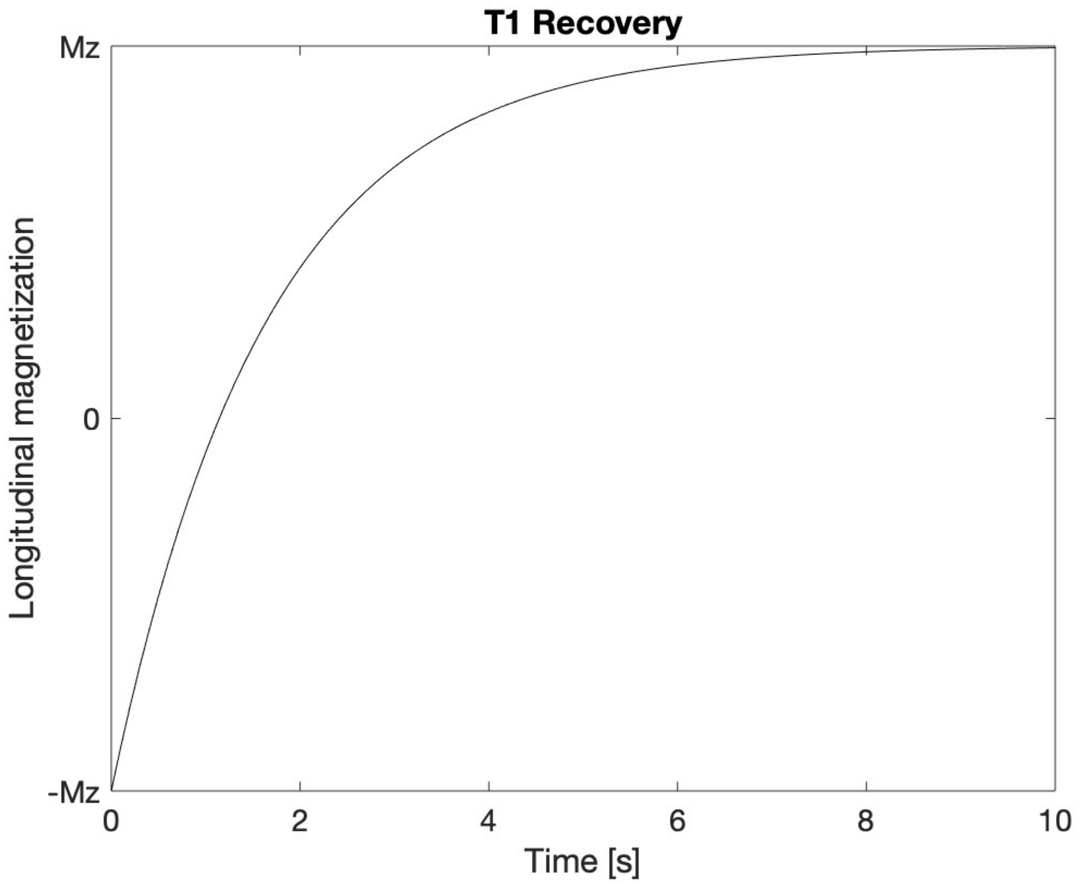
T1 Inversion Recovery

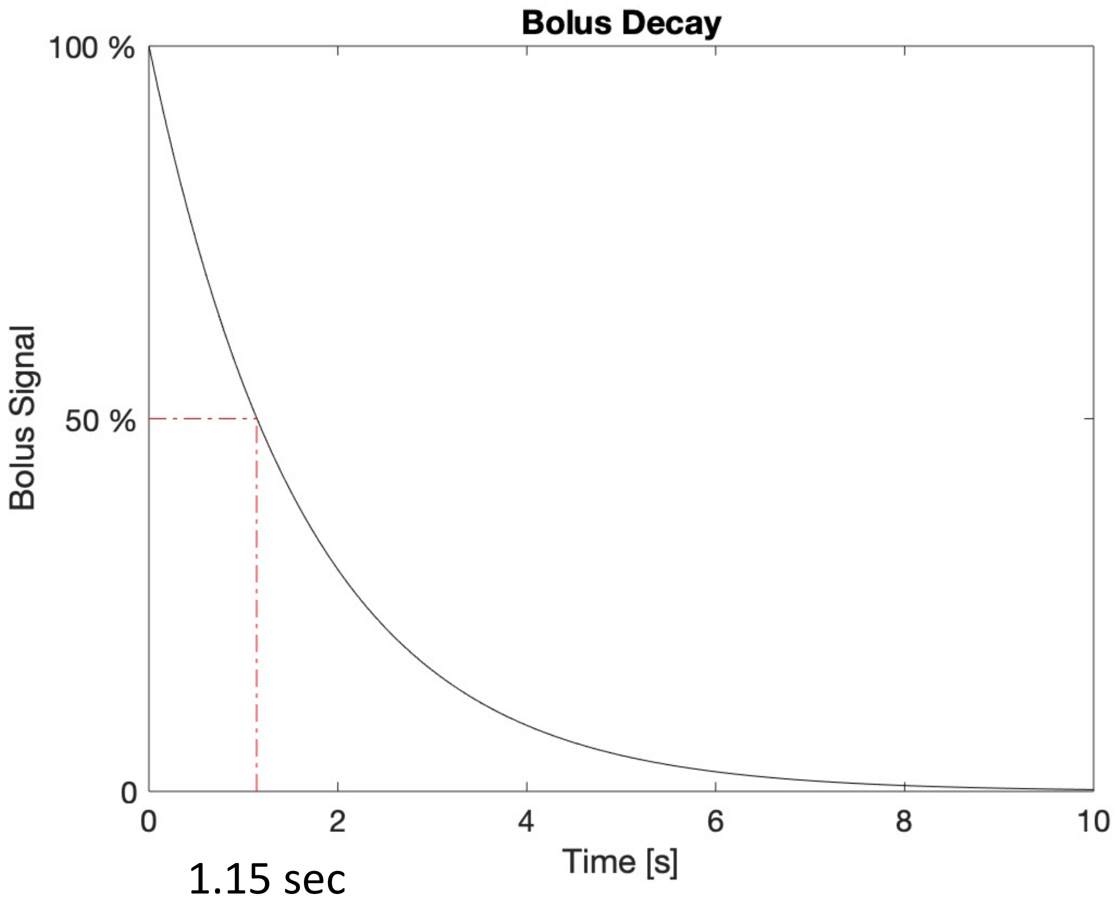




T_1 of blood @ 3T is 1650 ms

T1 Inversion Recovery





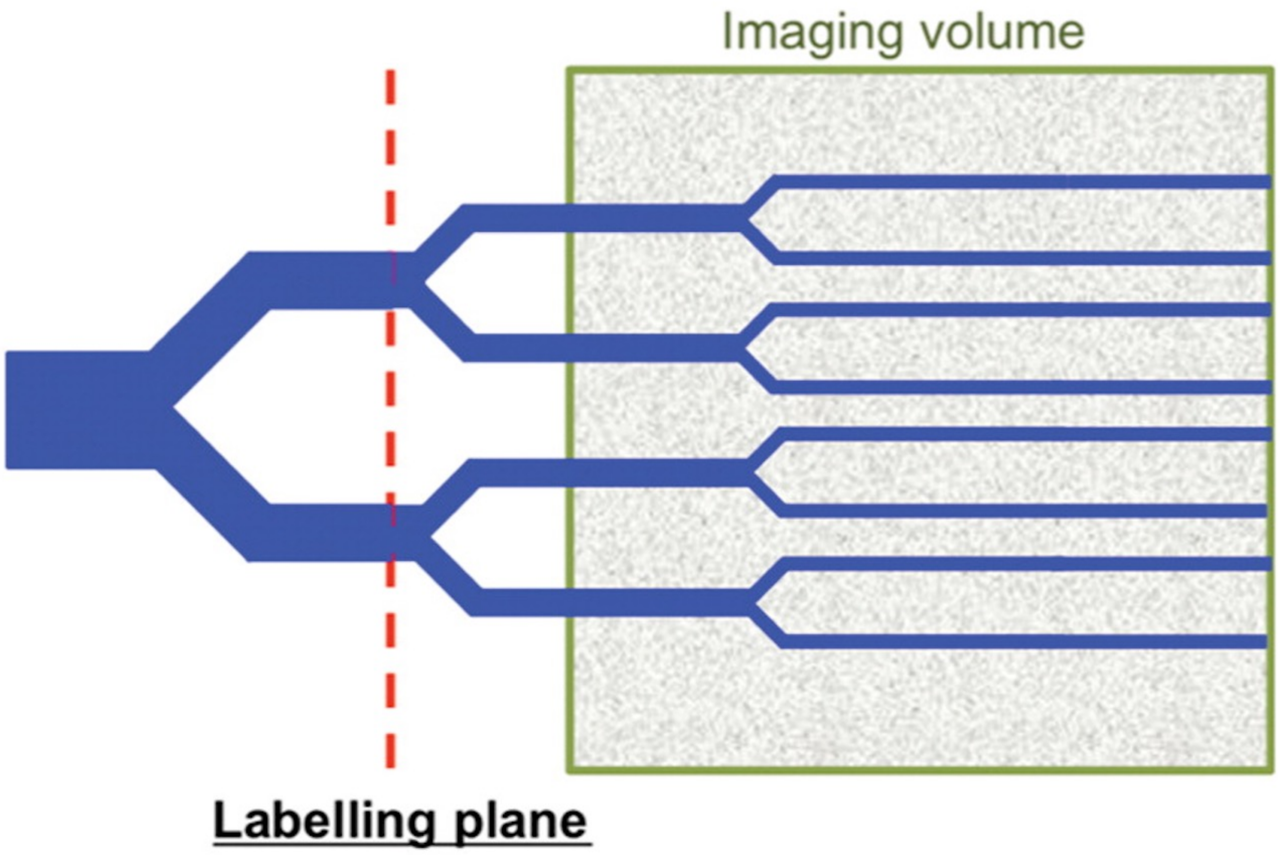
1.15 sec

T_1 of blood @ 3T is 1650 ms

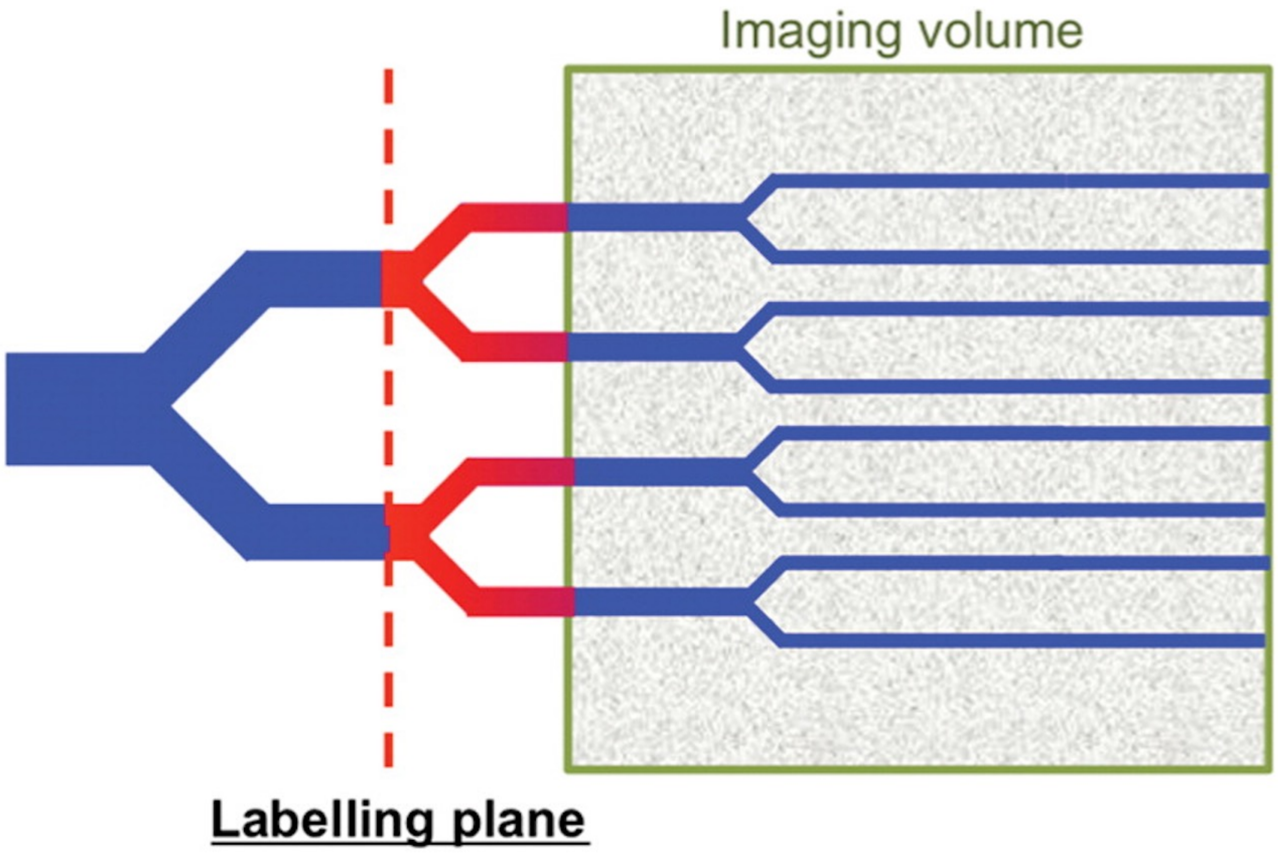
Delay

- Allow the labelled spins to travel to the regions of interest
- Also known as
  - Post-labelling delay
  - Inversion delay

