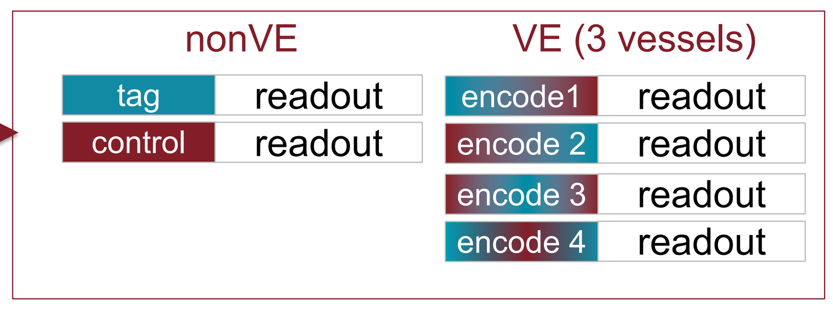
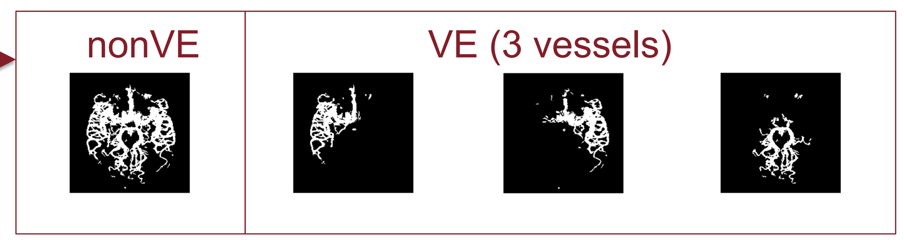
4D Vessel-Encoded pCASL Angiography in a Five-Minute Scan

S. Sophie Schauman (sophie.schauman@dtc.ox.ac.uk), Mark Chiew, Thomas W. Okell
Wellcome Centre for Integrative Neuroimaging, FMRIB, Nuffield Department of Clinical Neurosciences, University of Oxford

Introduction

- Vessel encoded VE-pCASL[1] angiography[2] provides potentially crucial information for a range of cerebrovascular diseases in a non-invasive way
- VE-pCASL is as SNR efficient as conventional pCASL, which is an advantage over single-artery selective methods
- Long scan times because of:
  - additional encoding steps (N+1 encodings for N vessels) compared to conventional (nonVE) angiography
  - many repeats needed to fill k-space at sufficient spatial (~1mm isotropic) and temporal (~ 200ms) resolution in 3D
- Can be accelerated by:
  - acquiring with trajectory that produces more benign undersampling artefacts (e.g. radial)[3]
  - reconstructing in a compressed sensing framework[4], exploiting the images' spatial sparsity VE is especially well suited for this due to higher relative sparsity than nonVE angiography

