REDUCING ARTEFACTS IN INVERSION RECOVERY PREPARED MRI CAUSED BY VARYING HEART RATE THROUGH REAL-TIME ADAPTATION OF THE INVERSION TIME

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Introduction: In MRI there are several techniques that rely upon ECG-triggered inversion recovery (IR) sequences, e.g. arterial spin labelling (ASL), black blood (BB) or late gadolinium enhancement. In most situations a steady heart rate is assumed, but in patients with cardiac arrhythmias this is not the case and the resulting fluctuation of the acquired signal amplitude causes severe artefacts. Recently the adaptation of the inversion time was proposed for BB MRI using the average of several RR intervals [1], however rapid changes of the heart rate still lead to artefacts. Here we present a theoretically complete correction method, based on a real time modification of the inversion time according to the length of the previous RR-interval.

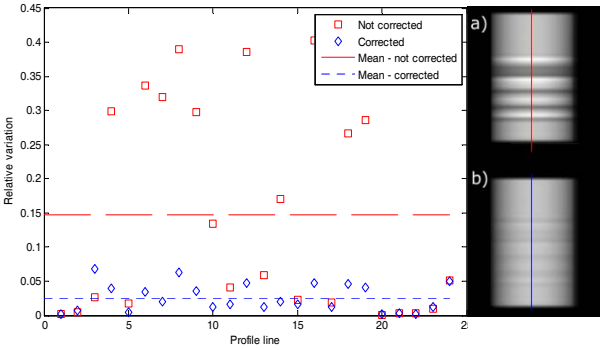

Fig. 2.Variation in signal strength from a 1D intensity scan without (a) and with (b) correction applied, relative to signal strength with a steady heart rate. Mean variation is reduced from 15% to 2.5%.

Methods: A diagram of a repeated IR sequence is shown in Fig. 1. After the initial 180° RF pulse (triggered by the ECG signal), longitudinal magnetisation is allowed to recover with the relaxation time T_1. Image acquisition occurs after the inversion time TI by flipping the recovered longitudinal magnetisation M_a into the transverse plane and acquiring different phase encoding steps with the amplitude proportional to the available magnetisation M_a. After image acquisition, the longitudinal magnetisation partially recovers, until another inversion pulse is triggered by the next R-wave. If triggering happens at regular intervals, M_a remains constant, whereas irregular heart rates will give rise to varying amplitudes of M_a, and consequently irregular signal modulation of the different k-space lines acquired will give rise to ghosting artefacts. To keep M_a at a constant level, TI can be dynamically adapted during the scan using following equation: $\Delta TI = T_1 \ln\{[\exp(-T0/T_1)-2]/[\exp((-T0-dRR)/T_1)-2]\}$, where *dRR* is the difference between the lengths of the average and last RR intervals, $T0 = RR_{avg} - TA - TI_{prev}$ is a parameter of the scan, connecting average RR interval length, acquisition time *TA* and *TI* used in previous cycle (TI_{prev}), and T_1 is the relaxation time for which the correction is applied.

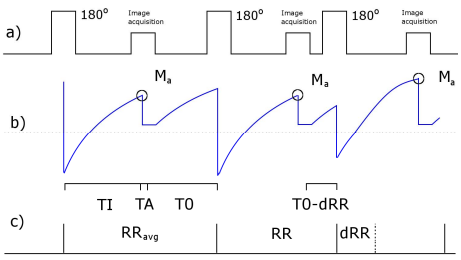

Fig. 1. Timings in a repeated IR sequence: a) RF pulses; b) longitudinal magnetisation and its values before acquisition begins – a delayed ECG trigger results in increase of M_a; c) ECG signal – first a normal RR interval (RR_{avg}), followed by a shorter one ($RR=RR_{avg}$-dRR).

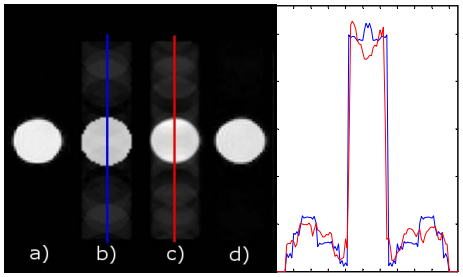

Fig.3. 2D scan and simulation of a gel phantom tube (T_1=765ms): a) scan, steady heart rate; b) simulation, varying heart rate; c) scan, varying heart rate, no correction; d) scan, varying heart rates, corrected. The plot compares simulated (blue) and measured (red) intensity profiles.

Simulations have been performed in Matlab to investigate the influence of heart rate variation on the image quality as well as the performance of the proposed correction. The correction scheme was implemented on a 3T Achieva MRI scanner (Philips, Best, The Netherlands) allowing the adaptation of the TI time (according to the equation) in real time during the scan. Experiments have been performed on phantoms with different T_1 times to obtain 1D projections of the phantom with simulated varying RR-intervals. The intensity of the projections demonstrates the signal variation along the different k-space lines. Different profile orders were compared by calculating the corresponding point spread function (PSF), and the predicted results were confirmed by 2D image acquisition. Finally the technique was demonstrated *in vivo* with IR-prepared (TI=400ms) brain scans in a healthy volunteer using a simulated unsteady ECG signal.

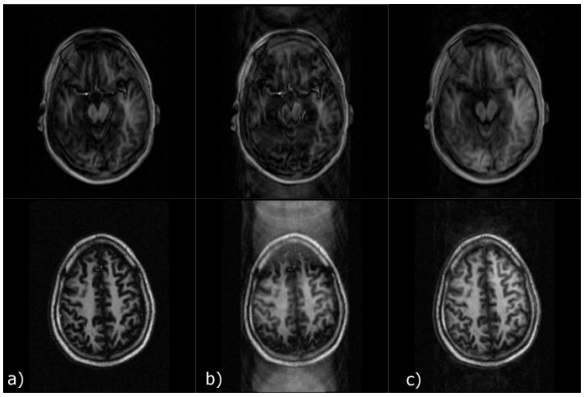

Fig.4. ECG-triggered IR scans of a healthy volunteer's brain. a) steady heart rate; b) varying heart rate without correction; c) varying heart rate, corrected. The correction reduces artefact strength, albeit with a slight change in contrast.

Results: Fig. 2 shows results from a 1D intensity scan with a varying ECG signal with and without corrections and the comparison of intensity variations obtained from profiles. The correction scheme was able to reduce the mean variation in signal strength relative to average level from 15% to 2.5%. Fig. 3 demonstrates the artefacts (b, c) and corrections (d) in a 2D scan and a simulation of single gel phantom tube (T_1 = 765 ms), along with comparison of simulated and measured intensity profiles. Fig. 4 illustrates the reduced fluctuations using the correction scheme in a scan *in vivo*.

Discussion: This novel correction scheme increases the image quality in ECG-triggered IR sequences by reducing the ghosting artefacts due to heart rate variations. However, the choice of the T_1 used for correction calculation is non-trivial and can vary depending on the application. We have chosen the correction T_1 value from the range of T_1 times of the tissue by finding the compromise for a minimal artefact level for all T_1-times. However this can result in a small change in the resulting image contrast (Fig. 4). This can be particularly important in applications in which nulling the signal from a particular tissue type is required. This effect can be reduced by carefully choosing the heart rate for which the corrections are calculated. Overall the method offers a promising way of reducing artefacts that is easy to implement on current scanner hardware.

Reference: [1] He *et al.*, *JMRI* 24: 580-585 (2006).