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Quantiphyse: Quantitative BOLD for mapping OEF

Nicholas Blockley

Oxygen Extraction Fraction

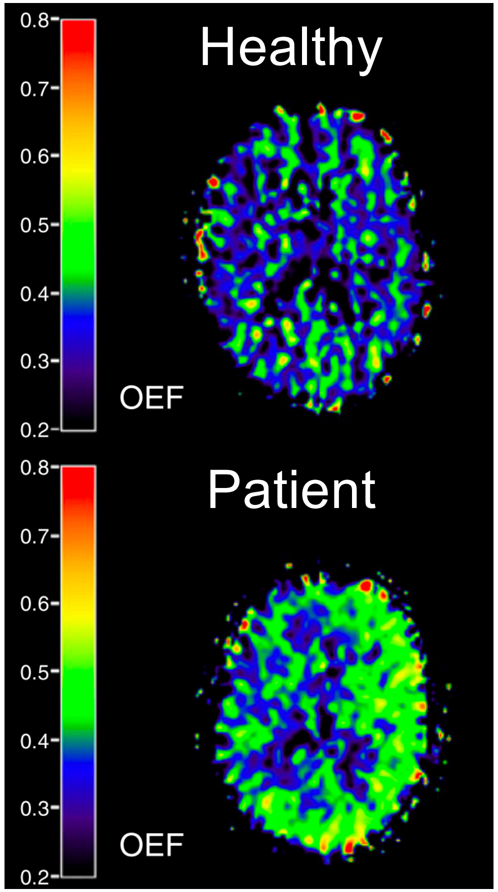
OEF is a measurement of oxygen consumed by metabolism

- Tightly coupled to perfusion
- Function of perfusion and oxygen metabolism
- Can be combined with perfusion to measure oxygen metabolism
- Arterial-venous difference in blood oxygen saturation

OEF is dimensionless

- Healthy resting brain value: 0.3-0.4

^{15}O PET OEF measurements



Bremmer JP, et al. Mol. Imaging Biol. 2011;13:759–768.

