Echo combination to reduce temperature measurement errors in the presence of fat

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Introduction Lipids create errors in temperature estimation with the proton resonant frequency (PRF) shift method. Normal liver tissue can contain more than 6% lipid while diseased liver may consist of lipid signal on the order of 20% or more [1]. Fat suppression is commonly used, but increases imaging time and is difficult at low field strengths. In this study, we investigate a simple method to substantially reduce these errors by refocusing several gradient echoes and combining the corresponding temperature maps. This echo combination technique eliminates the need for fat suppression in tissues such as the liver.

Methods Simulation of temperature errors were made as a function of echo time (TE) and fat percentage, and an echo combination scheme was developed. To verify the simulation results, experiments were performed in pure water, pure fat and a homogeneous mixture of approximately 80% water and 20% fat that were heated to 90°C and imaged during cooling to room temperature. For the echo combination, data was acquired at three echo times (TE1/TE2/TE3= 14.3, 21.4, 28.6 ms) corresponding to 2π, 3π, and 4π phase angles between fat and water. All echoes were acquired in a single refocused gradient echo acquisition. Additional imaging parameters were TR = 60 ms, flip angle = 60, FOV = 16 cm, BW = 15.6 kHz, slice thickness = 8 mm, matrix size 128×128. For comparison, temperature maps of a GRE sequence were acquired with the same imaging parameters but with a single echo at TE = 25 ms and BW = 6.9 kHz. Phase drift was measured in a reference phantom at room temperature and corrected in all temperature maps. In addition, temperature in the test tubes was measured with a fiberoptic temperature sensor. SNR, temperature uncertainty, and temperature errors were compared for the different acquisitions.

Results Figure 1 shows simulated errors as a function of echo time in a mixture of 80% water and 20% fat. Due to the cyclic nature of the error phase [2], measurements at different TEs can cause either overestimation or underestimation of the temperature. Therefore, echo combination can substantially reduce the error as shown in Fig. 2, where the three echoes were combined as 0.25*Echo 1 + 0.5*Echo 2 + 0.25*Echo 3. Absolute errors after echo combination are in the order of 1°C compared to up to 10°C in the individual echoes for this water and fat ratio. Experimental results verified the simulation as shown in Fig. 3. The deviation of the combined measurement from that of pure water over time occurred due to slightly different cooling rates in the two insulating containers.

Measurement of the SNR and temperature uncertainty of the three echo sequence showed that the signal averaging of the three echoes compensates for most of the signal decrease due to the higher bandwidth in the individual echoes. Temperature uncertainty measured in water was σT = 2.3, 1.6 and 1.4 for the individual echoes and σT = 1.0 after echo combination, which was identical to σT measured in the single echo sequence.

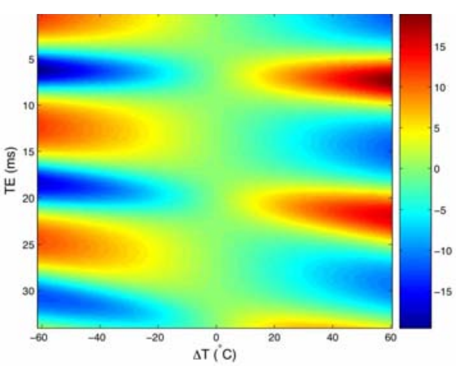

Figure 1: Temperature error for temperature changes from –60 to 60°C as a function of echo time.

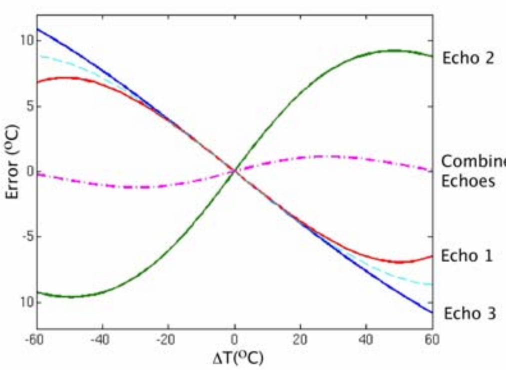

Figure 2: Temperature errors as a function of temperature change for three different echo times and their combination.

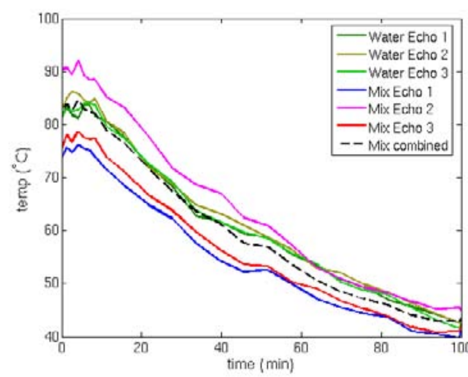

Figure 3: MRI temperature measurements during cooling of pure water and a mixture of water and fat. Echo combination (dotted line) significantly reduces errors from fat compared to the individual echoes.

Discussion The results show that echo combination successfully reduces errors caused by low fractions of fat (up to 20% fat). The proposed pulse sequence and echo combination allows for temperature measurement with improved accuracy while maintaining a low temperature uncertainty. The method can be used to replace fat suppression in organs such as the liver or it can be combined with existing fat suppression techniques for improved accuracy if fat suppression .

References [1] Woodard H.Q. et al. Br J Radiol. 59(708), 1209-18, 1986.
[2] Kuroda K. et al. Magn Reson Med. 38(5), 845-51, 1997.

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