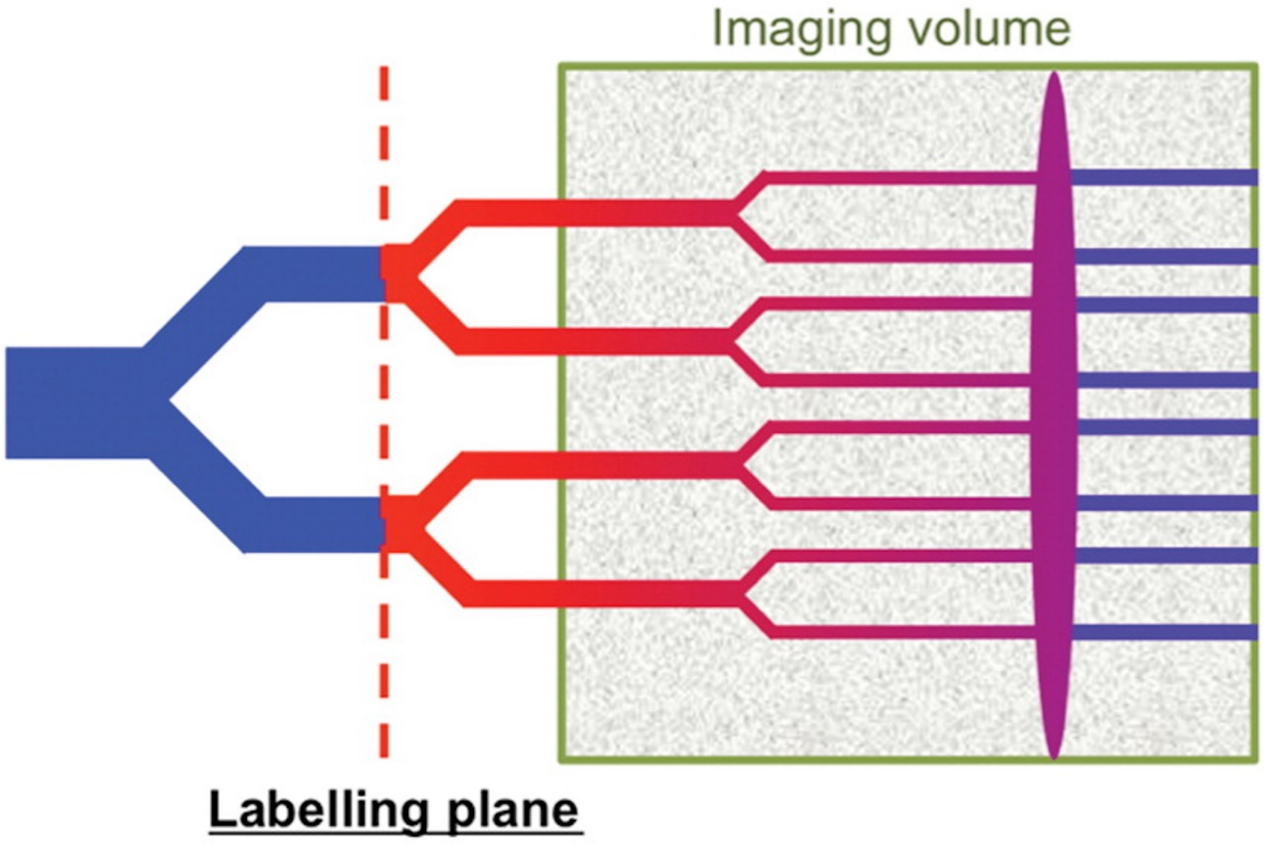
Delay



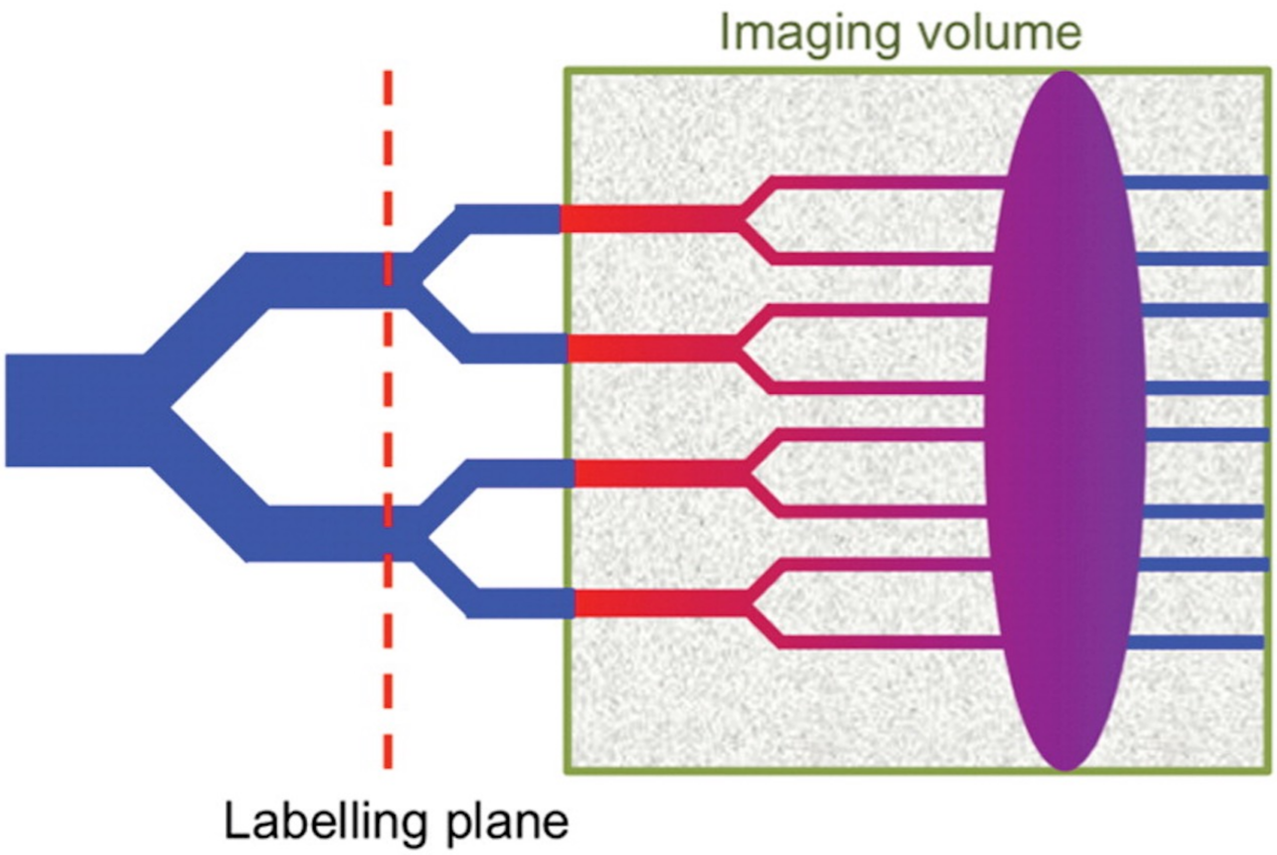
Delay



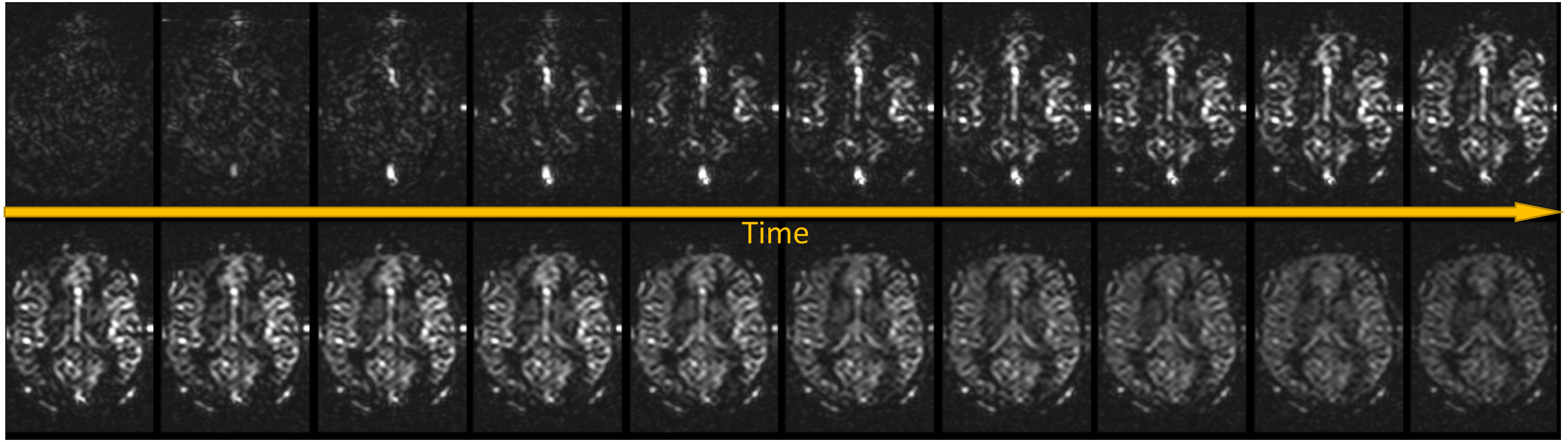
Delay



Delay

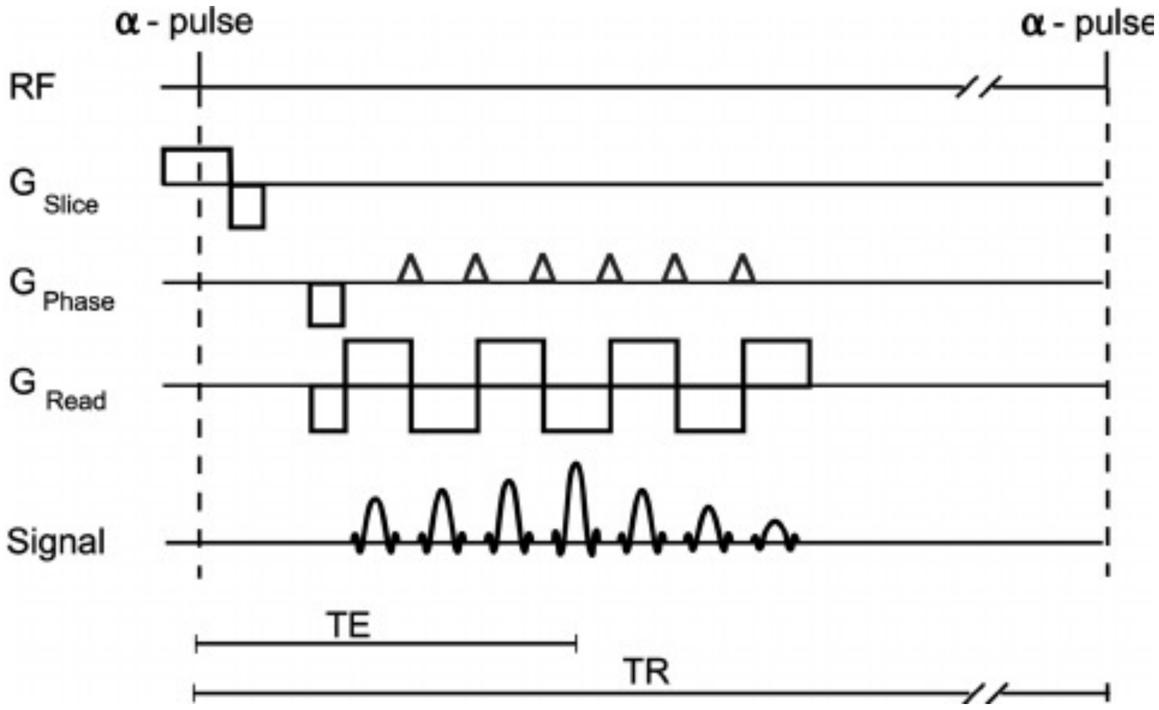


Delay

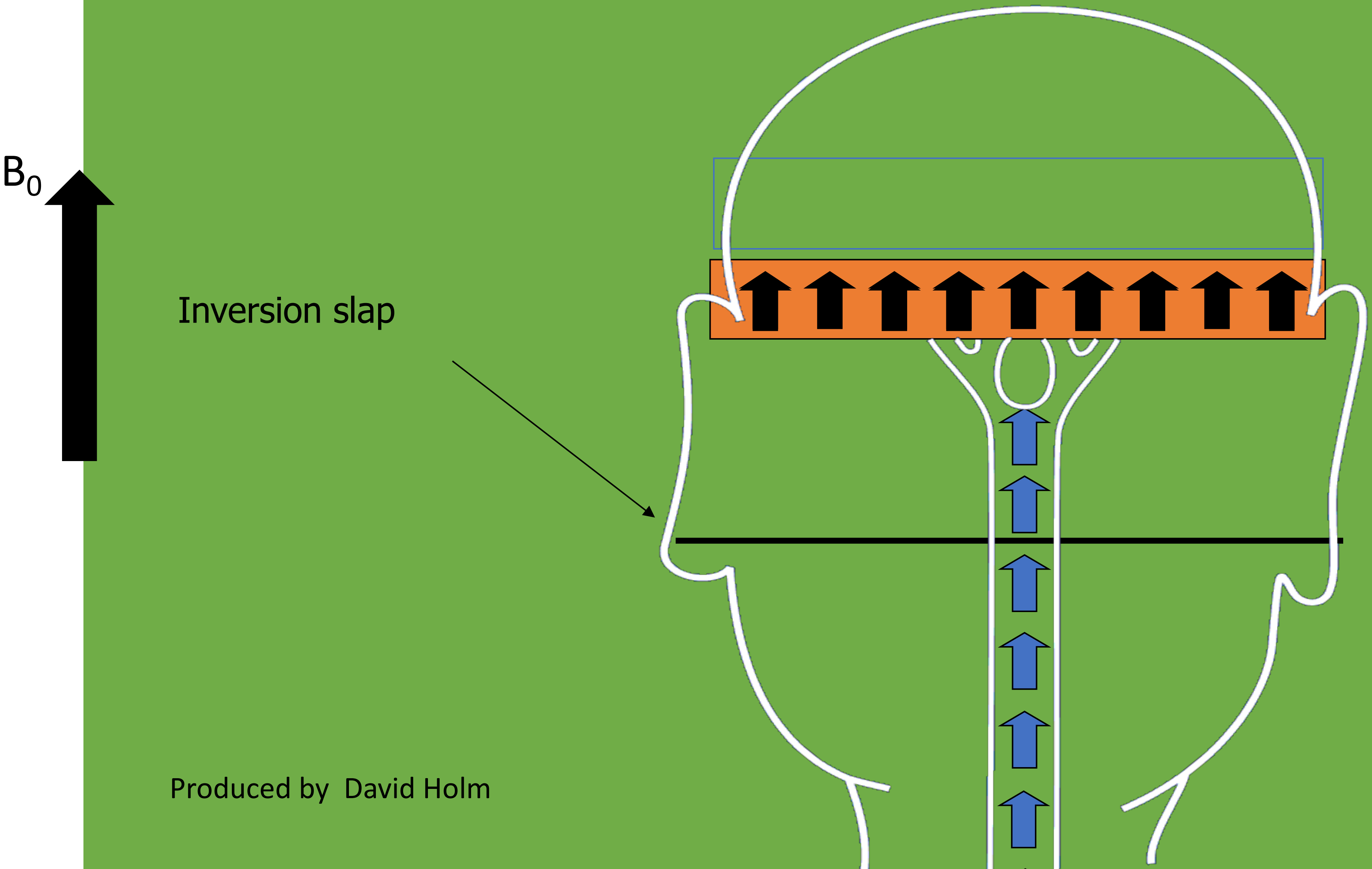


Imaging

- Needs to be fast due to shortlived bolus
  - 2D EPI
- 3D methods also exist
  - Segmented – multiple chunks
    - New label required
  - Spiral read out

