Ramped Hybrid Encoding for Improved Ultrashort TE Imaging

Hyungseok Jang[1,2], Curtis N Wiens[1], and Alan B McMillan[1]

[1]*Radiology, University of Wisconsin, Madison, WI, United States,* [2]*Electrical and Computer Engineering, University of Wisconsin, Madison, WI, United States*

Target Audience Researchers interested in applications of ultra-short TE (UTE) imaging in MR.

Purpose New methodologies for UTE imaging have been explored to enable MRI for imaging of objects with extremely short transverse relaxation times such as bone, ligament, or teeth. In particular, a hybrid encoding (HE) technique termed Pointwise Encoding Time Reduction With Radial Acquisition (PETRA)[1] that combines single point imaging (SPI) with frequency encoding has been explored to resolve these problems. In PETRA, central regions of k-space are acquired using SPI, while the outer k-space is measured by frequency encoding. *In this study, we propose an enhanced scheme: ramped hybrid encoding (RHE), where the gradients are ramped immediately following the application of the RF pulse to provide balance between slice selectivity/RF bandwidth limitations of PETRA[2] and encoding time, thus enhancing imaging quality, especially for species with extremely short transverse relaxation times*.

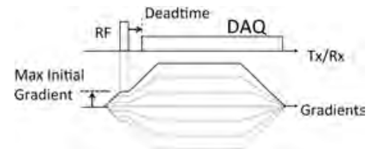

Fig 1. The Ramped Hybrid Encoding (RHE) pulse sequence is similar to PETRA with the exception of ramped gradients immediately following the RF pulse to minimize encoding time.

Methods Figure 1 shows pulse sequence diagram for RHE. In this scheme, constant amplitude gradients are applied during RF excitation (gradient amplitude can be adjusted with respect to the RF pulse bandwidth[2] thus minimizing unwanted slice selectivity). Immediately after RF excitation, gradients are ramped to obtain samples from outer k-space regions as quickly as possible. One potential limitation of RHE is the ambiguous k-space positions of measured data during gradient ramping due to system- and eddy-current-dependent distortions. To address this issue, a calibration method was developed using a rapid, low-resolution SPI encoding (61x61 2D Cartesian) in the axial and coronal planes (to obtain x, y, and z gradient calibrations). k-Space sampling locations can be recovered by reconstruction of the SPI data across multiple phase encoding time delays, where the time-dependent spatial scaling factor between neighboring time delays is linearly proportional to the k-space sampling position. Scaling factors were determined using unconstrained nonlinear optimization methods (Nelder-Mead Simplex). After obtaining the calibrated k-space trajectory, gridding reconstruction is applied to obtain final images.

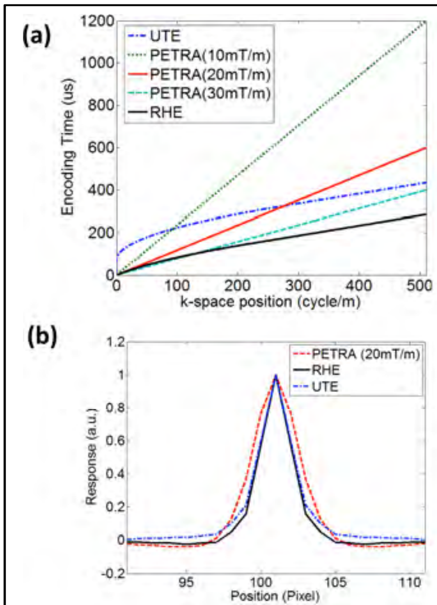

Fig 2. (a) RHE enables the shortest encoding time compared to other techniques, and (b) the most narrow PSF for resolving short relaxation time species.

