FAIR Perfusion Measurements in the Neonatal Piglet

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Introduction

An established animal model of perinatal hypoxia-ischaemia demonstrates a delayed 'secondary energy failure' (SEF) 8–24 hours after the primary insult [1], as observed with phosphorus [2] and proton [3] spectroscopy and diffusion imaging [4]. Cerebral perfusion measurements are required to increase our understanding of the mechanisms underlying SEF and the impact of potential therapies, such as hypothermia [5]. Arterial spin labelling (ASL) should be used to permit repeated measurements without an accumulation of contrast agent affecting other scans. Continuous ASL has proved impractical at high fields due to its large power deposition.

A pulsed ASL perfusion measurement technique, based on FAIR [6], has been developed and evaluated for use in this model. A surface coil was used for signal excitation and reception. Frequency-offset-corrected inversion (FOCI) pulses [7] were used for both inversion and imaging, to reduce the inflow time of labelled blood and to optimise the usable slice-thickness ratio (STR) between selective inversions and the imaging slice.

Methods

FAIR [Kim] was implemented on a 7T Bruker Biospec scanner using a single-shot echo-planar imaging (EPI) readout. To reduce the usable STR, a FOCI pulse [7] was used for the slice-selective inversion [8], and a pair of identical FOCI pulses were used to form the spin echo, in a similar fashion to spin echoes formed from a pair of hyperbolic secant pulses [9]. A similar 'pancake flipper' sequence has been developed by Pell [10], leading to effective crushing of the out-of-slice signal [11].

Weak diffusion gradients were included to crush the intravascular signal [12]. Volume coil excitation was not possible because of space constraints, so a home-made, doubly-tuneable, 5 cm surface coil was used for signal excitation and reception. This provided sufficient inversion coverage to obtain a reliable semi-quantitative measurement of cerebral perfusion, without significant inflow of unlabelled blood, suitable for assessing changes over a time-course measurement.

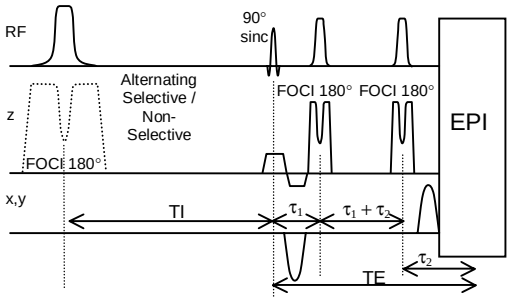

Fig 1. Pulse sequence for FAIR measurements

The sequence was implemented using TE = 70 ms, TR = 15s, TI = 2000 or 2250 ms, image matrix 64×64, FoV 5 cm, EPI readout duration 49 ms. 20 averages each were taken of the (interleaved) selective and non-selective inversions. The data for each average were reconstructed separately, so any measurements affected by subject motion could be repeated.

The FOCI pulse parameters were adjusted to give sharp slice profiles, consistent with the available RF power and gradient strength, within a short time for imaging pulses and with low adiabatic threshold power for the inversion pulses, to maximise the volume of the non-selective inversion. Values used were β=1185 s^{-1}, μ=10.8, T_p=12 ms, G_{max}/G_{min}=4.125 for the inversion pulse, and β=3200 s^{-1}, μ=4, T_p=3.25 ms, G_{max}/G_{min}=3.3 for the pair of refocusing pulses. For on-resonance slices, negligible subtraction images were obtained down to a STR of 1.15, in broad agreement with ref [10], but a more conservative STR of 1.5 was used in practice, since the FOCI slice profile was slightly degraded off-resonance. T1, reference signal and inversion efficiency (typically > 0.95) were measured with an inversion-recovery series based on the same sequence.

Perfusion maps were calculated according to ref. [13]. Using an arterial blood sample and an inversion-recovery series, we measured an arterial blood T1 of 2250 ms, in agreement with other findings at 7T [14]. The T1 of neonatal brain at 7T is very close to this value, so compartment-exchange quantification errors should be smaller than at lower fields.

7 neonatal piglets, of age < 24 h, were scanned without insult. Two post-mortem measurements confirmed that the background subtraction signal was approximately an order of magnitude below typical *in vivo* values. On a further two animals, a series of measurements taken with varying TI demonstrated the optimum inversion time to be 2000-2250 ms, with very short transit time for labelled blood and negligible inflow of unlabelled blood at these TI values [15]. The work was approved by the UK home office and the local research ethics committee.

Results

Fig 2 shows a typical perfusion map obtained from an axial slice covering subcortical white matter. The mean signal was measured in a large ROI. Over all 7 animals, the perfusion had a mean of 38 ml/100g/min with a standard deviation of 8 ml/100g/min.

Fig 2: perfusion map covering subcortical white matter

Discussion and Conclusions

We present a method for semi-quantitative perfusion measurements in this important animal model. This method was adapted for surface coil excitation, which appears to provide sufficient inversion coverage to avoid inflow effects up to the TI used in this study. This method will enable a systematic comparison between local perfusion-ischaemia-reperfusion changes and the subsequent emergence of SEF, and allow monitoring of changes as a result of hypothermia or other therapies. The insult may also be better characterised by investigating perfusion changes over much shorter timescales during and immediately after the insult. To facilitate this, the sequence could be extended for rapid measurements using a reduced TR [15].

References

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