Echo Planar MRI Cardiac Frequency Maps in a Single Shot Using Simultaneous Echo Refocusing (SER)

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Current methods of cardiac shimming suffer serious limitations. Frequency maps, used for shimming, must be calculated by comparing multiple acquisitions with different phase evolution times. The background phase of these acquisitions must be stable in the presence of changing position, velocity, and time-dependent field variations. Previously we have used a pair of symmetric-asymmetric spin echo EPI images to rapidly calculate frequency maps for rapid and accurate shimming [1]. In the present abstract, we describe a simultaneous echo refocusing (SER, [2]) method for calculating frequency maps. SER collects all the needed data for a 2D frequency map in a single EPI shot. This effectively freezes motion, providing phase stability for the frequency measurement. Here we demonstrate the stability and reproducibility of this new method for cardiac shim data collection.

Methods and Results: The gradient echo SER pulse sequence described in [3] and shown below was used to test the frequency mapping technique by acquiring the same slice twice in a single acquisition. *In vivo* human cardiac data was collected using a GE 1.5T Signa MR scanner (LX, 8.2.5) and a custom 12x20cm flexible linear surface coil. Each excitation used a 45° tip angle, an evolution time τ between excitations of 4.4ms, an image matrix size of 64x64 (128x64 acquired), TE of 47ms and an in-plane resolution of 3.75mm. Slice thickness was 5mm and slice separation 12mm. Each acquisition was velocity encoded in one of 8 directions with a VENC of 6.3cm/s (see [3]), and was synchronized to the subject's ECG. The subjects held their breath for each different velocity encoding vector. All human studies were carried out with informed consent using an IRB-approved research protocol.

SER frequency mapping images were collected for the same subject over 8 different cardiac cycles. The resulting frequency maps are shown in figure 2. We acquired nearly identical frequency maps for each image, despite the background phase resulting from different position (due to different breath holds) and beat-to-beat contraction variation.

Discussion: The SER acquisition multiplexes signal from two sequentially encoded slices into a single EPI readout. Each line of the readout matrix contains a pair of echoes with different phase evolution. Each echo is from the same slice but is excited at a different time. The time separating these echo pairs in the readout is 200 to 300us, so short that the effects of coincident motion are effectively eliminated.

The images in figure 2 were acquired in the presence of a velocity encoding gradient mandated by our previous implementation of this sequence. This gradient was not required to make the frequency maps, but as seen in figure 2, it did not prevent making them. The velocity encode only affects the phase change in the axis of velocity encoding (ie change in phase with distance), and when comparing the same pixel in the two images to calculate frequency, cancels out.

The authors will use the present method for cardiac shimming, but the method could be used for other applications such as abdomen or thorax where the background phase variation with time is large in comparison to the phase variation due to pixel frequency.

Conclusion: We have demonstrated a method for acquiring a frequency image in a single EPI shot. This method should prove useful for shimming the heart, thorax and abdomen at high field, where the background phase variation due to position and velocity can be particularly problematic.

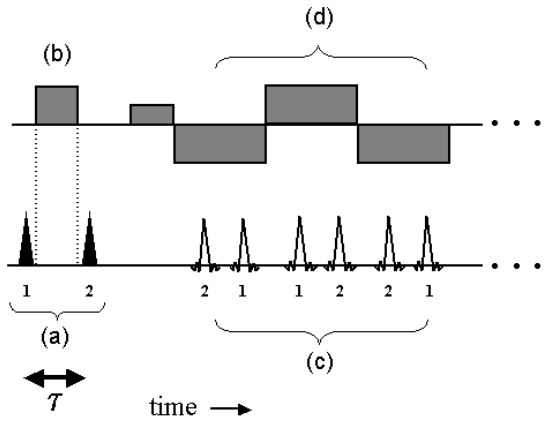

Figure 1: The pulse sequence diagram shows the two 45° excitation pulses (a) separated by phase evolution time τ. The readout prephasing gradient (b) places the gradient echoes (c) from each excitation pulse at different locations (1 and 2) in the EPI readout (d).

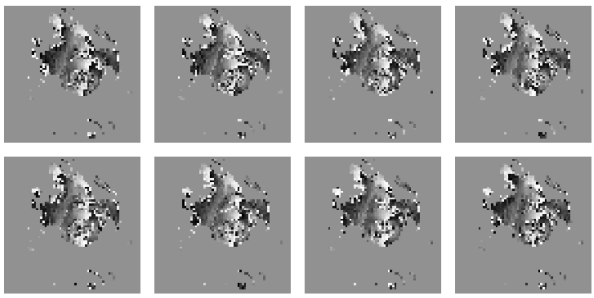

Figure 2: Cardiac frequency maps collected with eight different velocity encodes (VENC=6.3cm/sec) in eight different axes (the corners of a cube, {±1, ±1, ±1}) show nearly identical frequency maps. Each of these maps of the same slice was collected on a different cardiac cycle, and on different breath holds. The effectively simultaneous acquisition of the component images provides a stable background phase. This phase stability eliminates the deleterious effects of velocity, position, and time-dependent field variations.

[1] Reese TG, Davis TL, Weisskoff RM; JMRI 1995, 5(6):739-45. [2] Feinberg DA, Reese TG, Wedeen VJ; MRM 2002, 48(1):1-5. [3] Reese TG, Feinberg DA, Dou J, Wedeen VJ; MRM 2002, 47(4):665-76.