Oxygen Extraction Fraction

Oxygen consumption in brain

- Altered during disease/activity

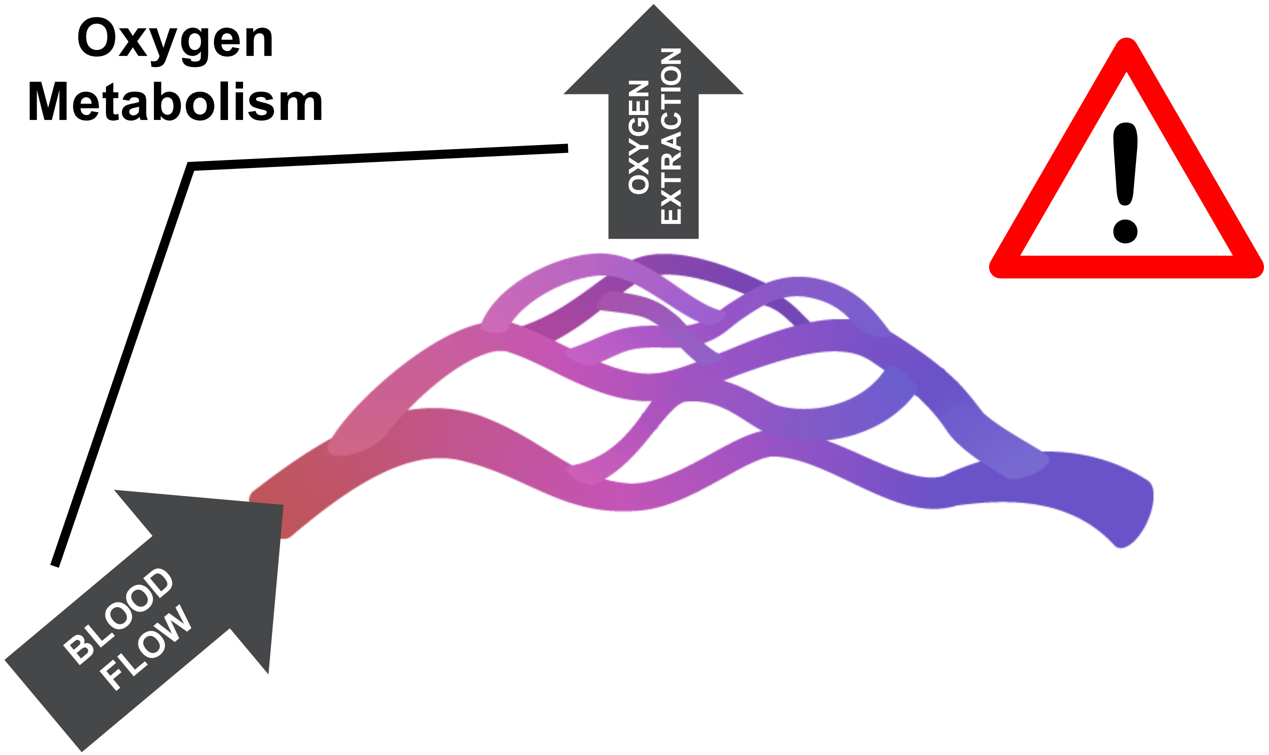
Gold standard

- Triple oxygen PET
- Expensive, invasive and time-consuming

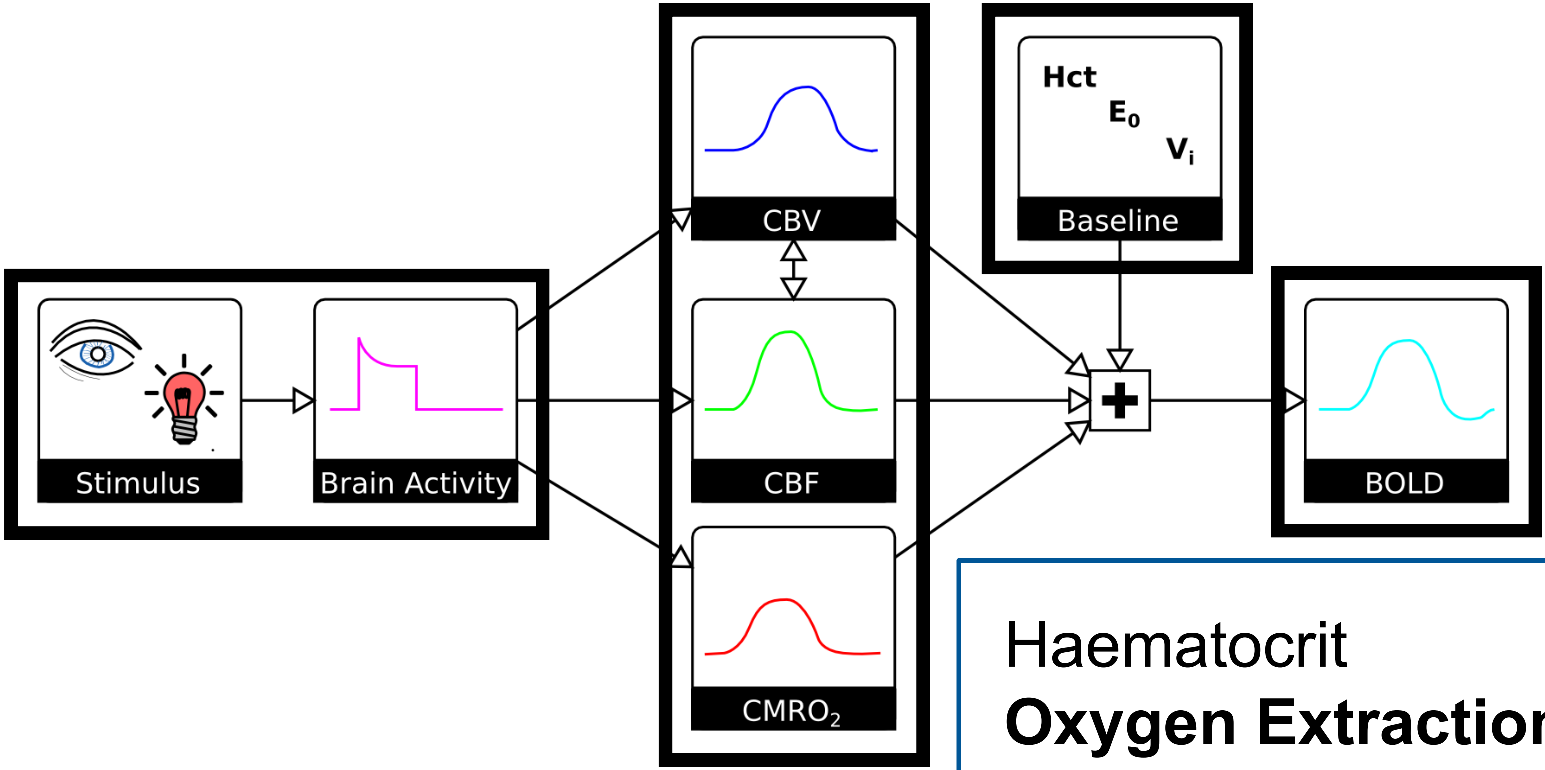
Need for quantitative technique

- Clinically applicable
- MRI inherently sensitive to blood oxygenation

Oxygen Extraction Fraction



BOLD Effect



Haematocrit

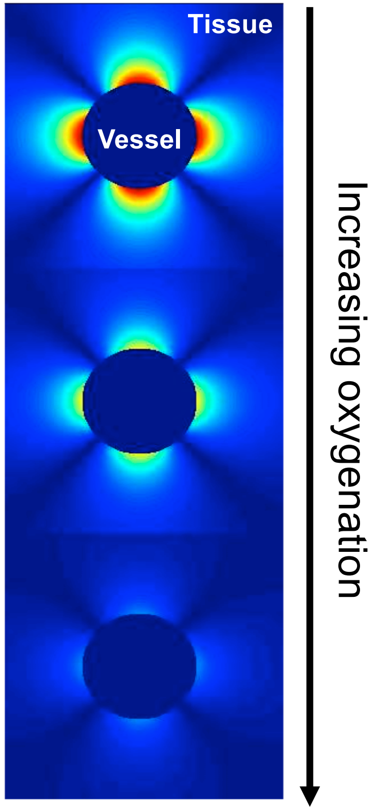
Oxygen Extraction Fraction

Venous Blood Volume

BOLD Effect

R_2' / T_2' effect

- Reversible transverse relaxation rate/time
- Signal dephasing at meso/macroscopic scale
- Relationship with blood oxygen saturation vessel size dependent
- Predominantly extravascular effect
- Tissue volume ~95% of voxel volume



Ogawa et al., Biophys J, 1993;64:803-812

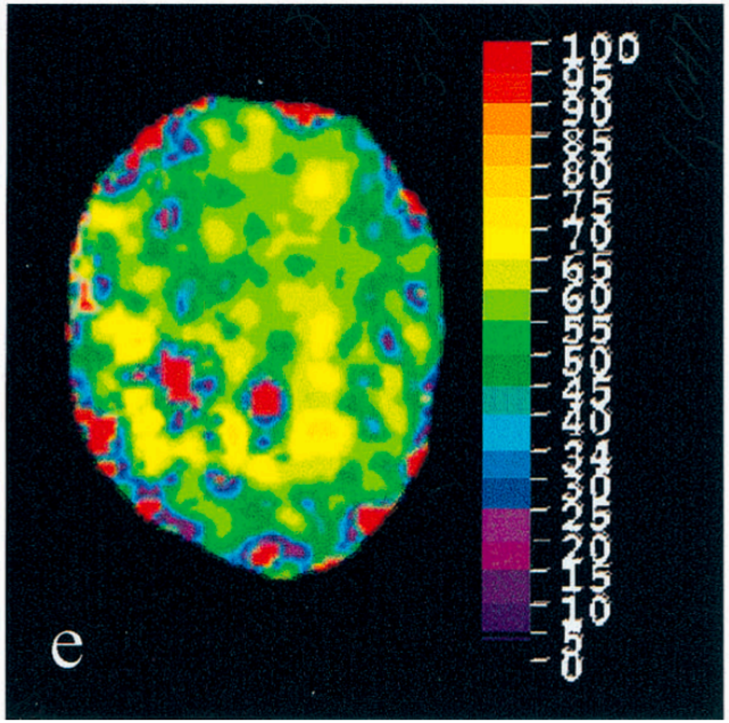
Quantitative BOLD

Quantitative BOLD (qBOLD)

