ZTE Imaging on a Human Whole-Body System

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Introduction MRI of short-T_2 samples is particularly effective with zero echo time, which can be achieved with 3D centre-out radial sequences in which the readout gradient is switched on before signal excitation [1-6]. The hard-pulse variant of this approach (ZTE) is shown in Figure 1. Data obtained with this scheme are slightly incomplete in the *k*-space centre due to the initial dead time Δ that is caused by the finite length of the RF pulse, transmit-receive (T/R) switching, and digital filtering. The *k*-space gap can be addressed by radial acquisition oversampling and algebraic reconstruction, involving finite support extrapolation [7, 8]. However, the gap size must be limited to approximately two to three Nyquist dwell times to avoid significant noise amplification and correlation [9]. The ZTE approach has been demonstrated to offer high resolution and signal-to-noise ratio (SNR) yield for the imaging of samples with transverse relaxation times of several hundreds of µs [6]. However, ZTE studies to-date have been limited to small-animal and microscopic applications (e.g. [10, 11]) because sufficiently fast T/R switching is not commonly feasible on human-size clinical MR systems. The switching problem can be circumvented by complementary strategies for sampling central *k*-space [12-14], which however compromises the resolution, the SNR, or the robustness against off-resonance and eddy current effects. Alternatively, in the present work we report the implementation of the full ZTE approach for human applications, relying on rapid T/R switching in the µs range.

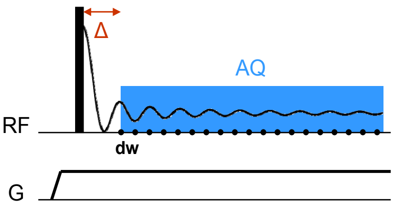

***Figure 1** ZTE acquisition scheme for one radial readout with dead time Δ and dwell time* dw

Materials The experimental setup was based on a 7 T human whole-body MRI scanner (Philips Achieva) complemented with custom-built RF transmit and receive systems. The latter included a 1 kW RF power amplifier (Bruker BLA1000), dedicated T/R switches and receive chains, as well as a separate spectrometer based on packaged ADC and FPGA components (National Instruments) [15]. Two-stage PIN-diode T/R switches were optimised to achieve high isolation between the transmit and receive ports (70 dB per stage) and high-speed switching between the two modes of operation (4.2 µs). Two different T/R-coils were employed, a commercial quadrature birdcage head coil (Nova Medical) and a custom-built proton-free surface loop coil of 12 cm diameter. The RF systems and external spectrometer were synchronised with gradient operation on the Philips system by means of a trigger line.

Methods RF hard pulses of duration 5 | 3 µs were performed with the birdcage | surface coil using 1 kW output power of the RF amplifier. After T/R switching, data was acquired with a bandwidth of 250 MHz and digitally filtered and decimated to 1 MHz using a filter of 5.3 µs total length. Corrected for group delay, the effective dead time thus amounted to 8.9 | 7.9 µs. Per 3D data set, 131170 radial acquisitions were performed with gradient strength 10.4 | 20 mT/m and a repetition time of 8 | 5 ms. ZTE images were obtained by algebraic reconstruction of 1D radial projections and 3D gridding was then used to generate the volume data set [6]. Images were reconstructed with matrix size 320 | 310 by using 640 | 780 µs of data per readout, corresponding to radial oversampling of 4 | 5, effective dwell time dw = 4 | 5 µs, bandwidth 250 | 200 kHz in the field-of-view (FOV) 562 | 235 mm, angular undersampling 2.5 | 2.3, and isotropic spatial resolution 1.76 | 0.78 mm. With respect to the reconstructed signal bandwidth the dead time was 2.2 | 1.6 dw.

Results ZTE imaging of the head of a healthy volunteer was performed using the birdcage coil. Three orthogonal slices are depicted in Figure 2. To avoid aliasing artefacts, it was necessary to reconstruct a large FOV that comprises all signal sources detected with ZTE, including parts of the RF coil, the RF cables, and the head support. The strong intensity variations in the head are due to B1 inhomogeneity as typically observed with birdcage coils at 7 T. Apart from these effects, the head is imaged with high fidelity, indicating clean T/R switching and accurate timing of the radial acquisition. As a more typical short-T_2 application, ZTE imaging of the knee of a healthy volunteer was performed with the surface coil. Figure 3 shows three orthogonal views from this data set, depicting bone, tendons, and ligaments. With this setup, no background signal was received from parts of the coil, which permits limiting the FOV to the actual region of interest. Partial coverage in this data set is due to the limited sensitive range of the single coil loop used.

Discussion Using dedicated RF hardware, the feasibility of ZTE imaging has been demonstrated in a whole-body MRI system, thus deploying the unique features of this efficient, robust, and silent technique for human applications. Initial human data illustrate the successful implementation of suitably short excitation pulses, rapid T/R switching, sufficiently short digital filtering, consistent timing, and combined algebraic and gridding reconstruction. Based on these capabilities, several routes are available for enhancing the performance of the technique. Its speed and SNR yield will benefit critically from higher-power RF transmission with dedicated transmit coils, which will permit Ernst-angle operation at short repetition times. On the receive side, separate receive arrays with provisions for rapid tuning and detuning will offer higher sensitivity and the potential of parallel imaging [16]. The capability of resolving extremely short-T_2 materials increases with the available gradient strength, for which the ZTE approach is more amenable than UTE [12] because it requires only minimal gradient switching and thus minimal reactive power from the gradient amplifiers. A general drawback of zero-echo-time methods is the need for large-bandwidth excitation and the associated increase in specific absorption rate. If critical, this issue can be addressed very effectively by choosing a lower baseline field strength, for which the methodology used in this work holds without modification.

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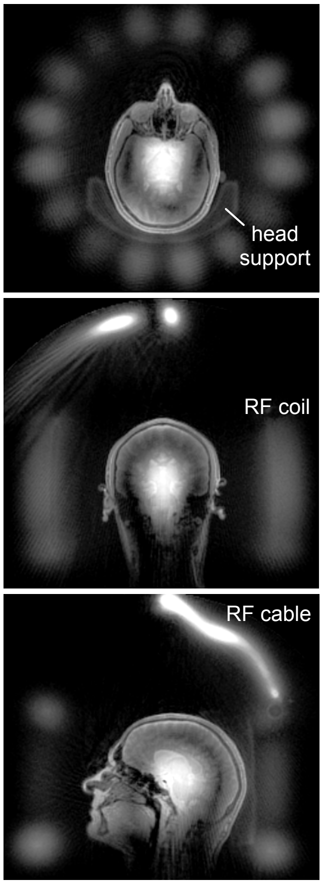

***Fig. 2** ZTE MRI of a human head*

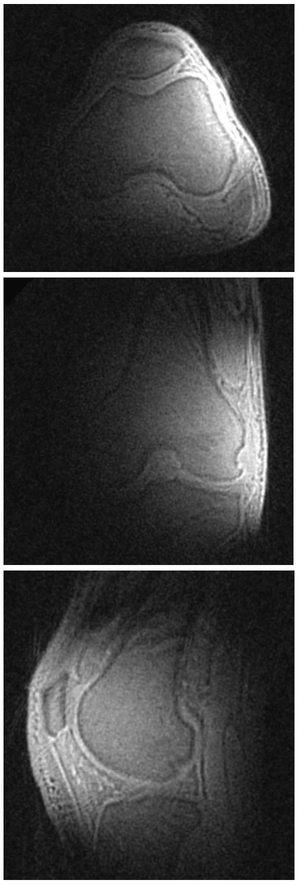

***Fig. 3** ZTE MRI of a human knee*