B_0 insensitive biexponentially weighted ^{23}Na imaging

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PURPOSE

The intracellular sodium concentration is of great interest since it is a potential measure for small changes of the sodium ion homeostasis. Double echo and biexponentially weighted imaging have been proposed as methods to allow a weighting toward intracellular sodium.[1] However, these sequences are based on the generation of a weighted subtraction image and are thus highly influenced by inhomogeneities of the magnetic field. Long echo times used to acquire the second image lead to signal dropouts which highly affect the final subtraction image. For the biexponentially weighted sequence two different pathways contribute to the second image, so destructive interference can also lead to signal. The separate detection of different pathways has been proposed for triple-quantum filtered imaging to avoid destructive interference of the contributing pathways.[2,3] In this study, the pathways of the two pulse sequence have been acquired separately to obtain an intracellular weighted ^{23}Na image which is more robust to variations of the main magnetic field.

METHODS

The pulse sequences were implemented on a 7-Tesla whole-body MR system (Magnetom 7 T, Siemens, Erlangen, Germany). A double-resonant (^{1}H/^{23}Na) birdcage coil (Rapid Biomed GmbH, Würzburg, Germany) was used for the measurements. Sequence diagrams are shown in Fig. 1. Two images are acquired during the two density adapted 3D radial readout gradients[4]. The images are weighted to account for T_2^* relaxation of the cerebrospinal fluid (CSF) and subtracted to generate the intracellular weighted image. The blue and the red gradient select the desired pathways (either the free induction decay (FID) or the spin echo (SE) like pathway).

The experiments have been performed on a phantom consisting of seven small cylinders (inner diameter: 43 mm) mounted concentrically in a bigger cylinder (inner diameter: 190 mm). The small cylinders are filled with 0.9% saline solution dissolved in 1%, 2%, 3%, 4%, 5%, 6% and 7% agar gel. The surrounding cylinder contains pure 0.9% saline solution and thus should be suppressed in the difference image (DIM).

Sequence parameters: TE_1 = 0.55 ms, $TE_2 = \tau$ = 11 ms (TE_2^* = 22 ms), TR = 150 ms, T_{RO} = 10 ms, Δx^3 = (5 mm)^3, projections = 5000, averages = 1, T_A = 12:30 min.

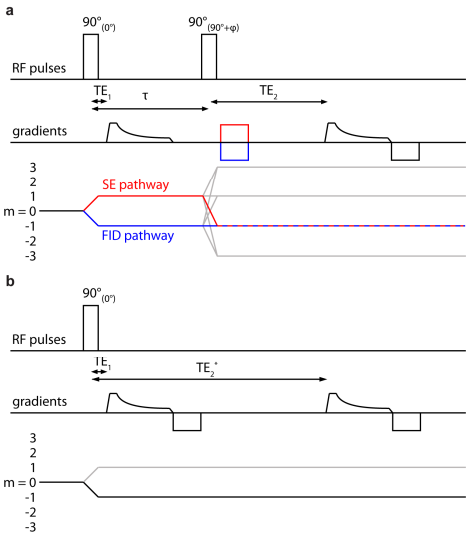

Fig.1: Sequence diagrams for two pulse (2P) (a) and double-echo imaging (b). Both pathways contributing to the second image in the 2P-sequence can be detected separately with refocusing gradients.

RESULTS & DISCUSSION

The different second images and corresponding B_0 field maps are shown in Fig. 2. One slice with minimum field variation and two slices with severe field inhomogeneity are shown. First the SE image is shown which exhibits a smooth signal intensity. In contrast, severe signal dropouts appear in the FID image. However, acquiring both pathways leads to even more signal voids due to destructive interference. The same signal dropout as in the FID image are also present in the second image acquired with the double-echo sequence. And finally, combining the magnitude images of both pathways of the 2P sequence leads to a smooth image with signal voids only in regions with severe off resonance.

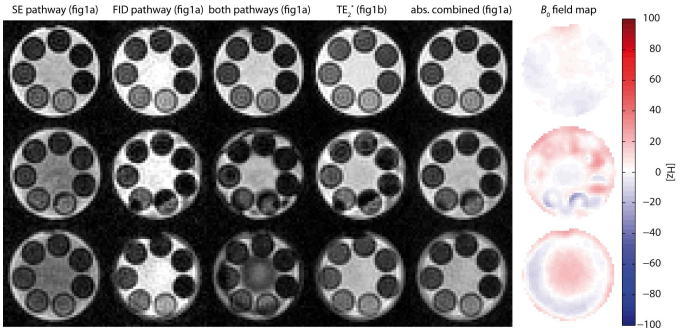

Fig.2: Second acquired image of both sequences. The two pathways of the 2P sequence are shown separately and acquired together. The double echo image, the proposed combination of the pathways of the 2P sequence and the field maps of the slices are also shown.

The difference images of both sequences are compared in Fig. 3. The 2P-DIM shows insufficient suppression of the pure saline solution as was expected considering the images in Fig. 2. The double-echo DIM exhibits less artifacts. The proposed method, where both pathways of the 2P sequence are acquired separately and magnitude images are combined leads to a corrected 2P-DIM image with insufficient suppression of saline solution only in areas with high off resonances. The signal in the small cylinders in the phantom is biexponentially weighted which means the signal is less dependent on relaxation compared to the double-echo DIM. However, due to signal losses introduced by the separate detection of the pathways leads to more noise in the final image (in this example: 1.7, can also be calculated with Eq.[31] in Ref.[1]).

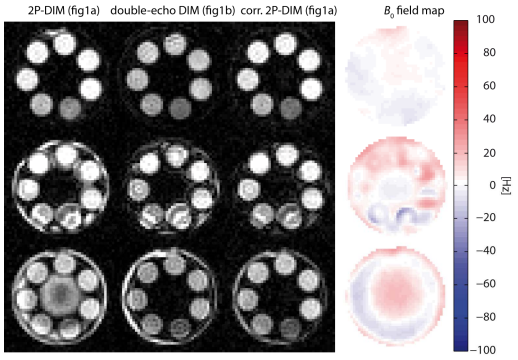

Fig.3: Difference images of the standard 2P sequence, the double echo sequence and the proposed corrected 2P sequence and corresponding field maps.

CONCLUSION

It was shown that acquiring the pathways of the 2P sequence separately leads to a better suppression of the unwanted signal while also providing the biexponentially weighted contrast that shows less relaxation weighting.

REFERENCES [1] Benkhedah et al., J Magn Reson (2014) 240: 67-76, [2] Matthies et al., J Magn Reson (2010) 202: 239-244, [3] Fiege et al., J Magn Reson (2013) 228: 32-36, Magn Reson Med (2009) 62: 1565-1573

ACKNOWLEDGEMENTS Parts of the work were founded by the National Center for Tumor Diseases Heidelberg (NCT) and the Deutsche Forschungsgemeinschaft (DFG) under NA736/2-1.