- Models MR signal decay in a vessel network
- Sensitive to amount of deoyhaemoglobin
- Through the reversible transverse relaxation rate R_2'

$$R_2' = R_2^* - R_2 \propto dHb$$

Oxygen Saturation*

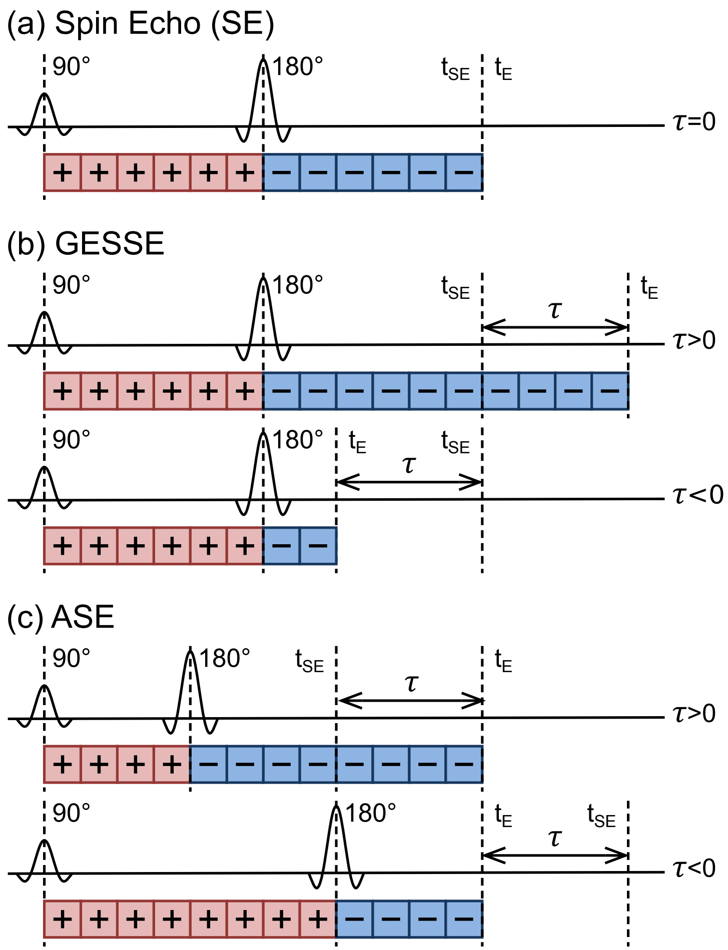


*An H & Lin W. J. Cereb. Blood Flow Metab. 2000;20:1225–1236.
He X & Yablonskiy DA. Magn. Reson. Med. 2007;57:115–126.

Quantitative BOLD

How do we measure R_2'?

- Introduce R_2'-weighting in to images using a modified spin echo sequence
- GESSE: Gradient Echo Sampling of Spin Echo
  - Acquires many closely space tau/TE values
  - Refocussing pulse is static
- ASE: Asymmetric Spin Echo
  - Acquires only a single TE
  - Refocussing pulse is moved



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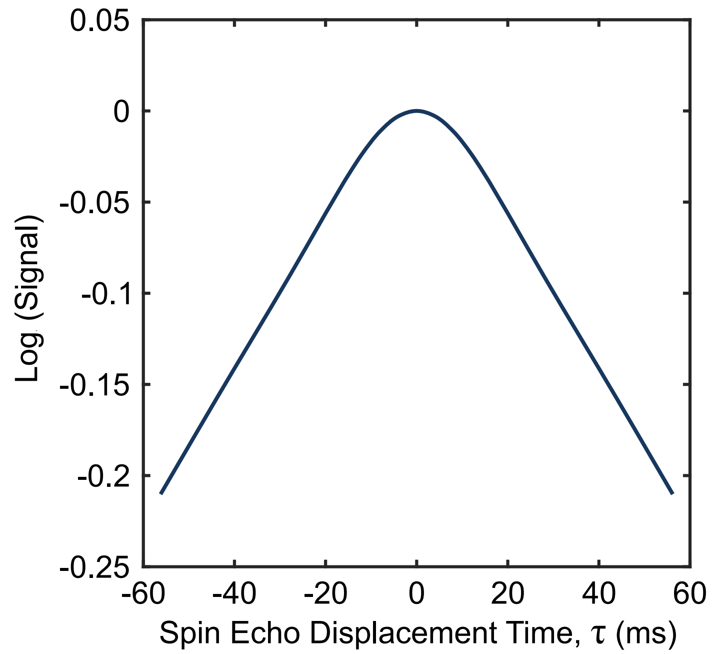
Quantitative BOLD

How do we quantify OEF?

1. Acquire R_2'-weighted data
   - Asymmetric Spin Echo
   - Gradient Echo Sampling of Spin Echo



Quantitative BOLD

How do we quantify OEF?

1. Acquire R_2'-weighted data
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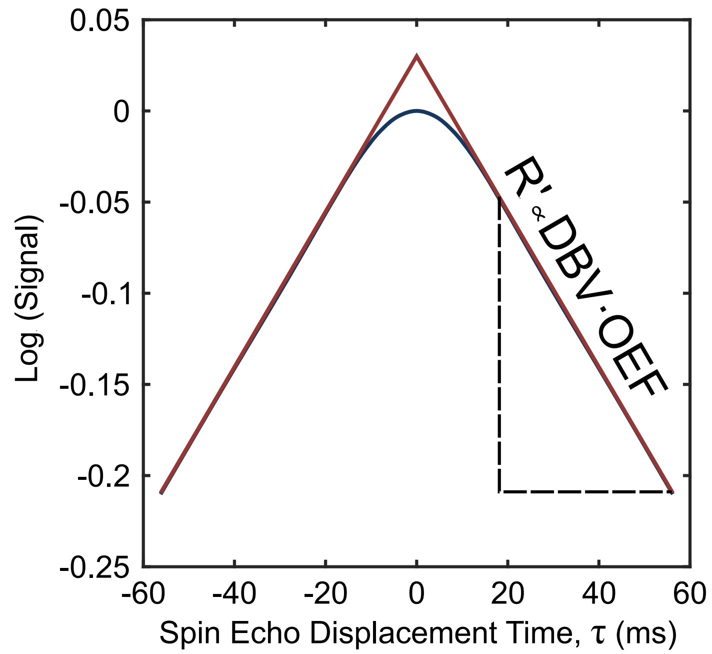
2. Estimate R_2' from long tau data
   - Log-linear fit to tau>15ms data
   - R_2' is proportional to OEF x DBV



