Double Spin Echo Volume Selective NMR Spectroscopy with a 1.5 T Whole Body Imager

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For volume selective nuclear magnetic resonance spectroscopy with protons a modified version of the double spin echo method has been implemented on a 1.5 T whole body imager. The high performance of the localization sequence has been verified with phantoms and tissue. A spectral resolution of about $2 \cdot 10^{-8}$ was obtained. The volume elements are well shaped and positioned, the minimal size was 2.2 cm^3. Spectra of porcine leg muscle tissue with different echo times are presented.

Introduction

Volume selective NMR spectroscopy finds now various applications in medical and biological investigations. Different localization methods have been proposed and employed [1, 2], and all of them have inherent advantages and drawbacks. One of the earliest published methods using field gradients and frequency selective excitation was the double spin echo sequence of Gordon and Ordidge [3] but only minor attention was payed to it so far. The reason for this is presumably the use of two 180° pulses which give rise to problems e.g. with slice profiles. We have implemented a modified version of the double spin echo volume selection sequence on a whole body imager and present results which demonstrate the high performance of this method.

Method

The whole sequence with the timing of the rf pulses and the magnetic field gradients is given in Fig. 1: The localization procedure starts with a frequency selective 90° pulse in the presence of e.g. a gradient G_z exciting a slice oriented in z direction, i.e. a z-slice. After the time τ a frequency selective 180° pulse and a gradient G_y are applied. The result is an inversion of the magnetization isochromates in a y-slice. After the time τ a spin echo could be observed from a strip resulting from the two orthogonal slices. The signal from e.g. a cube out of the strip can be obtained if again the time τ later a second 180° pulse and a gradient G_x are employed.

For a perfect volume selection process the unwanted transverse magnetization introduced by the 180° pulses must be destroyed. This is performed by prolonging the slice selection gradients and adding further gradients as given in Figure 1. By this procedure signal contributions from outside the volume of interest are avoided. The additional gradients give rise to eddy currents which introduce distortions in the spectra especially for short echo times. But the method works well for any echo time from 40 ms upwards with the imager in use.

The slice selective pulses used are 2.56 ms numerically optimized pulses based on the sinc function with some variations at the wings. They are calculated with 512 support points by an external pulse generator originating from B. Kiefer, Erlangen. A pulse bandwidth of 1070 Hz is employed together with gradients of $2 \cdot 10^{-3}$ T/m for slices of 13 mm.

The first pulse given in Figure 1 is only introduced if a strong water signal in the sample must be suppressed. It is a 35.84 ms sinc pulse with a corresponding bandwidth of 75 Hz.

The localization method has been implemented on a Siemens Magnetom 1.5 Tesla whole body imager. A circularly polarized head- and bodycoil is available as well as further special coils delivered by the manufacturer. The homogeneity of the magnetic field in the target volume can be optimized with this sequence by shimming on the observed second half of the spin echo signal. The result of this shim procedure can be controlled by using the MAGNEX magnetic field map-

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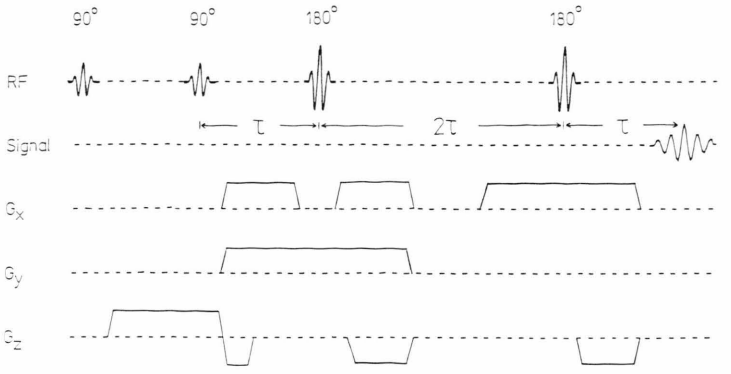

Fig. 1. Double spin echo pulse sequence for volume localized spectroscopy with water suppression.

ping method [4, 5], which provides spin echo images of the field distribution within the sample, where a resolution between 1 ppm and 0.125 ppm can be choosen.

