Fast T1 Mapping Using a CPMG Sequence

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Introduction: Knowledge of the T1 relaxation rate of tissues in vivo may be used to identify pathological tissue and discriminate disease (1). A method that can quickly and accurately measure the T1 relaxation rate of tissue would be important for many diagnostic applications. The Carr-Purcell-Meiboom-Gill (CPMG) sequence is a rapid imaging method that has been implemented on most commercial MR systems (e.g. fast spin echo (FSE)). A novel method for measuring T1 relaxation times using a CPMG sequence is presented.

Materials and Methods

Theory: A Bloch equation analysis of a CPMG sequence with an arbitrary number of refocusing pulses, N, a given repetition time, TR, echo spacing, esp and T1 relaxation time yields the following expression for the steady state magnetization, m_{ss},

$$m_{ss} = m_{init} \cdot \left[1 + (-1)^{N-1} \cdot e^{\left(\frac{-TR}{T1}\right)} + 2 \cdot (-1)^{N} \cdot e^{\left(\frac{-TR}{T1}\right)} \cdot \left(\sum_{i=1}^{N} (-1)^{(i-1)} \cdot e^{\frac{-(2i-1)\cdot esp}{2T1}} \right) \right] \qquad (1)$$

If the TR and the esp are held constant and the echo train length (etl) is increased, the time for recovery of the longitudinal magnetization decreases. So, the image signal intensity is inversely proportional to the echo train length. **Imaging:** Imaging of a phantom and normal human calf muscle in vivo was performed on a 3T GE Signa scanner. A 250 ml phantom was prepared with a 0.1 mM solution of Gd-DTPA (Magnevist) in water. To obtain a reference value for the T1 of the phantom, a saturation recovery experiment (1) was performed using a spin-echo sequence that was repeated 11 times with the TR increasing from 30 ms to 5 S. A fast spin echo (FSE) sequence was then performed with TR = 1.5 S, esp = 15 ms, effective echo time = 15 ms, matrix = 256 x 256, FOV = 15 cm, slice thickness = 5 mm and 6 dummy scans applied before each data acquisition. The sequence was repeated 6 times with etl's of 2, 4, 8, 16, 32 and 64 while all other parameters were held constant. The imaging protocol was repeated for a normal human subject with the FOV increased to 30 cm and five FSE scans performed with etl's of 2, 4, 8, 16, and 32. The total scan time for the in vivo CPMG acquisition was 7 minutes. **Data analysis:** To determine the reference T1 values of the phantom and muscle, the signal data from a 6 x 6 pixel ROI taken at the center of the phantom or in the soleus muscle in each of the 11 saturation recovery images were fit to the expression for T1 relaxation using a gradient expansion algorithm (IDL, Research Systems, Inc, Boulder, CO). To calculate the T1 values based on the FSE (CPMG) image data, the signal intensities from the same ROI locations in the FSE phantom and soleus muscle acquired using different etl's were fit to equation 1.

Results: The T1 values that were calculated from the saturation recovery and the CPMG method are listed in Table 1. Note the close agreement between the T1 values that were determined by the saturation recovery and the CPMG methods for both the phantom and the in vivo skeletal muscle. The CPMG (FSE) experimentally measured signal data is plotted along with the theoretical fit data in Figure 1.

Discussion: The T1 values that were determined from the CPMG signal intensities agree closely with the widely accepted saturation recovery method. The T1 values that resulted from both measurement methods were similar to the 3T T1 values of skeletal muscle that have been measured in other studies (2). The shape of the curves that represent the CPMG experimental data presented in Figure 1 are very similar to the curves that represent the theoretical fit curves. Further studies using longer echo train lengths will determine whether accurate CPMG T1 measurements can be made in shorter times. For example, using etl's of 8, 16, 32, 48 and 64 would result in a total T1 measurement time of less than 2 minutes. The results presented here suggest that the CPMG imaging sequence may reduce the time required for accurate T1 measurements just as it has already done for anatomical imaging

References: 1. Kingsley, PB, Concepts Magn Reson, 11:243-276, 1999

2. Stanisz, et al Magn Reson Med, 54:507-512, 2005

Table 1. T1 values measured using the saturation recovery and the CPMG methods

T1 Measurement Method	0.1 mM Gd-DTPA Phantom	Human Skeletal Muscle (Calf)
Saturation Recovery	948 ms	1268 ms
CPMG	946 ms	1211 ms

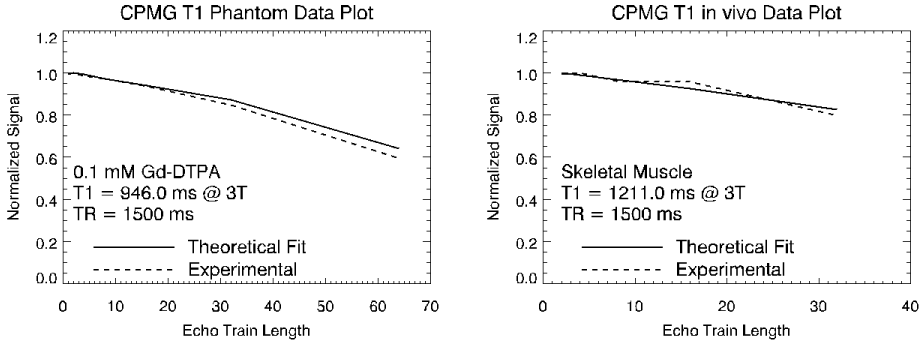

Figure 1. The normalized signal intensity values from that were acquired from (a.) a phantom and (b.) human leg muscle using a series of FSE scans with different echo train lengths are plotted. The resulting theoretically fitted values are also plotted.