A Multi-echo Acquisition Method with Reduced Echo Spacing for Robust IDEAL Water-Fat Decomposition at 3T

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Introduction MR imaging with multi-echo GRE (Gradient-Recalled Echo) sequences is emerging as a valuable clinical tool. Recently, there has been interest in combining multi-echo sequences with chemical-shift based multi-point water-fat decomposition methods, such as Dixon and IDEAL [1-3]. Compared to conventional multi-echo multi-TR approaches, multi-echo single-TR Dixon and IDEAL are more efficient and thus particularly valuable in breath-held liver imaging [1]. However, multi-echo sequences also pose a limitation on the minimum achievable echo spacing. As a result, imaging parameters such as bandwidth and imaging matrices often need to be compromised in order to achieve the required water-fat phase shifts between the echoes: π for Dixon techniques [2] and 2π/3 for 3-pt IDEAL methods [4]. We recently introduced the concept of imaging liver disease using a 6-echo acquisition, which allows simultaneous water-fat decomposition and R2* mapping [5]. For a 6-pt IDEAL reconstruction, the water-fat phase shift no longer needs to be 2π/3 to achieve optimal noise performance. This relaxes the echo spacing constraint to some extent. However, the minimum water-fat phase shift often exceeds 2π at 3T, making robust water-fat separation much more challenging. In this work, we propose the use of a multi-echo 2-TR hybrid approach. The echo spacing is effectively reduced to half of the minimum echo spacing in a multi-echo single-TR acquisition. As a result, fast and reliable water-fat decomposition with simultaneous R2* mapping is made possible without compromising imaging parameters, particularly at 3T.

Theory In this work, the echo spacing is presented in the format of the water-fat phase shift for convenience. An echo spacing close to 2π results in an ill-conditioned and thus noisy water-fat decomposition, with all source signals having approximately the same water-fat phase shifts. We studied the noise performance of the 6-pt IDEAL and found that the SNR of the decomposed images is significantly reduced from the optimal value (NSA=6) when the echo spacing is in the range of 2π±0.4π. Furthermore, IDEAL uses an iterative method to estimate the field map, or Bo field inhomogeneity map, on a pixel-by-pixel basis. An initial guess of the field map needs to be provided for each pixel. The robustness of the IDEAL reconstruction largely depends on the accuracy of this initial guess, as the iteration may converge to local minima with a remote initial guess, leading to water-fat swap. The locations of the local minima are strongly correlated with the echo times. Therefore, the robustness of a set of echo times can be measured by the size of the tolerance zone, defined as the range of the initial guesses that will converge to the correct solution. Figure 1 shows the cost function curves for two sets of echo times. As indicated, the tolerance zone for the echo times with an echo spacing of 2.7π is only ±52Hz, allowing ample risk of converging to a local minimum. In contrast, an echo spacing of 1.3π results in a doubled tolerance zone of ±105Hz. In general, a smaller echo spacing results in a bigger tolerance zone. It was found that the echo spacing should be less than 1.4π to avoid water-fat swap for our IDEAL implementation.

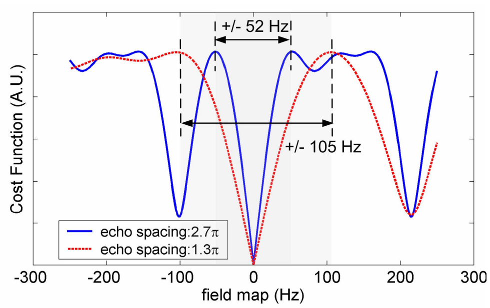

Figure 1 (left): IDEAL cost functions for two sets of echo times. The purpose of the IDEAL iteration is to search for the minimum (0Hz in this example) of the cost function curves. To avoid converging to local minima, the initial guess needs to be within the marked tolerance zone. In general, a shorter echo spacing is associated with a bigger tolerance zone, thus offering more reliable decomposition.

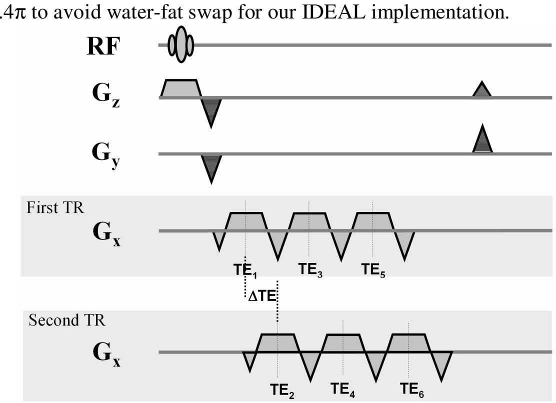

Figure 2: The sequence diagram of the multi-echo 2-TR GRE sequence to reduce ΔTE. The echo times of the second TR are shifted relative to those in the first TR, effectively reducing the ΔTE to half.

