INTERNATIONAL SOCIETY FOR ISMRM MAGNETIC RESONANCE IN MEDICINE
ONE COMMUNITY FOR CLINICIANS AND SCIENTISTS
25TH Annual Meeting & Exhibition • 22–27 April 2017
SMRT 26th Annual Meeting • 22–24 April 2017
HONOLULU, HI, USA
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Declaration of Financial Interests or Relationships

Speaker Name: Aaron Oliver-Taylor

I have the following financial interest or relationship to disclose with regard to the subject matter of this presentation:

Company Name: Gold Standard Phantoms Limited
Type of Relationship: Employee, Shareholder

A Calibrated Perfusion Phantom For Quality Assurance of Quantitative Arterial Spin Labelling

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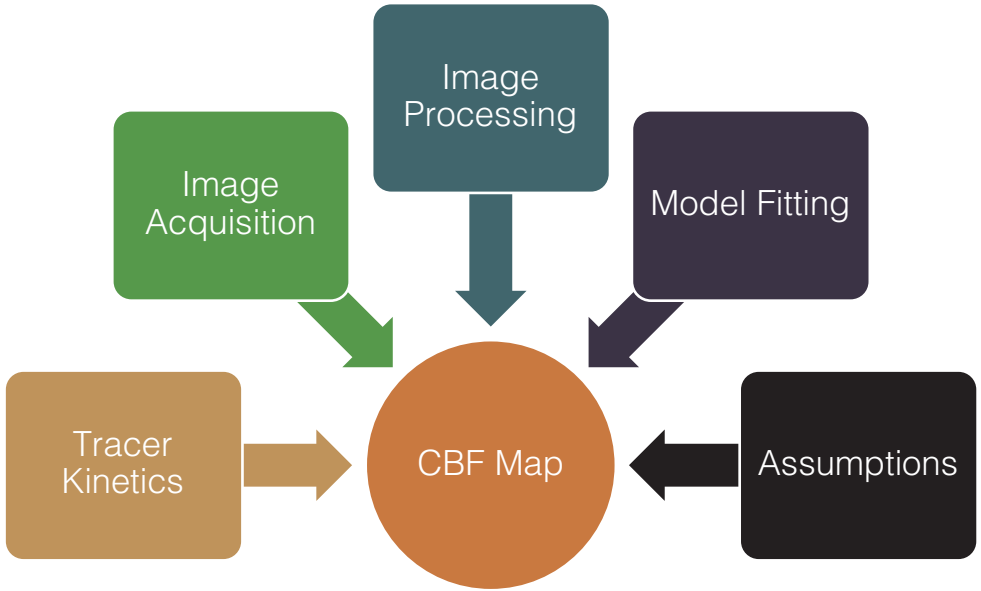
The need for a reference standard

Arterial Spin Labelling MRI is used to measure perfusion.

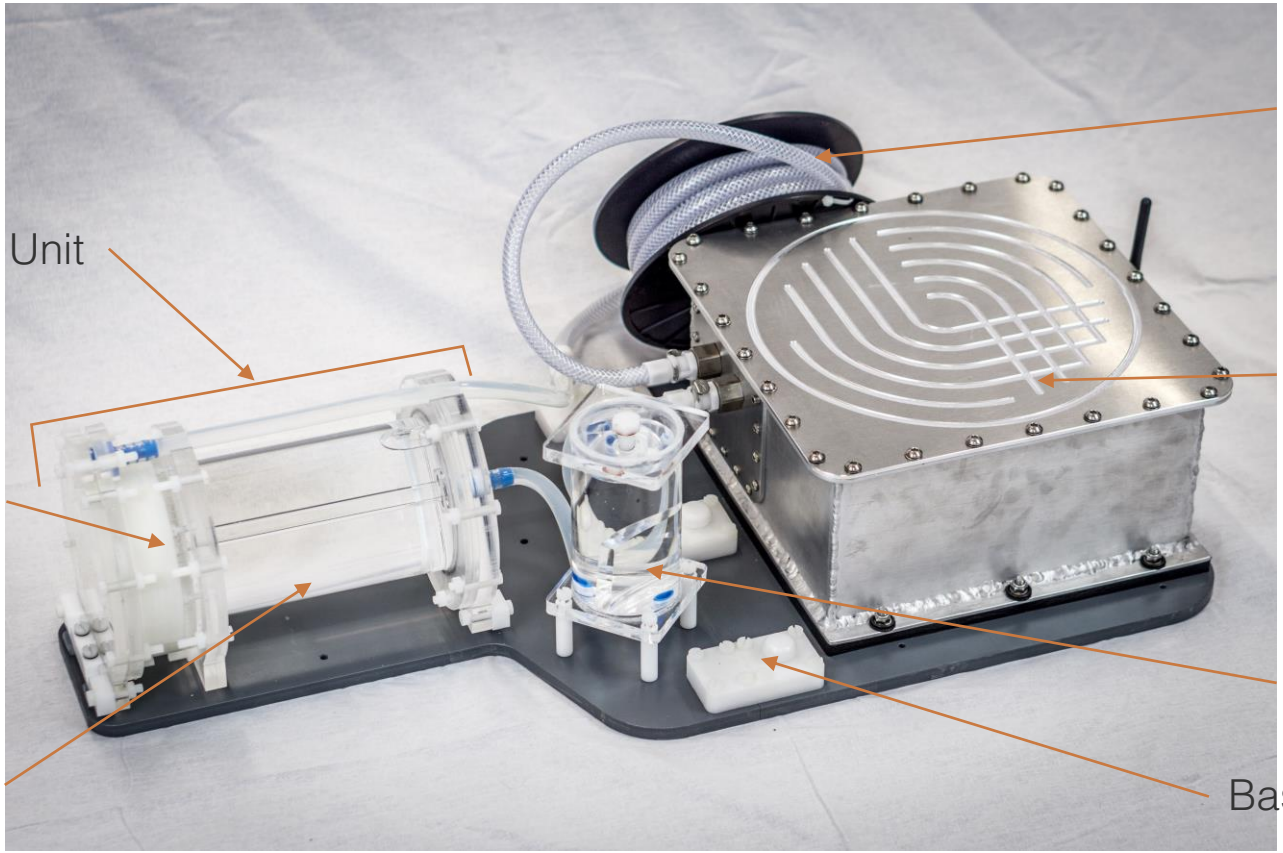


For ASL to be truly quantitative, it is important to:

