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

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Introduction The oxygen extraction fraction (OEF), which quantifies the ratio of oxygen consumption to oxygen delivery, is an important parameter of brain function. There are two types of MR methods to assess OEF: one is developed to estimate oxygenation in large vessels, while the other acts at the tissue level. The latter can be distinguished in BOLD and techniques that exclusively measure venous blood, as a result of which no contaminations due to either pathology or iron deposition occur. An example of this last concept is QUantitative Imaging of eXtraction of Oxygen and TIssue Consumption (QUIXOTIC) MRI[1], which uses velocity-selective (VS) spin labeling[2] to isolate the MR signal exclusively from blood flowing above a cutoff velocity (v_C) on the venous side of the circulation on a voxel-by-voxel basis. This allows direct measurement of venous oxygen saturation (Yv) and can be related to OEF and ultimately cerebral metabolic rate of oxygen ($CMRO_2$) with additional cerebral blood flow and hematocrit measurements. This method of evaluating brain function locally is especially useful in localized pathologies, such as stroke, carotic artery stenosis and occlusion. The downside of QUIXOTIC is the low SNR, because it is based on the outflow of venous blood during the ~1 second encoding time. Moreover, it uses two VS-labeling modules, causing greater T_2 relaxation and, since it is not cardiac triggered, suffers from differences in labeling efficiency during systole and diastole. By selectively labeling the whole venous blood pool, the SNR per unit time could be increased. Here, a new method called Inflow QUIXOTIC (IQ) is introduced, which employs a pulsed ASL module applied $T_{1,blood}$*ln(2) seconds before VS-labeling to null the arterial pool. By nulling the arterial signal, the venous pool will be labeled exclusively by a single VS-module. Moreover, not only the venous, but also the arterial T_2 can be calculated using the same sequence, when the control PASL is also acquired in combination with the VS-control module. Here, this new technique, with and without QUantitative Imaging of Perfusion using a Single Subtraction (QUIPSS)[3] to suppress fresh inflow, is compared to QUIXOTIC.

Materials and Methods The IQ-OEF-technique cycles through four different labeling combinations. The pulsed ASL labeling module can be alternated to provide inclusion and exclusion of the arterial signal in addition to the venous signal. Furthermore, label and control images for pairwise subtraction are obtained using the VS-module, as shown in figure 1. QUIPSS can be applied to saturate the trailing edge of the slow flowing spins in the inverted region (TI_{QUIPSS}=640ms). The spins were inverted by the pulsed ASL labeling module (STAR, 150mm label thickness) 856ms after the pre-saturation pulse, followed by a delay of 1144ms before the VS-labeling module, assuming T_{1blood}=1664ms, read out was performed by GE-EPI acquisition of 17 slices of 7mm thickness at a delay of 110ms. The VS-labeling module parameters were δ=0.7ms, Δ=26ms, G=22mT/m, corresponding to a v_C of 2cm/s. In QUIXOTIC the first VS-labeling module was performed 2700ms after the pre-saturation pulse, followed by a 725ms delay before the second VS-labeling module, both using the same parameters as IQ, with an inversion pulse at 380ms. Six healthy volunteers were scanned on a 3T Philips Achieva MRI scanner using a 32 receive channel head-coil. After co-registrating the images to a standard brain with SPM8, the image with arterial and venous signal was thresholded to obtain a grey matter (GM) mask and the different sequences were compared with a 2-way ANOVA statistical test using Matlab. For one volunteer a single slice, multi-echo IQ (MLEV T_2-prep, TE=0, 40, 80, 160ms) was added to the protocol and the average ASL signal over the GM-mask was fitted to a mono-exponential resulting in both a T_2-estimate and also the ASL signal at TE=0ms.

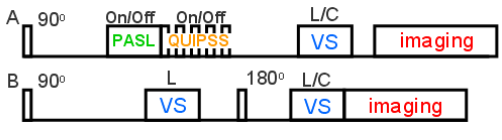

Fig. 1: IQ (A) and QUIXOTIC (B) pulse scheme

Results Figure 2 shows the arterial and venous difference image from IQ from a volunteer. The SNR at the arterial and venous side in GM from IQ with and without QUIPSS and QUIXOTIC are shown in figure 3. The venous SNR in GM from IQ was significantly higher than the arterial SNR and that of QUIXOTIC. While there was a significant difference in arterial SNR with and without the use of QUIPSS, there was no difference in venous SNR. The SNR and signal difference (data not shown) from QUIXOTIC was approximately a factor of five lower in GM compared to IQ. 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.

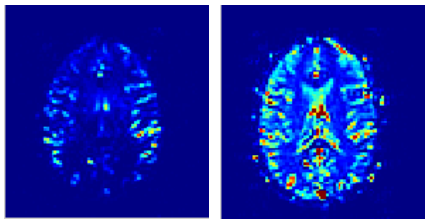

Fig. 2: Arterial (left) and venous difference image from IQ with QUIPSS

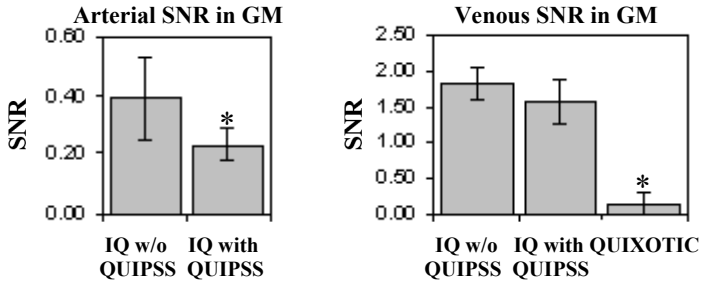

Fig. 3: The SNR at the arterial (left plot) and venous side in GM from IQ without QUIPSS, with QUIPSS and QUIXOTIC, * P<0.05 with paired t-test.

Discussion and Conclusions By selectively labeling the venous blood pool, the IQ-technique showed a great improvement in SNR and difference signal compared to QUIXOTIC. However, this could partially be attributed to the inclusion of some arterial signal, due to too-high velocity encoding compared to the arterial arrival time. Future research will focus on an optimized trade off between SNR and arterial suppression. IQ-OEF enables selection of the local venous blood pool, and 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, remain challenging due to partial volume and imaging artifacts.

References [1] D.S.Bolar et al. MRM 2011 [2] Wong et al. MRM 2006;55:1334–1341 [3] Wong et al. MRM 1998;39:702-708

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