Ultra-Short TE Imaging with Single-Digit (8μs) TE

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Introduction: Ultra-short echo-time (UTE) imaging allows visualization of short-T_2 structures that have low or zero signal on conventional images. Prior work has explored diverse applications including imaging of lung parenchyma, atherosclerotic plaque, tendons, menisci, cortical bone, periosteum, cryosurgery-induced ice balls, as well as short T_2 components in the abdomen, pelvis, spine, and brain (1-11).

TE is a critical performance indicator in UTE imaging since the shortest detectable T_2 is on the order of TE (1). Over the past decade, the achievable TE has been progressively reduced from 200 μs (1-8), to 80 μs (9,10), and most recently to 60 μs (11). By capitalizing on advancements in hardware performance and software flexibility, we have achieved a TE of 8 μs, an order-of-magnitude reduction compared to prior 1.5 T implementations (1-10).

In this work, we demonstrate our capability to image at 8 μs TE. We also discuss the limits of spatial resolution for the very short T_2 components that can now be detected.

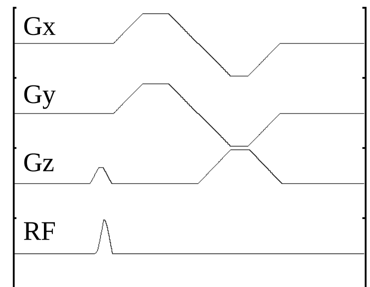

Figure 1: 8-μs TE pulse sequence

Methods: Figure 1 depicts our UTE pulse sequence, which was implemented on a 1.5T Signa TwinSpeed (GE Medical Systems, Milwaukee, WI) with maximum gradient performance of 40 mT/m and 150 mT/m/ms. A variable-rate half-pulse excitation (1) is followed by a center-out radial acquisition. TE is traditionally defined as the interval between excitation of the DC component in excitation k-space and acquisition of the DC component at the center of acquisition k-space. When imaging very short T_2 components, each spatial frequency could be considered to have its own TE. As will be discussed below, transverse relaxation limits the achievable slice profile and image resolution. However, for simplicity our stated TE conforms to the traditional definition and is therefore determined by the 8-μs interval between the end of the variable-rate half-pulse excitation and the start of the radial acquisition. Additional data can be acquired optionally at later delays TE2, TE3, etc. Images are reconstructed using an on-line gridding reconstruction.

In previous work, TE was limited by the RF subsystem switching time from transmit to receive mode (2-11). Eddy current induced mismatches between the two half excitations have also been identified in some implementations (7,11). We have demonstrated an 8 μs transition from transmit to receive using body-coil transmit with surface coil receive as well as transmit-receive coils. To date, no eddy current induced lags have been detected through comparison of in-bore sensor measurements and gradient current measurements.

Our implementation allows the user to select between RF pulses optimized to achieve specific performance metrics including minimum slice thickness, maximum flip angle, and desired slice profile for long and/or short T_2 components. Figure 2 plots the simulated T_2-dependent slice profiles for an RF half-pulse with a duration of 400 μs. As illustrated in the figure, transverse relaxation is the dominant effect limiting the achieved slice thickness and profile shape in very short T_2 components. Similarly, the in-plane resolution achieved in very short T_2 components is limited by the performance of the gradient subsystem relative to the rate of T_2 decay. The theoretical limit of spatial resolution can be characterized by the full-width-half-maximum of the Lorentzian profile corresponding to the spatial frequency at which the applied k-space weighting has fallen to 1/e due to T_2 decay (1).

To demonstrate the potential of our UTE method, six healthy volunteers were imaged following informed consent. A 3-inch general-purpose surface coil was used for signal reception. Imaging parameters included: 256 points acquired on 512 rays, BW=+/-125kHz, FOV=15cm. Images acquired at later delays were subtracted from the 8μs TE image to isolate short-T_2 components (1).

Results: Figure 3 presents a difference image (TE1=8μs minus TE2=4.6ms) illustrating the short-T_2 components in the Achilles tendon of a healthy volunteer. In the 8μs TE images, signal was observed in cortical bone and periosteum as well as in the Achilles and patellar tendons. The fascicular pattern of the tendons was clearly seen and fibrocartilage was apparent at the insertion. The difference image highlighted the short-T_2 components and increased the conspicuity of these structures. Similar results were observed in other volunteers.

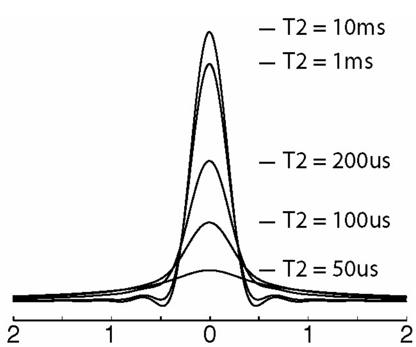

Figure 2: Simulated slice profile for 400μs -duration half-pulse.

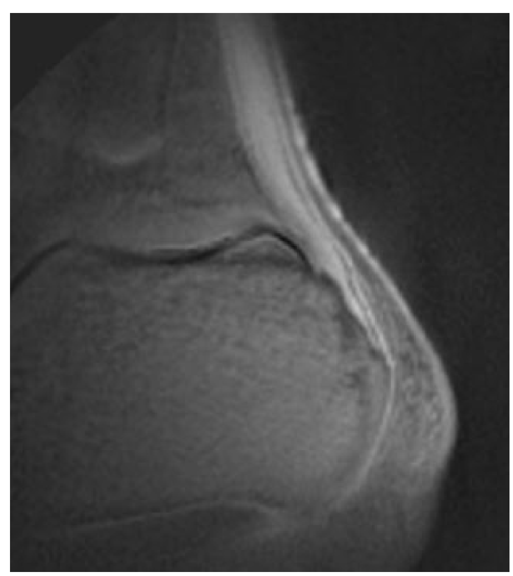

Figure 3: Difference image of Achilles tendon illustrating high-signal short-T2 components in tendon and periosteum.

Conclusion: Our UTE imaging method achieves a TE of 8 μs. This order-of-magnitude reduction in TE compared to previously reported 1.5-T implementations holds promise for imaging of very short T_2 components and provides a platform for exploration of the limits of achievable resolution when imaging such tissues.

References:
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