Generating Quantitative Susceptibility Maps from 3D Interleaved Phase Sensitive Inversion Recovery Data.

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Target audience: Researchers and clinicians interested in iron mapping, susceptibility mapping, and T1-weighted imaging of the human brain.

Purpose: Phase Sensitive Inversion Recovery (PSIR) is a method for generating T1-weighted images with a high contrast to noise ratio. Recent studies have shown that high quality PSIR data can be efficiently acquired at high magnetic field strengths using a 3D interleaved sequence in which two separate Turbo Field Echo (TFE) readouts are applied after each inversion pulse[1,2]. We propose that the phase data associated with the second TFE readout of a 3D interleaved PSIR sequence can be used to form 3D maps of magnetic susceptibility via the recently developed quantitative susceptibility mapping (QSM) technique. In recent years, QSM in the human brain has become an area of intense research due to the sensitivity of susceptibility maps to iron deposits in tissue[3,5]. In this study, we show that, despite the short echo times (TE) associated with the TFE readouts, PSIR phase data has sufficient signal to noise ratio to generate useful QSM data in vivo.

Methods: (Acquisition) MRI data was acquired in vivo from 8 healthy subjects (4 male, 4 female) 25-53 years of age using a 7T Achieva Philips scanner. PSIR data was acquired from each subject using a 3D interleaved PSIR sequence[1,2] with imaging parameters: TI1=780ms (first TFE read out), TI2=2380ms (second TFE readout), shot to shot interval (SSi) =5000ms, flip angle =8°, TE/TR=6/13ms, 0.6mm^3 isotropic resolution, field of view 200x180x120 mm^3, acquisition time 12 minutes. To validate the PSIR-based QSM, data was acquired from each subject using a more traditional long-TE gradient echo sequence[3] with imaging parameters: TR/TE = 150/20 ms, 0.5mm^3 isotropic resolution, field of view = 192x164 x85mm^3, acquisition time 10 minutes. **(Processing)** The PSIR acquisition generates 4 data sets (see Fig.1): magnitude and phase data from the first TFE readout (m_1, p_1), and magnitude and phase data from the second TFE readout (m_2, p_2). A PSIR image, corrected for transmit field inhomogeneities was produced by dividing the polarity restored m_1 by the smoothed sum of m_1 and m_2, as described by Pitoit *et al*.[4]. A TKD method proposed by Schweser *et al*.[5], including filtering and masking steps[5], was applied to m_2 and p_2 to yield a PSIR-based QSM (QSM_{PSIR}). Similar processing was applied to the phase and magnitude data generated using the traditional GE sequence to yield a GE-based QSM (QSM_{GE}). ROI's were drawn in all 8 subjects imaged at 7T in both brain hemispheres on several axial slices of the QSM_{GE} image inside the globus pallidus (GP), putamen (PU), caudate nucleus (CN), internal capsual (IC), pulvinar of the thalamus (PV), the remaining thalamus (TH), and frontal WM (FWM). These regions were chosen as they are known to have a wide range of susceptibility values and exist in a similar axial plane of the brain. Mean susceptibility values were measured in each region on the QSM_{PSIR} and the QSM_{GE} data sets across all eight subjects.

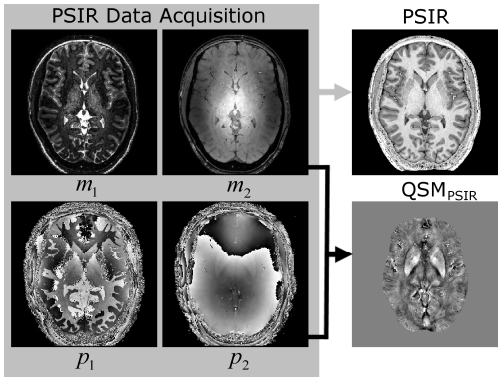

Fig.1 *Representative axial slices showing the acquired PSIR data and the results of PSIR and QSM processing.*

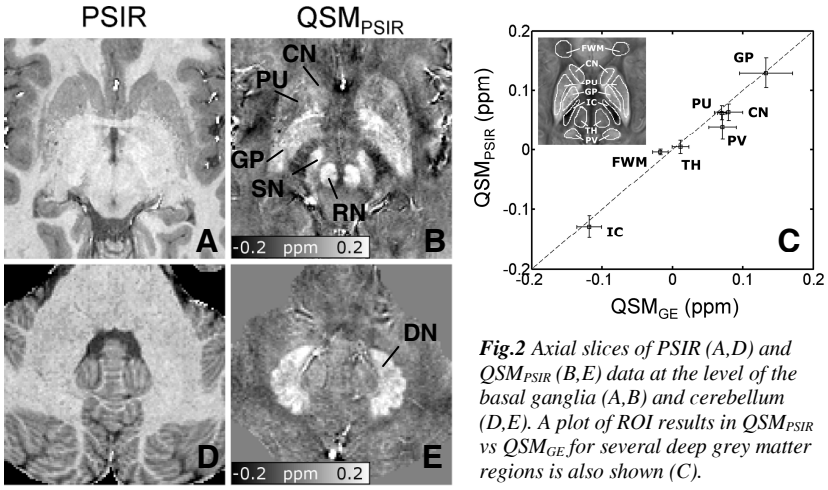

Fig.2 *Axial slices of PSIR (A,D) and QSM_{PSIR} (B,E) data at the level of the basal ganglia (A,B) and cerebellum (D,E). A plot of ROI results in QSM_{PSIR} vs QSM_{GE} for several deep grey matter regions is also shown (C).*

Results: The PSIR data shows excellent tissue contrast between GM, WM, and cerebrospinal fluid (CSF) which appears to be relatively insensitive to any transmit field effects (Fig.2A,D). In the QSM_{PSIR} images, deep grey matter structures are clearly visible as regions of positive susceptibility relative to surrounding tissues (Fig.2B,E). Several well-known deep grey matter regions have been labelled on the QSM_{PSIR} images such as the GP, PU, CN, red nucleus (RN), substantial nigra (SN), and the dentate nucleus (DN). Of these six labelled regions, only the PU and CN are clearly visible in the corresponding PSIR data. The results of the ROI analysis are plotted in Fig.2C. Of the 7 regions investigated only the FWM and PV regions showed significant differences between the QSM_{PSIR} and the QSM_{GE} data across the 8 test subjects.

Discussion: The clustering of the results around the line of identity (dotted line) in Fig.2C suggests a good level of agreement between the QSM_{PSIR} and QSM_{GE} data. This result is encouraging, as it suggests that there is sufficient SNR in the short-TE phase associated with the second TFE readout of the PSIR sequence to yield QSM data with useful quantitative information at 7T. The high level of agreement in the CN, PU, and GP regions is particularly important, as these regions have been shown to have higher susceptibility values in MS patients compared to controls[3].

Conclusions: The results presented in this article demonstrate that T1-weighted anatomical images and iron-sensitive QSM data can be acquired simultaneously from a single 3D interleaved PSIR scan. This methodology should prove useful for studies in which scanning time is limited.

References: 1. Van de Moortele et al., Neuroimage, 2009, 46:432-446. **2.** Marques et al., Neuroimage, 2010, 49:1271-1281. **3.** Al-Radaideh et al., Mult Scler, 2013, 19:896-903.**3.** Pitiot et al., 2013, Proc ISMRM. 0934. **5.** Schweser et al., Neuroimage, 2010, 54:2789-2807.