- **Validate** each of these processes
- Quantify and associate **uncertainties**

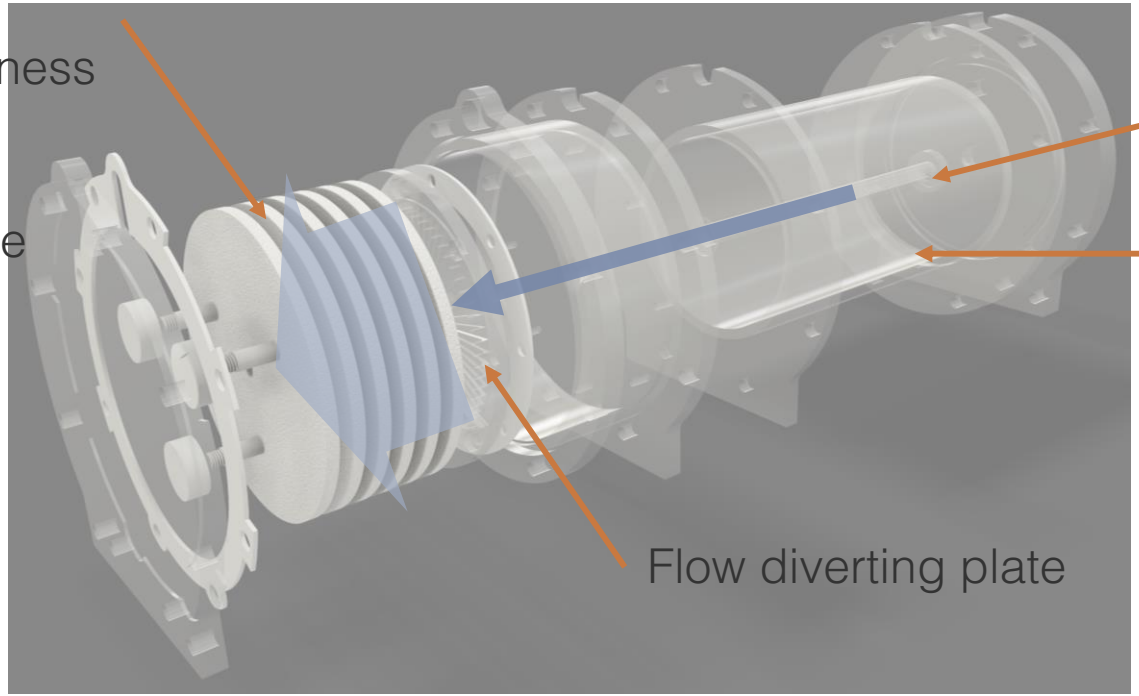
This cannot be done in-vivo, hence a reference standard is required

ASL Perfusion Phantom

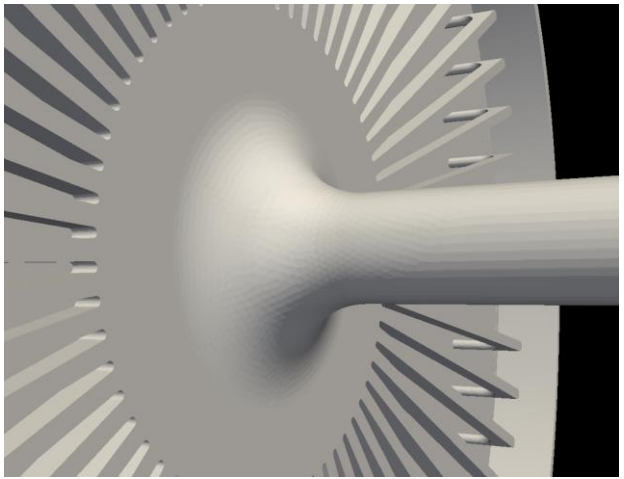


Perfusion Exchange Unit

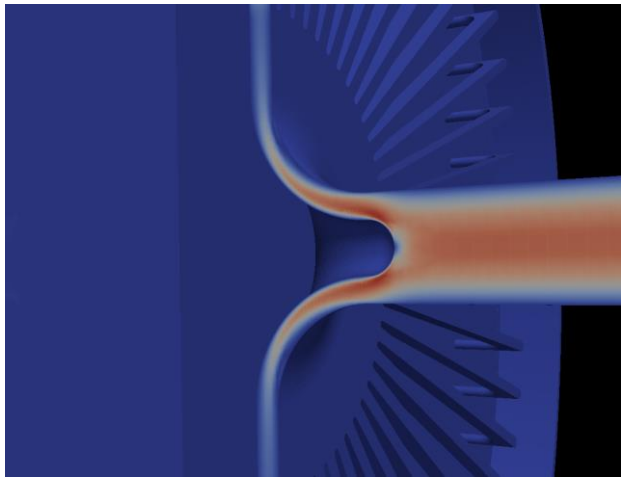
Perfusion medium: Porous UHMW-PE Discs
6 layers
4.75mm layer thickness
32% void volume
-> λ=0.32
7um mean pore size