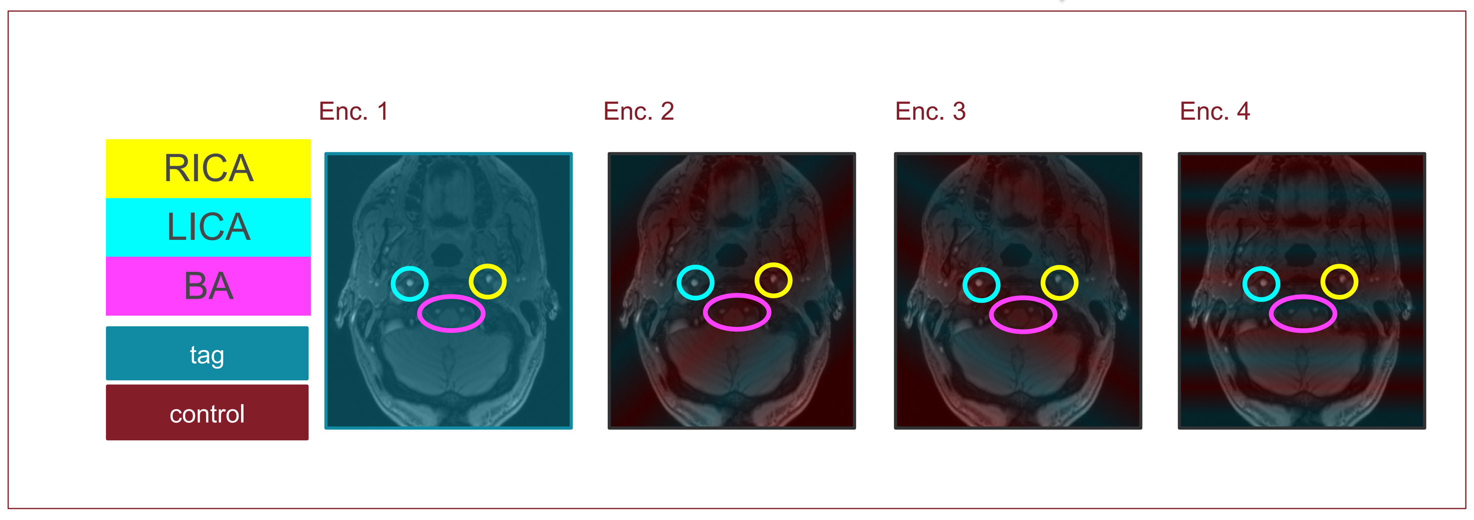




Methods

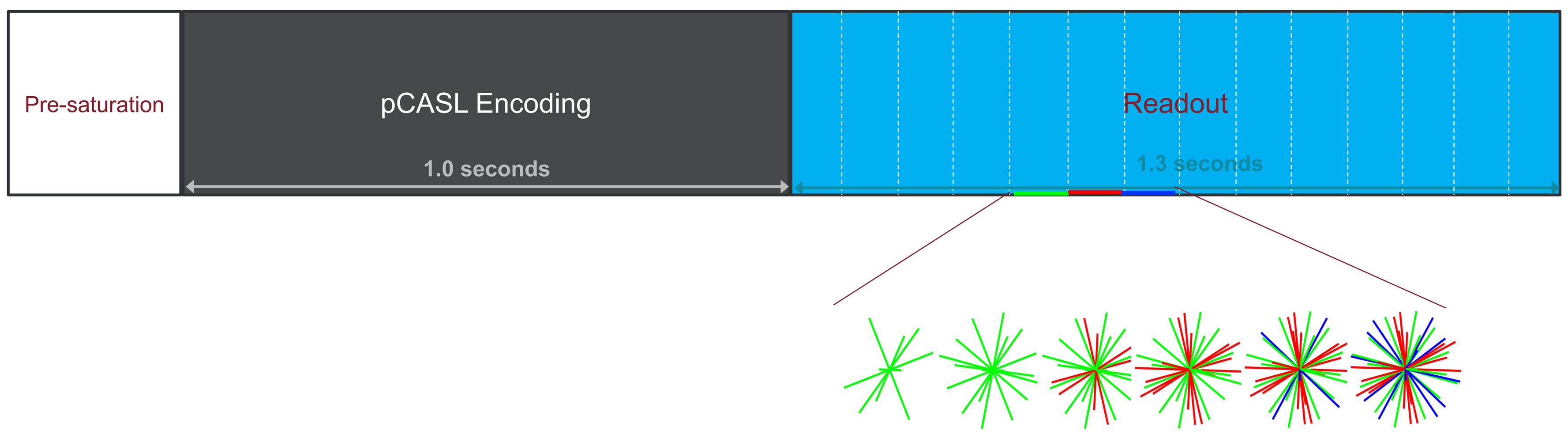
Acquisition:

- Proof-of-principle study on one healthy volunteer, acquired on 3T Siemens Verio
- Three vessels (right and left internal carotid arteries (RICA, LICA) + basilar artery (BA)) were labelled with a Hadamard encoding scheme
- Scan parameters:
  - Trajectory: 3D golden angle radial spokes[4]
  - TE/TR = 5.9/11.6ms - Flip angle = 7º
  - Labelling duration: 1.0s
  - Readout time: 1.3s (108 readout spokes acquired per ASL preparation)
  - Total scan time: 5:16min (label + readout 33 times for each encoding) Acceleration factor, R = 97



Reconstruction:

- Compressed sensing with spatial sparsity enforced + coil sensitivity estimation
  - Combining vessel decoding with image reconstruction
- Cost function:
  $cost = \frac{1}{2}|\mathbf{Ex} - \mathbf{d}|_2^2 + \lambda|\mathbf{x}|_1$
  $\mathbf{E} = acquisition\ operator,\ \mathbf{x} = image,\ \mathbf{d} = data,\ \lambda = regularisation\ weighting$
- Reconstruction algorithm: FISTA[5]
- Reconstruction parameters:
  - Spatial resolution: 1.1mm isotropic
  - Temporal resolution: 210ms (6 frames)



