Self Weighted Combination of SSFP Echoes within a Double Echo Steady State (DESS) Sequence

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Introduction: Orthopaedic MR imaging needs high resolution and high tissue contrast; 3D sequences are established to fulfill both demands. To keep the measurement time sufficiently short, rf spoiled gradient echo based sequences with short TR and TE time reveal only a proton density to T_1 contrast. T_2 weighted 3D imaging is difficult to achieve with fast gradient echo sequences. A T_2w DEFT based scheme is not efficient because of the four rf pulse arrangement to retain the transverse magnetization [1]. Tendency is to generate an isotropic T_2w 3D data set to be sensitive to very small defects e.g. a meniscus fissure, but this accompanies with a low S\N ratio. With help of the two Steady State Free Precession (SSFP) signals S+ (FISP=F) and S- (PSIF=P) simultaneous acquired in an constant readout gradient one could solve this problem [2]. The sequence was termed **D**ouble **E**cho **S**teady **S**tate (DESS), here both signals are added into one resulting diagnostic image with enhanced T_2 weight [3]. Because of the uncorrelated noise in both data sets the SNR improvement is $\approx \sqrt{2}$ for pure fluid. These signals with their quite different tissue contrast allow a flexible data handling, therefore the contrast to noise ratio could be improved further.

Method: The basic idea can be described as follows: The algorithm keeps the interesting T_2w tissue contrast of the PSIF image and suppresses the low signal regions according to the P/F ratio. This ratio is controlled via the exponent $\kappa > 1$ and the weighting factor $\lambda > 1$. To ensure that all images of the 3D set are comparable, the global maximum value of F has to be used :

sw_DESS ~ F + λ (P / F_{max})$^{\kappa}$ P ; the image calculation is performed pixel wise. The expression resembles to the expansion of the sum of squares formula: F + ½ (P/F) P + ... but with help of the two additional parameters one gain the enlarged flexibility to enhance the essential contrast between cartilage and synovial fluid. The new algorithm needs no interactive thresholding or clipping values, therefore a smooth signal contribution from the S- signal to the S+ signal is realized with increasing T_2 values. As a by-product of this data combination the background noise is reduced by $\sqrt{2}$. To illustrate the behaviour of the signals at low T_2 values the expressions: $F = f \exp(-TE_1/T_2)$ and $P = p \exp(-TE_2/T_2)$ are plotted in Fig.1. The ssfp signals f and p are calculated and multiplied with the T_2 weighting factors accordingly [4]. In the region of long T_2 values the plain signal addition leads to a SNR gain of $\approx \sqrt{2}$, whereas for short T_2 values the SNR loss is $\approx \sqrt{2}/2$. The weighting function (dotted curve) leaves this region untouched for the sw-DESS image calculation, leading therefore to the full SNR.
MRI was performed on a standard 1.5T clinical scanner using a transmit/receive knee coil. Typical sequence parameter were TR = 13 ms, TE_1 = 4 ms, TE_2 = 2TR - TE_1 = 22 ms, α = 40 deg., BW = 200 Hz/pix., FoV = 150 mm, slice thickness = 1.5 mm.

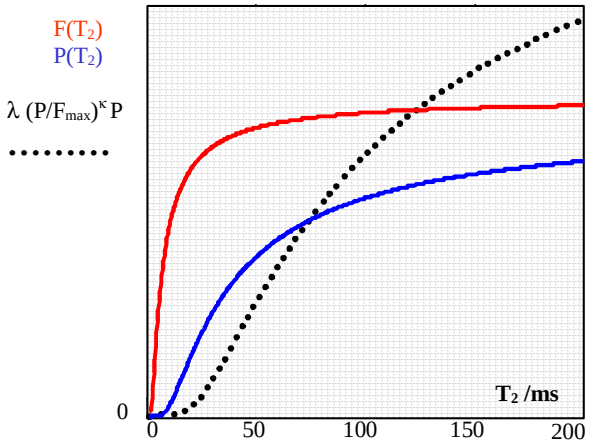

Fig.1 T_2 dependence of **$F(T_2)$** , **$P(T_2)$** and the self weighting function **$\lambda\ (P/F_{max})^{\kappa}\ P$** ; here with κ = 2, λ = 1.5. SSFP signal simulation with TR = 13 ms, α = 90°, T_1 = 1600 and T_2 = 800 ms

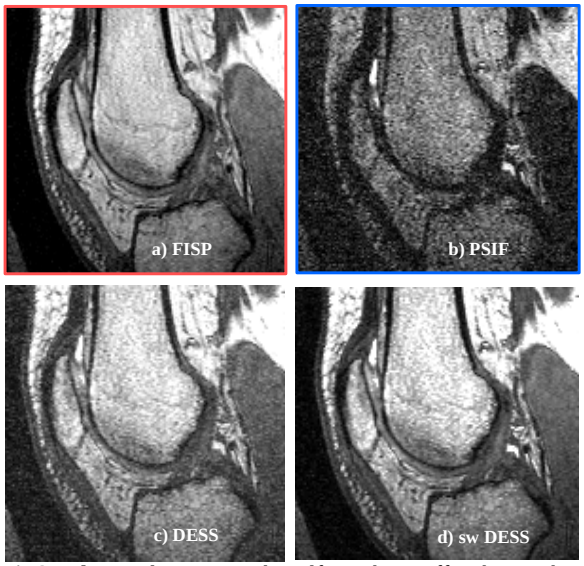

Fig.2 a-d To demonstrate the self weighting effect better, the very low SNR at **Bo = 0.2T** of one thin slice of a 3D data set is depicted. Compared to the simple addition in the DESS scheme (c), the higher SNR in the muscle **and** the better fluid contrast are easy to recognize **as well** as the reduced background signal in the sw-DESS image (d).

Results and Discussion: The comparison of a simple addition scheme within a DESS sequence with the new sw-DESS post-processing method is shown in Fig. 2c and 2d. The synovial fluid is much more clearly depicted in sw-DESS compared to the signal addition of F and P. Especially the muscle- and cartilage homogeneity is improved due to the non-contribution of the very noisy PSIF signal to the composed image. Due to the small T_1/T_2 ratio of about 4 of fat, the ssfp signal is rather strong in both images and is according to the weighting function further enhanced. Therefore for most orthopaedic applications, fat sat or better a water excitation pulse should be preferred. Compared to a true FISP based sequence the DESS scheme is completely inert against field inhomogeneities leading in balanced SSFP sequences to the known off resonance banding artifacts. The disadvantage is the inherent motion sensitivity of both SSFP signals, because of the non-vanishing zero and first moment at the TR time; since orthopaedics is a key application of DESS this is not a relevant issue. Further effort in evaluating the weighting parameter κ and λ has to be made.

Conclusion: We propose a simple, but effective algorithm to improve significantly image contrast, to reduce noise and to suppress the background signal of a sw-DESS image. The inherent signal loss of the PSIF sequence part due to inherent diffusion effects accompanied at very high resolution imaging is overcompensated by using this weighting function.

References:

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