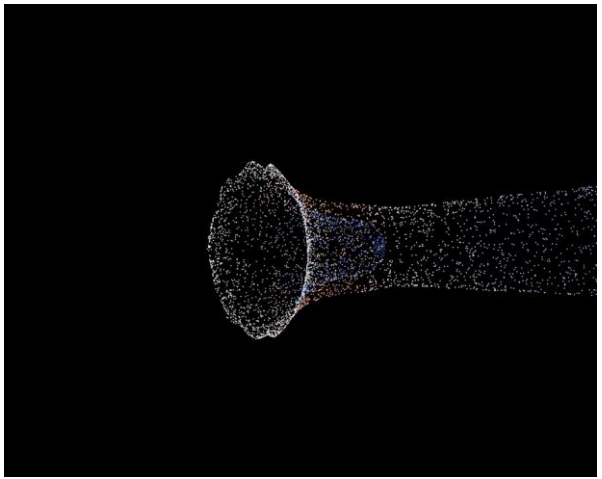
Perfusion chamber design optimisation



Geometric model



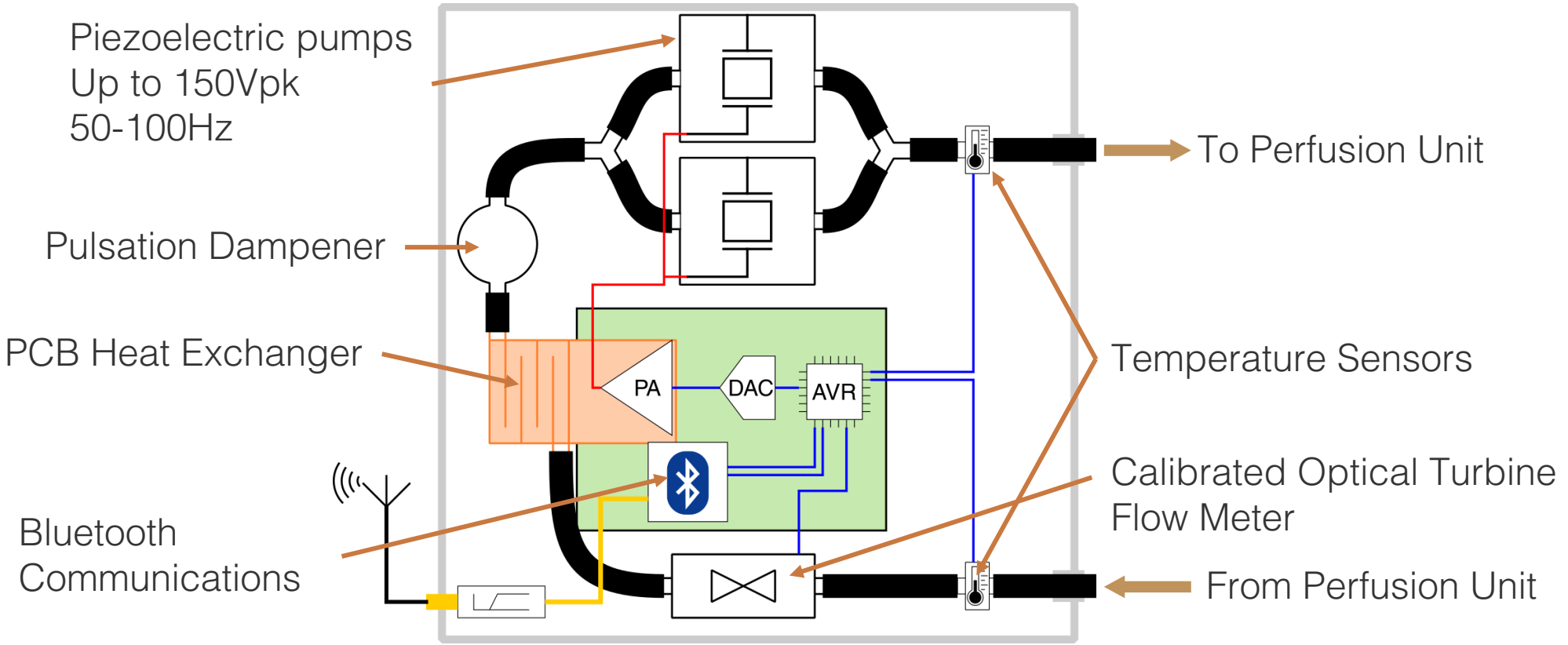
Velocity Map



Particle simulation

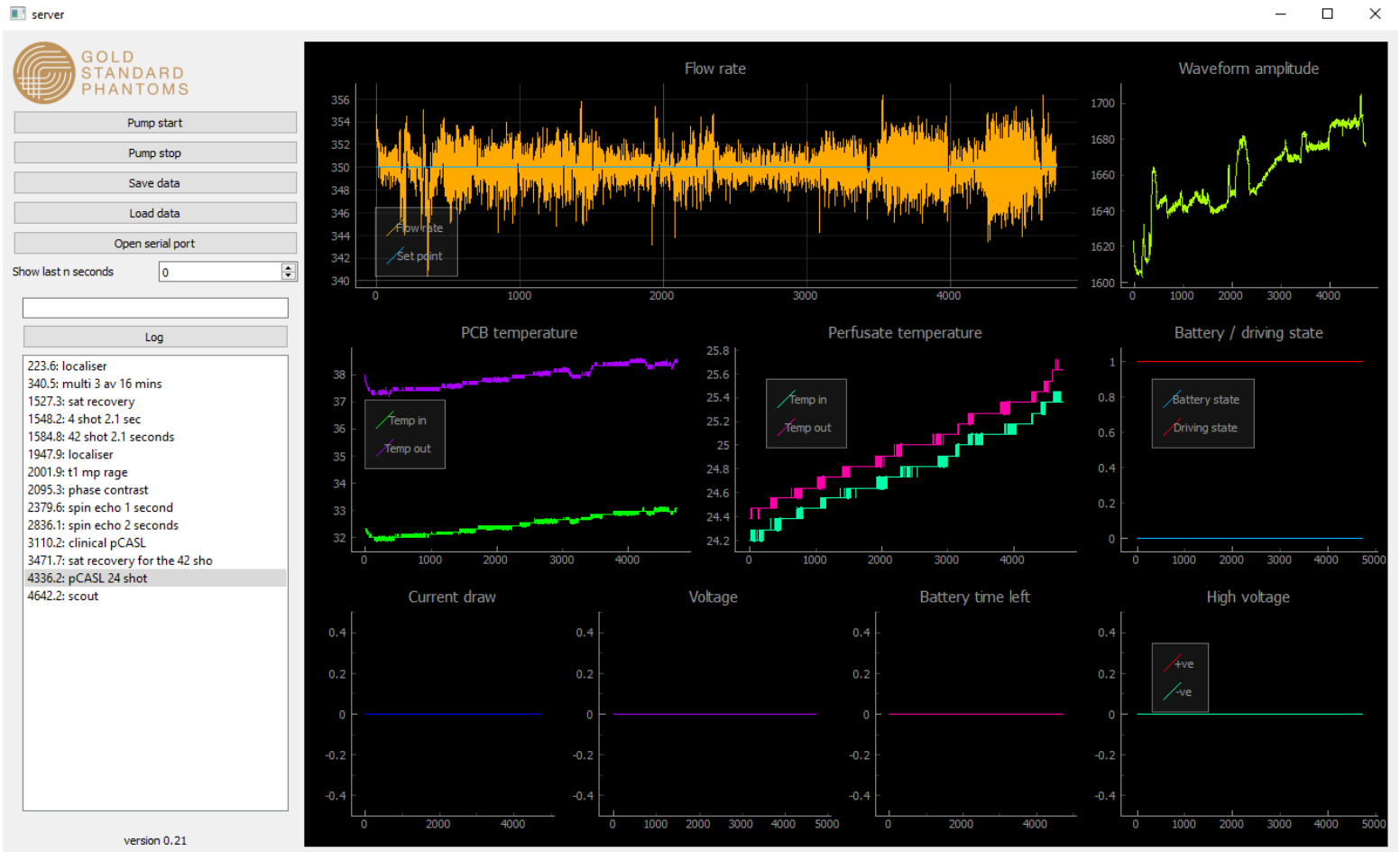
- CFD performed in OpenFoam (www.openfoam.com)
- Achieved Arterial Transit Time of 0.5 – 1.5s @ 350ml/min
- So that the CFD solver converges, flow must be laminar -> increase perfusate viscosity (glycerol-water mix 22.85% v/v).