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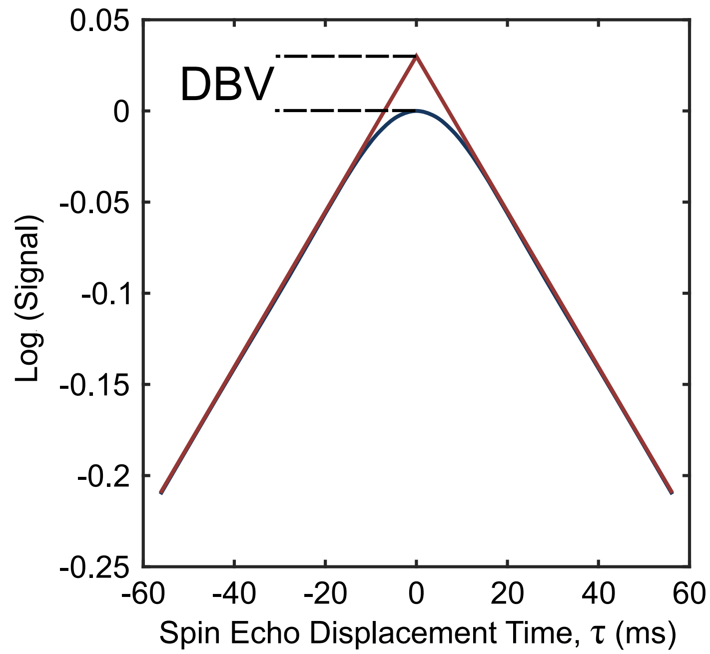
3. Estimate DBV from spin echo
   - Difference between intercept and measured spin echo signal



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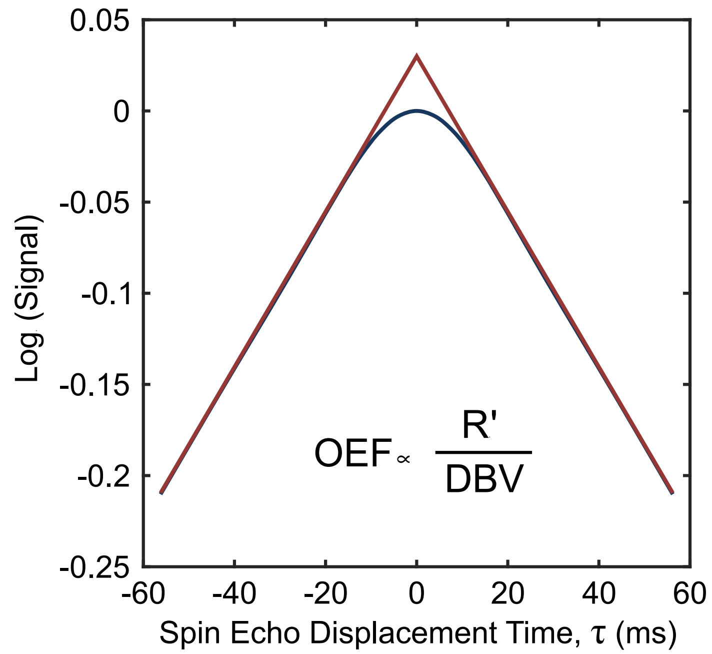
3. Estimate DBV from spin echo
   - Difference between intercept and measured spin echo signal
4. Estimate OEF from R_2' and DBV
   - Known constants of proportionality used to quantify OEF



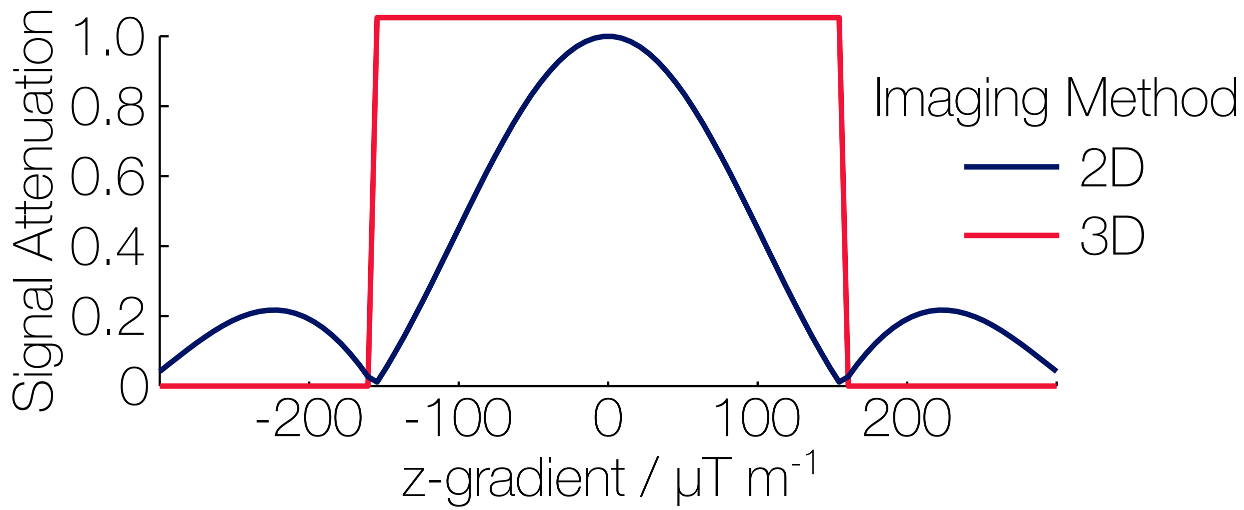
Confounding Effects

Magnetic Field Inhomogeneity

- Slice selection: Gradient in z-direction causes signal attenuation
  - Signal decays with form of Sinc function
- Phase/Frequency encoding: smaller effect than in z-dimension

Correction approaches

- 2D: correction in post-processing
  - Requires a high resolution field map
- 3D: prospective correction
  - 3D phase encoding compensates for z-gradient