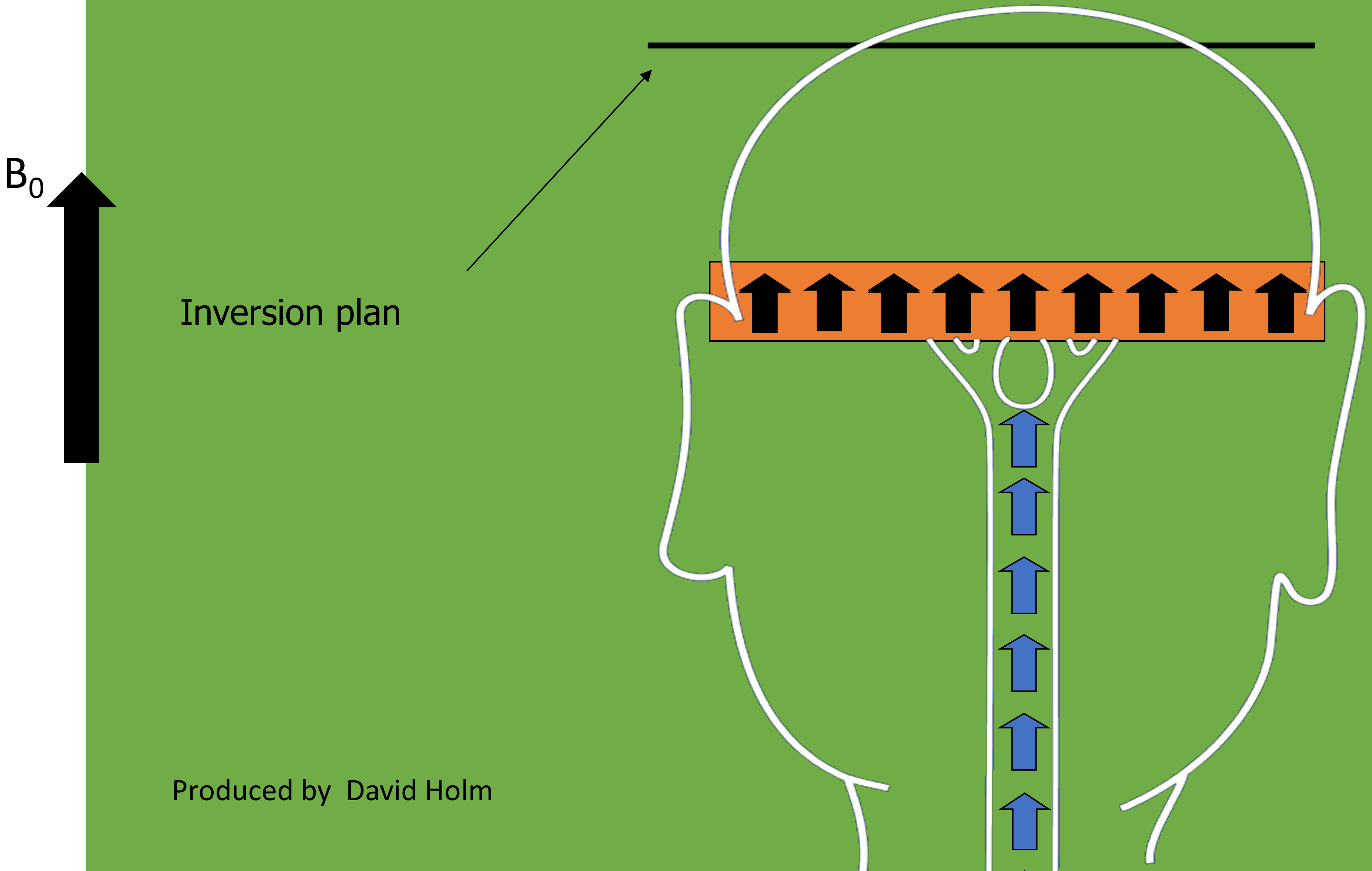


CASL – labelling image



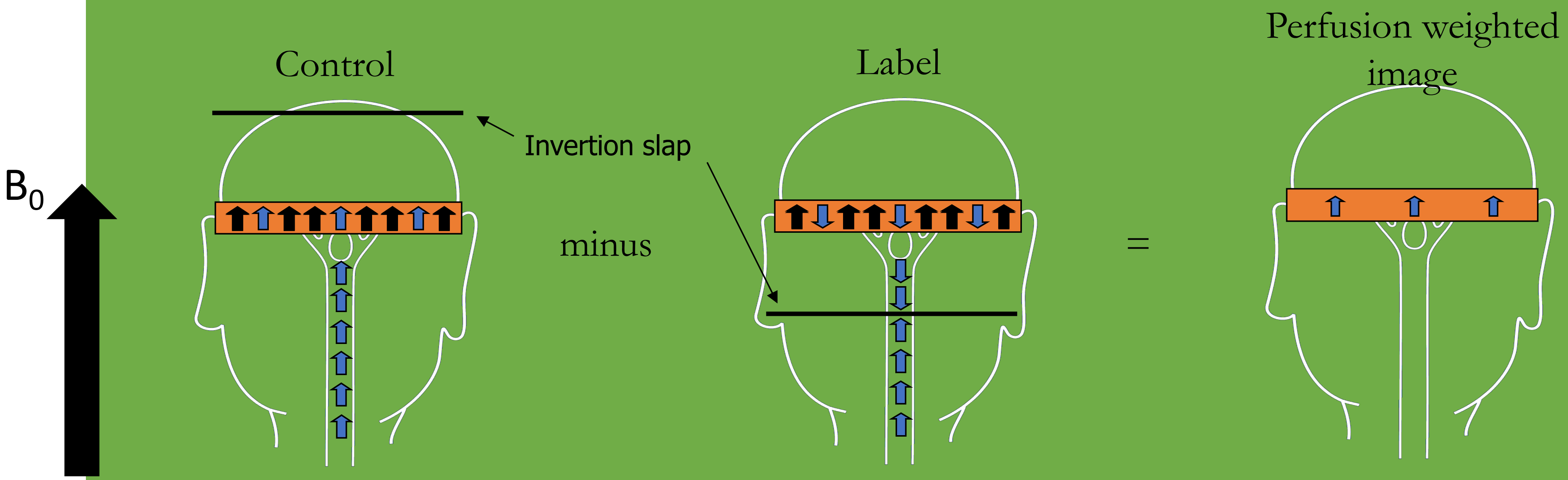
Produced by David Holm

CASL – no-labelling image



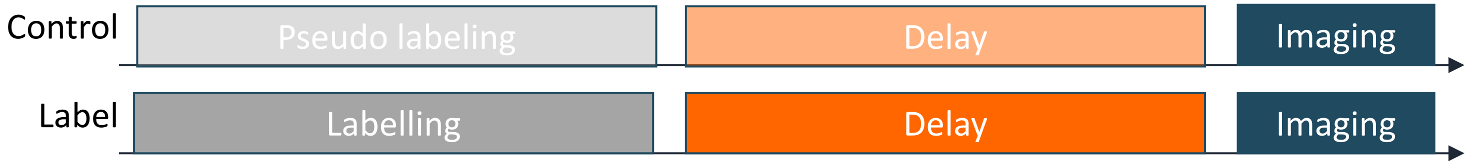
Produced by David Holm

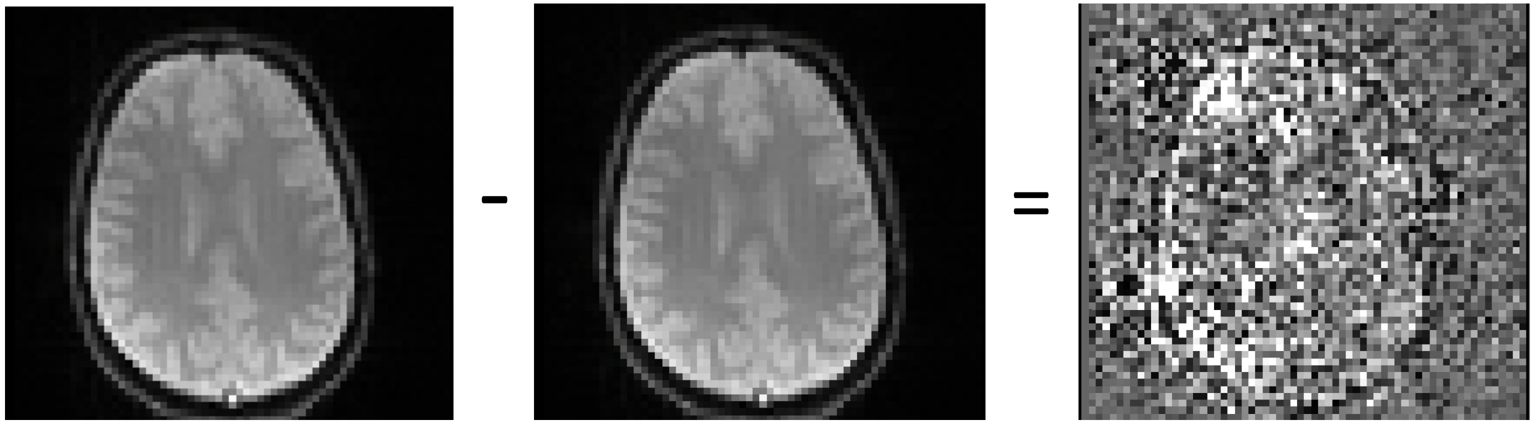
CASL – summing up



HBWL

Imaging 2D EPI





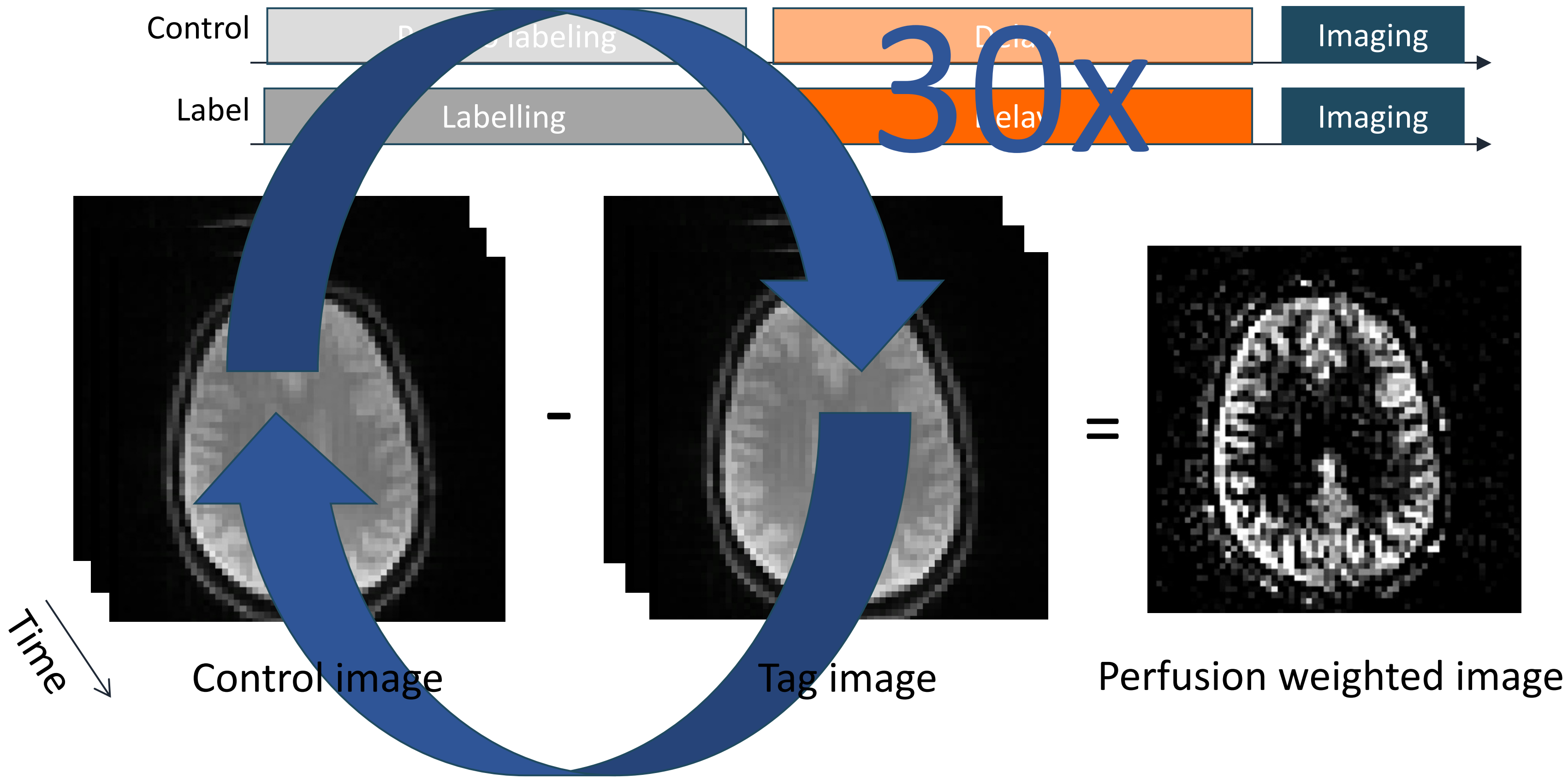
Control image

Label image

Difference image ΔM

ΔM is typically ~1% of the control signal

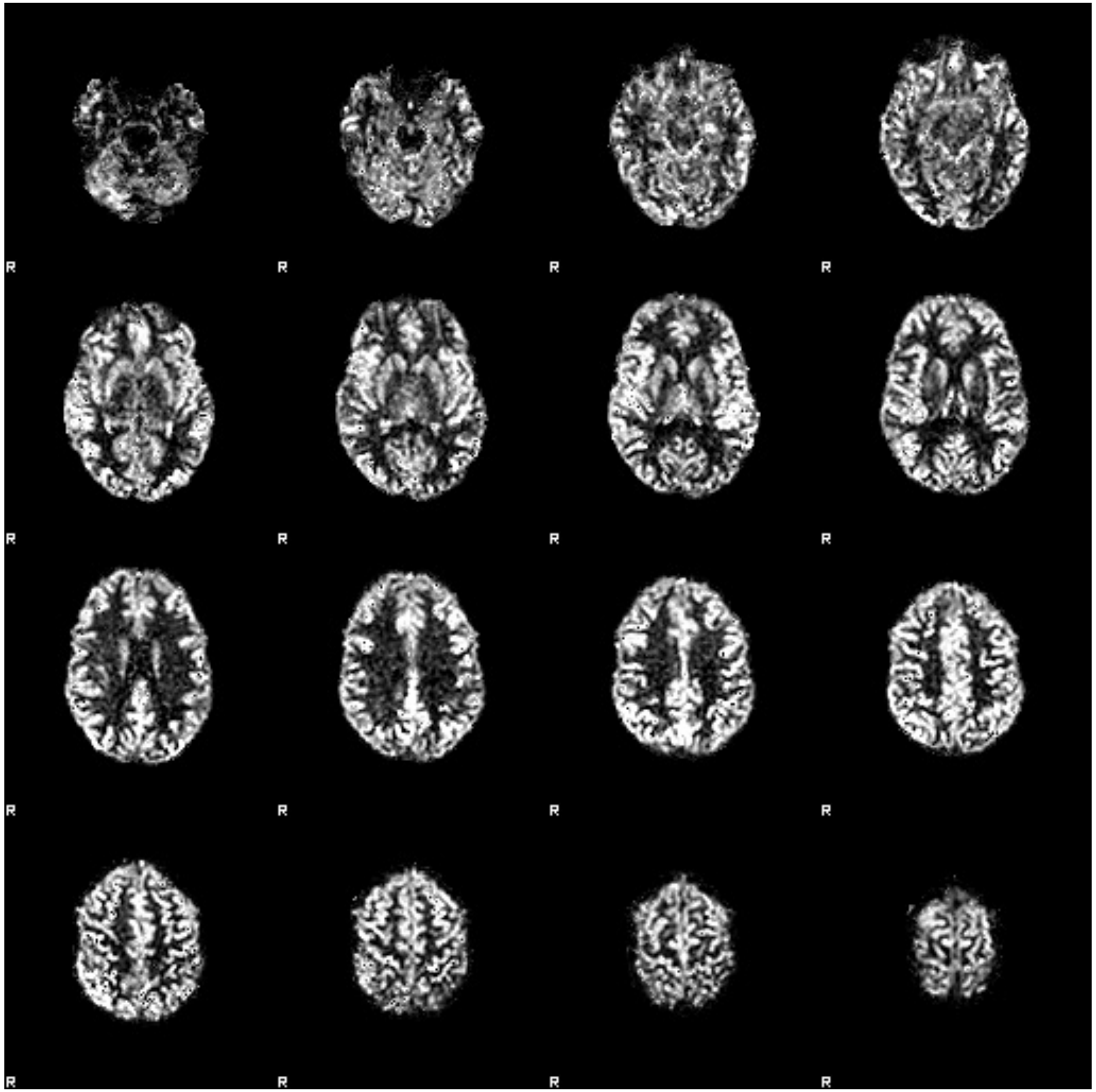
Imaging



Control
Label
Labelling
Imaging
Imaging
30x
-
=
Time
Control image
Tag image
Perfusion weighted image

Perfusion weighted image

Signal proportional to perfusion but NOT quantitative



Quantification

ΔM

Post-labelling delay

$$\mathrm{CBF} = \frac{6000 \cdot \lambda \cdot (\mathrm{SI}_{\mathrm{control}} - \mathrm{SI}_{\mathrm{label}}) \cdot e^{\frac{\mathrm{PLD}}{T_{1,\ \mathrm{blood}}}}}{2 \cdot \alpha \cdot T_{1,\mathrm{blood}} \cdot \mathrm{SI}_{\mathrm{PD}} \cdot (1\text{-}e^{-\frac{\tau}{T_{1,\mathrm{blood}}}})} \quad [\mathrm{ml}/100\ \mathrm{g}/\mathrm{min}]$$

Magnetic Resonance in Medicine 73:102–116 (2015)

Recommended Implementation of Arterial Spin-Labeled Perfusion MRI for Clinical Applications: A Consensus of the ISMRM Perfusion Study Group and the European Consortium for ASL in Dementia

David C. Alsop,[1] John A. Detre,[2] Xavier Golay,[3] Matthias Günther,[4,5,6] Jeroen Hendrikse,[7] Luis Hernandez-Garcia,[8] Hanzhang Lu,[9] Bradley J. MacIntosh,[10,11] Laura M. Parkes,[12] Marion Smits,[13] Matthias J. P. van Osch,[14] Danny J. J. Wang,[15] Eric C. Wong,[16*] and Greg Zaharchuk[17†]

Values To Be Used in Quantification of ASL Data

Parameter	Value
λ (blood–brain partition coefficient)	0.9 mL/g (74)
$T_{1,blood}$ at 3.0T	1650 ms (10)
$T_{1,blood}$ at 1.5T	1350 ms (75)
α (labeling efficiency) for PCASL	0.85 (17)
α (labeling efficiency) for PASL	0.98 (19)

Tracer Kinetic Modelling

A General Kinetic Model for Quantitative Perfusion Imaging with Arterial Spin Labeling

Richard B. Buxton, Lawrence R. Frank, Eric C. Wong, Bettina Siewert, Steven Warach, Robert R. Edelman

MRM 40:383–396 (1998)

From the Departments of Radiology (R.B.B., L.R.F., E.C.W.) and Psychiatry (E.C.W.), University of San Diego, San Diego, California; and the Department of Radiology (B.S., S.W., R.R.E.), Beth Israel Hospital, Boston, Massachusetts.

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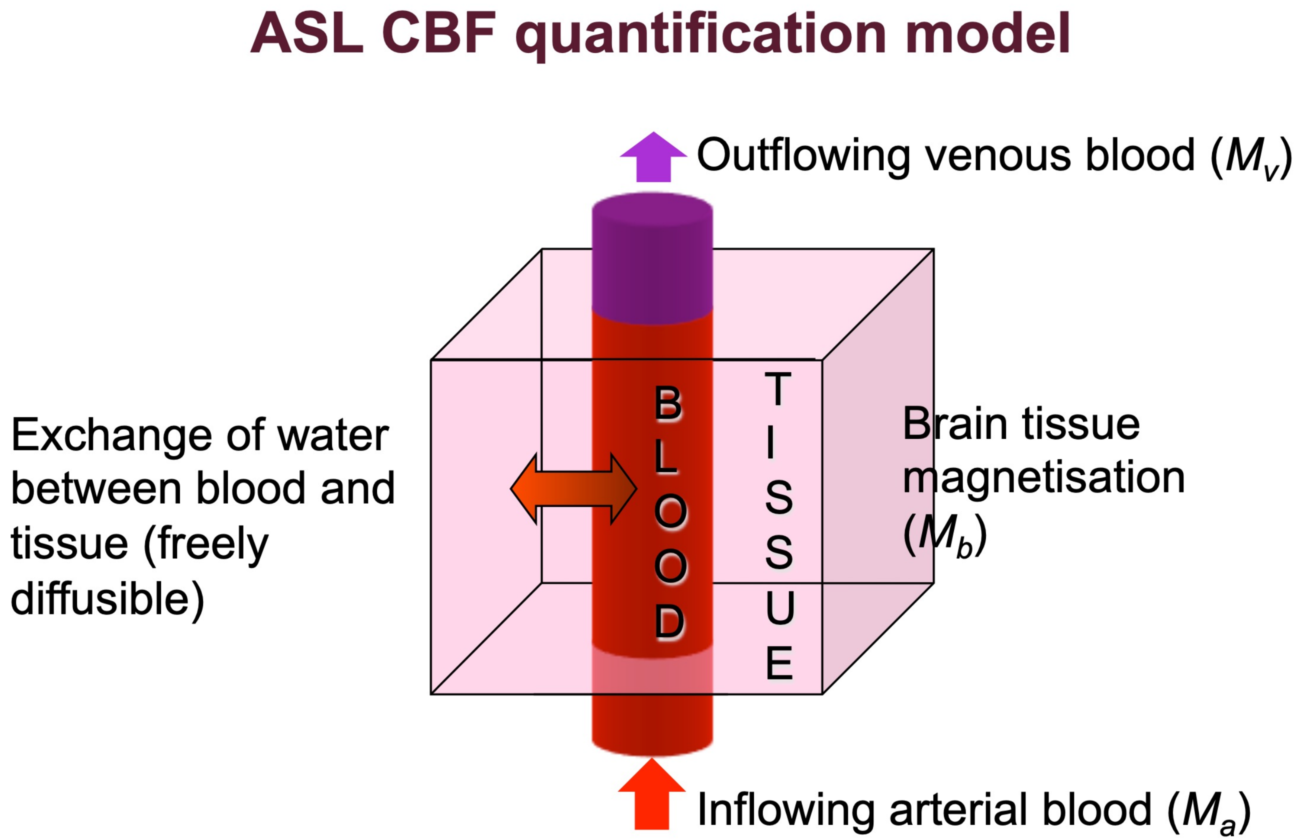
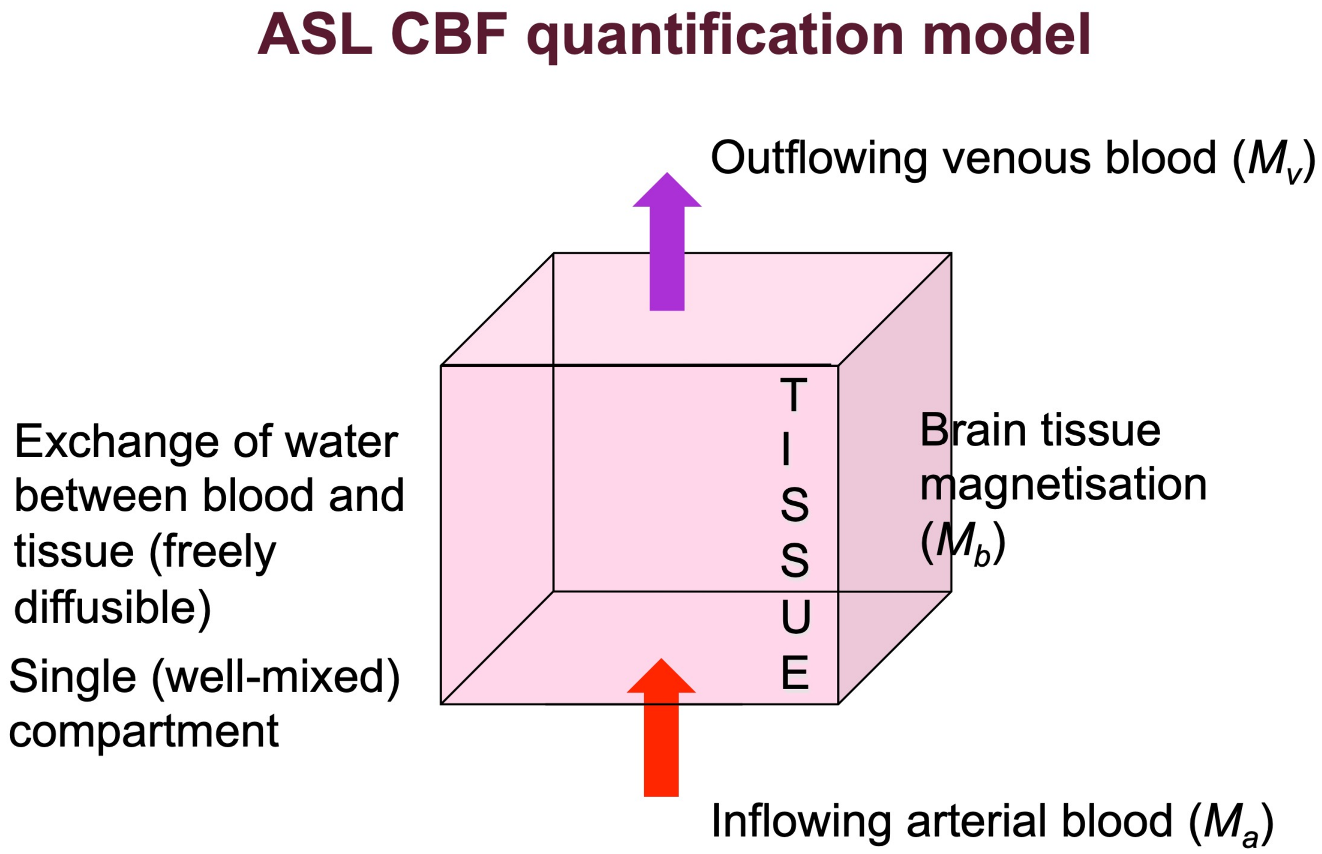
Received September 10, 1997; revised December 10, 1997; accepted February 15, 1998.