MRI Compatible Pump



Phantom Control Software

- Python based
- Multi-OS
- Monitor flow rate, driving amplitude, temperatures
- Control flow rate set point, amplitude, pump frequency, on/off.
- Log MR scan start times



MRI Evaluation

Siemens Prisma 3T, syngo MR E11

Structural Scan: Sagittal 2D T1 Weighted

- 2.5mm slice thickness, FOV 170x140mm, 352x282x31 image matrix
- TR=250ms, TE=3.03ms, BW=303Hz/Px, FA=70deg

T1 Map

- Multi-TR Spin Echo
- 3mm slice thickness, 64x64x3 image matrix
- TR = 1, 2, 3, 5s
- TE = 7.2ms

- Pump turned **off**

- Fit to $\mathrm{Im} = M_0(1 - e^{-\frac{TR}{T1}})$
- Manually draw elliptical ROI in centre of slice (pure perfusate, no porous plastic)
- Calculate average T1.

MRI Evaluation: ASL

Multi-TI FAIR PASL 3D-GRASE

- Product Sequence
- TI = 350-2600ms, interval 250ms
- 3 averages, 4 shot segmented (EPI Factor 15, Turbo Factor 32)
- 3mm slice thickness, FOV 170x170mm, 64x60x32 image matrix
- TR=4000ms, TE/ΔTE=14.12ms, BW=2298Hz/Px
- Repeated in 3 sessions

- Phantom Flow = 350ml/min

- Manual quadrant segmentation
- Mean ΔM for each quadrant calculated at each TI.

pCASL 3D-GRASE

- WIP Sequence
- Labelling duration = 1800ms, Post labelling delay = 1800ms
- 4mm slice thickness, FOV 220x220mm, 64x60x28 image matrix.
- TE/ΔTE=13.28ms, BW=2242Hz/Px
- 4 shot segmented (EPI Factor 15, Turbo Factor 28), TR=4600ms
- M0 image acquired as first in series (no tag/control), TR=4000ms

- Phantom Flow = 350ml/min

CBF Quantification

Single subtraction pCASL CBF quantification as per the ASL White Paper*

$$CBF = \frac{6000 \cdot \lambda \cdot (SI_{control} - SI_{label}) \cdot e^{-PLD/T_1}}{2 \cdot \alpha \cdot SI_{PD} \cdot (1 - e^{-\tau/T_1})}$$

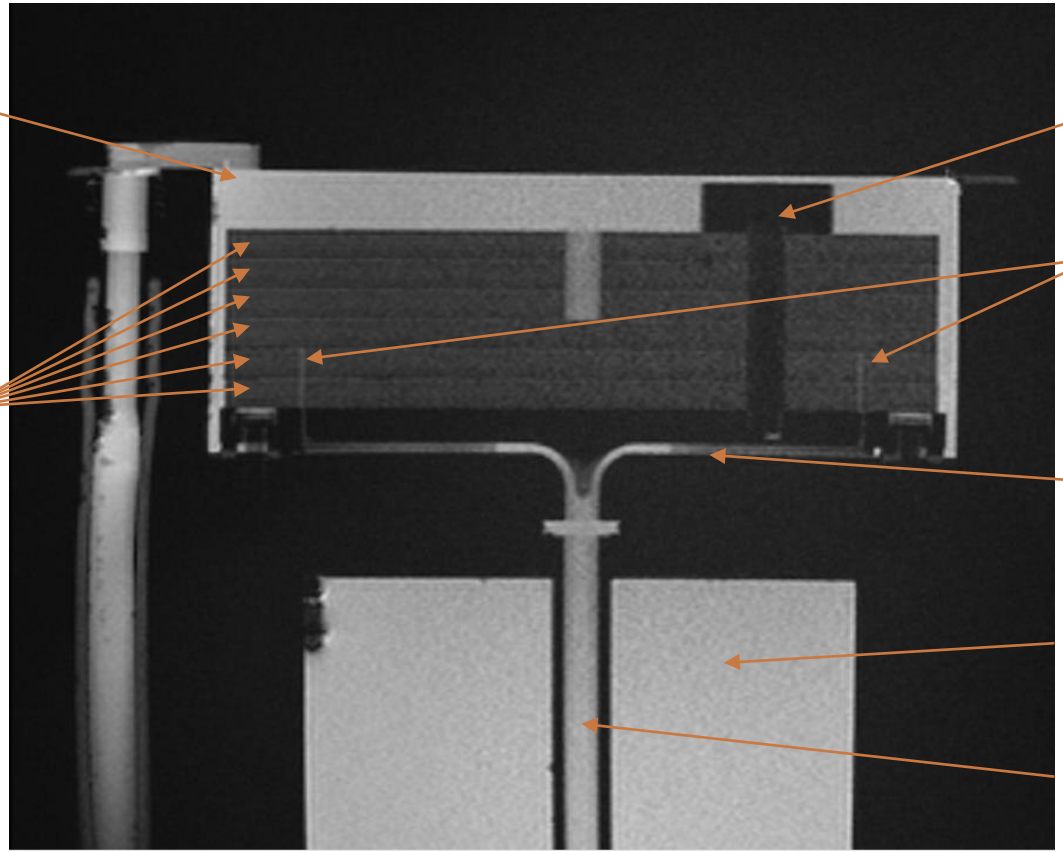
T1 as measured in the multi-TR spin-echo acquisition