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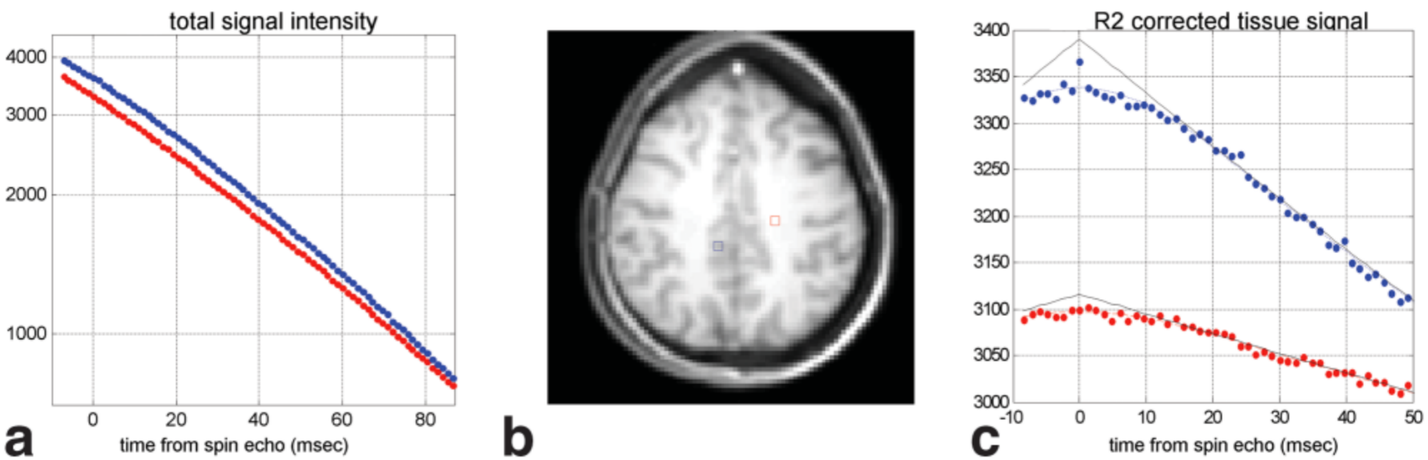
Confounding Effects

Underlying T_2/R_2 signal decay

- Tissue signal is TE dependent
- Independent of R_2'

Correction approaches

- GESSE: Post-processing to correct for tissue signal decay
- ASE: No post-processing required since R_2-weighting is constant



He X & Yablonskiy DA. Magn. Reson. Med. 2007;57:115–126.

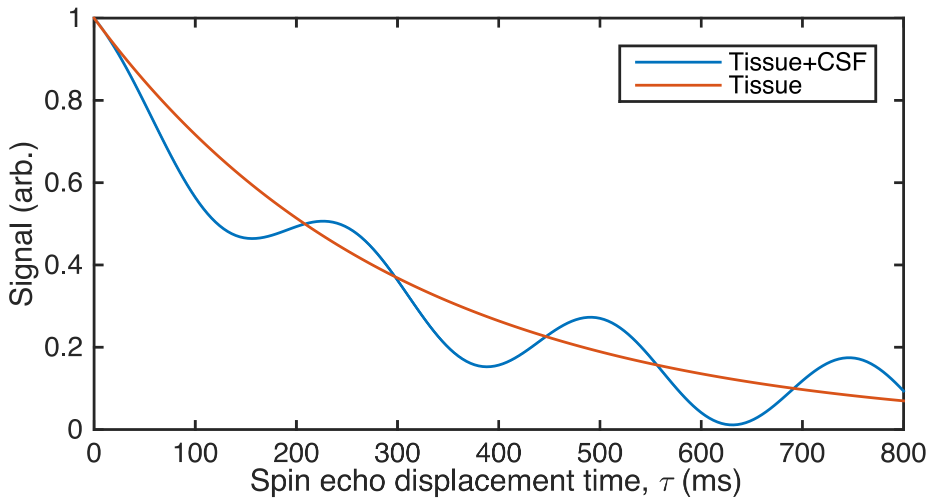
Confounding Effects

Cerebral Spinal Fluid

- Off-resonance w.r.t. tissue water
- Overestimation of R_2'
  - Leading to overestimation of OEF

Correction approaches

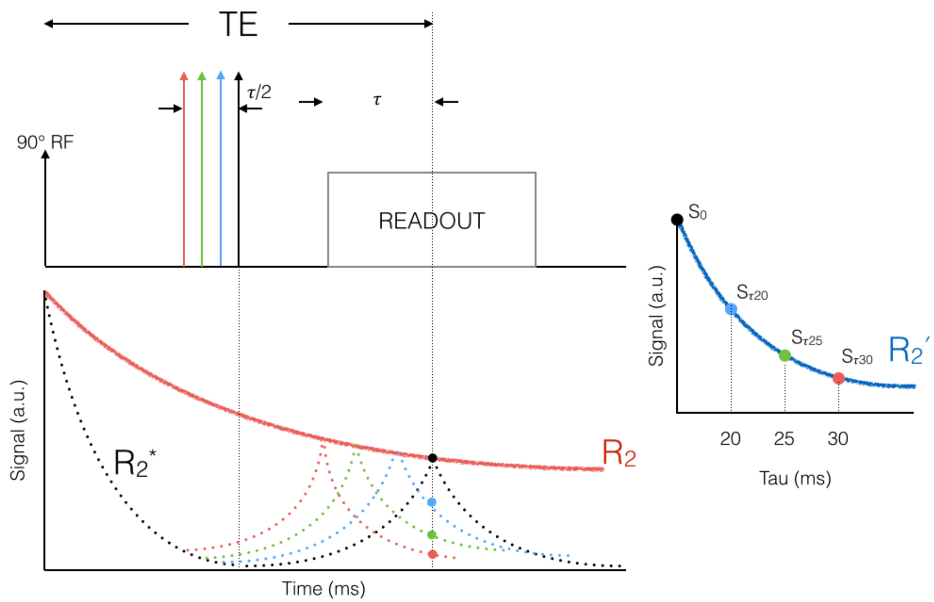
- FLAIR: Fluid Attenuated Inversion Recovery
  - Use differing T_1 properties of CSF & tissue
- Postprocessing using a model of CSF/tissue signal decay



He X & Yablonskiy DA. Magn. Reson. Med. 2007;57:115–126.

