Improved selection of the venous blood pool for OEF determination: IQ-OEF

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Introduction

Oxygen extraction fraction (OEF) is the oxygen consumption to oxygen delivery ratio and an important brain function parameter

QUantitative Imaging of eXtraction of Oxygen and TIssue Consumption (QUIXOTIC) MRI[1] uses velocity-selective (VS) spin labeling[2] to isolate MR signal from blood with a flow velocity higher than the cutoff velocity (v_c) on the venous side of the circulation.

QUIXOTIC allows direct measurement of venous oxygen saturation, can be related to OEF and ultimately to cerebral metabolic rate of oxygen ($CMRO_2$). Unlike BOLD, no contaminations occur due to either pathology or iron deposition.

The disadvantages of QUIXOTIC are the low SNR, since it is based on the outflow of venous blood during the ~1second encoding time and that it uses two VS-labeling modules. Therefore it will have a greater T_2 relaxation and the labeling efficiency will be different during systole and diastole, because no cardiac gating is used.

Labeling whole venous blood pool will increase the SNR as was shown with velocity selective excitation and arterial nulling (VSEAN)[3] combined with phase sensitive signal detection to isolate the venous blood signal.

Aim of this study

Inflow QUIXOTIC OEF (IQ-OEF) is introduced with pulsed ASL module applied $T_{1,blood}$*ln(2) seconds before the VS-labeling to null the arterial pool and exclusively label the venous blood pool by a single VS-module.

Venous and arterial T_2 can be obtained using a single sequence

This new technique, dubbed **Inflow QUIXOTIC OEF**, with and without QUantitative Imaging of Perfusion using a Single Subtraction (QUIPSS)[4], is compared with QUIXOTIC.

Materials & methods

IQ-OEF (figure 1A) :
- The spins were inverted, 856ms after the pre-saturation pulse, by the pulsed ASL labeling module (STAR, 150mm label thickness), followed by a delay of 1144ms before the VS-labeling module , assuming $T_{1,blood}$=1664ms.
- To saturate the trailing edge of the slow flowing spins in the inverted region (TI_{QUIPSS}= 640ms) QUIPSS can be applied.
- The VS-labeling module parameters were δ=0.7ms, Δ=26ms, G=22mT/m, corresponding to a v_c of 2cm/s.
- Read out was performed by GE-EPI acquisition of 17 slices of 7mm thickness at a delay of 110ms.

6 healthy volunteers were scanned on a 3T Philips Achieva MRI scanner using a 32ch receive head-coil.

In QUIXOTIC (figure 1B) the first VS-labeling module was performed 2700ms after the pre-saturation pulse. Followed by an inversion pulse 380ms later and the second VS-labeling module after a 725ms delay, both using the same parameters as IQ.

For one volunteer a single slice, multi-echo IQ-OEF (MLEV T_2-prep, TE=0, 40, 80, 160ms) was added to the protocol and the average ASL signal over the grey matter (GM) mask was fitted to a mono-exponential resulting in both a T_2-estimate and also the ASL signal at TE=0ms.

Images were coregistrated to a standard brain with SPM8. The image with both arterial and venous signal was thresholded to obtain a GM mask. The different sequences were compared with a 2-way ANOVA statistical test using Matlab.

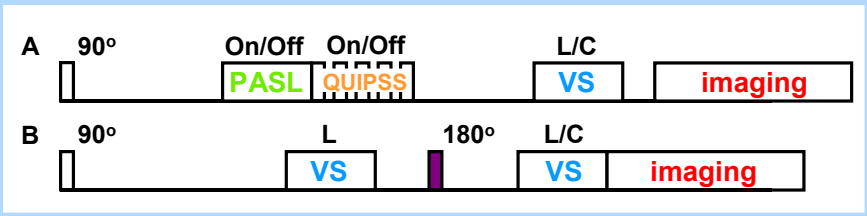


Figure 1 Schematic overview of Inflow Quixotic OEF (A) and QUIXOTIC (B) pulse sequence.

Labeling combinations

The **Inflow Quixotic OEF**-technique (figure 1A) cycles through different labeling combinations:
- PASL on/off → inclusion/exclusion of the arterial signal in addition to the venous signal.
- VS-module L/C → label/control images for pair wise subtraction.
- QUIPSS on/off → with/without suppression of fresh inflow.

Results

Figure 2 shows the arterial and venous ASL image from IQ-OEF. The SNR at the arterial and venous side in GM from IQ-OEF with and without QUIPSS and QUIXOTIC are shown in figure 3.

The venous SNR was higher than the arterial SNR. The venous SNR was higher for IQ-OEF compared with QUIXOTIC. The arterial SNR for IQ-OEF without QUIPSS was higher than for IQ-OEF with QUIPSS.

The SNR and signal difference (data not shown) from QUIXOTIC was approximately a factor of five lower in GM compared with IQ-OEF.

The T_2 values were on average 178ms on the arterial side, 72ms in the sagittal sinus and 150ms in the venous part of the tissue.

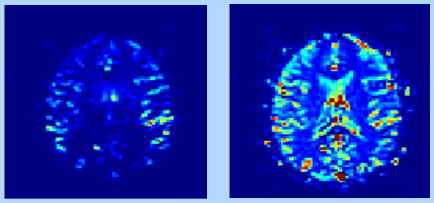
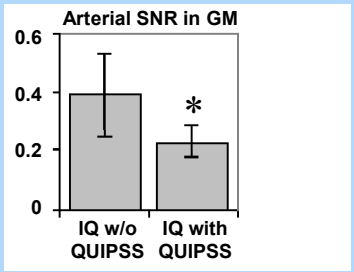


Figure 2 Arterial (left) and venous (right) ASL maps from IQ-OEF with QUIPSS from a single volunteer.



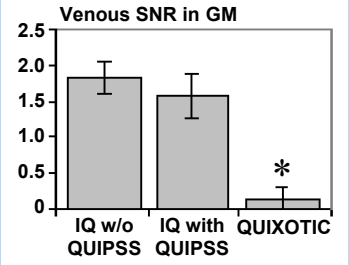


Figure 3 The SNR at the arterial (top plot) and venous (bottom plot) side in GM from IQ-OEF without QUIPSS, IQ-OEF with QUIPSS and QUIXOTIC (only venous). * P<0.05 with paired t-test.

Discussion & Conclusions

Inflow Quixotic OEF enables selection of local venous blood pool by arterial nulling.

The SNR was improved compared with QUIXOTIC and the ASL signal was higher, although this can partially be attributed to inclusion of some arterial signal due to too-high velocity encoding compared with the arterial arrival time.

Future research will focus on an optimized trade off between SNR and arterial suppression.

Since IQ-OEF does not use a global inversion pulse, which also attenuates the signal of venous blood and brain tissue and is not based on the venous outflow during ~1second, more venous signal was acquired.

IQ-OEF provides also the opportunity to not only estimate the venous, but also the arterial T_2, which is another advantage over QUIXOTIC, since it does not require an extra scan.

T_2-measurements in larger vessels (both arteries and veins) were shown to be feasible with our current sequence, but the venous T_2-estimate in tissue, however, remains challenging due to partial volume and imaging artifacts.

IQ-OEF has a relatively low temporal resolution compared with VSEAN due to the subtraction scheme.

References

[1] D.S.Bolar et al. MRM 2011; 66: 1550-1562
[2] E.C. Wong et al. MRM 2006; 55:1334-1341
[3] J. Guo et al. MRM 2012
[4] E.C. Wong et al. MRM 1998; 39:702-708

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