STEAM localization sequence using asymmetric 90° RF pulses and improved water suppression scheme

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Introduction: During the last few years, substantial developments have been made in localized in vivo NMR spectroscopy acquiring chemical-shift spectra from well-defined volume elements at selected locations in the sample. At present, localization techniques which allow spectra to be obtained from a single volume of interest (VOI) defined by the intersection of three slices selectively excited by frequency-selective RF pulses in the presence of three mutually orthogonal B_0 gradients, are most widely used in proton MR spectroscopy. STEAM is one of the basic representatives of single voxel localization techniques. The localizing part of the STEAM (Stimulated Echo Acquisition Mode) sequence can be written in an abbreviated form as

90° - TE/2 - 90° - TM - 90° - TE/2 - Acq.

where TE is the echo time and TM is the delay independent of TE. In proton MR spectroscopy, the localizing part of the STEAM sequence is preceded by a preparation period (TP) in which mainly water-suppression (WS) sequences are placed. For WS sequences in TP, effective water suppression requires complete dephasing of the transverse water magnetization and nulling of the longitudinal water magnetization at the time of the first RF pulse in the localization sequence. The fulfillment of this requirement is often complicated especially by the static magnetic field, B_0, and RF field, B_1, inhomogeneities and the dispersions of T_1 and T_2 relaxation times.

B_0 inhomogeneity can reach several ppm over the excited area of the sample. In this case, spectral-selective suppression of the water signal can be very low outside the VOI (over which the B_0 field shimming is performed). To reduce the water signal outside the VOI, spatial-selective suppression must be employed. The construction of both spectral- and spatial-selective suppression approaches must take into account the dispersion in the RF field strength and T_1 and T_2 relaxation times. The design of well-working water suppression schemes is a very delicate task and can vary from one system to another.

The efficient nulling of both transverse and longitudinal water magnetizations before the application of the localizing part of the STEAM sequence will considerably reduce the magnitudes of the FID signals occurring after each slice-selective RF pulse in the sequence and, subsequently, the demands on the gradient powers necessary for destroying these FID signals. As a results, both TE and TM in the STEAM sequence can be shortened without degrading the resulting NMR spectra.

Another way enabling one to shorten the echo time in the STEAM sequence is the use of asymmetric slice selection RF pulses instead of symmetrical ones.

Methods: In this contribution we present the STEAM sequence with an improved water suppression procedure and with the use of only asymmetric 90° slice selecting RF pulses in the localization part of the sequence.

For the spectral-selective water suppression a sequence of 6 identical asymmetric RF pulses with the flip angles around 100 - 120° (optimum value of the flip angle must be experimentally adjusted to provide the best water signal suppression) and one asymmetric

180° pulse are employed. Each pulse is followed by a properly chosen gradient dephasing pulses and eddy current delays. The spatial-selective water suppression is performed by the application of four hyperbolic secant RF pulses in the presence of G_x and G_y gradients adjusted so that the water signal in the outside of the VOI is efficiently saturated. These pulses are located in the time periods before and after the 180° RF pulse in the spectral-selective part of the water suppression sequence.

The slice-selective asymmetric 90° pulses (Fig. 1) employed in the localization part of the STEAM sequence (1) are characterized by the slice profile close to rectangular, low value of the ratio $\nu_1/F_{1/2}$ (ν_1 is the RF field strength in Hz and $F_{1/2}$ is the full width half maximum of the profile), and the low value of the product $T_pF_{1/2}$ (T_p is the pulse length). The selectivity of these pulses is approximately the same as that of self-focusing BURP pulses used in the STEAM sequence by Topp et al. (2) but in contrast to these the RF power demands of our pulses are at least 15 times less. The amount of the rewinder gradient required by our asymmetric 90° pulses is about four times less than that required by symmetric 90° pulses (for instance Hamming filtered sinc pulses) possessing the same slice-selection performance. The localizing part of the employed STEAM sequence is shown in Fig. 2. The second 90° pulse is the sequence partitioning the spin isochromats into a transverse and a longitudinal component, respectively, is the mirror image of the first and third excitation 90° pulses. In order to improve the water suppression in regions where the magnitude of the RF field differs from the nominal a hyperbolic secant 180° pulse together with the G_z gradient (defining the last slice in the sequence) is applied in the TM interval.

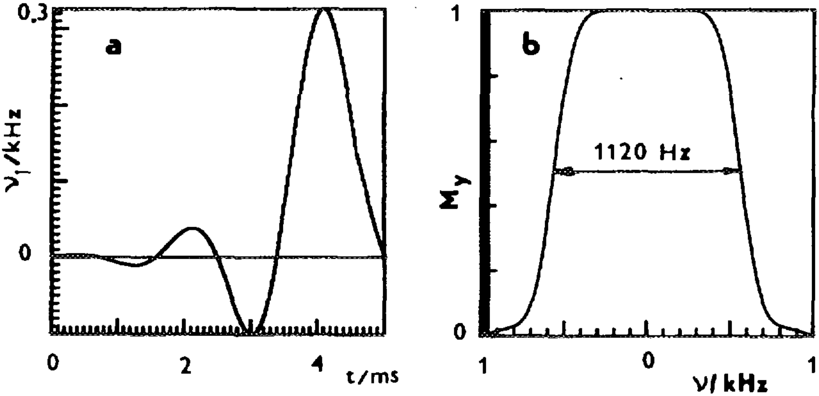

Fig. 1. Time-domain profile of the EX-1 90° excitation pulse (a) and M_y spectrum generated by this pulse (b).