0740-3194/98 $3.00

Tracer Kinetic Modelling



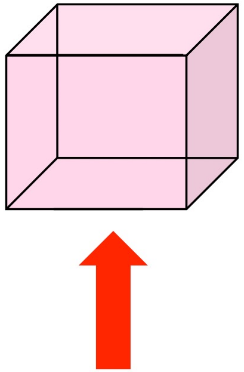
Tracer Kinetic Modelling



Tracer Kinetic Modelling

ASL CBF general kinetic model

Retention of the tracer in the voxel
Residue function



Tissue voxel

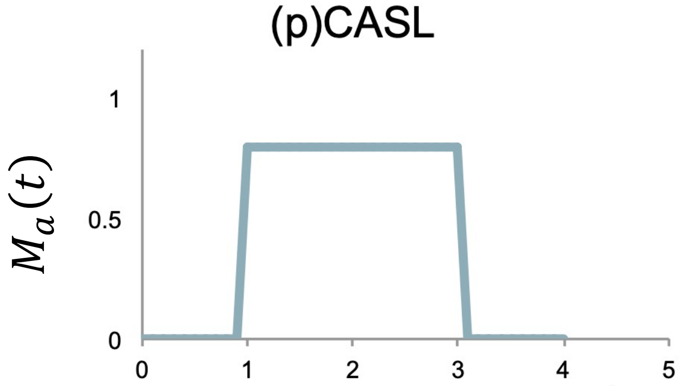
Delivery of the tracer to the voxel
Arterial Input Function (M_a)

- Need to know what these functions are

Tracer Kinetic Modelling

ASL CBF general kinetic model

- Arterial Input Function (AIF)



$M_a(t) = 0$ when $t <$ bolus arrival time (Δt)
$M_a(t) = 0$ when $t > \Delta t$ + bolus duration (τ)

$M_a(t) = 2M_a^0.\alpha$ *for (p)CASL*

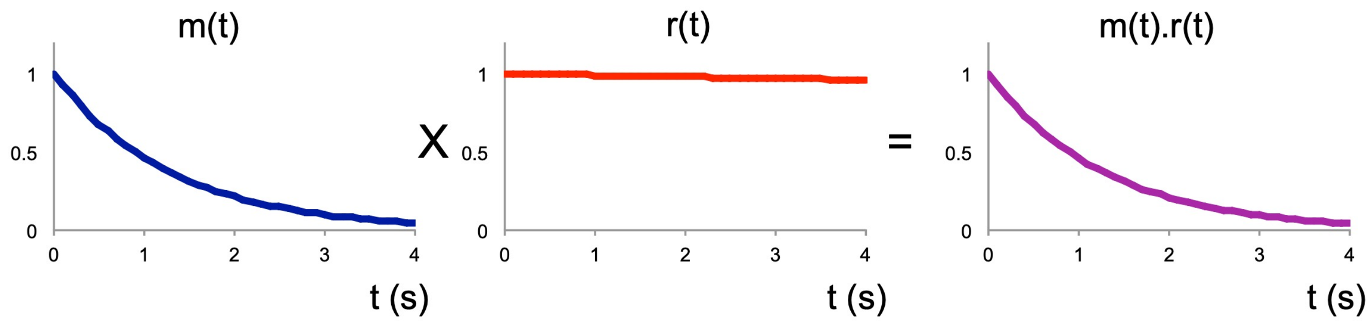
α = inversion efficiency

Tracer Kinetic Modelling

ASL CBF general kinetic model

- Residue function (Res)
  - Tracer reduces due to T_1 relaxation of label
    $m(t) = \exp(-t/T_1)$
  - Tracer lost due to venous outflow
    $r(t) = \exp(-f/\lambda.t)$

$$Res = m(t).r(t)$$



Tracer Kinetic Modelling

ASL CBF general kinetic model

- Equation for general kinetic model

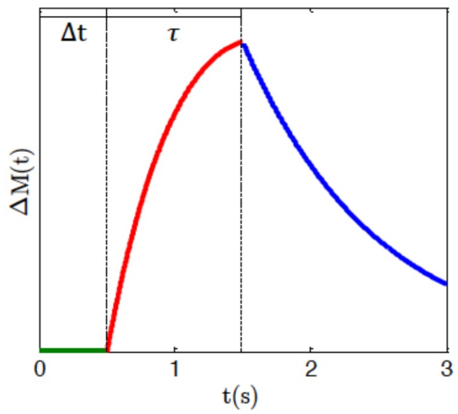
$$\Delta M(t) = CBF \times [AIF(t) * Res(t)]$$

Tracer Kinetic Modelling

ASL CBF general kinetic model

- Solution for general kinetic model

$$\Delta M(t) = \begin{cases} 0, & 0 < t < \Delta t \\ 2M_{0b} f (t - \Delta t) \alpha e^{-\frac{t}{T_{1b}}} q_p(t), & \Delta t < t < \Delta t + \tau \\ 2M_{0b} f \tau \alpha e^{-\frac{t}{T_{1b}}} q_p(t), & t > \Delta t + \tau \end{cases}$$



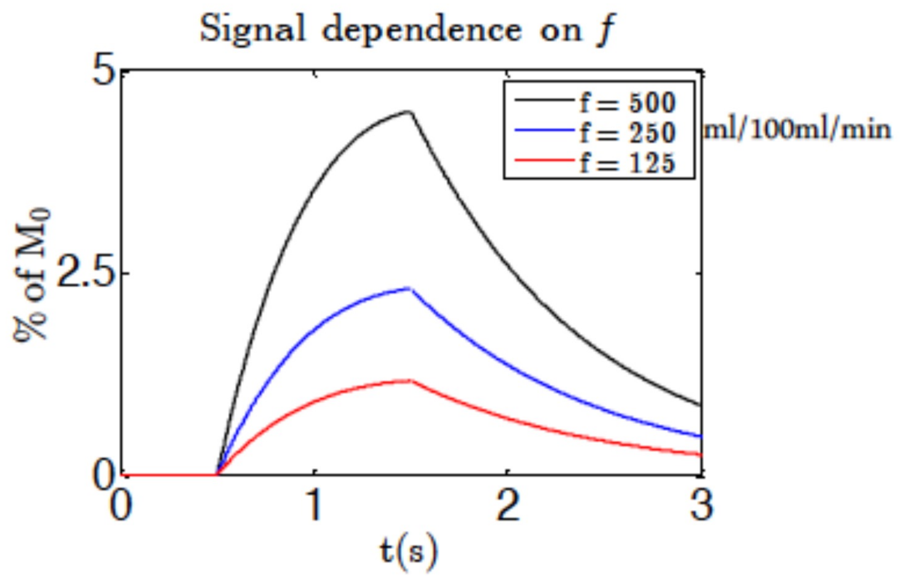
Where

$$q_p(t) = 1 - e^{-\frac{(t-\Delta t)}{T1'}} \qquad \Delta t < t < \tau + \Delta t$$

$$q_p(t) = 1 - e^{-\tau/T1} \qquad \tau + \Delta t < t$$

Tracer Kinetic Modelling

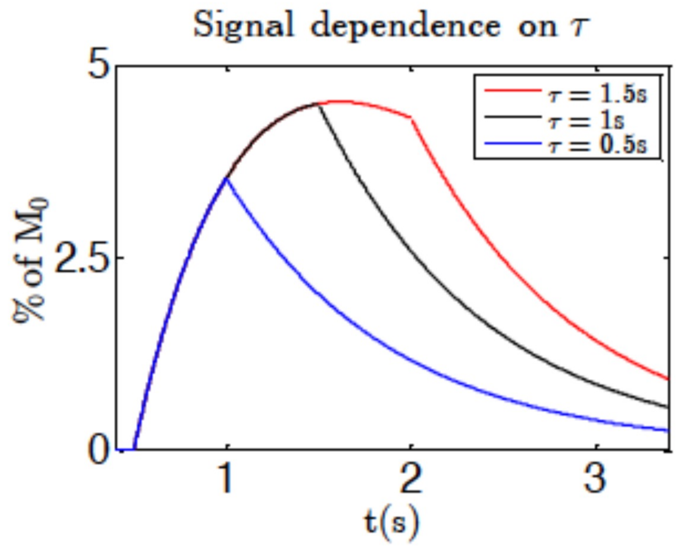
Parameters of the general kinetic model



Sensitivity to blood flow

Tracer Kinetic Modelling

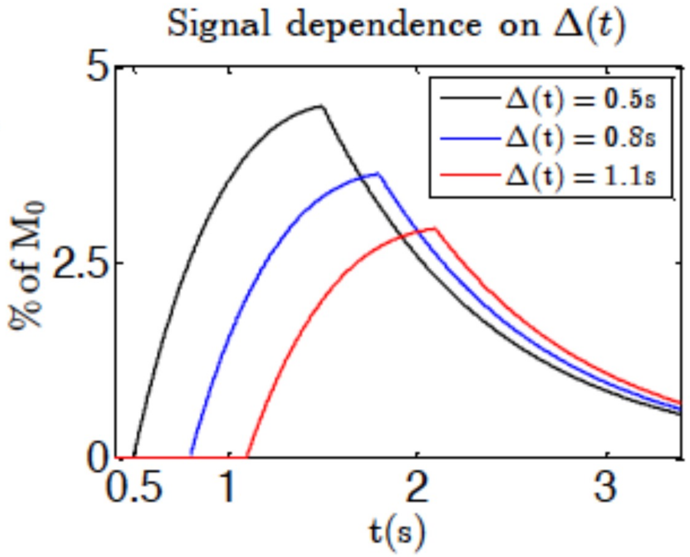
Parameters of the general kinetic model



Sensitivity to bolus width

Tracer Kinetic Modelling

Parameters of the general kinetic model

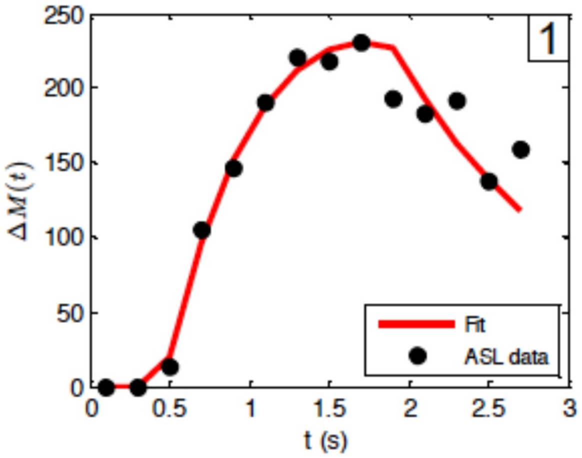


Sensitivity to bolus arrival time

Tracer Kinetic Modelling

Quantification of CBF using ASL data

- Acquire ASL images over a range of inflow times
- Fit the data to the general kinetic model



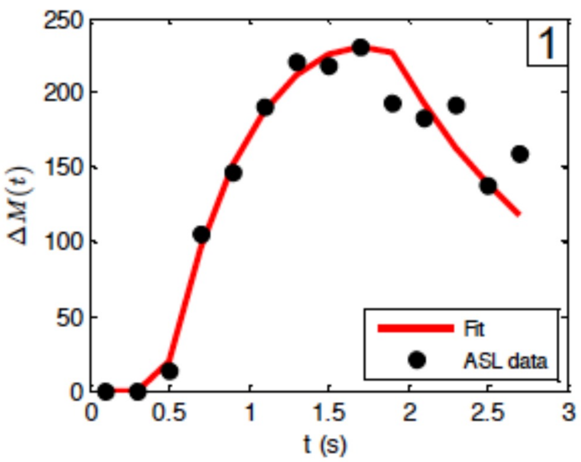
Fitted parameters: **CBF, Δt, τ**

Other parameters needed:
T_{1b} (blood T_1)
M_a^0 (equilibrium blood signal)
Tissue T_1
α (inversion efficiency)
λ (blood:brain partition coeff)

Tracer Kinetic Modelling

Quantification of CBF using ASL data

- Acquire ASL images over a range of inflow times
- Fit the data to the general kinetic model



Fitted parameters: **CBF, Δt, τ**

Other parameters needed:

