Increase in SNR of 370 % for 31P MR spectroscopy by adiabatic multi-echo polarization transfer and adiabatic multi-echo direct detection in one repetition time

Wybe JM van der Kemp, Vincent O Boer, Peter R Luijten, and Dennis WJ Klomp

Radiology, UMC Utrecht, Utrecht, Netherlands

Introduction

Phosphomonooesters (PME) and phosphodiesters (PDE) have shown clinical potential to be used as biomarkers in oncological and degenerative diseases. Direct \( ^{31}P \) measurement of these metabolites in vivo is hampered by an intrinsic low sensitivity. SNR enhancement for PME and PDE can be obtained by polarization transfer techniques, for instance by an adiabatic BINEPT i.e. a BINEPT. We have shown before that direct detection of \( ^{31}P \) can be combined with polarization transfer in the same scan time without compromising the polarization transfer signal, since a different pool of spins is observed. However, the direct detection signal is hampered by the polarization transfer sequence because it contains a 180 pulse on the \( ^{31}P \) channel that inverts the z-magnetization of the \( ^{31}P \) spins, i.e. it makes the direct detection part an inversion recovery sequence. However, this effect can be minimized by doing multi-echo polarization transfer with an even number of 180 pulses on the \( ^{31}P \) channel as we will show here. Moreover, recently we demonstrated that adiabatic multi-echo spectroscopic imaging (AMESING) can boost SNR even further, particularly in tissues with short T2 like in the breast. In this work we acquire practically all signals possible, coming from both \(^1\)H and \(^{31}P \) pools in the detection of phospholipid metabolites: we capture the signal of the BINEPT, as well as adding an even number of refocusing pulses to capture signal with long T2’s, without distorting the \(^{31}P \) pool. In addition, within the same TR we detect the direct \(^{31}P \) pool multiple refocusing, all at the optimal TR of 1.2 times the T2 of the \(^{31}P \) spins. The combined sequence that we propose (BINEPT-ME-AMESING) is depicted in Fig. 1. Using phantom measurements we demonstrate that multi-echo direct \(^{31}P \) detection can be merged into a BINEPT multi-echo sequence without adversely affecting the SNR of polarization transfer or direct detection. In addition, we demonstrate its application in the detection of very low concentrations of PME in the healthy human breast.

Experimental

The BINEPT-ME-AMESING sequence was tested on a spherical phantom containing aqueous phosphoethanolamine (PE) phosphocholine (PC), inorganic phosphate (Pi) and glycerophosphocholine (GPC). For comparison a fully Ti-relaxed \(^{31}P \) MRS spectrum was measured and \(^{31}P \) spectra using the AMESING sequence without the BINEPT-ME were acquired. The sequence was subsequently used for measuring \(^{31}P \) spectra in the breast of three healthy female volunteers. All measurements were performed with a whole body 7 Tesla MR system (Philips, Cleveland, USA) using a home-build dual-tuned coil.

Results and discussion

The phantom measurements are shown in Fig. 2 for the BINEPT-ME-AMESING and the AMESING sequences. Note that the BINEPT spectrum of the J-coupled metabolites corresponds well to the fully Ti relaxed direct detection inlay spectrum (AHP TR = 25 s) shown in Fig. 2a. The small Pi peak is because of pulse imperfection of the segmented BIR-4 0 pulse on the \(^{31}P \) channel and not using phase cycling. The subsequent direct detection FID spectrum Fig. 2b, that was measured after 3 s of the start of the BINEPT-ME, is only marginally lower in SNR than the spectrum shown in Fig 2c that is the FID of an AMESING acquisition without polarization transfer. Fig. 3 shows a comparison of the \(^{31}P \) spectra acquired in a voxel of fibro-glandular tissue of three healthy female volunteers with the BINEPT-ME-AMESING sequence and the AMESING sequence. The spectra shown in Fig. 3 are the average over three volunteers. Note that the FID spectra are of similar signal intensity, implying very little signal loss by combining the BINEPT-ME with the AMESING in one TR. The PE-weighted spectra reveal the increase in SNR that is obtained when a weighted average of FID and all echoes are calculated using the fitted TR = 165 ms for PE. The SNR gain for the phosphomonooesters acquired with the new sequence is 400 % when compared to the direct detection FID, or approximately 370 % when compared to a low flip Ernst angle excitation pulse acquire. The peaks usually assigned to GPC and GPE are mainly signals from a mobile fraction of membrane phospholipids (MPL), with short T2; that show hardly any enhancement. Only GPC that is under the GPE-MPL peak surfaces after one echo time.

Conclusion

The SNR per time unit of the signals of heteronuclear J-coupled \(^{31}P \) metabolites can be increased by using an adiabatic multi-echo polarization transfer technique with an even number of 180 refocusing pulses on the \(^{31}P \) channel combined with an adiabatic multi-echo direct detection sequence in one TR, without adversely affecting the polarization transfer or the direct detection signal. The in vivo increase in SNR for phosphomonooesters as compared to low flip Ernst angle excitation pulse acquire can be up to 370%.

References