Design of Cosine-Modulated Very Selective Suppression Pulses for 3D MRSI at 3T

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INTRODUCTION: At higher field systems ($\geq$3T) there are inherent advantages for MR spectroscopic imaging (MRSI) of brain tissue, including improved spectral resolution and increased sensitivity. An important aspect of localization in point resolved spectroscopic (PRESS) MRSI is saturating unwanted tissues surrounding the region of interest, such as pericranial lipid in brain MRSI, which can contaminate the spectra [1,2]. The challenge of suppressing outer volume lipid is more difficult at higher fields because of the increased effect of chemical shift misregistration on the selected volume. Conventional outer volume saturation techniques at lower field strengths addressed this issue by supplying more RF pulses per saturation band. At higher field care the radio frequency (RF) power deposition that is required to achieve the same effect is increased and may limit factor the number of pulses that can be used. This project presents a cosine modulated very-selective suppression (VSS) pulse scheme that was optimized for high field strengths in order to obtain improved saturation with a smaller number of pulses.

METHODS: A non-linear phase SLR [3] RF pulse with a time-bandwidth of 18 was designed with the phase optimized to minimize the peak RF power using methods as in [4-5]. This RF pulse was used as the basis for creating a cosine modulated very selective suppression (VSS) pulse (see Fig1). The low stopband ripple (0.01) and non-linear phase of the basis RF pulse resulted in minimal interaction between the dual saturation bands of the cosine modulated pulse (see Fig2). The VSS pulse had a nominal B1 of 0.116G, a pulse width of 3.0ms, and bandwidth that was 5868Hz. Two symmetric saturation bands were produced using a single RF pulse by modulating the RF pulse by a cosine function, as demonstrated in a phantom in Figure 2b. The excitation of the cosine modulated pulse was optimized to generate similar suppression as a single pulse while maintaining an adequate power level. The cosine modulated VSS pulse that was generated in real time produced two saturation bands that were spatially placed based on the desired prescription of the localization volume. Four cosine-modulated VSS pulses were used in generating eight saturation bands in-plane in order to achieve a volume selectivity that would contour to the shape of the head, as shown in phantom in Figure 1d and in volunteer in Figure 3b. Phantom and volunteer studies were performed on a GE 3T MR scanner using body coil excitation and reception with an 8 channel phased array head coil. The pulse was implemented in 3D MRSI using point resolved spectroscopic (PRESS) volume localization and chemical shift selective saturation (CHESS) pulses for water suppression in 9 minutes with TR/TE = 1100/144ms. These acquisitions employed spectral arrays of 12 x 12 x 8 acquired with k-space sampling that was restricted to the central elliptical region of the array with fields of view corresponding to a nominal spatial resolution of 1cc.

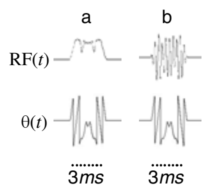

Figure 1: (a) RF pulse prior to cosine modulation, (b) cosine modulated VSS pulse.

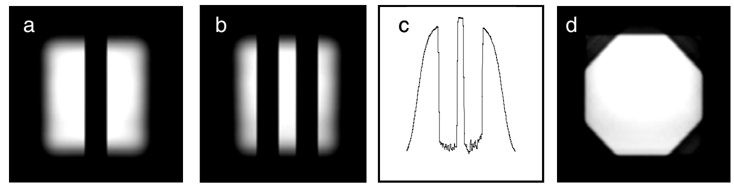

Figure 2: Demonstration of the functionality of the pulse. (a) One single band VSS pulse. (b) One dual-band cosine modulated VSS pulse shown as two symmetric bands. (c) A linear intensity profile generated from figure (1b). (d) Four dual-band cosine modulated VSS pulses making an octagon shaped volume selection.

RESULTS: The phantom studies using the cosine modulated VSS pulse demonstrated the high spatial selectivity of the saturation bands with minimal interaction between the bands, as shown in Figure 2c. The efficiency of saturation of water from the VSS pulse was 90% in phantom analysis and 86% in volunteers. The time taken to play out the VSS pulses was less than if pulses were played individually, which in turn improved water suppression. In addition, time was conserved further from the additional crusher gradients and the ramp time from the spatial selective gradient. The time saved from crusher gradients and gradient ramp time was 1.7ms per pulse. Two symmetric saturation bands were generated at distances down to 2mm apart with no interaction between the bands. Cosine modulation of the VSS pulse along with the phased modulated low peak power characteristic allowed for over 30 saturation bands to be implemented in the volunteer dataset while still keeping the power deposition under the FDA approved specific absorption rate (SAR) limit.

CONCLUSION: This study demonstrated the feasibility of generating improved outer volume suppression pulses for maximum lipid suppression and improved water suppression in phantoms and human subjects by employing cosine modulated VSS pulses. Water suppression was improved and SAR limits were maintained while generating more than double the amount of saturation bands.

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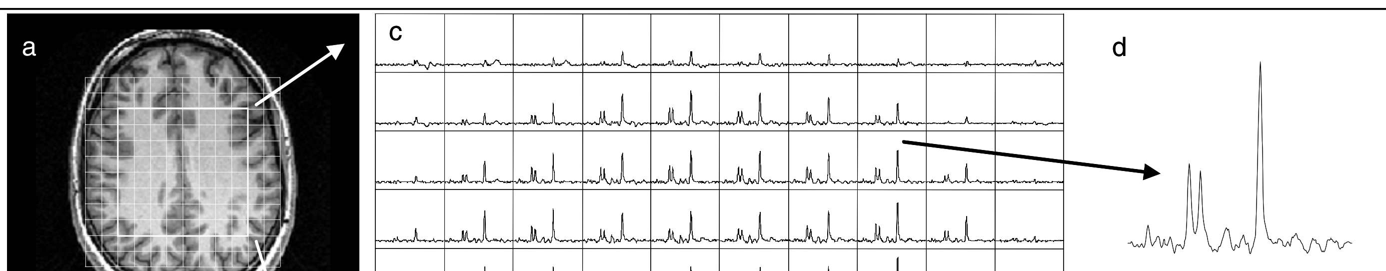

Figure 3: In vivo volunteer data with 4 VSS pulses performing 8 saturation bands into an octagon shaped volume selection. (a) T1 SPGR with overlay of MRSI. (b) MRS selection volume demonstrating the irregular contour. (c) Full MRSI array demonstrating an array high quality spectra with desired contour selection. (d) Spectra coming from a voxel adjacent to saturation band demonstrating high selectivity of cosine modulated VSS.