Two-Point Dixon with Single Species Domination Assumption

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TARGET AUDIENCE: MR physicists and clinicians who are interested in water-fat imaging.

PURPOSE: 2-pt Dixon water-fat separation is often used with T1-weighted imaging to eliminate bright fat signal and improve the image contrast. Conventional 2-pt Dixon method [1,2] requires the input source echo images to be close to the ideal Out-Of-Phase (OOP)and In-Phase (IP). Theoretically, this is true when the water/fat ratio of the pixel data is unknown. In this work, we made the assumption that most in-vivo pixel data are either very water or fat-dominant. With this single species domination assumption, it is experimentally demonstrated that robust water/fat separation can still be achieved using the same OOP/IP signal model, even when the two TEs deviate from the ideal OOP-IP combination substantially.

THEORY: When the input TEs are exactly IP and OOP, the field map can be calculated by taking the phase difference of the two echo images, as shown in Eq. 1, regardless of water/fat ratio. For water-dominant/water-only pixel, the field map can be also calculated as the phase difference between the two echoes, as shown in Eq. 2, regardless of the input TEs. For fat-dominant pixels, the field map will have two components: one is chemical shift induced (i.e. water-fat frequency difference, referred to as φ_{CS}) and the other one is not (e.g. B0 inhomogeneity, referred to as φ_{nonCS}). From this standpoint, two important properties can be noted: 1) TE for the frist echo is relatively less important, with the single species domination assumption. 2) as long as φ_{nonCS} is not too big to cause swap (theoretical threshold of 90 deg), it will not cause water-fat swap when region growing pixel is crossing water-fat interface.

METHODS: A healthy volunteer was scanned on a clinical 3T scanner (MR750, GE Healthcare, Waukesha, WI, U.S.A.), under an approved IRB protocol. Two sets of experiments were conducted. In the first experiment, the first echo time (TE_1) was fixed at OOP, and the echo spacing (ESP) was increased gradually by delaying the second echo time (TE_2). In the second experiment, the ESP was kept fixed at 180 degree, and both TE_1 and TE_2 was increased gradually. The two complex echo images were used for a 2-point Dixon water-fat separation algorithm [1,2], with the assumption that the first and second echo images are always OOP and IP, respectively, regardless of the actual TE_1 and TE_2.

$S_1 = \|W - F\|e^{i(\varphi_0 - \varphi)}$ $S_2 = (W + F)e^{i\varphi_0}$ $\varphi = \arg(S_2 \cdot S_1^*)$ or $\varphi = \pi + \arg(S_2 \cdot S_1^*)$	Eq. 1: IP-OOP input, no assumption about water/fat ratio
$S_1 \approx We^{i(\varphi_2 - \varphi)}$ $S_2 \approx We^{i\varphi_2}$ $\varphi = \arg(S_2 \cdot S_1^*)$	Eq. 2: Water-dominant pixels
$S_1 \approx Fe^{i(\varphi_2 - \varphi_{CS} - \varphi_{nonCS})} = Fe^{i(\varphi_2 - \varphi)}$ $S_2 \approx Fe^{i\varphi_2}$ $\varphi = \varphi_{CS} + \varphi_{nonCS} = \arg(S_2 \cdot S_1^*)$	Eq. 3: Fat-dominant pixels. Field map φ has chemical-shift (CS) and non-chemical-shift components.

RESULTS: Figure 1 shows the results from the two experiments. In the first experiment, robust water-fat separation is still accomplished when ESP is up to 180+90 degree (Fig. 1b-d). When separation fails when ESP is 180+120 degree (Fig. 1e), which matches what the theory predicts. In the second experiment, robust water-fat separation is achieved for all TE_1 ranging from 180 degree to 180+120 degree (Fig. 1f-i). When TE_1 deviates from the ideal 180 degree, such as 180+120 degree, grayish fat signal can be observed in the water images (Fig. 1i).

DISCUSSION AND CONCLUSION: In this work, it is shown experimentally that, robust water-fat separation can be achieved with the assumed OOP/IP signal model even when the two TEs deviate substantially from the ideal OOP/OP combination. From the theoretical analysis with a single species domination assumption, successful water-fat separation can be achieved as long as echo spacing is less than 180+90 degree. The separation is rather in-sensitive to actual first echo time. However, when TE_1 is too long, grayish fat signal is observed. This is likely to due to the absence of multi-peak modeling of fat and the actual echo times [3,4], as well as other effects, such as T_2* decay [5]. Further image quality assessment is needed to investigate the impact of this assumption for various clinical applications.

REFERENCES: [1] Ma, MRM, 52:415 (2004) [2] Ma et al., MRM, 60:1250 (2008) [3] Yu et al., MRM, 60:1122 (2008) [4] Eggers et al., MRM, 65:96 (2011) [5] Yu, et al., JMRI, 26:1153 (2007)

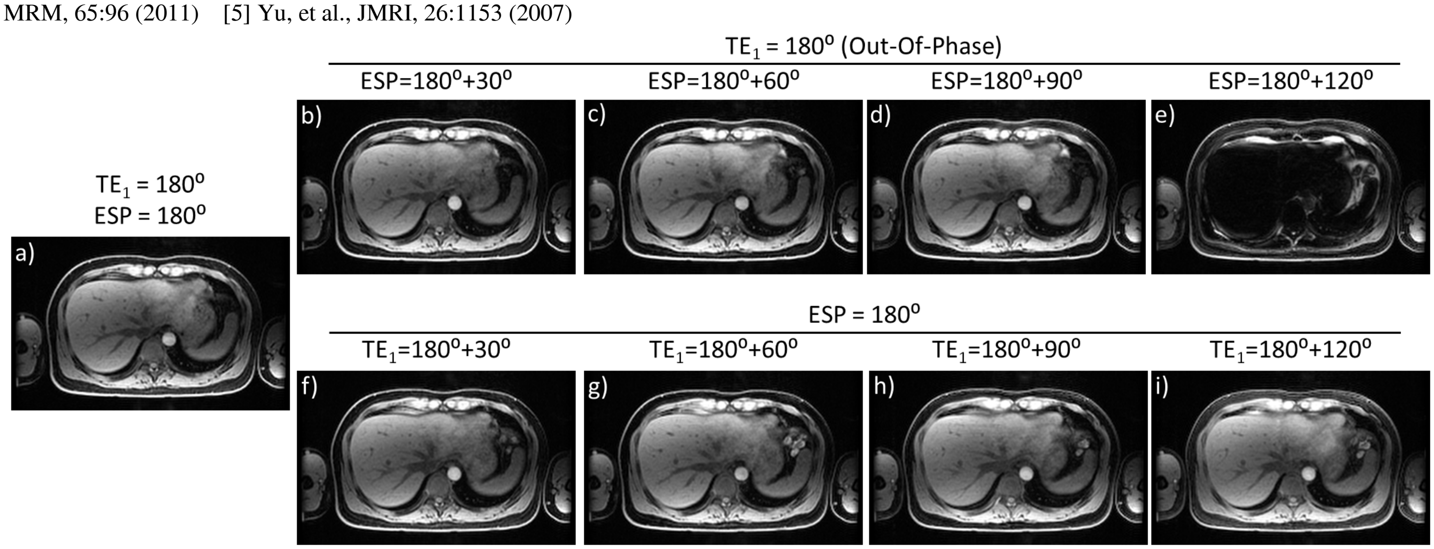

Figure 1. Water images separated from various TE_1/ESP combinations, using a conventional 2-pt Dixon method, which assumes the input echo images are OOP and IP, respectively. Echo spacing has direct impact on the robustness of the separation.