Results

For a test of the localization method a simple phantom has been found to be very convenient [6]. It consists of two concentric cylinders with diameters of 170 mm and 43 mm, the inner of which is filled in this case with a 10% aqueous solution of ethanol. In Fig. 2 a typical double spin echo proton spectrum of the CH_2- and CH_3-parts of the ethanol spectrum is presented. The spectrum is taken from a volume element of $(13 \times 13 \times 13)$ mm^3. From this highly resolved spectrum a linewidth of about 1 Hz can be derived, resulting in a spectral resolution of less than $2 \cdot 10^{-8}$, which is rather high for a whole body imager and very sufficient for localized in vivo proton spectroscopy.

The position of the selected volume element can be easily controlled by imaging the volume of interest using a slightly modified sequence with additional read out and phase encoding gradients. The shape of it can be obtained with this imaging sequence when the voxel is placed within a homogeneous water phantom. The intensity profile across such an image is given in Figure 3. For this, a direction was selected in which a 180° pulse is involved. The shape is not quite rectangular but no signal contributions from outside the desired volume are observed. An example for the performance of the method in tissue is given in Figure 4. Two spectra of a volume element of $(13 \times 13 \times 13)$ mm^3 of muscle tissue of a porcine leg are presented. The difference between both is the echo

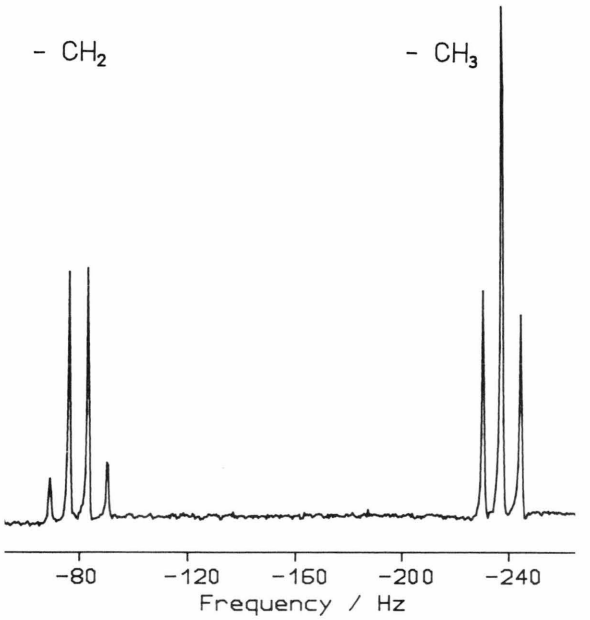

Fig. 2. Volume selective high resolution proton NMR spectrum of a $(13 \times 13 \times 13)$ mm^3 volume element placed within a small ethanol containing bottle (10% aqueous solution) inside a large cylinder filled with slightly doped water. Experimental parameters: 1 acquisition, 2 k data size, dwell time = 500 μs, $T_E = 1128$ ms, fouriertransformed and phased only, no further data manipulation. Water suppression: frequency selective saturation pulse. The whole body coil acted as transmitter coil while the signals were received with a Helmholtz coil 17 cm in diameter and with a coil distance of 11 cm.

time of 76 ms and 156 ms, respectively. Due to the different relaxation times of the observed species the shape of the spectra is very different. The intensity of the strong signal of the CH_2-protons (a) of fat decreases drastically in comparison with the nearby situated signal of the CH_3-protons (b) in the case of the

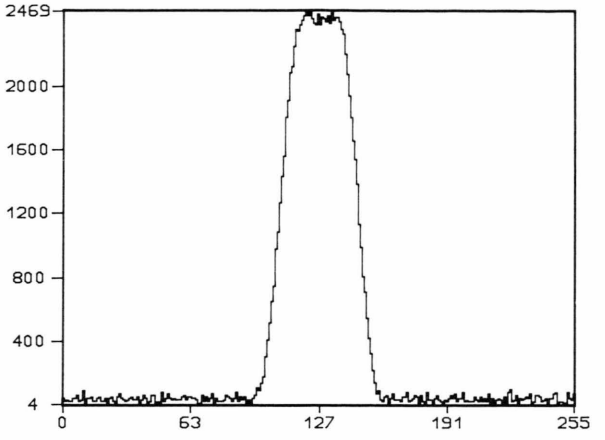

Fig. 3. Intensity profile across the image of the volume of interest, $(13 \times 13 \times 13)$ mm^3, representing a projection of one of the two slices excited by the 180° pulses. The volume element was placed within a cylindrical phantom containing slightly doped water.