λ=0.32

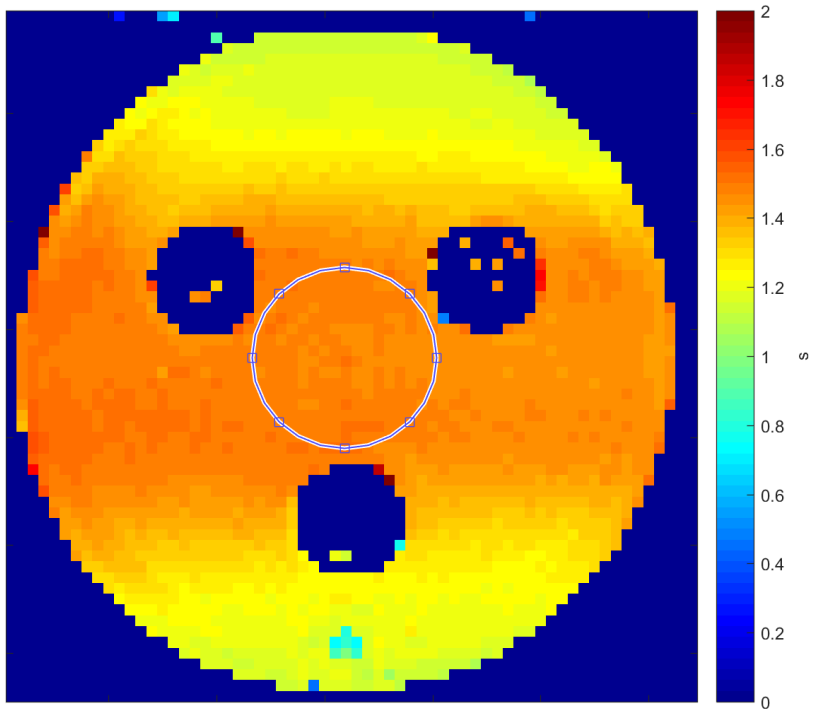
τ = 1.8s, PLD = 1.8s

*Alsop DC, et al. MRM 2015; 73: 102-116

Results: Structural



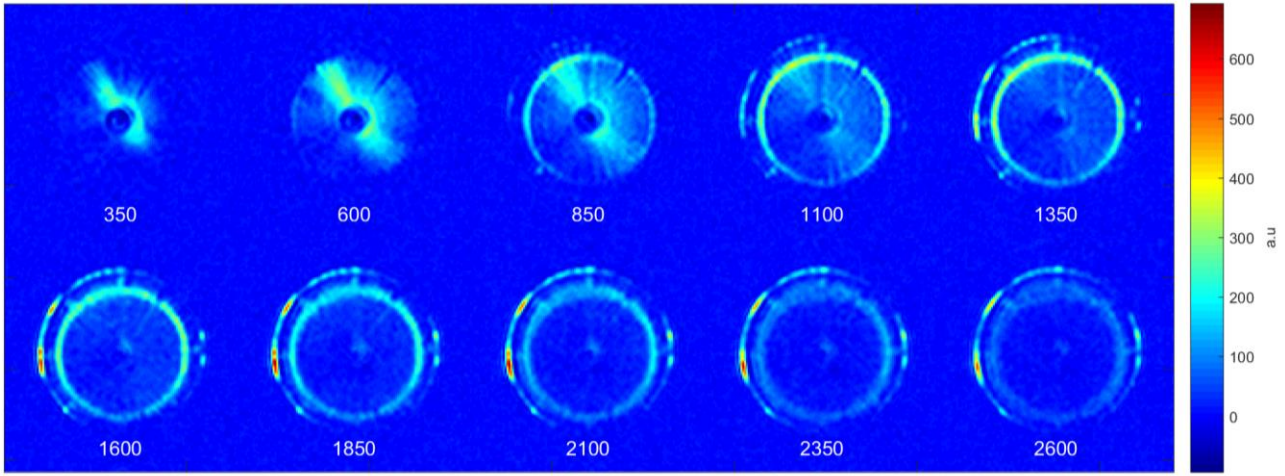
Results: T1 Map



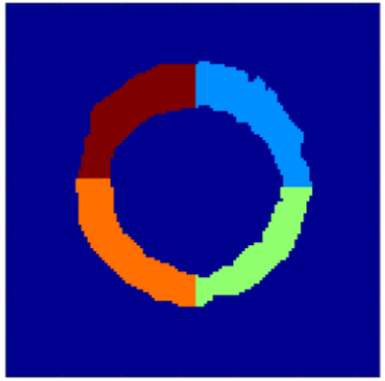
T_1 = 1474 ± 13 ms

Close to $T_{1,blood}$

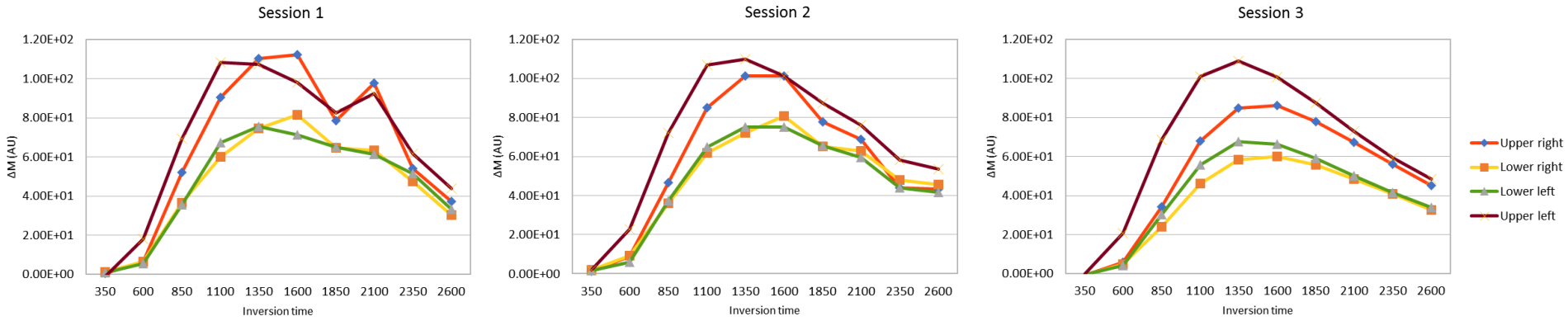
Results: Multi-TI FAIR PASL

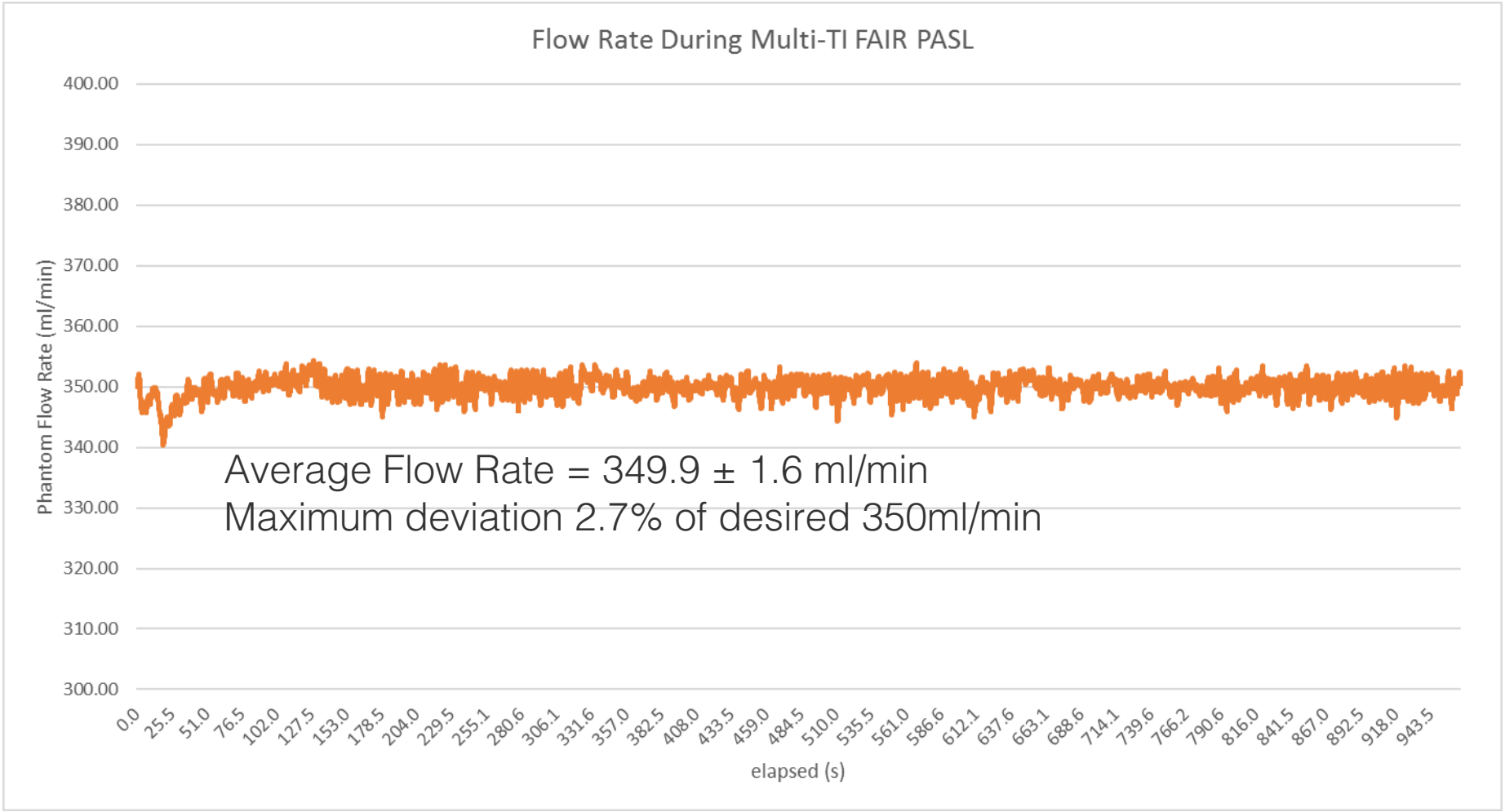


ΔM Images

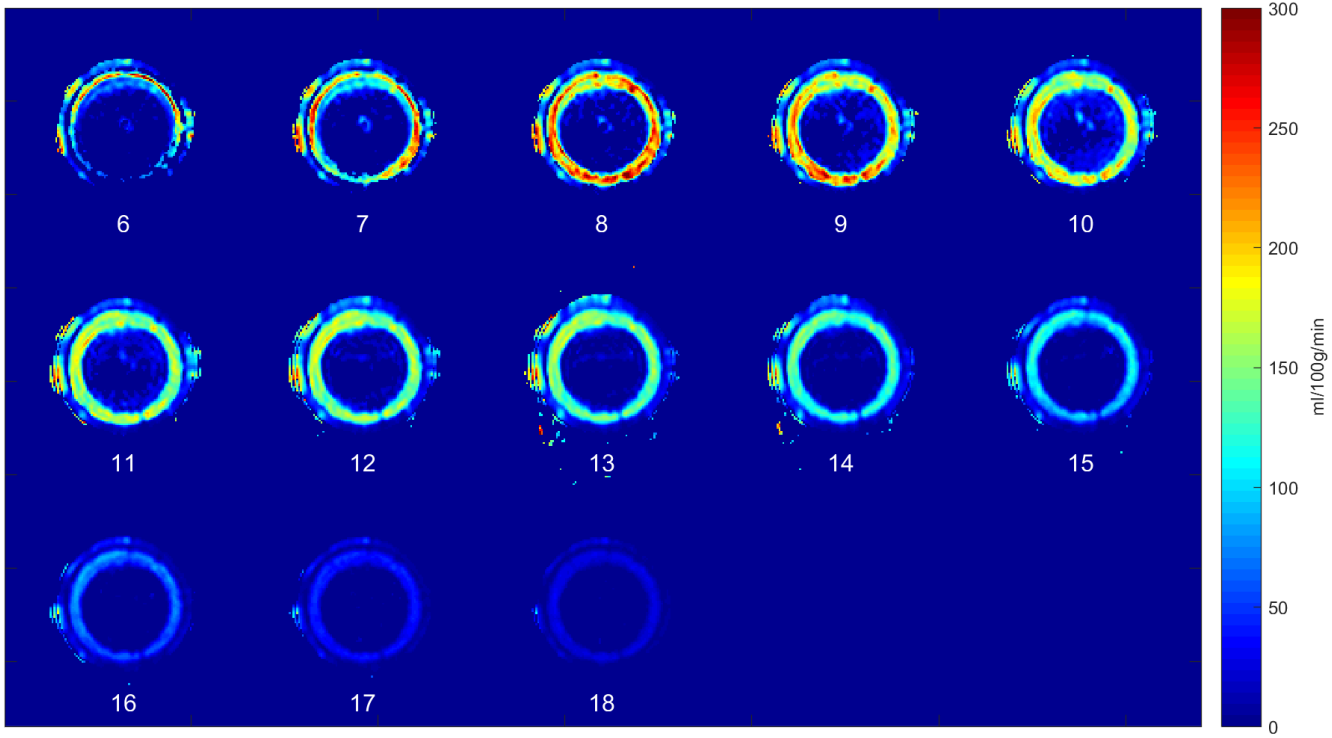


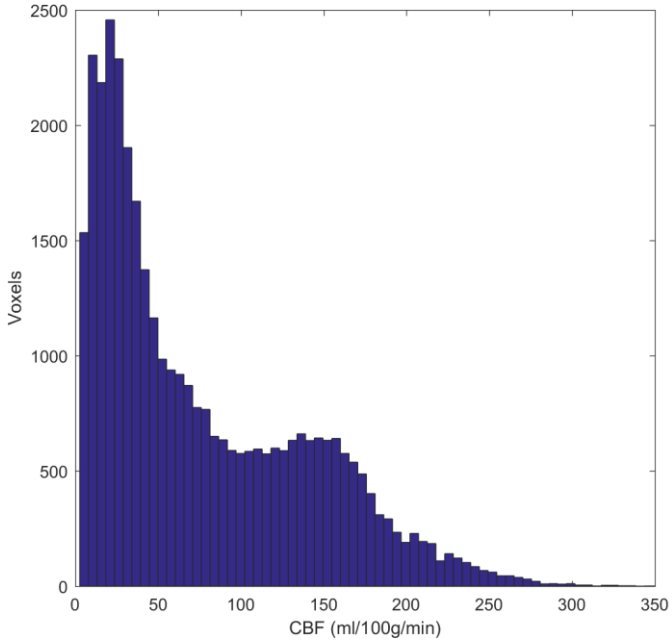
Segmented Mask

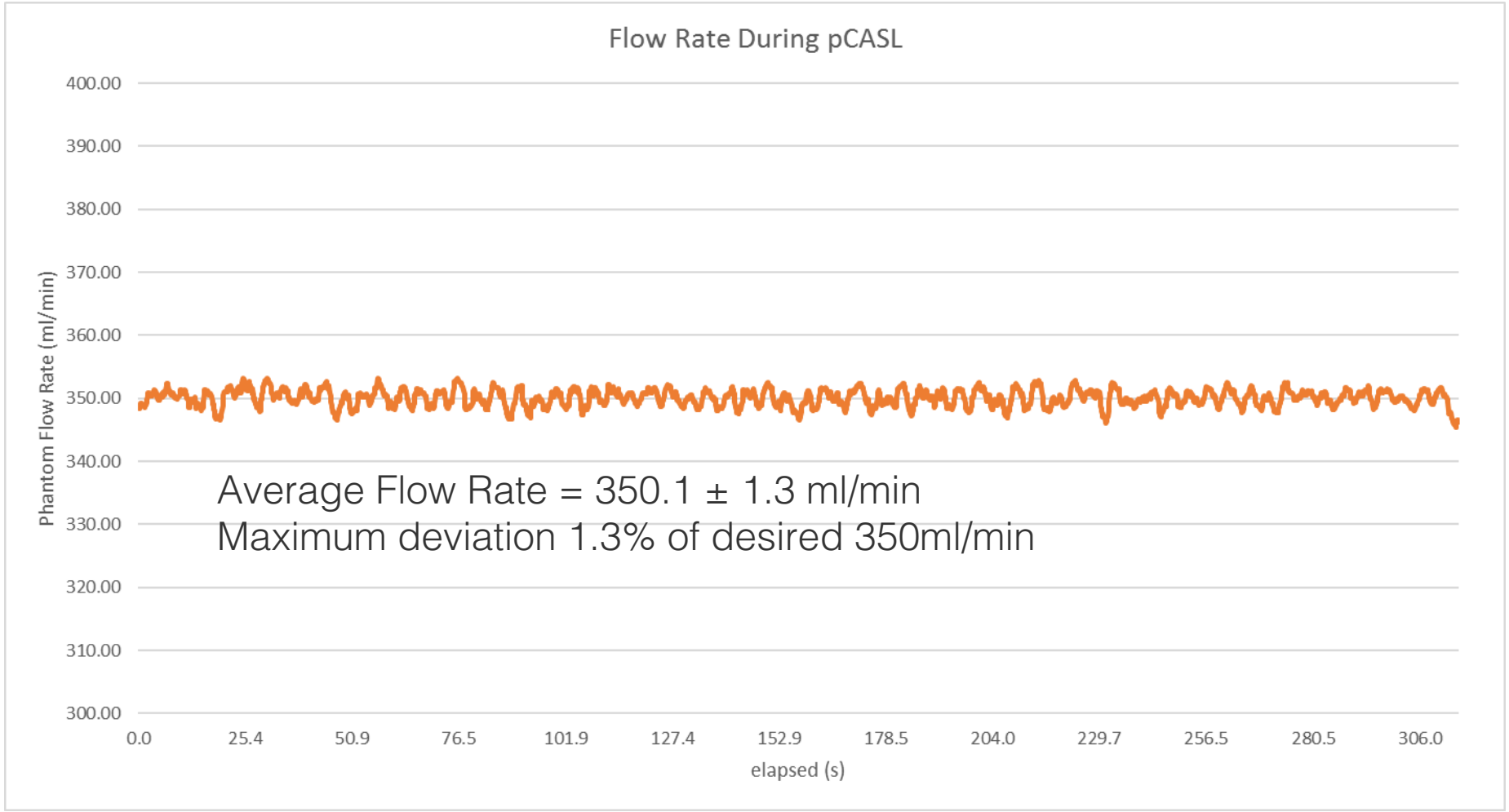



Flow Rate During Multi-TI FAIR PASL
Phantom Flow Rate (ml/min)
400.00
390.00
380.00
370.00
360.00
350.00
340.00