Results and Discussion Figure 2-a shows the encoding time needed to measure k-space using three different methods: UTE (conventional frequency encoding), PETRA, and RHE with system parameters of G_{Max}=50mT/m, slew rate=200mT/m/ms. For UTE, trapezoidal gradients are used to ramp to G_{Max} of 50mT/m immediately after deadtime (70us). For PETRA, constant gradients with G_{Max} of 10, 20, 30mT/m are depicted, while for RHE gradients (G_{RF}) were set to 10mT/m during RF excitation and ramped to G_{Max}=50mT/m after RF excitation. As seen, RHE enables encoding that reaches the edge of k-space within the shortest time. Figure 2-b shows the corresponding PSFs for T_2*=100us. RHE outperforms UTE and PETRA in terms of spatial resolution owing to the shorter encoding time. Figure 3 shows the result of MRI experiments with an acrylonitrile butadiene styrene (ABS) plastic phantom (LEGO) and the left knee of a human subject, performed in a 3T MR scanner (GE Precision Eight T/R Knee Coil, GE Healthcare Discovery MR750, Waukesha, WI). 80,000 half-projections were acquired, with a spherical region within radius of 0.15N (N=201) was obtained using SPI. A wide-bandwidth Fermi-shaped RF pulse of 24us duration was used for excitation with a flip angle of 2 degrees. Images were reconstructed with a TE of 70us, matrix of 201x201x201, and FOV of 200mm. Scan time was approximately 3m 30s (identical for PETRA and RHE), but an additional 20s was required to obtain calibration images for RHE. Images were obtained using PETRA with G_{Max}=10, 20, 30 mT/m, and RHE with G_{RF}=10 mT/m and G_{Max}=50 mT/m. The times to reach outer k-space were 1170us, 585us, 390us (at G_{Max} 10, 20, 30 mT/m, respectively) for PETRA and 279us for RHE. As seen in Figure 3, images obtained using RHE preserve more high frequency details than PETRA. A benefit of RHE to be explored in future study is the flexibility in selecting gradient strength with respect to RF pulse shape and bandwidth limitations[2].

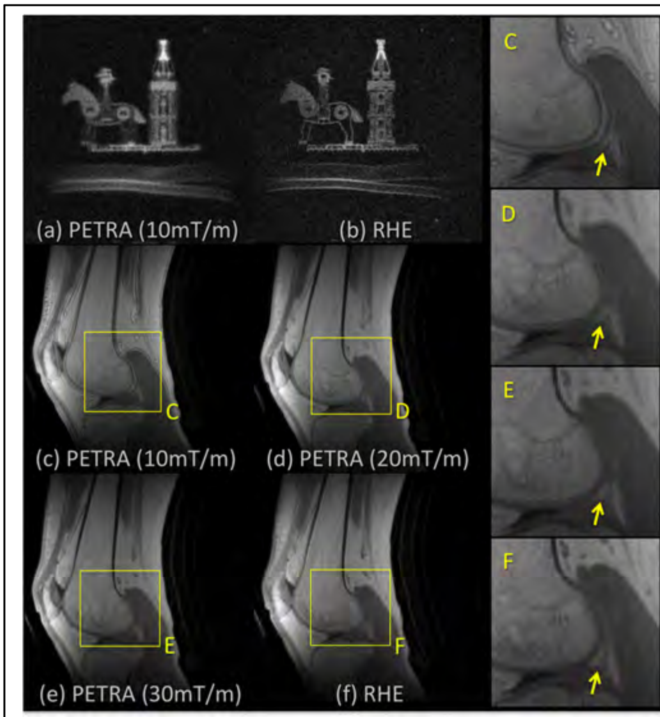

Fig 3. Reconstructed images. Spatial details are clearly improved for RHE compared to PETRA in an ABS plastic phantom [(a) vs. (b)]. Human knee images also depict improved image sharpness in RHE compared PETRA [(f) vs. (c),(d),(e)]. Note that a chemical shift artifact is apparent in PETRA with G_{Max}=10 mT/m (c).

Conclusion In this study, we have shown that HE acquisitions similar to PETRA can be optimized by the incorporation of ramped gradients. The use of an SPI calibration technique enabled estimation of k-space sampling positions to produce high quality reconstructions. RHE acquisitions reach the outer regions of k-space faster than other encoding techniques to provide improved spatial resolution.

References and Acknowledgements 1. Grodzki MRM 2012;67(2):510–8
2. Grodzki JMR 2012;214(1):61–7. We acknowledge support from NIH EB013770 and GE Healthcare.