Streamlined Quantitative BOLD

1. **Asymmetric Spin Echo (ASE) removes R_2 weighting**
2. Gradient Echo Slice Excitation Profile Imaging (GESEPI) reduces MFIs
3. CSF-nulling using FLAIR removes nuisance signal



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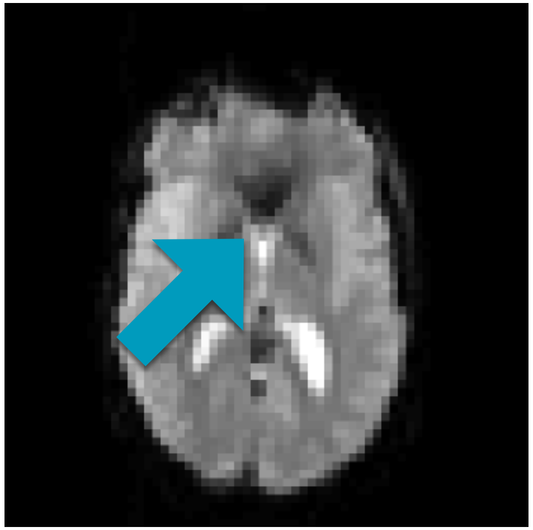
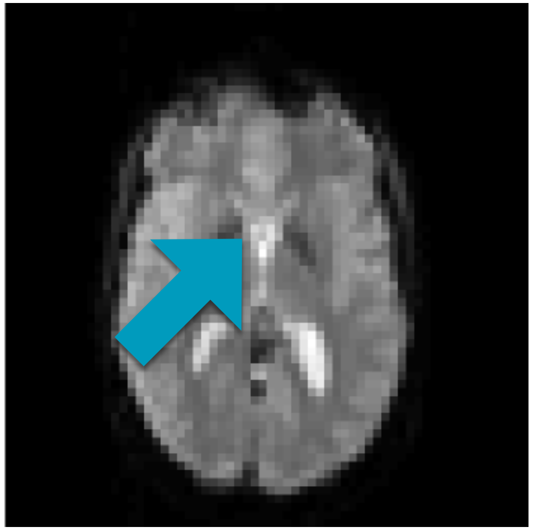
ASE



GESEPI-ASE



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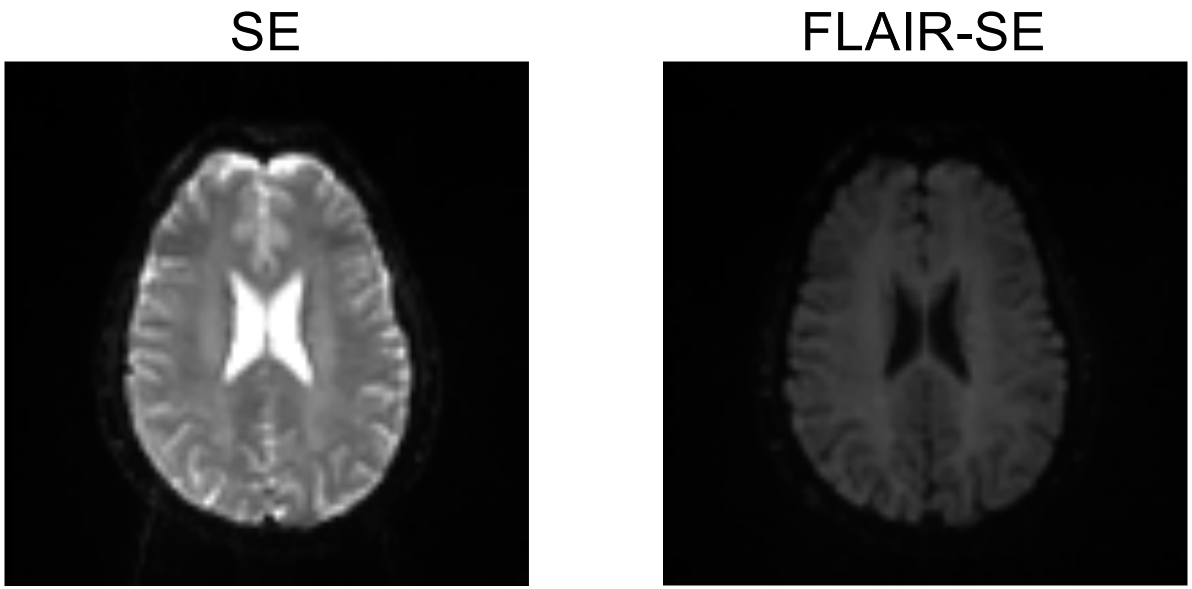


