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● *Technical Note*

CHEMICAL SHIFT-INDUCED AMPLITUDE MODULATIONS IN IMAGES OBTAINED WITH GRADIENT REFOCUSING

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One of the salient features of the gradient echo relative to the Hahn echo is its sensitivity to magnetic field variations caused by either magnetic field inhomogeneity or chemical shift. While by virtue of phase reversal Hahn echoes eliminate the dephasing effects caused by chemical shift,[1] gradient echoes behave more like free-induction decays (FIDs).[2] This clearly has implications on the signal amplitude in the MR images obtained with gradient refocusing[2,3] if the tissues involved contain more than one spectral component, such as adipose, which being composed of triacylglycerides (fat), contains protons in a variety of chemical environments. The major spectral component of adipose is the CH_2 moiety of the long-chain fatty acids with a minor component of unsaturated protons (–HC=CH–). Assuming a chemical shift difference of Δf Hertz, it is readily seen that the condition for the two spectral components to being in phase is

$$TE = n/\Delta f \ , \qquad (1)$$

with $n = 1, 2, 3, \ldots$. By contrast, the condition for antiphase orientation of the two components is

$$TE = (2n + 1)/(2\Delta f) \ . \qquad (2)$$

Since the pixel intensity is a weighted mean of the two constituents, an amplitude modulation with echo delay TE results, as the two components get in and out of phase.

In order to investigate this phenomenon a pulse sequence was designed so that the echo delay could be stepped automatically in increments of 0.25 msec. Figure 1 shows two transverse images of the upper abdomen of a normal subject imaged with gradient echo times of 13.5 and 15.75 msec. Note the differing appearance of the fat/muscle contrast in the two images. In Fig. 1a, the two tissues are nearly isointense whereas in the image in Fig. 1b, fat is markedly more intense than muscle even though the echo delays in the two tissues differ by only 2.25 msec.

In Fig. 2a, the ROI pixel intensities from the two regions labeled 1 (subcutaneous fat) and 2 (muscle) are plotted against TE. The plot from region 1 shows the expected modulation with a period of 4.2 ± 0.2 msec. This is in good agreement with the known chemical shift of 4.1 ppm (260 Hz at 64 MHz resonance frequency) between the vinyl CH protons and the CH_2 moiety of long-chain fatty acids.[4] In addition, we recognize, in the oscillation of Fig. 2a, a second low-frequency modulation with a period of approximately 20 msec (~50 Hz), which we ascribe to the chemical shift difference between the center CH_2 and the $-CH_2-O-$ protons of the fatty acid chains. By contrast, the plot from region 2 (muscle) exhibits simple exponential decay only, consistent with a single spectral constituent (Fig. 1b).

The modulation effect is particularly prominent in the junctional zone between subcutaneous fat and other tissues which primarily contain water, since in this zone the imaging voxel contains both tissues. This effect accounts for the low-intensity edges sometimes seen in these images. As one would expect, the intensity in this boundary zone follows a modulation similar to that found in subcutaneous tissue (Fig. 2b).

The boundary effect, caused by destructive interference of antiphase components is analogous to that reported for modulus inversion-recovery images, recorded with an inversion time close to that where signal nulling occurs.[5] Another boundary effect of similar nature is found for flow-related enhancement where vessels often show a dark outline. In this case, destructive interference of spin isochromats results from phase dispersion caused by the slice selection

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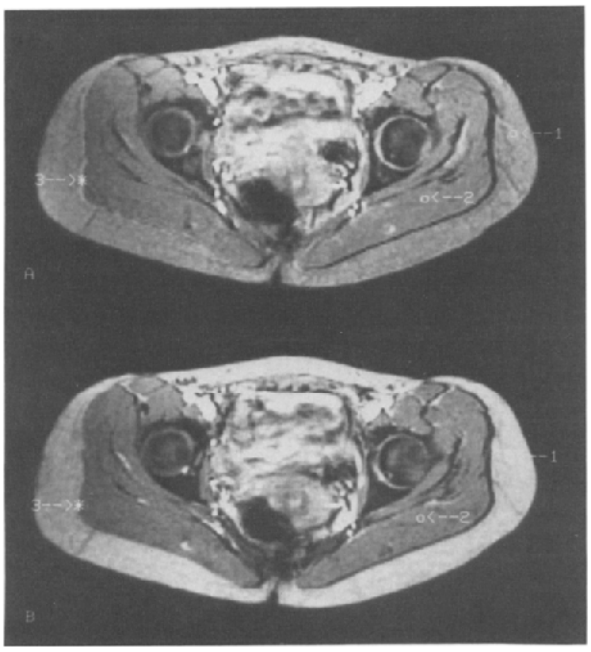