Results: The proposed modified STEAM technique was employed for acquiring proton spectra from the image-guided VOI from phantoms and from the brain of a anaesthetized Wistar rat. The experiments were carried out on a 200 MHz 40 cm-bore SISCO scanner using a non-standard RF coil system of 45 mm is diameter to transmit and receive RF signals. The length of frequency-selective pulses in the spectrally selective part of the water suppression sequence was 25 ms affecting the spectral bandwidth of about 200 Hz. Together with gradient pulses and the eddy-current delay, the time separation between the pulses was 100 ms. The length of hyperbolic secant pulses in the spatial-selection part of the water

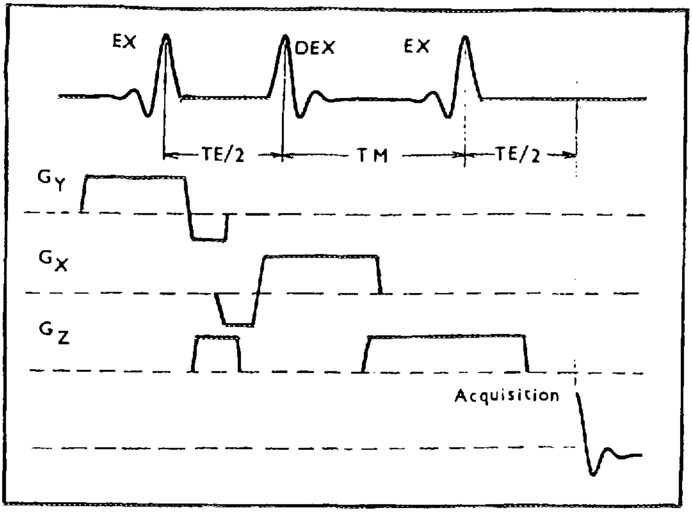

Fig.2. STEAM-AP localization sequence. DEX pulse producing the back rotation is a mirror image of the EX pulse.

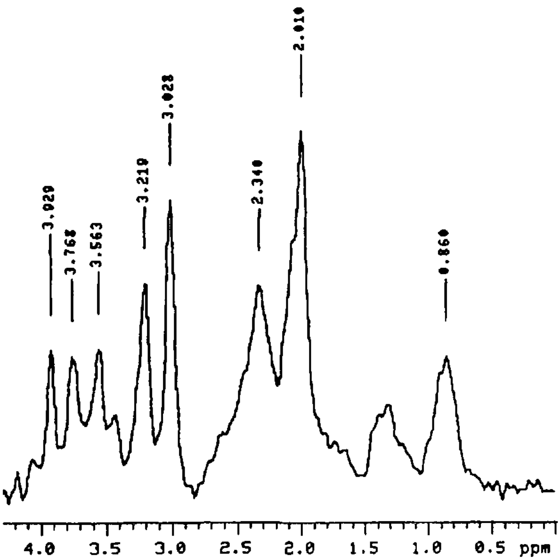

Fig.3. ^1H spectrum from the rat brain in vivo obtained by STEAM-AP sequence (TE = 16ms, TM = 30ms).

suppression sequence was 20 ms. The magnitude of gradients was accommodated in the bandwidths of excitation given by the position of the VOI in the sample. In the localizing part of the STEAM sequence, asymmetric 90° pulses with a duration of 2.5 ms and a bandwidth of 2 kHz were employed. The slice selection gradient strength was 10 mT/m. The gradient ramp time was 1 ms. Under these conditions, the echo time TE of 16 ms was achieved. The duration of the period was 30 ms. The length of the hyperbolic secant pulse applied during the TM for additional water signal suppression was 15 ms.

^{1}H spectrum which was acquired by the STEAM sequence modified as described from a $4.8\times4.8\times4.8$ mm^3 (110 μl) VOI of the rat brain in a measuring time of 19 minutes is given in Fig. 3. Evidently, the obtained in vivo proton spectrum is of a very good quality.
Conclusions: The STEAM sequence with a new water suppression procedure based on both spectral- and spatial water signal suppression and with a localization part employing only asymmetric slice-selective 90° pulses is described. The use of the proved water signal suppression and slice-selective pulses requiring less rewinder gradients make it possible to obtain high quality proton spectra even at very short echo times. This can result in obtaining spectra with a higher S/N ratio due to reduced T_2 losses and in reducing unwanted modulation distortions.

References:

1. Z. Starčuk et al., 2nd SMR Proceedings, 1137 (1994).
2. S. Topp et al. 12 SMRM, Book of Abstracts, 1214 (1993).