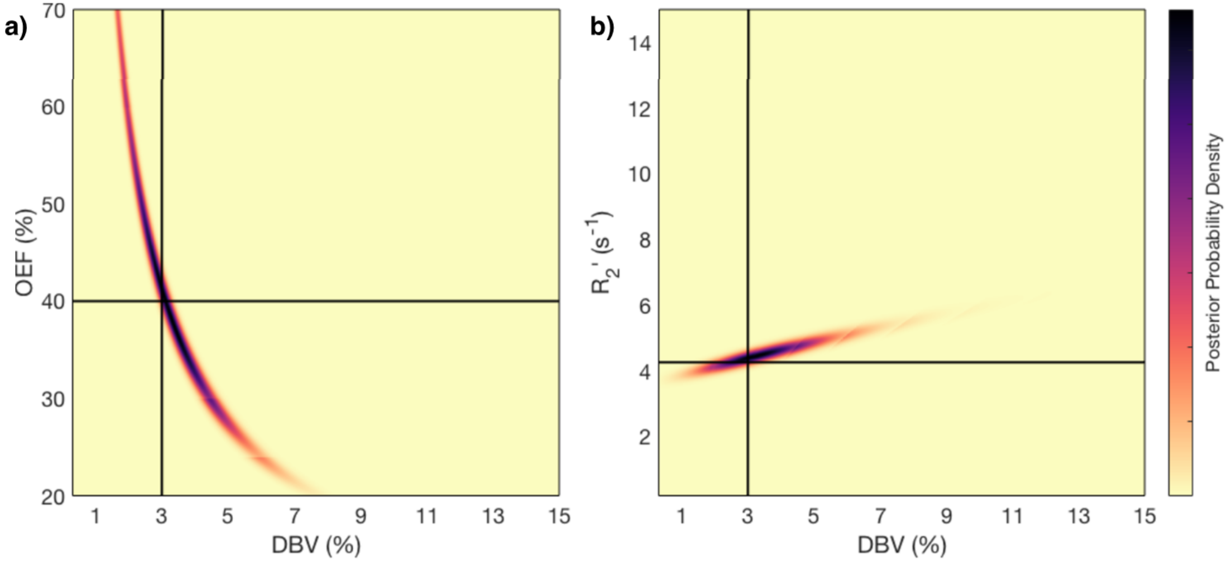
Streamlined Quantitative BOLD

Fitting directly for OEF and DBV

- Co-linearity between OEF and DBV makes finding a unique solution challenging

Fitting for R_2' and DBV

- Easier to identify optimal solution
- Can calculate OEF from R_2' and DBV

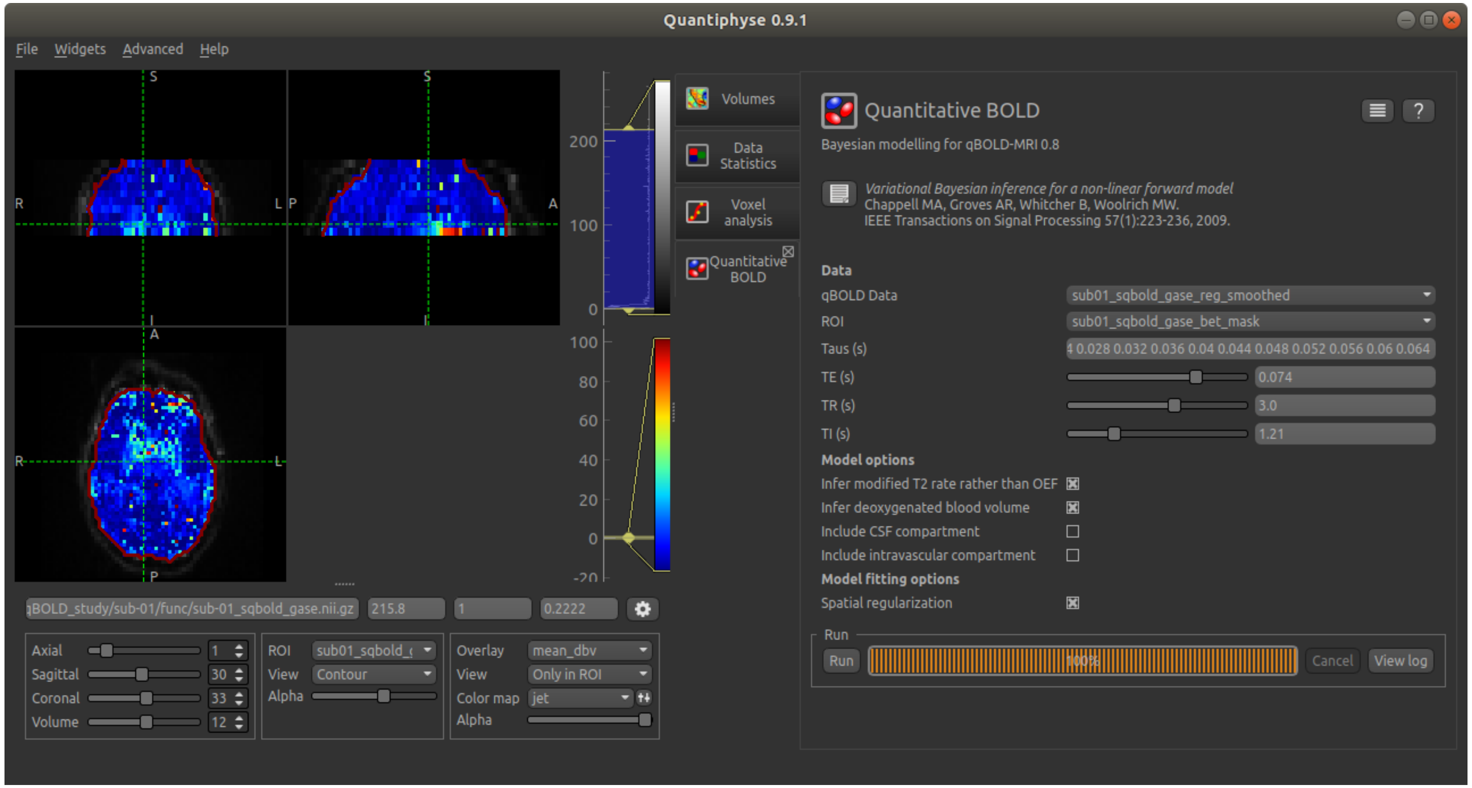


Cherukara MT, et al. Neuroimage 2019;202:116106.

Quantiphyse – qBOLD widget

Initial version designed to accept streamlined qBOLD data (FLAIR-GESEPI-ASE)

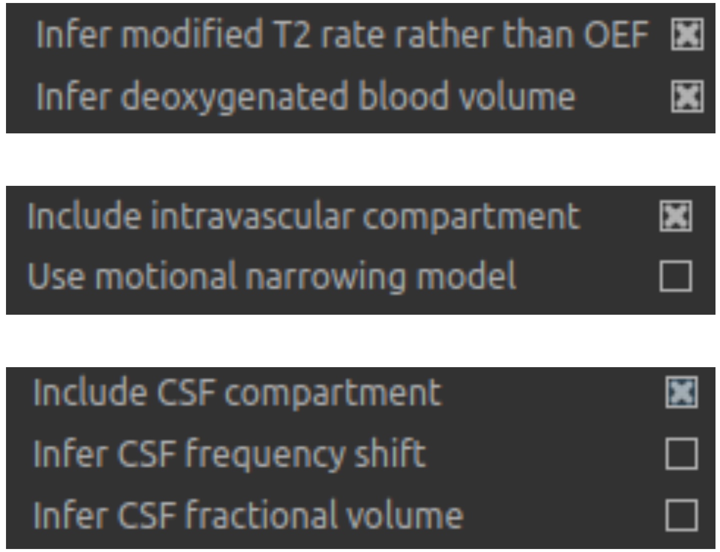
- Suitable for other data if appropriate pre-processing can be performed



