Desperately Seeking: Non-Balanced Steady State Free Precession Fluid Signal

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Introduction. Musculoskeletal (MSK) imaging benefits particularly from improved image quality, contrast, and resolution at higher field strengths, as higher resolution may improve diagnostic accuracy and confidence. Notably 3D steady state free precession (SSFP) sequences have gained increased interest at high fields, since they offer high SNR and short acquisition times and are thus ideal candidates to explore morphologic and functional MSK imaging. Double echo steady state (DESS) sequences offer a high contrast between cartilage and synovial fluid and thus have gained increased interest for MSK imaging (1,2). Here, we resolve the reason for a prominent loss of contrast between fluid and tissues, observed in high resolution DESS imaging between joint fluid and cartilage (3), but being inherent in all non-balanced SSFP sequences. In clinical routine, 3D SSFP scans are frequently acquired with high anisotropic resolution, typically featuring a high in-plane (~ 0.3x0.3mm), but low through plane (~ 2.0mm) resolution (4,5). We will show that for such anisotropic scans the contrast between fluids and tissues can be almost completely restored using an alternative dephasing concept.

Theory. Generally, gradient spoiling as applied in non-balanced SSFP requires a dephasing of 2π/voxel, which relates to the voxel dimension (i.e., resolution) according to

$$G\tau = 1/(42.6\times\text{resolution})\ [\text{mT}\cdot\text{m}^{-1}\cdot\text{msec}] \qquad [1]$$

Typically, spin dephasing is induced along the readout direction (as with DESS sequences, see Fig. 1). It is important to note that fluids have exceptional low relaxation rates that lead to very long persistence times of transverse and longitudinal magnetization paths. As a result, fluids show a considerable sensitivity to diffusion even for low dephasing moments ($G\tau$). As a result, a prominent loss of signal is expected for fluids with increasing resolution (see Eq. [1]). Thus, spin dephasing should preferentially be induced along the lowest resolution direction, as exemplarily displayed in Fig. 1 for DESS sequences, in order to avoid prominent diffusion effects for fluids.

Materials & Methods. A DESS sequence with minimal dephasing, termed "rephased" DESS from the rephasing of readout gradients, was implemented on a common clinical 3T scanner. In-vitro and in-vivo 3D DESS imaging (16 slices with 2mm slice thickness and 0.3x0.3mm^2 inplane resolution) was performed with water selective excitation pulses of 25°. A bandwidth of 299Hz/pixel was used for the rephased and 193Hz/pixel for the common DESS sequence yielding for both DESS variants a TR of 16msec (rephasing of the readout gradient typically prolongs the common DESS by only about 2msec).

Results & Discussion. Results from simulations were confirmed by measurements on aqueous probes (see Fig. 2). As expected, a prominent loss of signal is observed for the fluid signal with increasing resolution: Typically, signal loss for common DESS sequences starts at 1mm and reaches the level of tissues for resolutions exceeding 0.3mm. Anisotropic 3D DESS scans, however, can be performed with high in-plane resolution and high tissue-fluid contrast using rephased DESS, as exemplarily demonstrated with coronal and transversal MSK scans of the knee joint at 3T. This is in contrast to common DESS imaging, where the contrast between joint fluid and cartilage is almost completely lost from diffusion due to the considerably increased spin dephasing. Moreover, from the considerably reduced dephasing moments with rephased as compared to common DESS sequences, sensitivity to bulk motion is substantially reduced.

Conclusion. For anisotropic DESS scans, the high contrast between joint fluids and cartilage can be restored using low spin dephasing moments, as typically offered along the direction of slice selection. It is, however, evident that the same principle applies to all types of non-balanced SSFP sequences.

References. (1) Bruder H et al. MRM 1988; 7: 3542. (2) Hardy PA et al. JMRI 1996; 6: 329. (3) Friedrich KM et al. Eur. J. Radiol. 2010; in press. (4) Reeder SB et al. AJR 2002; 180: 357. (5) Duc SR et al. Radiology 2007; 245(1): 216 (6) Gold GE et al. AJR 2004; 183: 343.

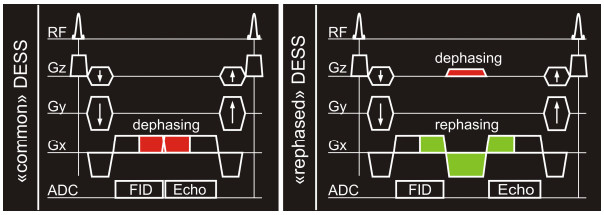

Figure 1: (left) The common 3D DESS sequence separates the S^+ (FID) and the S^- (Echo) paths through an extended unbalanced readout gradient (1). (right) The rephased DESS rewinds the readout gradient and induces a separation of the echoes along the direction of lowest resolution (which is typically along the slice selection).

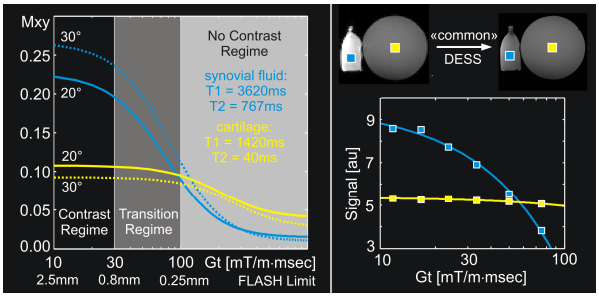

Figure 2: (left) DESS signal for synovial fluid and cartilage as a function of the resolution-related spin dephasing (see Eq. [1]). A prominent signal loss is predicted for fluids with spin dephasing and thus contrast between fluids and tissues can be lost depending on the resolution used. (Simulation parameters: TR = 16msec, D = 1.5 μm^2/msec (cartilage) and D = 2.5 μm^2/msec (synovial fluid), relaxation times were taken from Ref. (6)). (right) In-vitro scans confirmed the predicted dependency and sensitivity on dephasing moments and thus resolution (bottle with H_2O: T_1 ~ 3sec, T_2 ~ 2sec; sphere: 0.25mM MnCl2: T_1= 450msec, T_2 = 50msec).

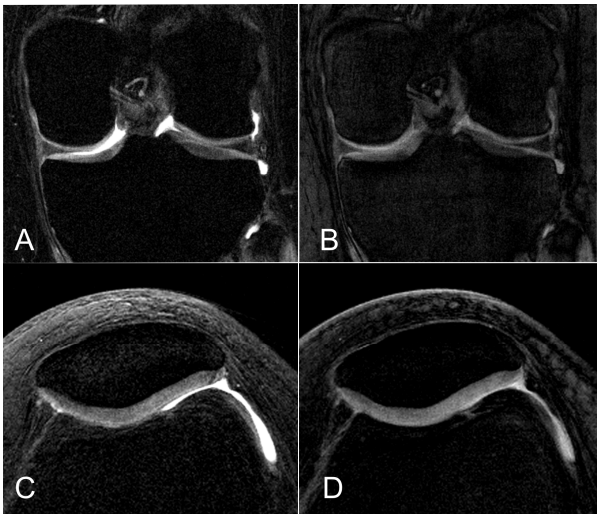

Figure 3: Comparison between rephased (A,C) and common (B,D) DESS for high-resolution coronal and transversal cartilage imaging in the knee joint. Contrast between joint fluid and cartilage is restored using rephased DESS, whereas a considerable loss of signal from fluids is observed using the common DESS approach.