Methods Figure 2 shows the sequence diagram of the multi-echo 2-TR strategy. Six echoes are acquired in two TRs. The echo times of the second TR are shifted from the first TR to achieve an effective echo spacing that is half that in a single-TR acquisition. In-vivo abdominal scans were performed. Both 6-echo one-TR and 6-echo two-TR scans were performed using identical imaging parameters except for the expected changes in TR and echo times. Image quality and scan time were compared. All scanning was approved by our IRB and informed consent was obtained.

Results Representative results from 3T scanning (General Electric Signa® HD scanner, GE Healthcare, Waukesha, WI) are shown in Figure 3. Imaging parameters include: TE_1=1.6ms (1.3π), ΔTE=1.3ms (1.1π), 384x224 imaging matrix, 37x30cm FOV, TR=10.6ms, BW=±167kHz, 16 locations, 4mm slice thickness and an 8-channel cardiac coil. The scan was accelerated using an efficient autocalibrating parallel imaging technique with a reduction factor of 2 [6], leading to a 35s breath-hold. As can be seen, uniform water fat decomposition is achieved. Six-echo IDEAL provides water and fat images with high SNR close to that from a 6-NEX acquisition. Simultaneous R2* mapping is also possible. No elevated R2* level is seen, suggesting no presence of iron in the liver. If limiting the six echoes to one TR, the echo spacing needs to be extended from the minimum value of 2.2π to 2.4π to avoid a noisy decomposition. Water-fat swap was observed with the echo spacing of 2.4π. The scan time was slightly shorter with a 29s breath-hold.

Discussion and Conclusion Multi-point water-fat decomposition methods require images collected at different echo times. Acquiring one echo in one TR allows more flexible prescriptions while collecting all echoes in one TR is faster and more efficient. The multi-echo single-TR approach is more challenging at 3T than 1.5T since achievable echo times result in larger water-fat phase shifts and increase risk of an ill-conditioned decomposition (echo spacing close to 2π) and water-fat swaps. In this work, a multi-echo 2-TR sequence is used to reduce the effective echo spacing. This approach allows the maximum number of echoes to be acquired per TR while still achieving the desired imaging parameters and robust water-fat separation. A shorter echo spacing may also help R2* mapping when fitting data from a short T2*. The sequence increases scan time slightly compared to a single-TR acquisition. The 35s breath-hold in the high resolution scan shown may not be feasible in all clinical situations. Higher parallel imaging accelerations would help to reduce the breath-hold time. In conclusion, the multi-echo 2-TR sequence offers fast and reliable water-fat decomposition at 3T without compromising imaging parameters.

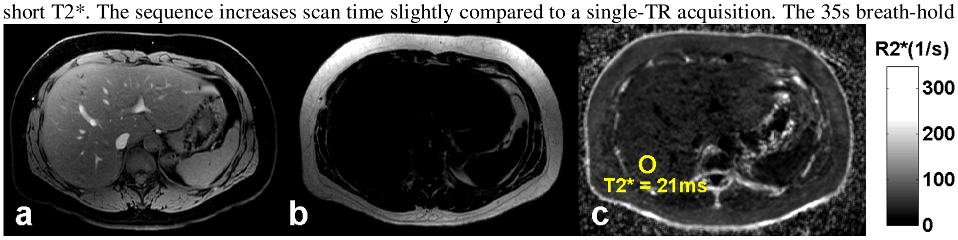

Figure 3: In-vivo results from multi-echo 2-TR abdominal scanning at 3T: water (a) and fat (b) images from 6-pt IDEAL reconstruction, and the R2* map (c) from 6-pt T2*-IDEAL reconstruction. The echo spacing was 1.3ms (1.1π). Uniform water-fat decomposition was achieved.

References

[1]. Ma et al. MRM 2004, 52:415-419.
[2]. Wieben et al. ISMRM 2005:2386
[3]. Reeder et al. ISMRM 2006:632.
[4]. Reeder et al. MRM. 2004; 51:35-45
[5]. Yu et al. ISMRM 2006:624.
[6]. Brau et al. ISMRM 2006:2462