Intrinsic Field Homogeneity Correction in Fast Spin Echo based Amide Proton Transfer MRI
Jochen Keupp1, and Holger Eggers2
1Philips Research, Hamburg, Germany

Introduction - Amide proton transfer (APT) is a novel technique for MR-based molecular imaging of endogenous cytosolic proteins or peptides [1] and reflects protein concentrations as well as local pH via the exchange rate. Promising clinical applications of APT-MRI are envisioned in oncology (enhanced protein concentrations in tumors [2]) and in neurology (ischemic acidosis in stroke [1]). Detection of amide protons is based on a magnetization transfer (MT) asymmetry analysis with symmetric RF saturation frequency offsets around the water resonance, which is strongly biased in the presence of local magnetic field inhomogeneity δB0 and needs precise correction methods. Separate B0 mapping, as typically used for this purpose, is prone to inaccuracy, since the actual δB0 distribution and f0 (reference value to the water resonance) must not change before/during the actual APT acquisition. B0 mapping integrated within the APT acquisition would be preferable for the precision of B0 correction, for scan time efficiency and for the clinical workflow. Previously, it was proposed to use multi-gradient echo APT acquisitions with intrinsic MT asymmetry analysis [3] B0 mapping and correction [4]. On the other hand, first spin-echo (FSE) and driven equilibrium sequences [5] were shown to provide a superior contrast-to-noise ratio for APT [6]. Thus, intrinsic Dixon-type APT should be translated to FSE sequences. We propose to acquire APT-MRI using an FSE-Dixon-based APT technique and to efficiently derive δB0 by an iterative Dixon reconstruction [7] across different saturation frequency offset images. Feasibility of FSE-Dixon-APT MRI in the human head is demonstrated using a clinical 3T scanner.

Methods - The study was performed on a 3.0T clinical whole-body scanner (Achieva, Philips Healthcare, NL) using a transmit/receive head coil. Acquisition software was modified to shift the timing of the acquisition window (echo-shift ΔTE) and the readout gradient during the scan series, which is different but equivalent to time-shifting of the refocusing pulse as in [3]. The low-power mode of the RF amplifier was enabled to use long saturation pulses [4]. A 2D single-shot FSE sequence with driven-equilibrium refocusing control [6] was used: matrix 128×128, resolution 1.8×1.8×5.0 mm3, TR=4090 ms, TE=4.8 ms, 3 echo-shift variants with water/fat in phase (IP) or out of phase (OP): ΔTE=-1.15 ms, 3.5ppm; 0ms, 3.9ppm; -1.15ms, saturation pulse-train Tsat=2 s (40:50 ms, Sinc-Gaussian shapes), B1rms=2.0 μT, 1/2 minutes total scanning time. From the full dataset (3×7 images), a δB0 map could be calculated for each saturation frequency offset by iterative Dixon reconstruction [7]. Alternatively, a “mixed” δB0 map was calculated by selecting only one echo-shift variant per positive saturation frequency offset (3.1ppm: ΔTE=+1.15ms, 3.5ppm: 0ms, 3.9ppm: -1.15ms), to demonstrate the possibility of a time efficient acquisition. Maps of the asymmetric MT ratio MTRasym=(S[-Δω]-S[+Δω])/S0 were calculated based on δB0 corrected, point-by-point interpolated water-only images S[-Δω] and S[+Δω]. In vivo feasibility was tested in a human volunteer, from whom informed consent was obtained.

Results and Discussion - From the full dataset, water and fat separation could be performed successfully for all 7 saturation frequency offsets, and the δB0 maps obtained were consistent within a standard deviation of 0.015 ppm. An example δB0 map is shown in Fig.1a, water/fat images in Fig.1c/d.e. The “mixed” δB0 map (Fig.1b), obtained from 3 images with different positive saturation offset and varied echo-shift, is very similar. A difference evaluation (Fig.1c) shows an almost spatially constant offset of about 2 Hz, which is negligible for a precise APT field correction. The signal amplitude S0 varies only by a few percent for δω=±3.5±0.4 ppm in brain tissue and typical tumor cases [2]. Furthermore, the δB0 reconstruction is robust to variations of the signal amplitude using the "OP/IP/OP+" echo scheme. Hence, the quality of the iterative Dixon-type δB0 mapping is not compromised by the moderate amplitude variations across positive saturation offsets. Nevertheless, for APT-MRI, negative saturation frequency offsets should be avoided for "mixed" δB0 estimation, because the saturation pulse may cause strong signal variations by partly cancelling the fat signal at -3.4 ppm. MT asymmetry analysis on the water-only images shows a strong offset without δB0 correction (Fig.1g), while the corrected MTRasym is low and homogeneous over the volunteer brain (Fig.1f), for any of the obtained δB0 maps. While 21 images were acquired in this study to analyze the precision, the technique can be implemented with efficient data sampling using only 7 different images (e.g.: +3.1ppmIP, +3.5ppm, +3.9ppm, -3.1, -3.5, -3.9, and S0). With the δB0 information available, water/fat separation may still be obtained for all images e.g. by a single-point Dixon approach [8]. For a stable water/fat separation, the negative frequency offsets and S0 should be acquired in quadrature (90° phase difference between water and fat) in this case.

Conclusion - A precise APT measurement in the human brain is demonstrated on a clinical MRI scanner using FSE-Dixon-APT MRI with intrinsic δB0 correction. δB0 could be precisely obtained from 3 images with different positive frequency offsets and varied echo-shift. This technique may enhance precision in a simplified clinical workflow without extra B0 calibration scans, while maintaining the scan time efficiency of the APT examination.

References

Figure 1: APT measurement obtained in a healthy volunteer using FSE-Dixon based water/fat separation and intrinsic B0 homogeneity correction. Equivalent δB0 maps are obtained from different echo-shifts for a single saturation offset (a) or from “mixed” positive saturation frequency offsets (b) – the difference is uniformly low (c). At each offset, water (d) and fat (e) images are obtained and MTRasym (“APT image”) (f) is interpolated from the water images. Uncorrected MTR images show a strong B0 homogeneity bias (g).

-50...50 Hz
-10...10 Hz
5%...-5%