330.00
320.00
310.00
300.00
0.0
25.5
51.0
76.5
102.0
127.5
153.0
178.5
204.0
229.5
255.1
280.6
306.1
331.6
357.0
382.5
408.0
433.5
459.0
484.5
510.0
535.5
561.0
586.6
612.1
637.6
663.1
688.6
714.1
739.6
766.2
790.6
816.0
841.5
867.0
892.5
918.0
943.5
elapsed (s)
Average Flow Rate = 349.9 ± 1.6 ml/min
Maximum deviation 2.7% of desired 350ml/min

Results: Single PLD pCASL





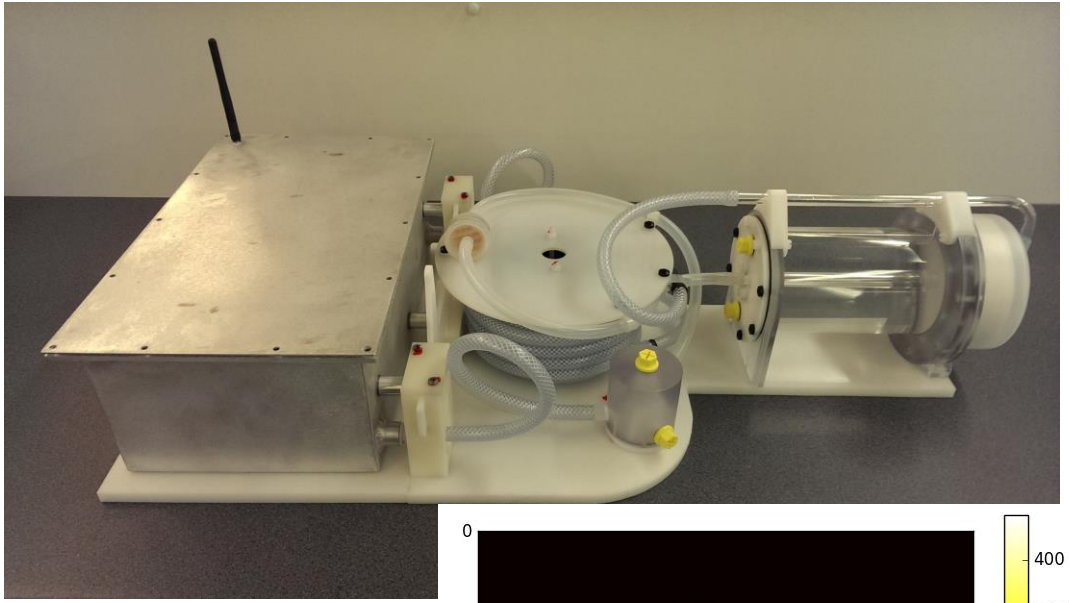

Flow Rate During pCASL
Phantom Flow Rate (ml/min)
400.00
390.00
380.00
370.00
360.00
350.00
340.00
330.00
320.00
310.00
300.00
0.0
25.4
50.9
76.5
101.9
127.4
152.9
178.5
204.0
229.7
256.5
280.5
306.0
elapsed (s)
Average Flow Rate = 350.1 ± 1.3 ml/min