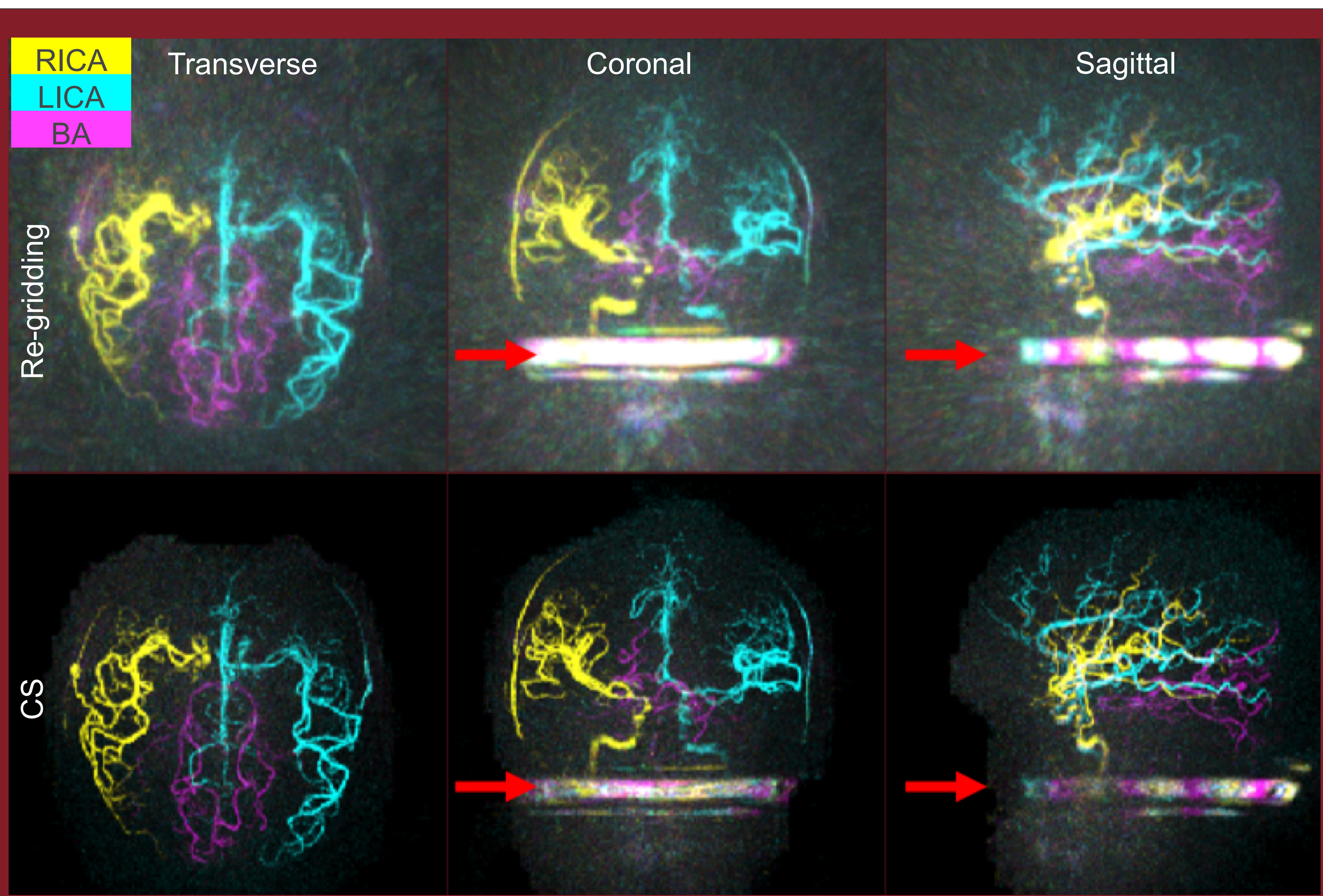


Figure 1: Above: Simple re-gridding reconstruction (temporal average MIP). Below: CS Reconstruction. The red arrows indicate the labelling plane artifact.

Results

- Less blurring and a clear increase in SNR for the CS reconstructed images compared with reconstruction using simple re-gridding and coil sensitivities only (Figure 1)
  - FWHM of an example vessel (Figure 2) was 1.93 for CS and 5.77 for re-gridding
  - 19% increase in the apparent SNR (although rigorous assessment of SNR with this type of CS reconstruction requires further work)
- Small and faint vessels visible even at later frames (Figure 3)

Discussion and Conclusions

- Promising as proof-of-principle but not yet optimized
- Will need to verify these results in a more quantitative way across a larger number of subjects
- Currently, offline reconstruction times are slow due to the large memory burden (>30 GB), but optimisations for processing speed and memory efficiency are being investigated
- Temporal smoothness can also be leveraged as additional regularizer
- Variable flip angle acquisition[5] or time-encoded ASL[7] might preserve signal in later frames more
- Potential clinical use in evaluating the relative blood supply from different arteries in steno-occlusive disease and in planning embolization therapy for arteriovenous malformations