T_{1b} Single value - assumed

M_a^0 } Measured – separate scans

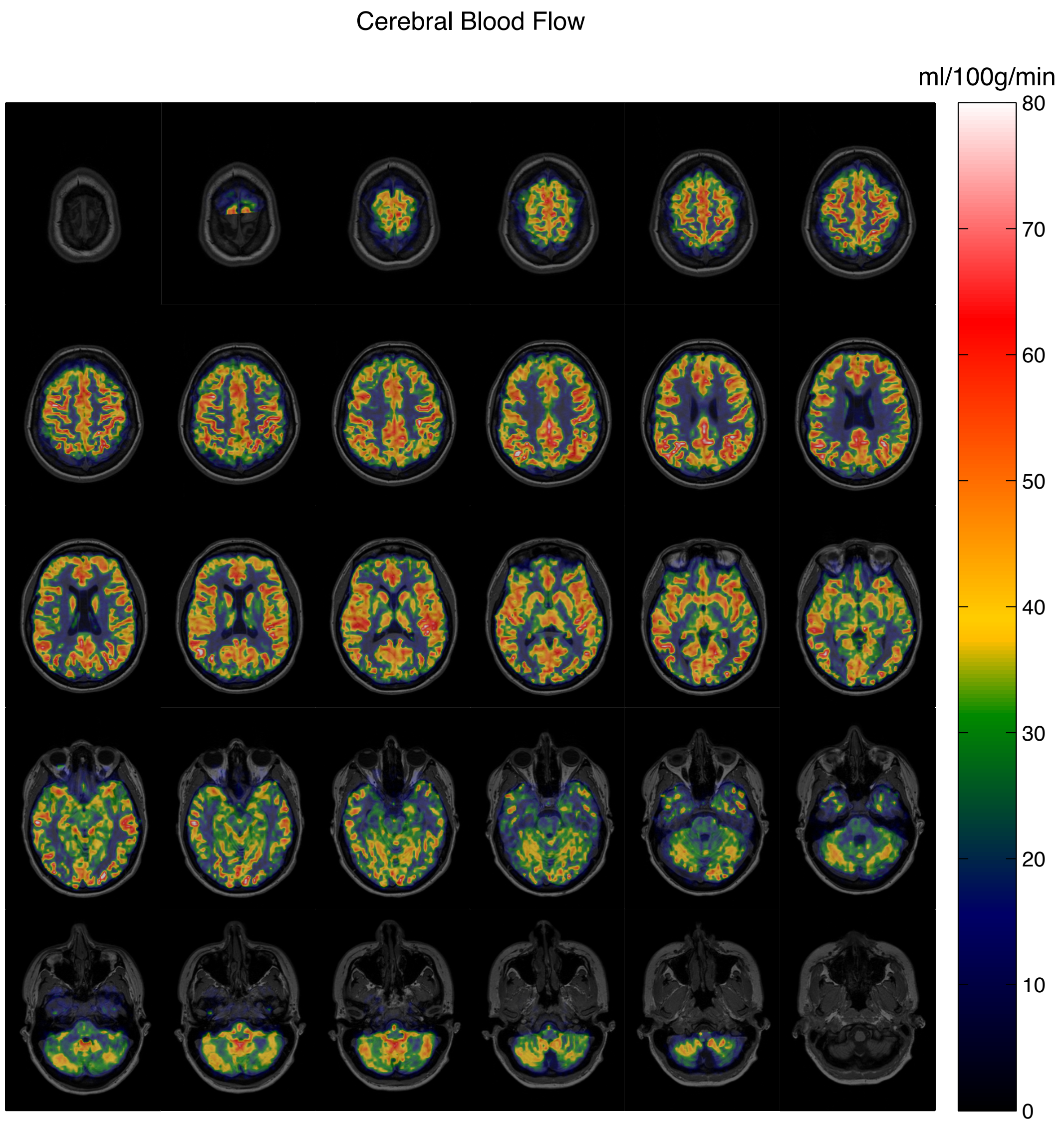
Tissue T_1

α Single value - assumed

λ Single value - assumed

Cerebral blood flow

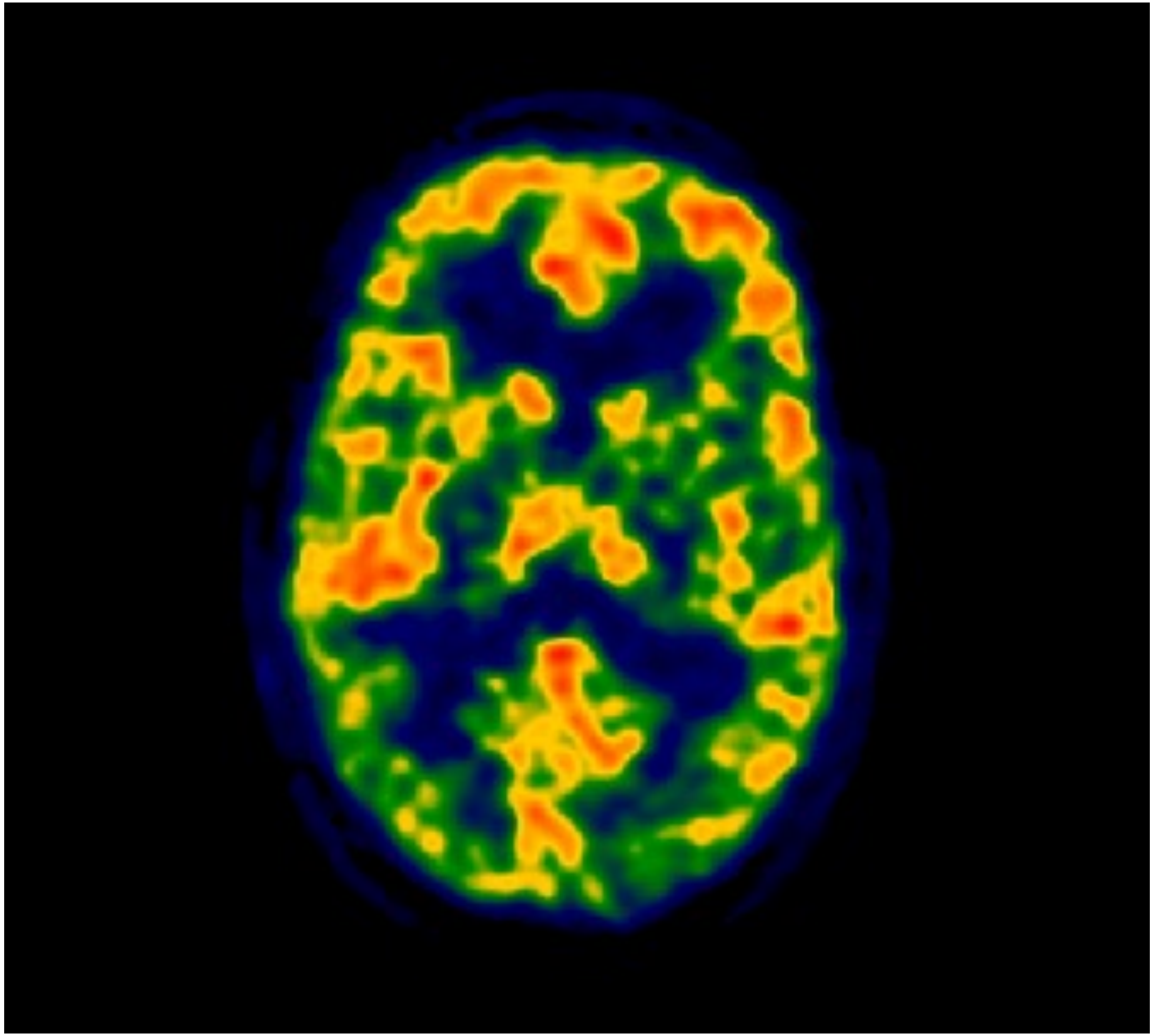
- Water is (almost) a freely diffusible tracer
- All labeled spins will cross the BBB when flowing through the microvasculature.
- Cerebral blood flow is therefore directly related to the amount of spins that arrived in the brain tissue
- When we label more spins, more signal will be detected



Analogy with O^{15}-H_2O PET

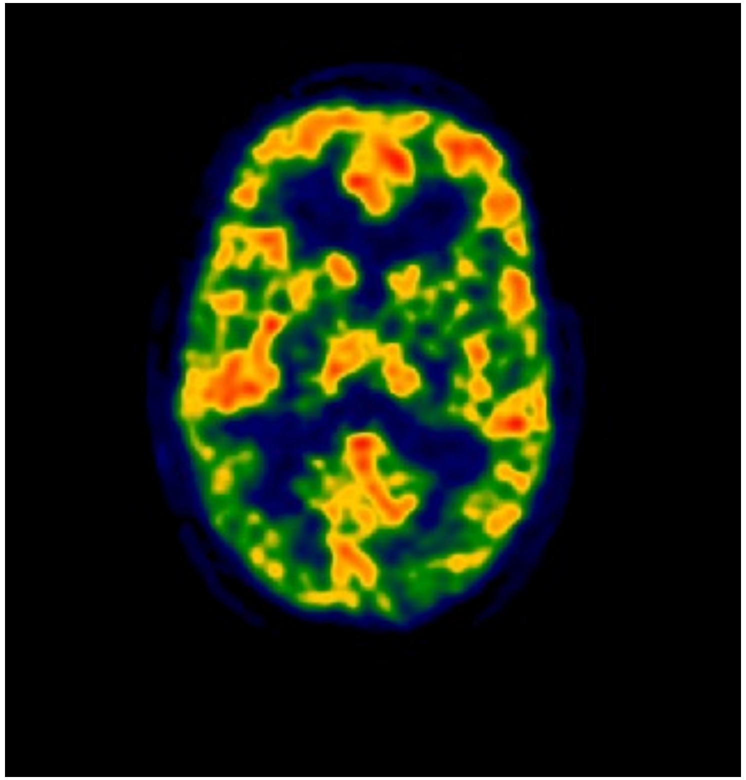
- With O^{15}-H_2O PET we **inject** radioactively labeled water to act as an **exogenous** tracer.

- With ASL we **magnetically label** the water in the blood to act as an **endogenous** tracer.

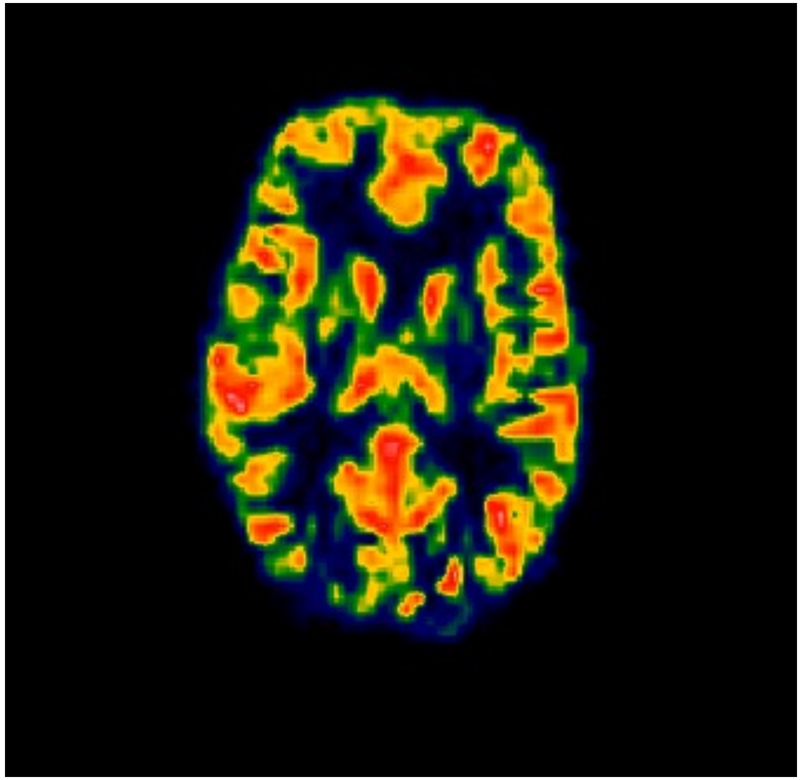


Analogy with O^{15}-H_2O PET

O^{15}-H_2O PET



ASL MRI



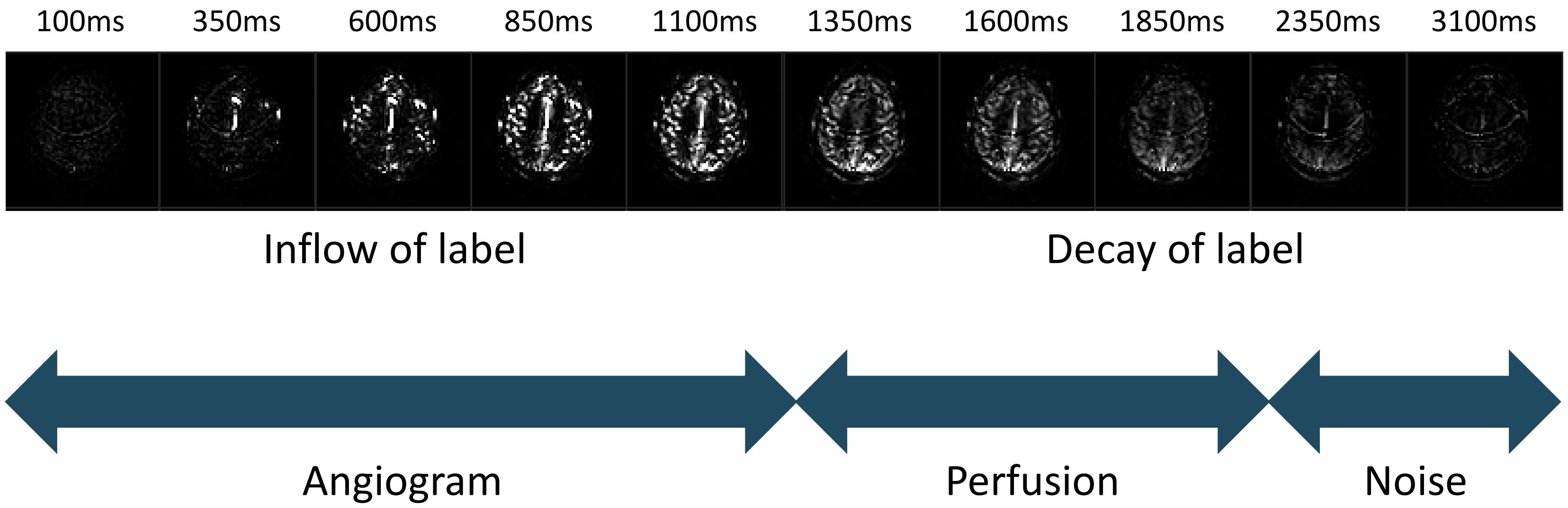
Analogy with O^{15}-H_2O PET

Property	$[^{15}O]$-water PET	ASL MRI
Tracer	Radiolabeled water (injected)	Magnetically labeled water (endogenous)
Half-life of tracer	2 min	1650 ms (at 3 T)
		1350 ms (at 1.5 T)
Ionizing radiation	Whole-body dose of 1.0–1.5 mSv	None
Spatial resolution	4–8 mm	1.8–4 mm
Acquisition time	3–10 min	3–6 min
Minimum time between scans	10 min	0 min
Reproducibility	5–10%	3–16%
Input function	Arterial blood sampling	Usually assumed; explicitly obtained in some ASL methods
Modeling	Kety–Schmidt (one-compartment) model	Microsphere model

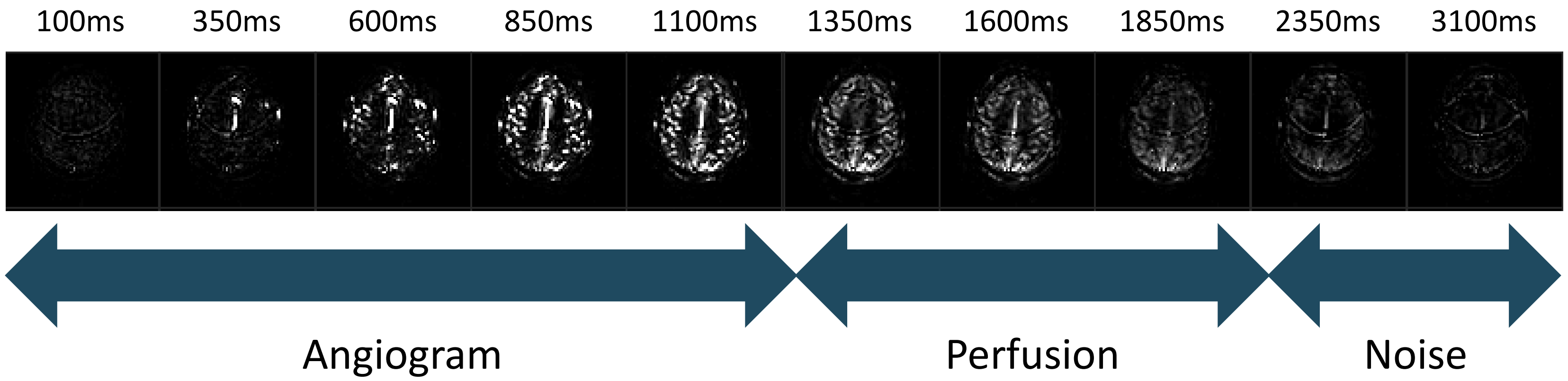
[m]ASL: arterial spin labeling; MRI: magnetic resonance imaging; PET: positron emission tomography; CBF: cerebral blood flow; mSv: milliSievert.