long echo time. For the signals of choline (c) and phosphocreatine (d) an inversion in the intensity and a relative enhancement compared with the signals (a) and (b) are observed. The signal at 8.2 ppm is a typical signal of dead tissue and has been found also in a cat study [7]. Further small signals can be observed but are not yet identified. This is the aim of further in vivo studies which obviously can be performed with this method [8], since the stability, resolution, and localization features are advantageous.

Conclusions

This sequence is relatively simple and can be easily implemented on a commercial whole body imager. It is a single experiment method and suffers not from the errors of multiexperimental subtractions. Since the method uses the signal of the spin echo, a higher signal-to-noise ratio can be achieved in comparison to the stimulated echo. The echo times can be varied in a wide range according to the problem in question. At very short echo times, eddy current problems may occur but this is also the case for other localization methods. Relaxation times can be measured by introducing an inversion pulse (T_1) or by varying the echo time (T_2).

If the spectra contain signals which exhibit a spin-spin coupling, phase and intensity problems can arise but their dependence on the echo time can be used for an identification of such signals. A more detailed investigation on this topic is running.

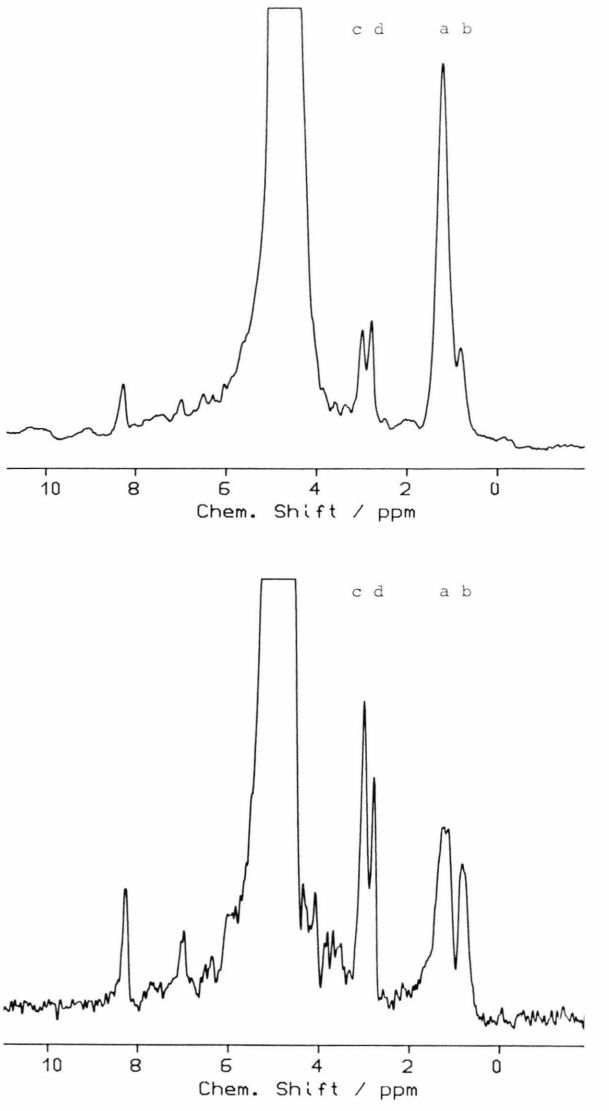

Fig. 4. Volume selective proton spectra of a $(13 \times 13 \times 13)$ mm^3 voxel in muscle tissue of porcine leg. $T_R = 2.0$ s, 256 acquisitions, measuring time 8.5 min, $T_E = 76$ ms (top), $T_E = 156$ ms (bottom). The second half of the echo was multiplied in the time domain with an exponential function (half height at 100 ms) and set zero at 300 ms upwards. The clipped peak is the remaining water signal, for the others see the text. These spectra were acquired using the standard linearly polarized saddle coil for extremities, while the transmitter coil was the whole body antenna.

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