MR PARAMETER QUANTIFICATION (T1, T2, PD) WITH INTEGRATED FAT WATER SEPARATION USING A MULTI-ECHO - PHASE CYCLED BSSFP-SEQUENCE

Thomas Benkert[1], Martin Ott[1], Riad Ababneh[2], Martin Blaimer[1], Peter Jakob[1,3], and Felix Breuer[1]

[1]*Research Center Magnetic Resonance Bavaria, Würzburg, Bavaria, Germany,* [2]*Yarmouk University, Irbid, Jordan,* [3]*Experimental Physics 5, University Würzburg, Würzburg, Bavaria, Germany*

Target audience: Physicists, clinicians

Purpose: Both fat-water separation and quantitative MR parameter mapping are of strong clinical and research interest. However these methods usually suffer from a long scan time due to the fact, that several separate images at different image contrasts have to be acquired for each of them. Furthermore, they are addressed separately, using different acquisition schemes. Therefore, we propose a new concept for simultaneous fat-water separation and T1, T2 and PD (proton density) mapping in a clinically acceptable scan-time using a single imaging sequence.
Recently it has been shown that mapping of T1, T2, PD and off-resonance frequency can be derived using a phase cycled bSSFP sequence[1]. Phase cycled bSSFP allows for long TRs without being susceptible to off-resonances. This makes a multi-echo readout[2] within each TR possible, enabling simultaneous fat-water separation. One possible application is imaging of the musculoskeletal system, particularly the assessment of articular cartilage.

Methods: Like indicated in Figure 1, we acquired eight different phase cycles with three echoes each. Experiments were performed on a 3.0T clinical scanner with a 4-channel flex coil on a healthy subject's knee. Images from eight phase cycles and three echoes for each cycle were obtained using the described sequence with the following parameters: 2D-acquisition, 192x156 matrix, slice thickness=5mm, TR=8ms, $TE_1/TE_2/TE_3$ = 2.58/4.00/5.42ms, flip angle α=40°, FOV=200x163mm², BW=840Hz/px.

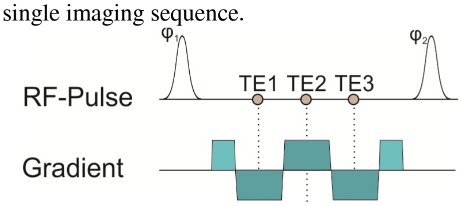

Fig. 1: Multi-echo bSSFP sequence. With this sequence images with different phase cycles φ_i are acquired

The middle echo of the eight phase cycles was fitted onto the bSSFP signal equation[3] to obtain T1, T2, PD and an off-resonance frequency map (not shown). Prior to calculating the fat and water images, the effects caused by the bipolar gradients were accounted for: the phase discrepancy between even and odd echoes was corrected according to Kim et al[4]. Furthermore, a high bandwidth was used to minimize chemical shift artifacts. The corrected echoes can now be processed on different ways: one possibility is to build the complex sum of all phase cycles for each echo followed by the fat-water separation[5] procedure. The resulting fat and water images usually don't show banding artifacts which can result from field inhomogenities. However, in the case of severe off-resonances, residual dark bands can still occur. To overcome this problem, we calculated the Cross-Solution[6] for each echo, using the different phase cycles. This allows for banding-free images, which can then be processed to obtain banding-free fat and water maps. Fat-water separation was performed using the IDEAL-technique in combination with a region-region scheme for fieldmap estimation[7].

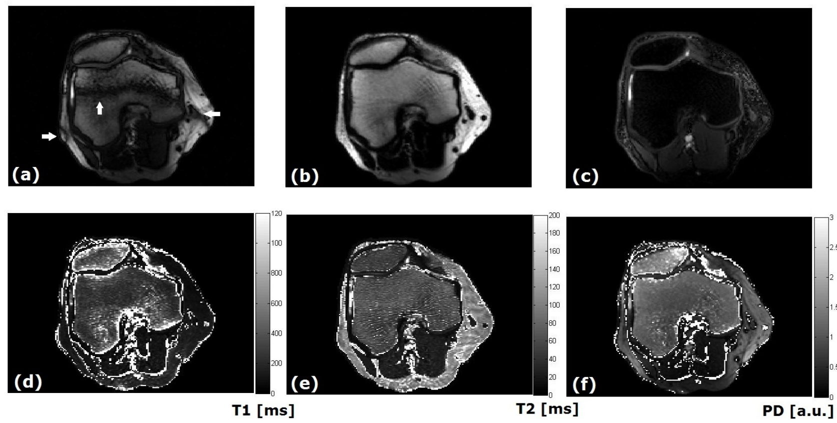

Fig. 2: (a): raw data signal with severe banding artifacts. (b)-(c): separated fat and water using the calculated Cross-Solution for the different echoes. (d)-(f): T1, T2 and PD maps obtained by fitting the different phase cycles to the signal equation.

Results: Figure 2(a) shows one echo of one phase cycled image with strong banding artifacts (indicated by the white arrows). The depicted fat and water images (b)-(c) show good separation and do not suffer from artifacts due to off-resonances. The T1, T2 and PD maps (d)-(f) are also free from these artifacts. The values obtained are comparable to values found in literature.

Discussion: The post processing procedure described earlier is just one of several possibilities. In general, the different images acquired with the sequence (in our case: eight phase cycles and three echoes for each cycle) allow a wide range of extensions: For instance, the field map obtained with the fat-water-separation can be used to improve the results of the fitting procedure to obtain T1, T2 and PD or to achieve comparable results with less phase cycled images, resulting in a shorter acquisition time. Another possibility is to use the field map, which is obtained by fitting of the phase cycled images, for the fat water separation, requiring just two echoes for the separation. Furthermore, it is also possible to extract the MR parameters out of the separated water and fat images thereby potentially overcoming partial volume effects.

Conclusion: The presented approach can serve as a "one-stop shop imaging tool", providing T1, T2 and PD maps (and hence the possibility to generate synthetically every desired contrast) as well as fat-water separated images with just one single sequence. The method is robust in the presence of off-resonances, allowing the utilization of high field strengths. Inaccuracies of the quantification results arising from effects like an imperfect slice profile, B_1-field inhomogeneity etcetera are subject of current research.

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