Audrey P Fan et al., J Cereb Blood Flow Metab. 2016 May; 36(5): 842–861

Delayed arrival



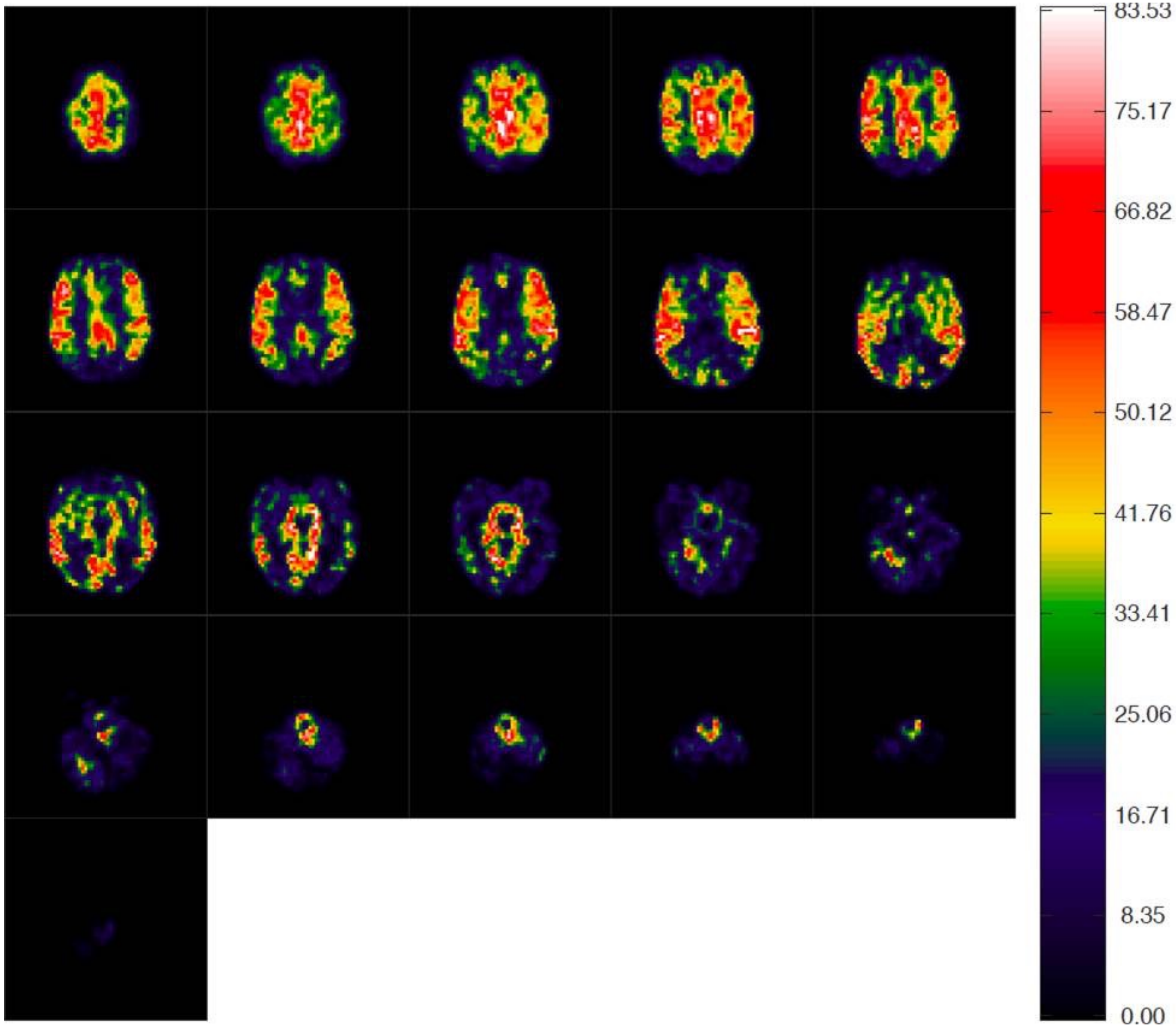
Delayed arrival



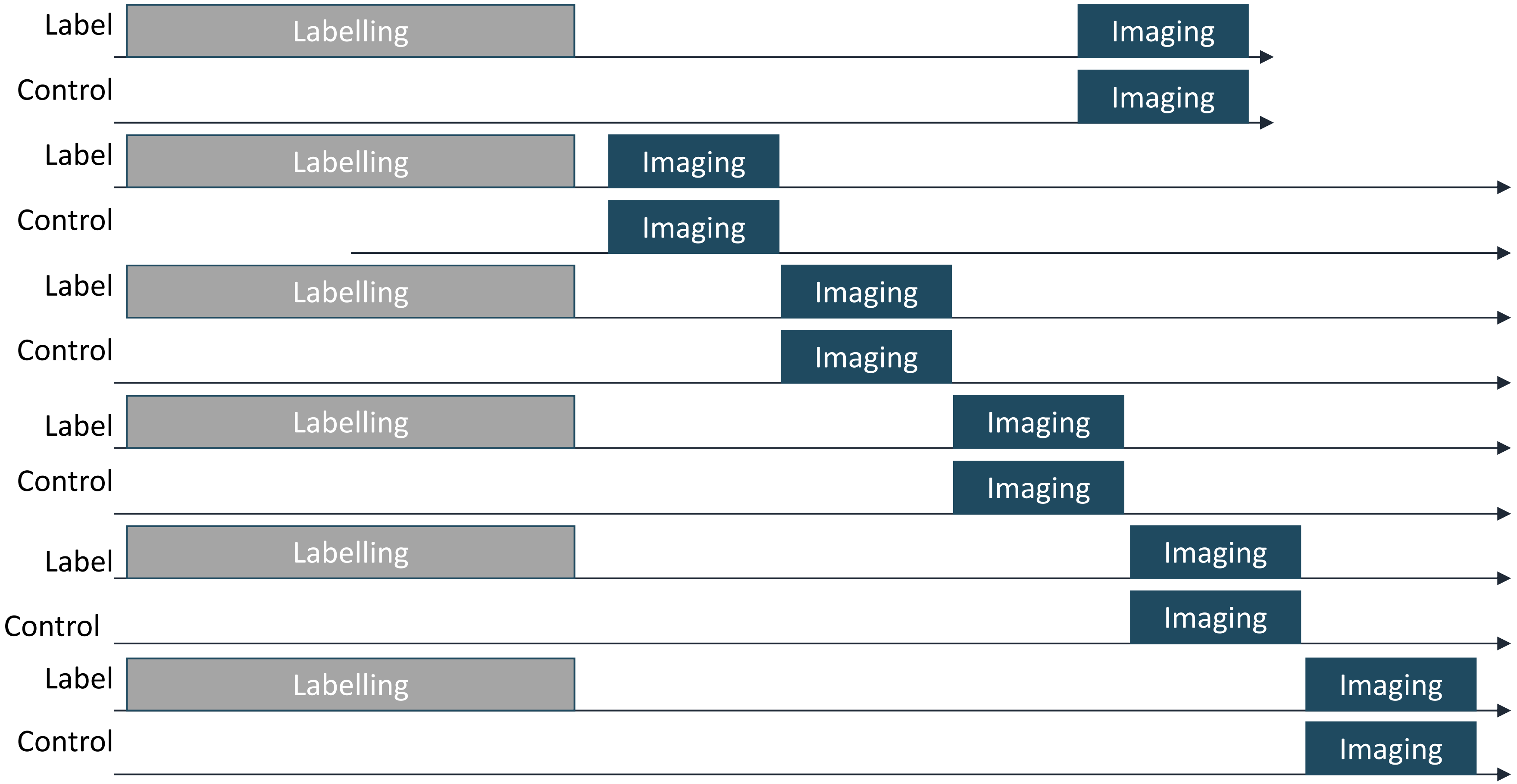
T_1 of blood @ 3T is 1650 ms

Delayed arrival

88 year-old

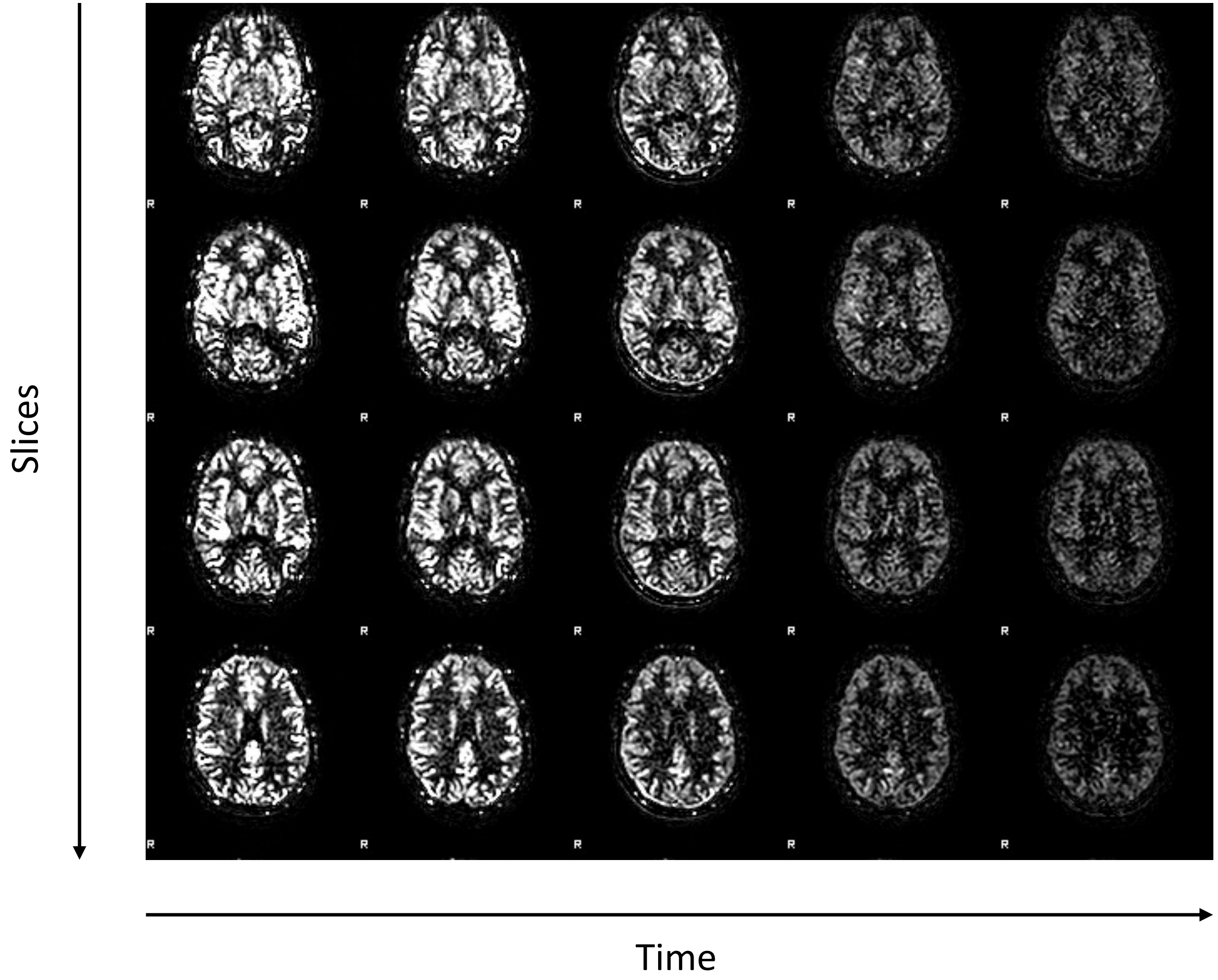


Multi delay ASL



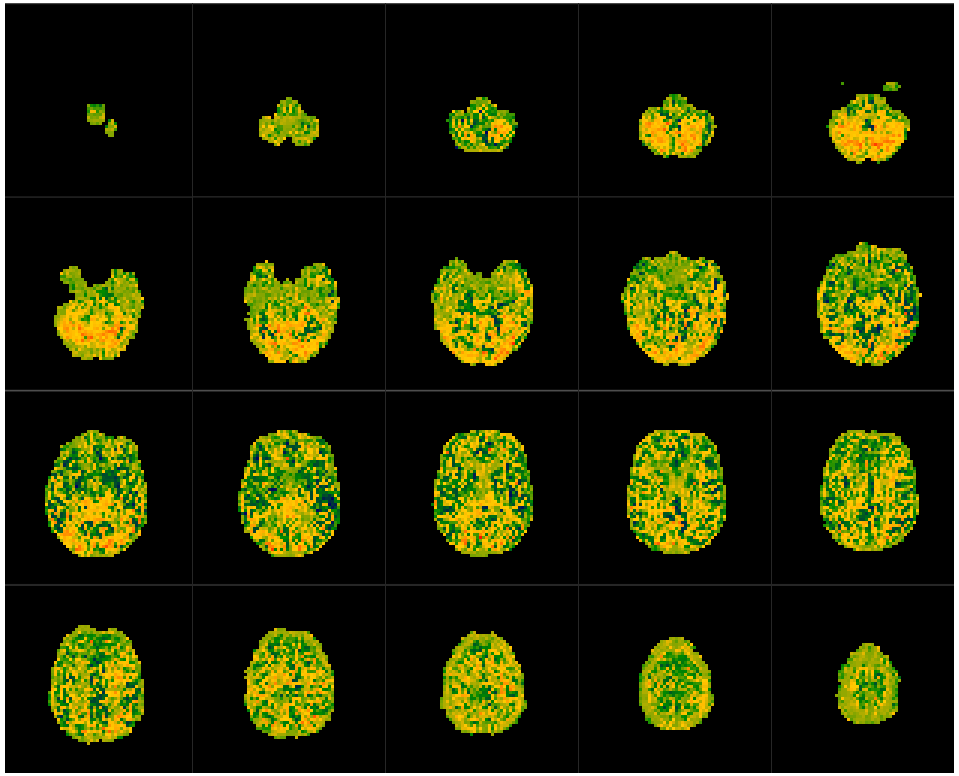
Multi delay ASL

- Captures the inflow of spins
- Model the bolus arrival time

