Comparison of Radially Sampled fbSSFP Sequences for Direct ^{31}P MRI

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Target Audience: Scientists and physicians interested in the field of non-proton MRI.

Purpose: Phosphorus (^{31}P) can be found in biomolecules in the human body. Especially phosphocreatine (PCr) plays a crucial role in physiological processes such as the energy metabolism. However, in comparison to hydrogen (^{1}H) the *in vivo* MR signal of ^{31}P is four orders of magnitude smaller. Due to the distinct chemical shift of ^{31}P molecules, frequency selective excitation may be used to differentiate various metabolites [1,2]. In human calf muscle tissue PCr features a concentration of ~30 mM [3], and relaxation times of T_1=*4* s, T_2=*0.2* s [4]. To investigate the SNR performance at a short TE and several contrasts, this work focuses on different 3D radial density-adapted sampling schemes [5] that were combined with a fully balanced Steady State Free Precision (fbSSFP) sequence.

Methods: ^{31}P MRI was conducted on a 7 T whole body MR system (Magnetom 7 T, Siemens Healthcare) using a double-resonant (^{31}P/^{1}H) quadrature birdcage coil (Rapid Biomed GmbH). The calf muscle of two healthy volunteers was examined. Frequency selective excitation was achieved by a Gaussian RF pulse with a bandwidth of 3.5 ppm full width at half maximum (FWHM). To determine the required bandwidth a spatially non-selective Free Induction Decay (FID) sequence (*TR=1500* ms, *TE=0.185* ms, *α=35°*, 100 averages) was performed prior to the measurements (cf. Fig. 3). We implemented three different (cf. Fig. 1) radially sampled and density-adapted 3D ^{31}P fbSSFP sequences (TR_{G1}=*6.36* ms, TR_{G2}=*7.21* ms, TR_{G3}=*9.54* ms, *TE=2.34* ms, *α=30°*, TA_1=*10* min, *BW=1000* Hz/px, 1000 projections, G_0=*3.7* mT/m, t_0=*0.5* ms, 1 cm isotropic resolution, 95 averages$_{G1}$, 84 av$_{G2}$, 63 av$_{G3}$). Here, the RO_1 corresponds to all gradient schemes, RO_{2a} only to G_2 and RO_{2b} as well as RO_3 to G_3. In order to reach a high SNR the absolute values of the acquisitions from each contrast (cf. Fig. 3) were summed up. A Hamming filter was used in order to reduce Gibbs ringing and to increase the SNR. Furthermore, the acquisitions were resampled applying zero filling in all directions. To represent the anatomy of the calf, ^{1}H Fast Low Angle Shot (FLASH) images (*TR=8.1* ms, *TE=4.9* ms, *α=10°*, *TA=6* min, *BW=500* Hz/px, 1 mm isotropic resolution) are displayed in the background (cf. Fig. 4).

Results and Discussion: The radial sampling schemes feature shorter echo times for their first contrast, which corresponds to a lower T_2 decay. Furthermore, additional contrasts were acquired applying G_2 and G_3 (cf. Fig. 3). The SNR of the first contrast (38) is four times higher than the SNR of the second echo (9), which proceeds at *TE=4.87* ms. Summing up those signals lead to an SNR of 45 (cf. Fig. 4B). PCr can mainly be found in muscle tissue excluding fat and bones. In comparison to the other sampling schemes, G_2 performs superior, although less averages can be acquired compared to G_1 and less contrasts are acquired compared to G_3. Even though the sequence with the elaborate G_3 gradient scheme leads to the lowest SNR in this case, it might be useful for sequences, where long repetition times are required.

Conclusion and Outlook: In this work, ^{31}P/^{1}H images of the human calf were examined applying several fbSSFP sequences. The highest SNR of 45 was achieved for a positive and negative radially sampled and density adapted gradient acquiring two contrasts. In the next step, we will combine our method with iterative reconstruction techniques [6], and further investigate the SNR gain by applying NOE pulses [7].

References: [1] Parasoglou et al, Magn Reson Med (2013) 70:1619–1625; [2] Lu et al, Magn Reson Med (2013) 69:538-544; [3] Kemp et al, NMR Biomed (2007) 20:555-565; [4] Bogner et al, Magn Reson Med (2009) 62:574-582; [5] Nagel et al, Magn Reson Med (2009) 62:1565-1573; [6] Gnahm et al, Magn Reson Med (2014) 71:1720-1732; [7] Rink et al, Proc ISMRM (2014) 22, 3165.

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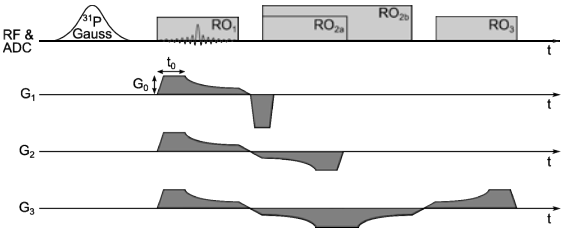

Fig. 1: Radially sampled and density adapted fbSSFP sequence diagrams for different gradient schemes G_x.

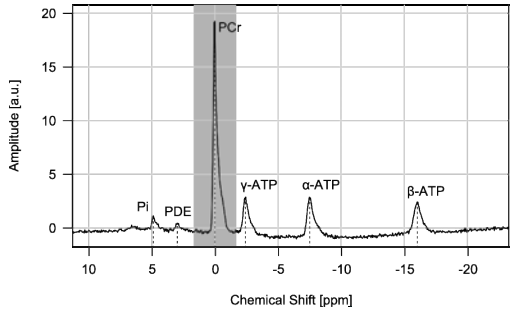

Fig. 2: ^{31}P spectrum of the human calf muscle examined with an FID sequence. The grey marked area indicates the selective excitation pulse used in the ^{31}P fbSSFP sequence.

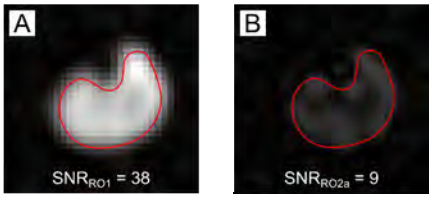

Fig. 3: PCr images of transversal slices of the calf muscle from a healthy volunteer acquired with sampling scheme G_2. (A) Reconstruction from RO_1, (B) RO_{2a}. The red marked area indicates a representative region of interest (ROI) used to determine the SNR in muscle tissue.

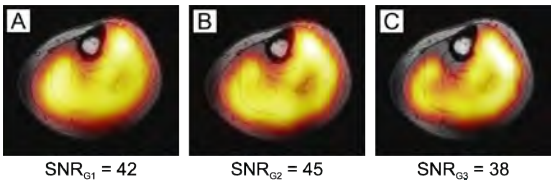

Fig. 4: Transversal slices of the calf muscle from a healthy volunteer. Anatomical information is represented by a ^{1}H FLASH image. In the overlay, the PCr image is superimposed in colorscale. (A) Radial sampling scheme G_1, (B) G_2, and (C) G_3.