Maximum deviation 1.3% of desired 350ml/min

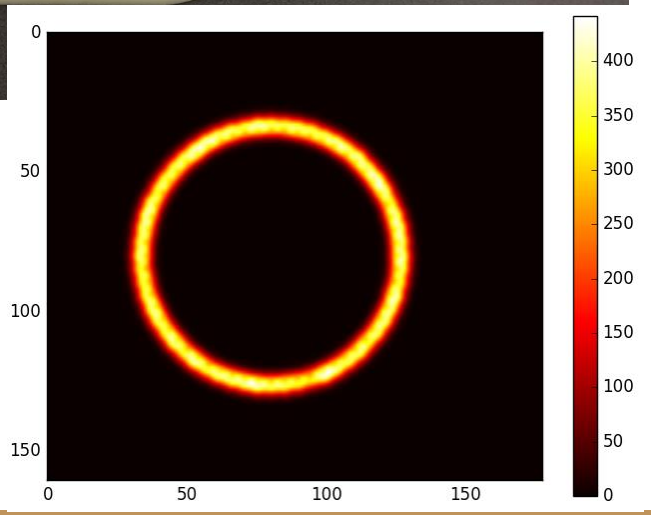
Discussion

- Stable, reproducible, and known flow rate in to the perfusion exchange chamber.
- Measured perfusion values encompass the range of expected values in most of the body – brain and renal.
- ATT within the range of for cerebral perfusion. Single-subtraction CBF quantification possible.
- Single compartment – no exchange
- Only the perfusate contributes to the measured signal.
  - No static background.
- Perfusate is always moving within the porous material
  - Source of labelled perfusate is adjacent voxels.
  - Skews multi-TI perfusion values by signal from earlier TI's.
  - Different perfusion distribution and value for each TI.
  - But the pump can be turned off!

Future Work

- Fully characterise and validate the phantom
- Can we make 10 that are the same?
- Generate a perfusion ground truth using our CFD-MRI simulation
- Develop an uncertainty model





Thank You!

Acknowledgements
This work was commissioned and funded by the SBRI Healthcare programme. SBRI Healthcare is an NHS England initiative, championed by the Academic Health Science Networks (AHSNs). The views expressed in the publication are those of the author(s) and not necessarily those of the SBRI Healthcare programme or its stakeholders.