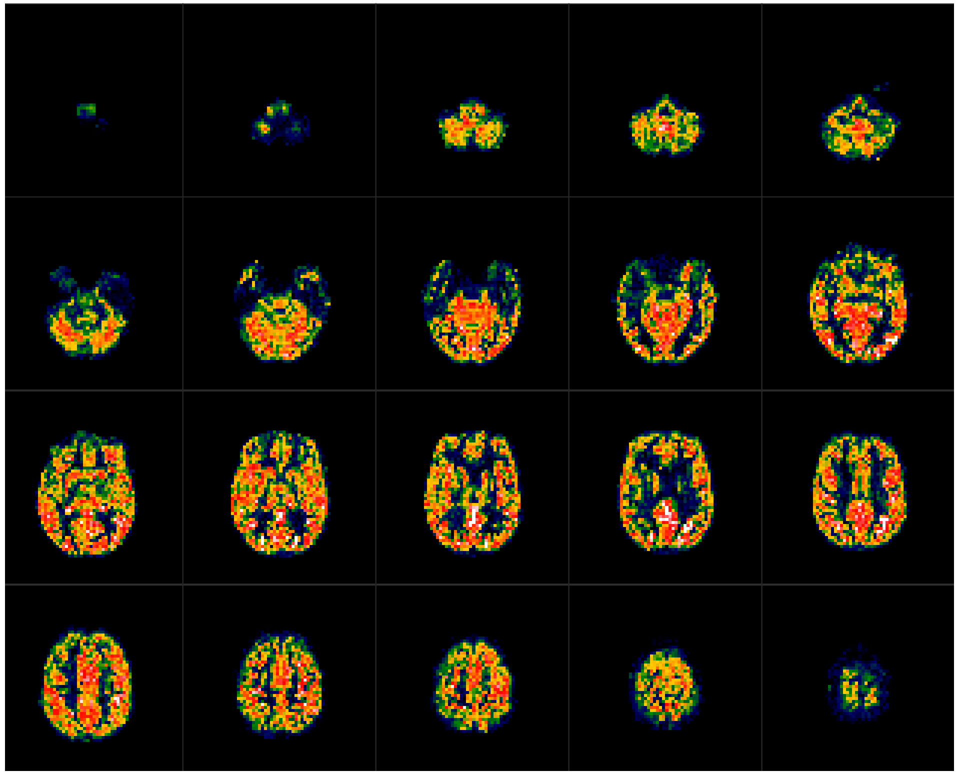


Multi delay ASL

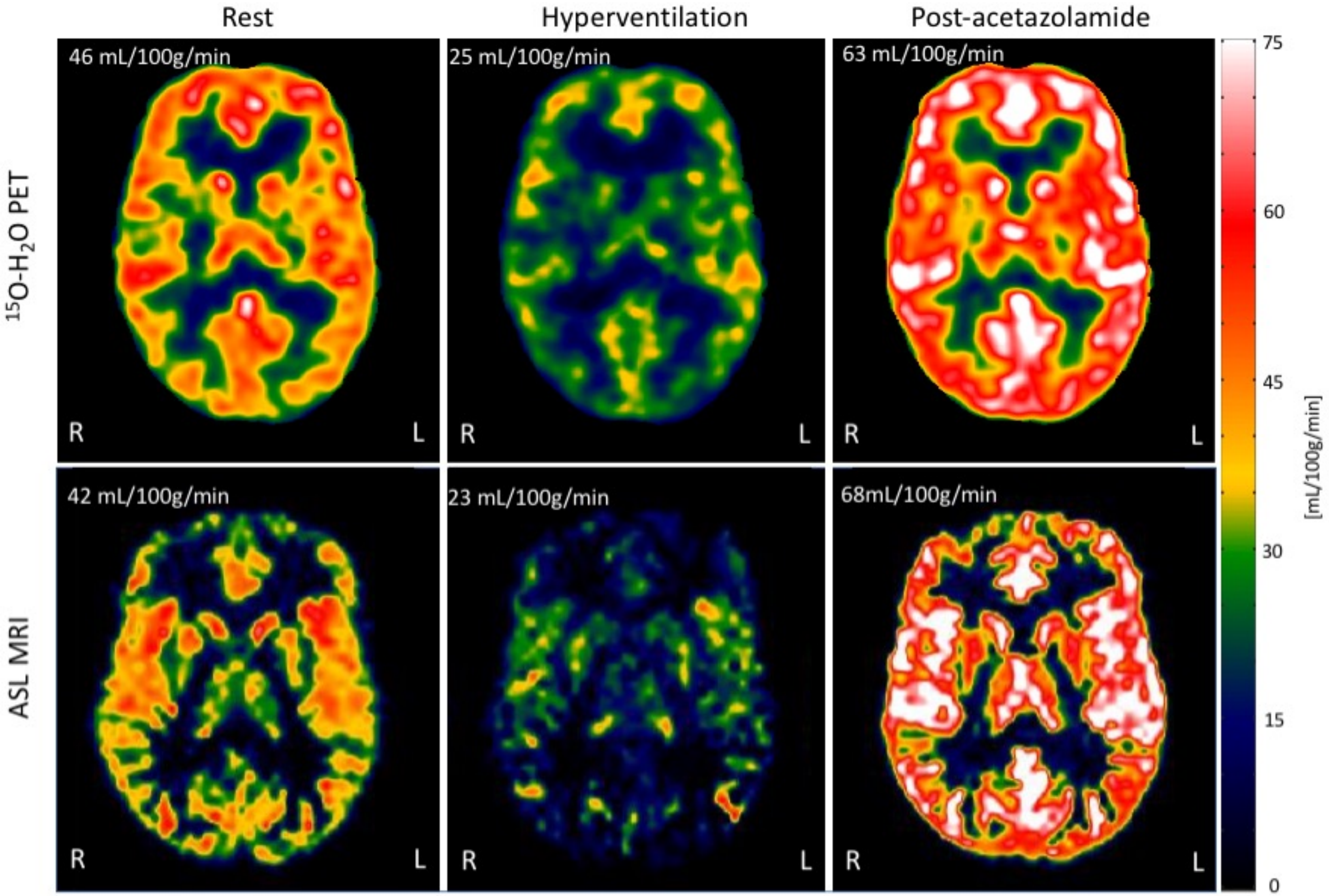
Bolus arrival time



Cerebral Blood Flow

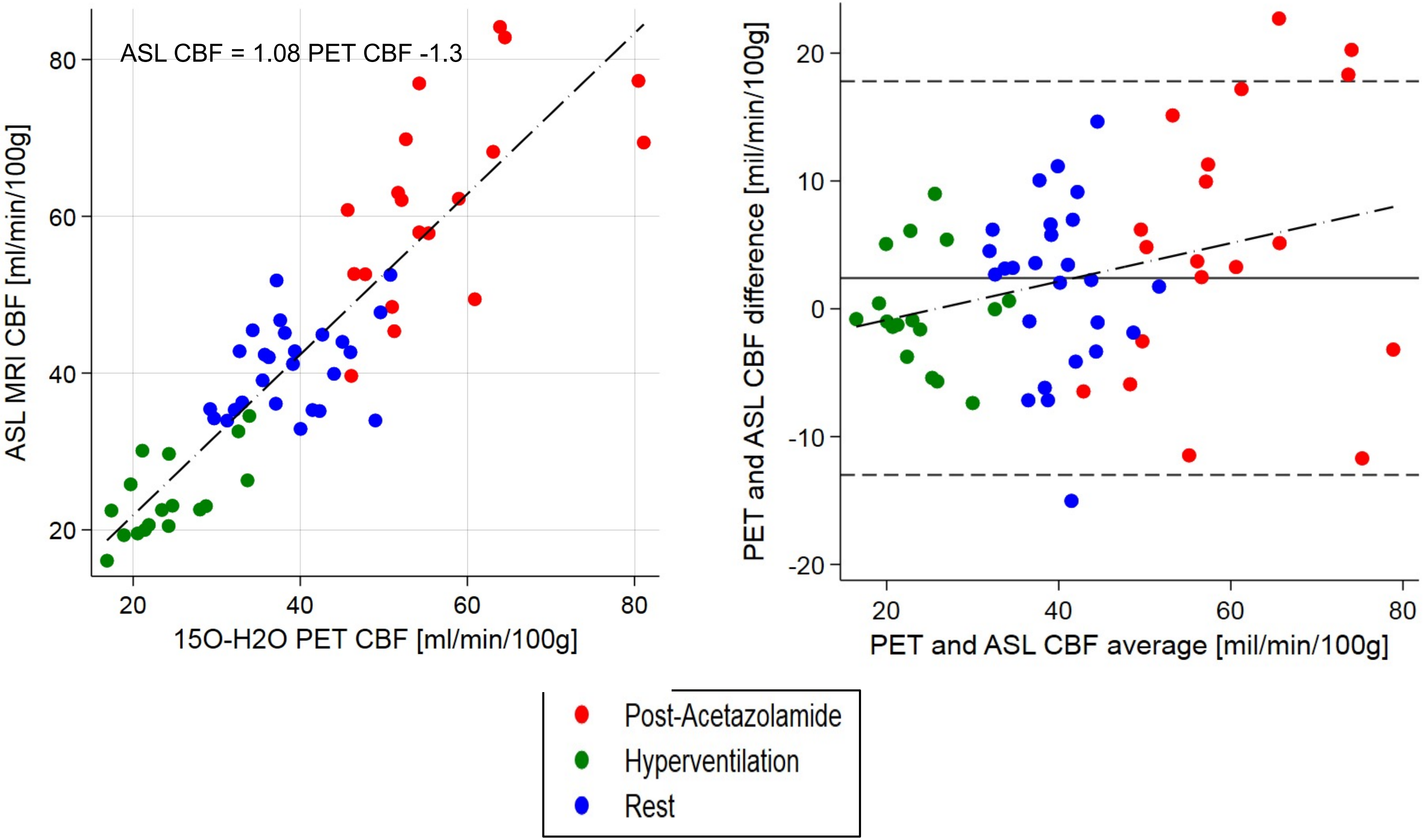


ASL MRI vs O^{15}-H2O PET



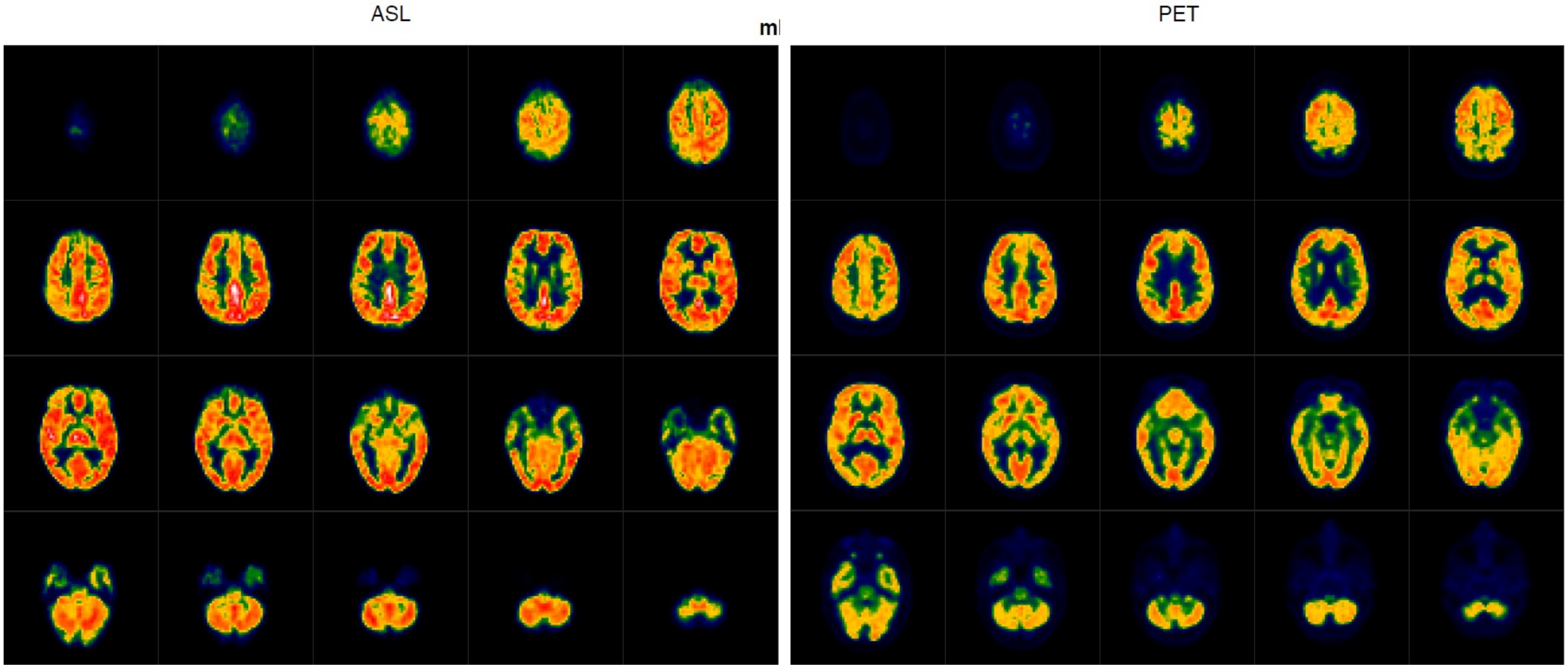
https://doi.org/10.1177/0271678X19874643

Valid

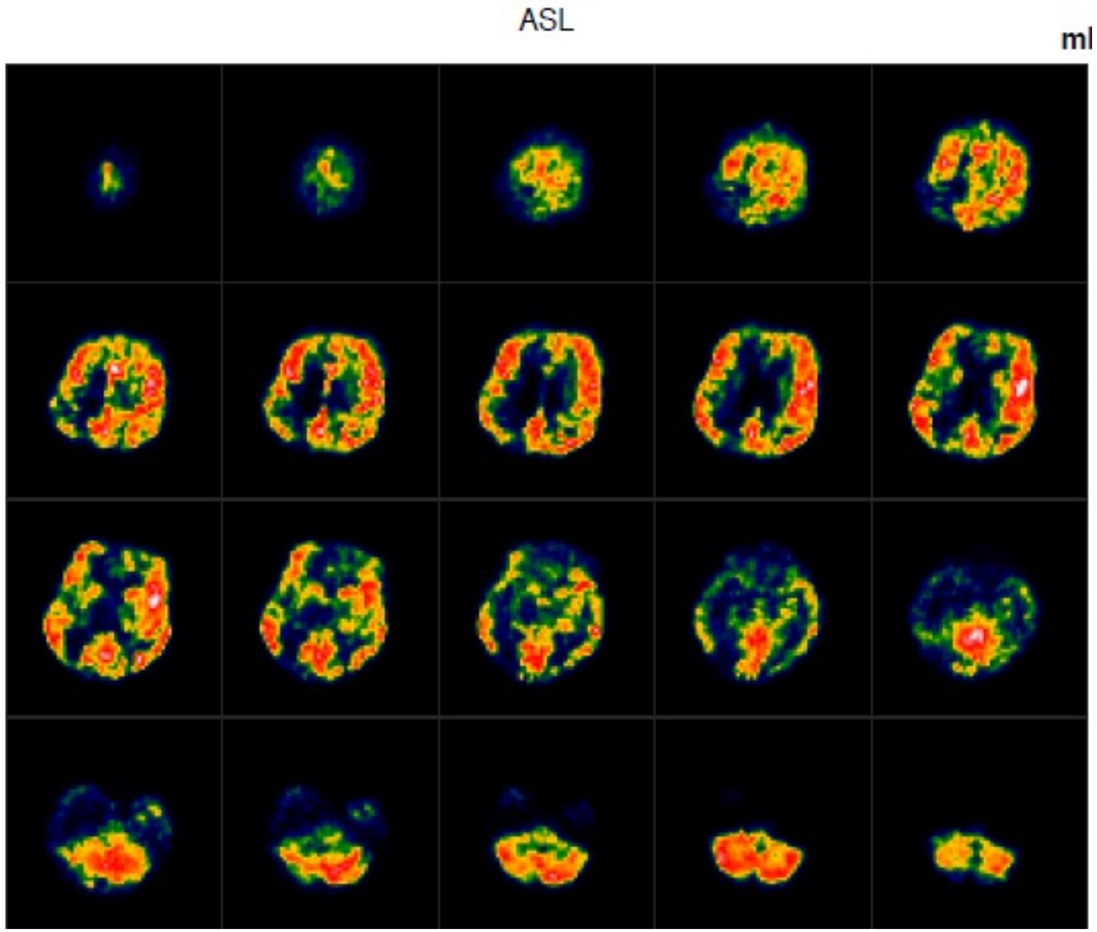


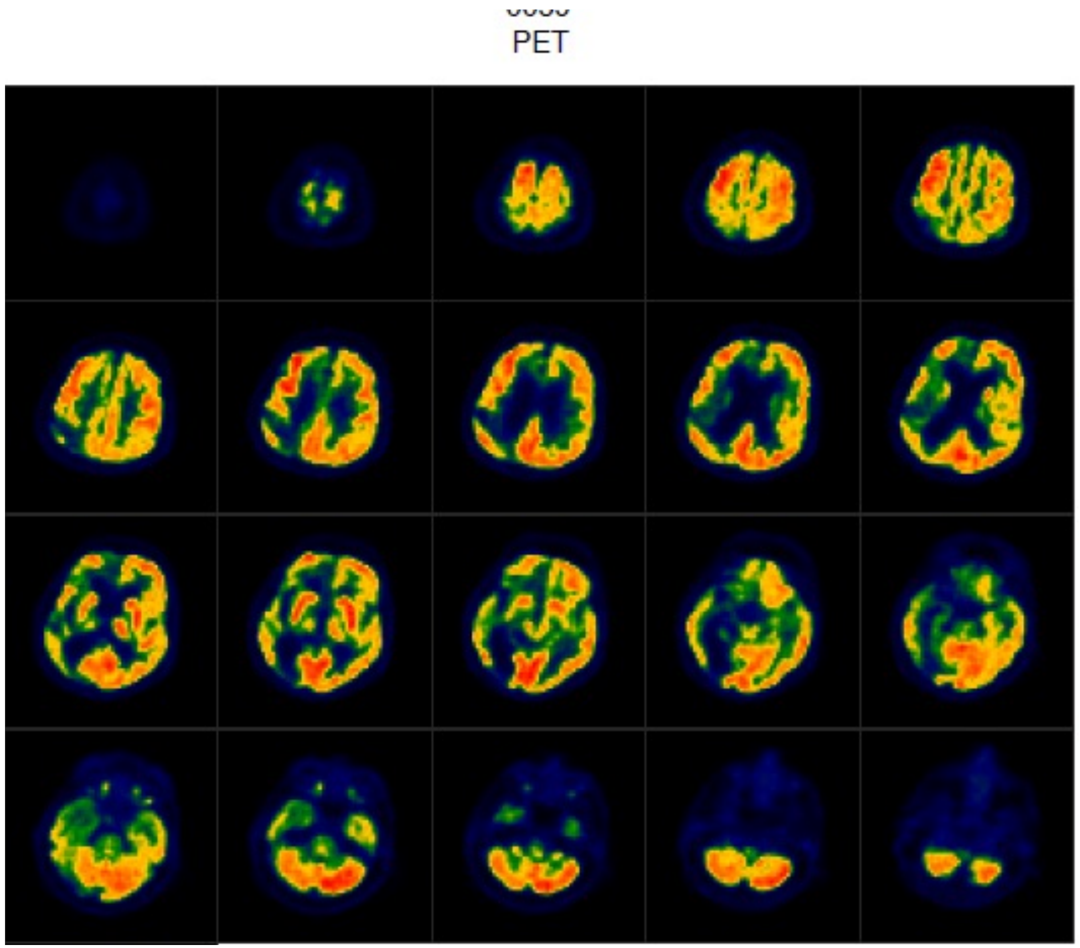
https://doi.org/10.1177/0271678X19874643