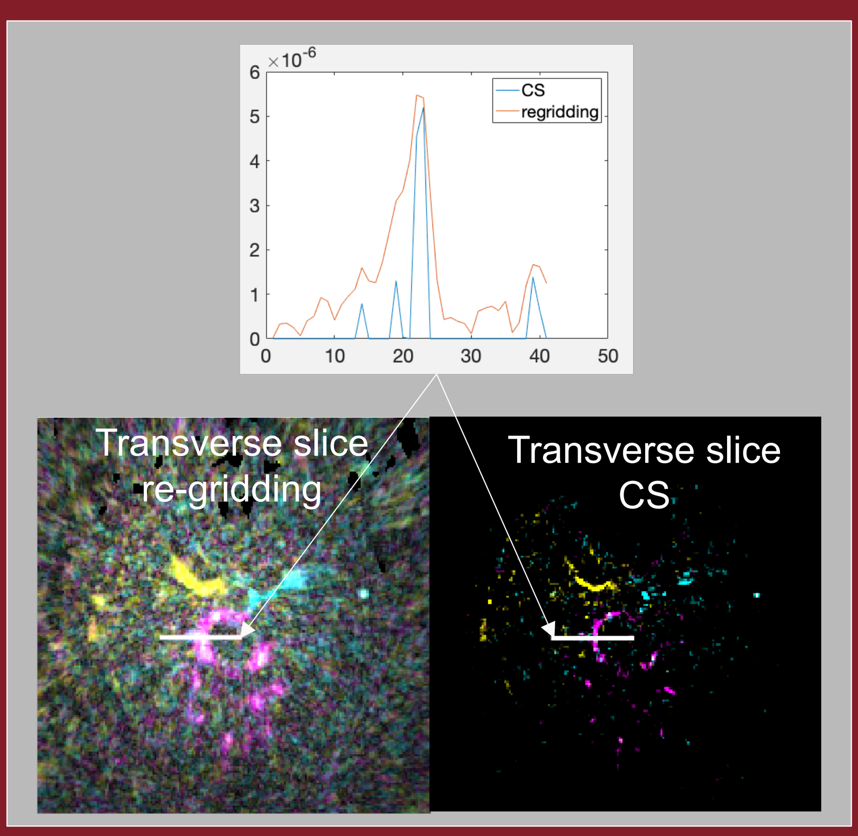


Figure 2: Example of increased SNR and lowered blurring for CS compared with re-gridding

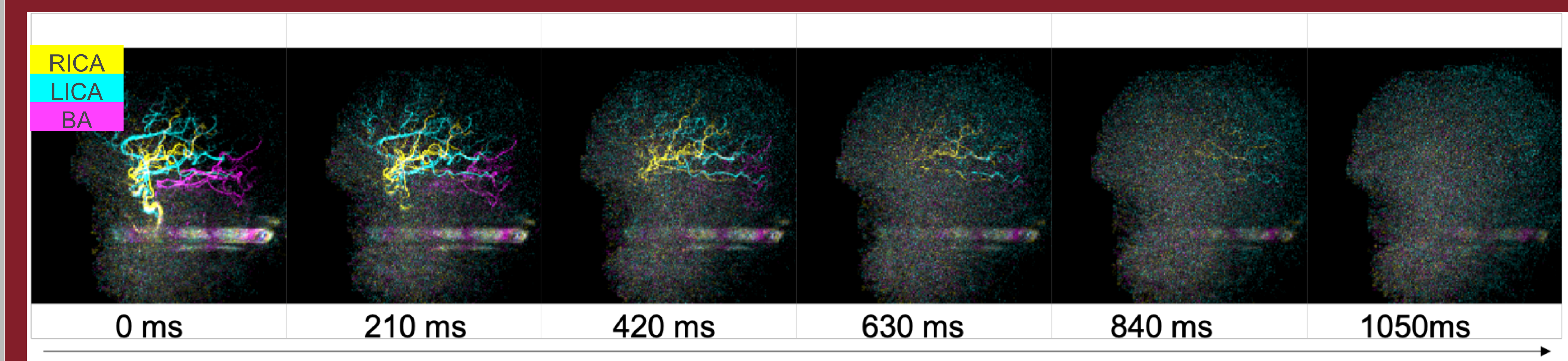


Figure 3: Temporal dynamics of the outflow of the labeled bolus. Sharp delineation of faint vessels is apparent even in later frames, despite the lower SNR. Effective post-labelling delays are shown beneath each frame.

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3. Wu H., et al., 2013. Noncontrast-enhanced three-dimensional (3D) intracranial MR angiography using pseudocontinuous arterial spin labeling and accelerated 3D radial acquisition.
4. Zhou Z., et al., 2018. Accelerated noncontrast-enhanced 4-dimensional intracranial MR angiography using golden-angle stack-of-stars trajectory and compressed sensing with magnitude subtraction.
5. Okell T.W., 2018. Combined angiography and perfusion using radial imaging and arterial spin labelling.
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7. Günther M., 2007, Highly efficient accelerated acquisition of perfusion inflow series by cycled arterial spin labeling. In Proceedings of the 16th Annual Meeting of ISMRM, Berlin, Germany

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UNIVERSITY OF OXFORD
The University of Nottingham
EPSRC-MRC Centre for Doctoral Training in Biomedical Imaging
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