Fig. 1. 64-MHz axial pelvic images obtained with gradient echoes and echo delays of 13.5 msec (a) and 15.75 msec (b).

gradient in the presence of a distribution of flow velocities (laminar flow).[6]

The phenomenon described here has clinical consequences. In order to obtain high contrast between fat and muscle (or fat and any other tissue primarily containing water), the echo delay has to be chosen so as to satisfy eqn (1) which using a period of 4.1 msec, predicts maxima at 4.1, 8.2, 12.3, 16.4, 20.5 . . . msec, in good agreement with the findings in Fig. 2a.

It is obvious that the phenomenon can be exploited to generate sum and difference images analogous to the method described by Dixon,[7] simply by appropriately selecting the gradient echo time as suggested recently.[8]

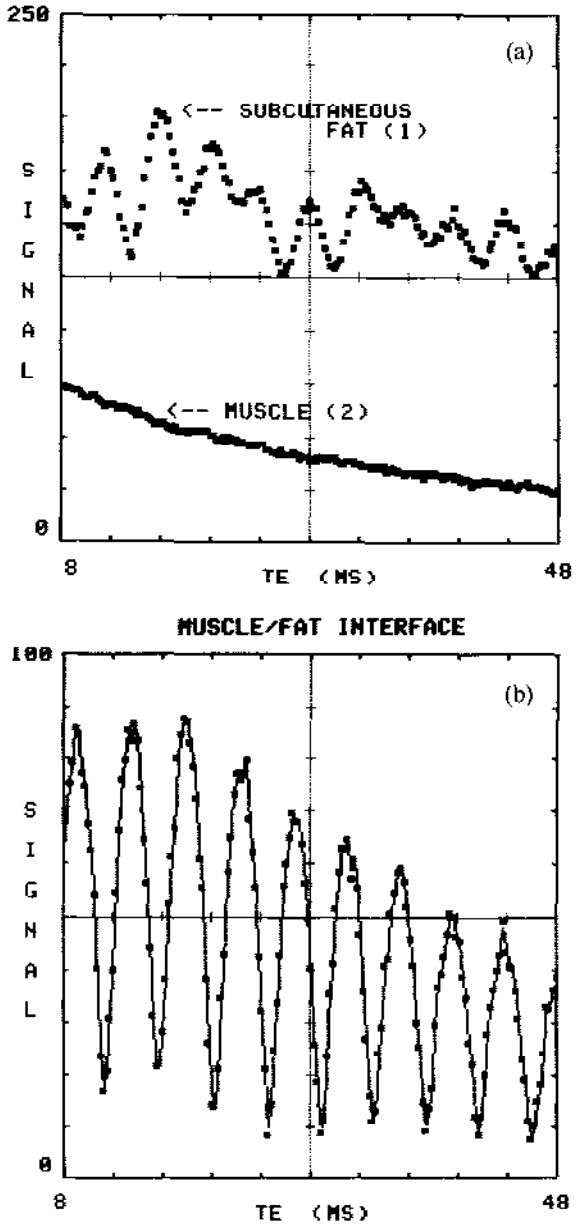

Fig. 2. (a) ROI pixel plots from regions 1 (subcutaneous fat) and 2 (muscle). Note the oscillation seen in region 1 caused by the chemical shift difference between the CH_2 moiety of the long-chain fatty acids in adipose and the vinyl protons (T = 4.2 msec), and CH_2 and the $-CH_2-O-$ group (T = 20 msec). No modulation occurs in region 2 which is spectrally homogeneous (H_2O). (b) Similar plot from junctional zone 3.

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