Dementia – ASL MRI vs F^{18}-FDG PET

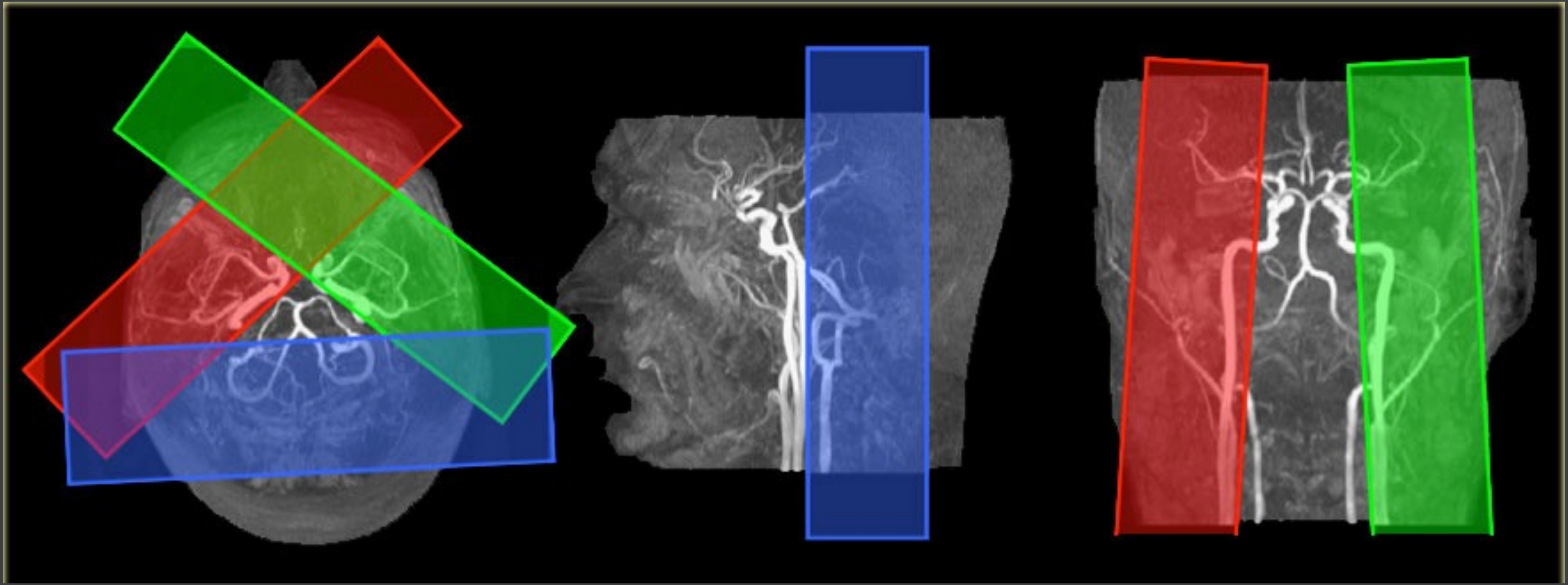


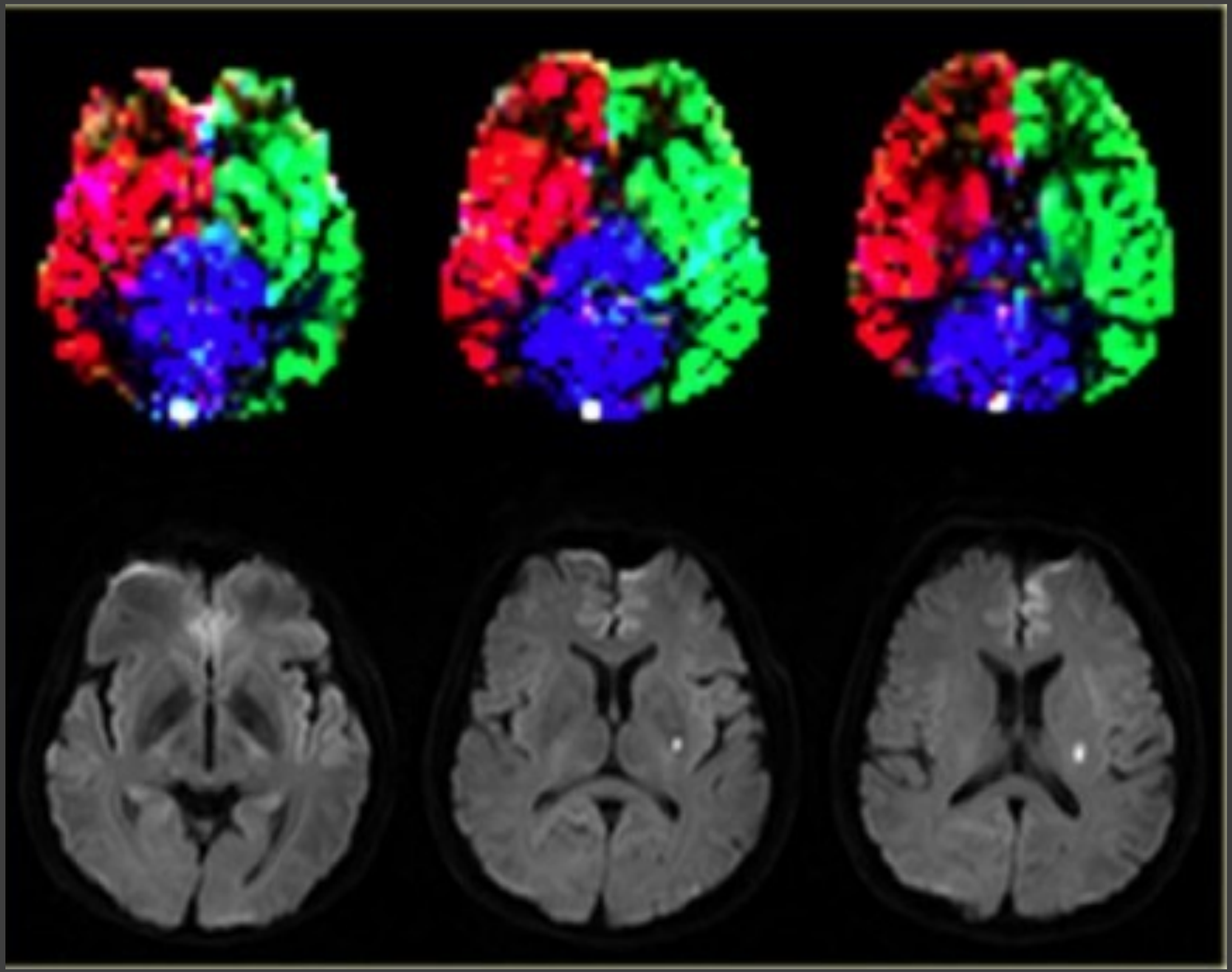
Dementia – ASL MRI vs F^{18}-FDG PET



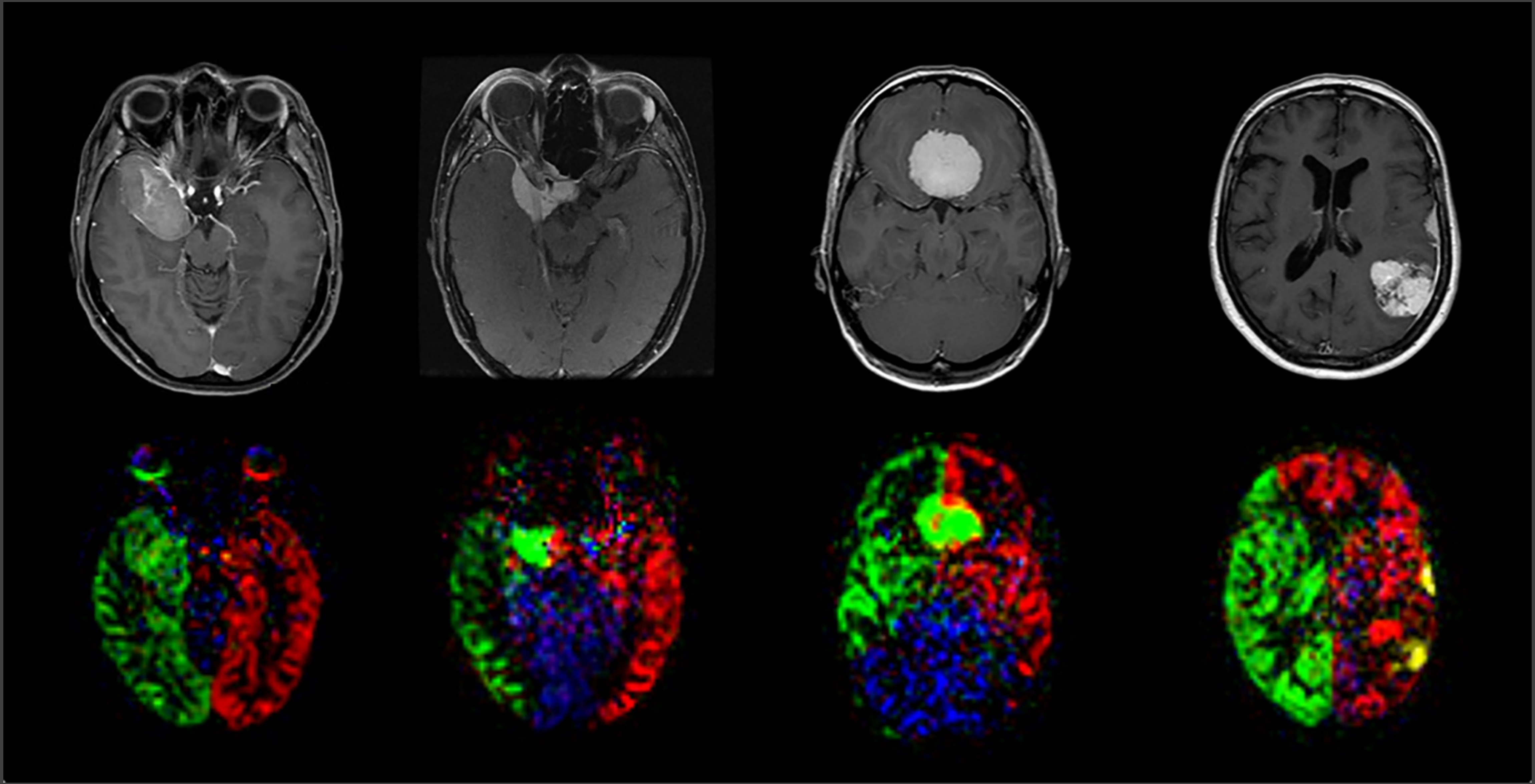


Vessel selective ASL





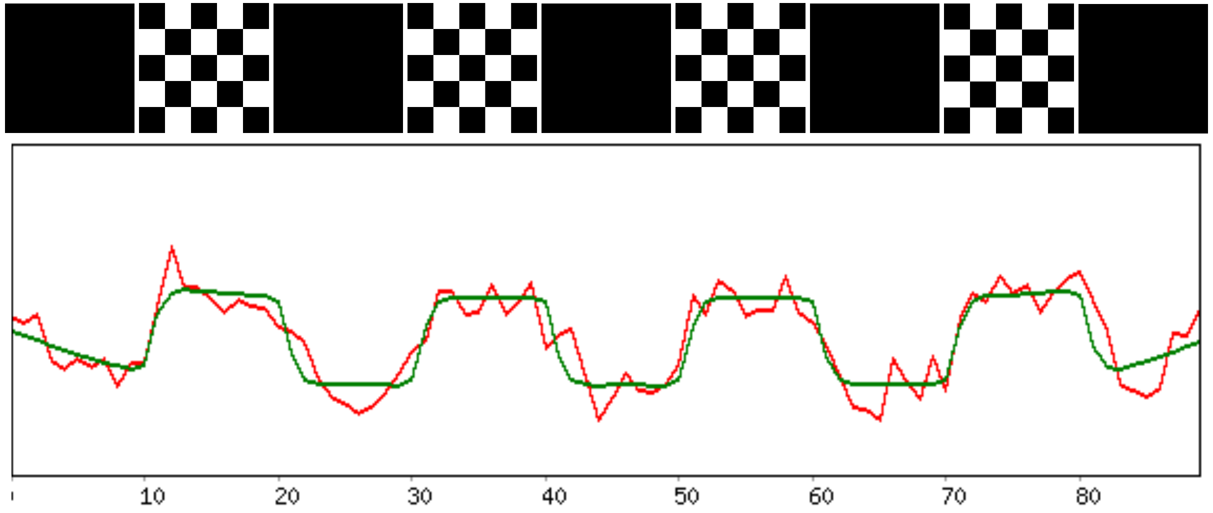
Vessel selective ASL

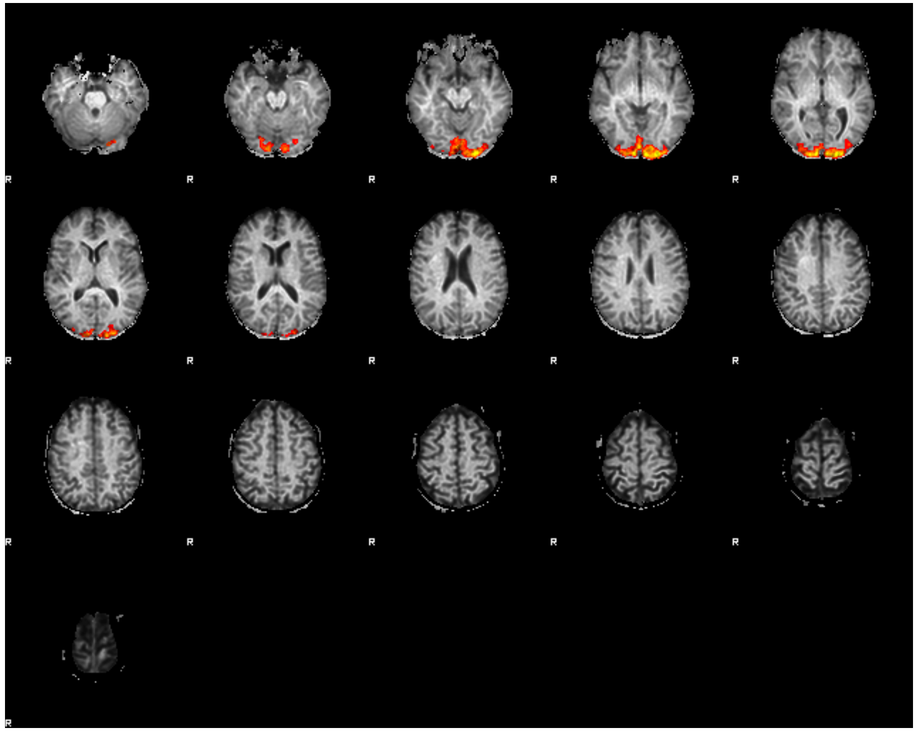


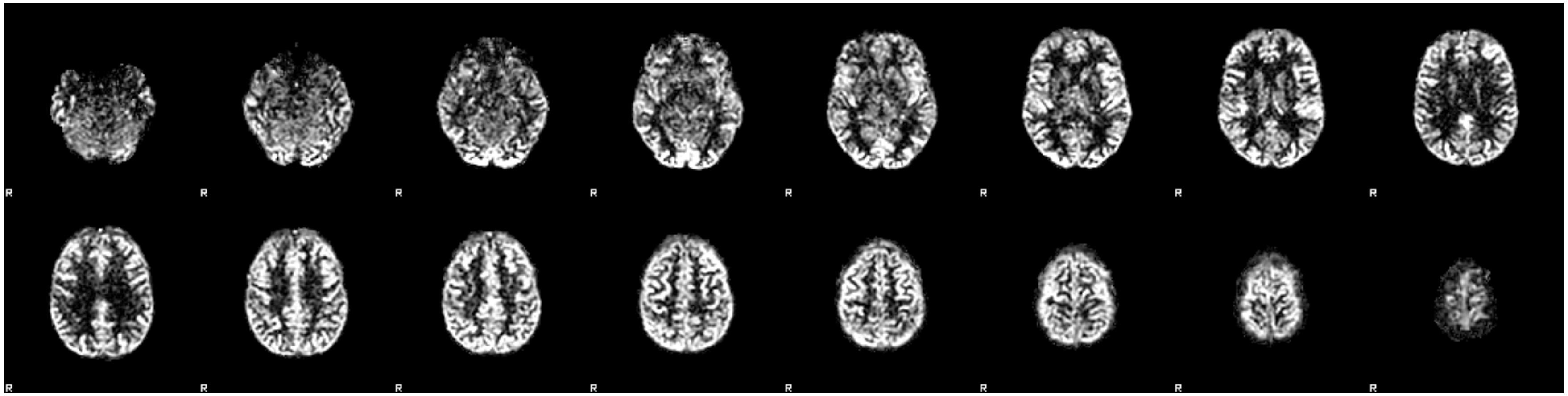
doi: https://doi.org/10.1371/journal.pone.0215145.g002

50+ % increase in CBF

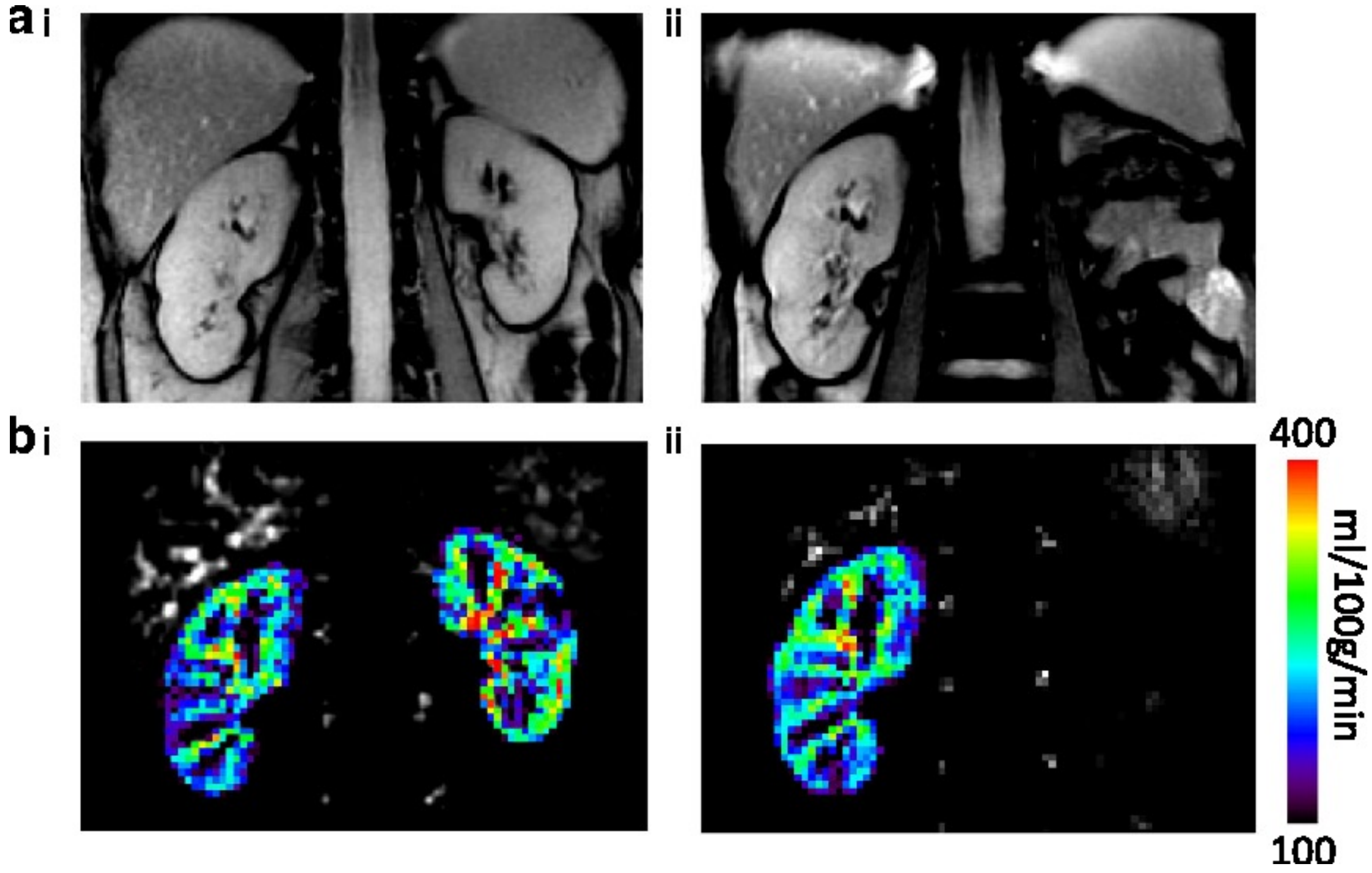
Functional ASL







Renal perfusion



Cutajar M et al., 2015,DOI: 10.1007/s00330-015-3594-6

Summary

- ASL provides a TRULY non-invasive method for the absolute quantification of CBF (ml/100g/min)
  - Labelling
  - Delay
  - Imaging
- Non-invasive perfusion
  - Endogenous water tracer
  - Analog to O^{15}-$H_2 0$ PET
  - Very shortlived bolus 1-2 sec
- Advanced use beyond other tracer methods
  - Functional blood flow
  - Vessel selective blood flow