Quantiphyse – qBOLD widget

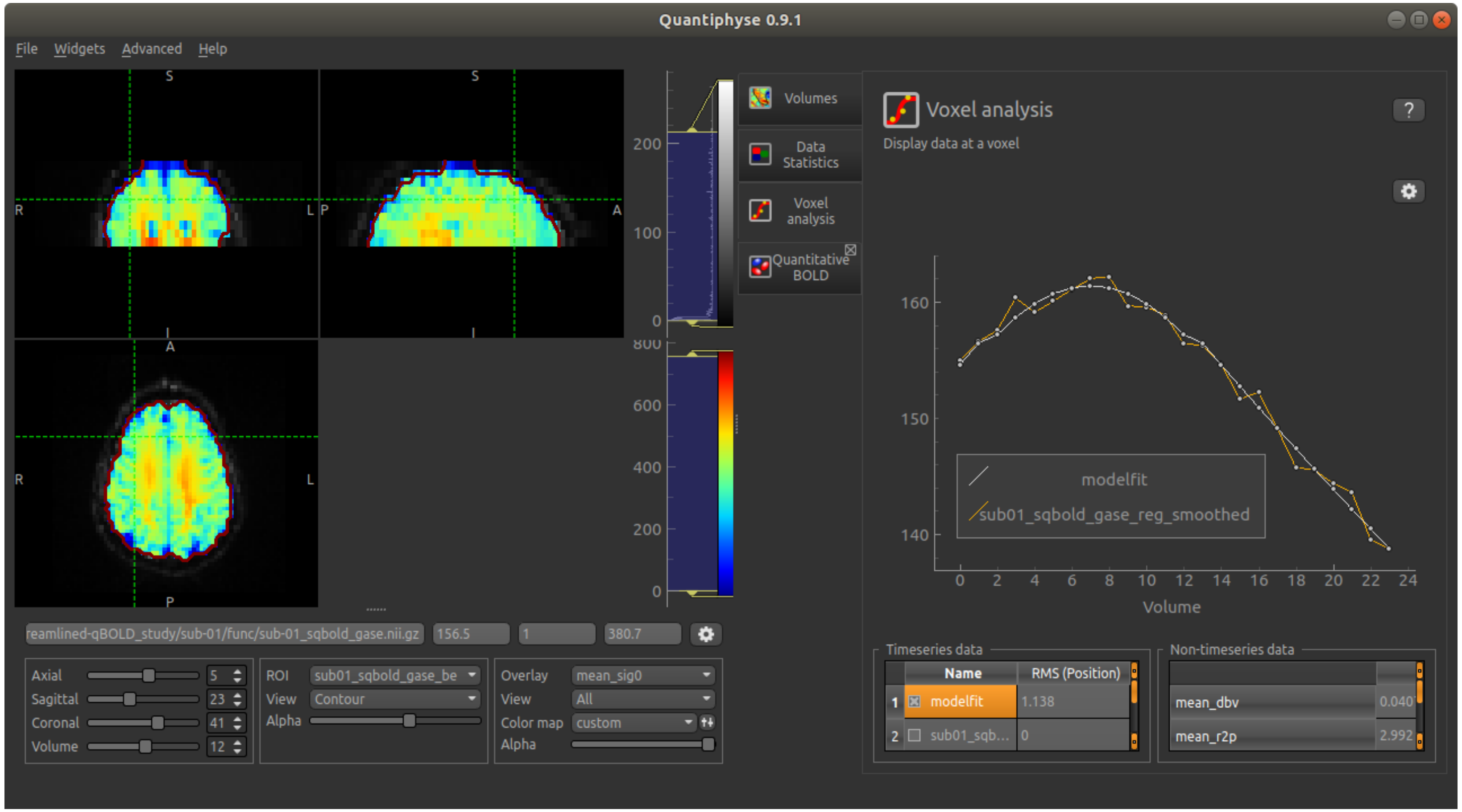
Processing options

- By default we fit for R_2' and DBV
- Can add model of the intravascular signal (default: powder model or motional narrowing model)
- Experimental support for including CSF
- Recommend only fitting for CSF fractional volume and assuming constant CSF frequency shift



Quantiphyse – qBOLD widget

Post-analysis visualisation of model fitting is a valuable feature of Quanitphyse



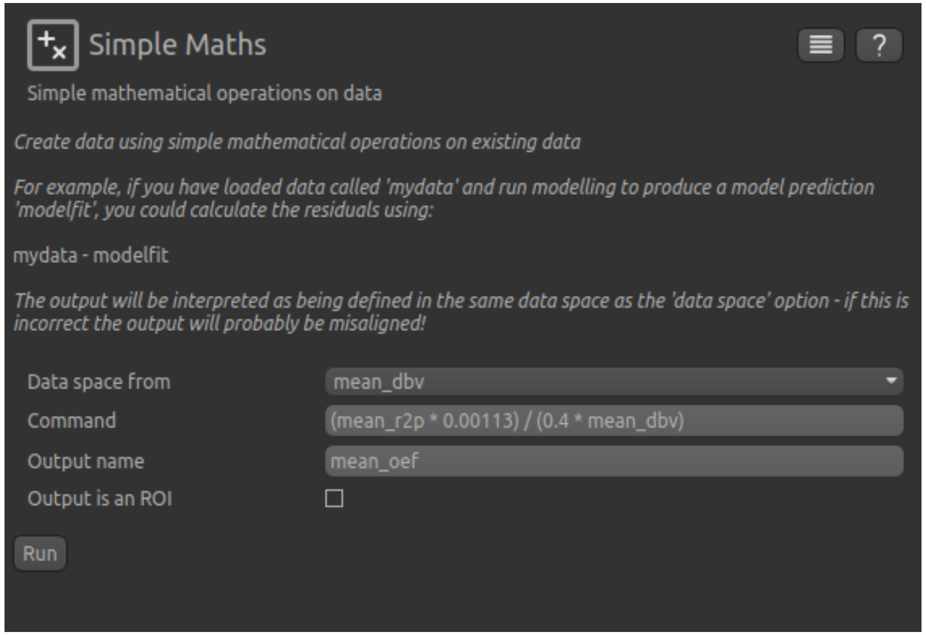
Quantiphyse – qBOLD widget

Calculating OEF

- Can be done within Quantiphyse using Simple Maths widget

$$(R_2' \times \text{const}) / (\text{Hct} \times \text{DBV})$$

- const – subsumes geometry and physical parameters
- Hct – haematocrit



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Summary

OEF is a valuable biomarker of brain health

Quantitative BOLD offers a rapid and non-contrast approach to measuring OEF

Important to know the limitations of the qBOLD model

- i.e. difficult to estimate OEF and DBV directly

Analysing qBOLD data in a Bayesian framework provides robust estimates of OEF

Quantiphyse provides a user friendly interface for Bayesian model fitting

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Thank you for listening