Signal amplitude dependence on object size and shape due to T2 decay during radial k-space readout in ultrashort TE sequences: A 2D ring model.

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Introduction: The ultrashort TE (UTE) pulse sequence permits direct imaging of bone, cartilage, and other tissues with extremely short T2 relaxation times by using fast T/R switching to minimize the TE interval to as low as 8µs [1]. Due to significant T2 decay during RF excitation and k-space readout, T2 dependent signal and contrast properties are significantly different in imaging short T2 tissues with UTE, compared to imaging long T2 tissues with standard clinical sequences [2-4]. Using a 2D disk model, object size has been shown to be a key factor in determining signal amplitudes resulting from T2 decay during UTE k-space readout [4]. Due to differences in k-space representation, other changes in object shape and size are also expected to lead to significant differences in signal amplitudes. In this abstract, we report signal amplitude curves comparing 2D rings of differing dimensions. We chose to investigate 2D rings since it serves as a model for the cross sectional shape of long tubular bones, an important tissue for ultrashort TE imaging such as in UTE-based bone water quantification techniques for evaluation of osteoporosis [5-6].

Results and discussion: Signal amplitude dependence on T2 decay during UTE k-space readout can be described using a filter function in k-space, Dec(**k**), given in equation 1, where *slew* is the gradient ramp slew rate, *gmax* is the constant flattop maximal gradient strength, and $k_{ramp} = \gamma gmax^2/(4\pi \cdot slew)$ is |**k**| at the end of gradient ramp. Using Dec(**k**), the final image I(**r**) is then given by I(**r**)=FT[S(**k**)•Dec(**k**)], where S(**k**) is the k-space representation of the source object/spin density s(**r**), i.e. S(**k**) = FT[s(**r**)].

$$\mathrm{Dec}(\mathbf{k}) \equiv \begin{cases} e^{-\sqrt{\frac{4\pi|\mathbf{k}|}{\gamma\cdot slew}}\,\frac{1}{T2}} & for\ |\mathbf{k}| \le k_{ramp} \\ e^{-\left[\sqrt{\frac{4\pi\cdot k_{ramp}}{\gamma\cdot slew}}\,\frac{1}{T2}+\frac{2\pi\left(|\mathbf{k}|-k_{ramp}\right)}{\gamma\cdot gmax}\,\frac{1}{T2}\right]} & for\ |\mathbf{k}| > k_{ramp} \end{cases} \quad \text{(Eq1)}$$

We choose s(**r**) to be a 2D ring of varying inner and outer diameters (i.e. D_{in} and D_{out}), with Gaussian filtering/smoothing applied to avoid Gibbs ringing at the edges. We define signal amplitude as $M \equiv I((D_{out}/2+D_{in}/2)/2)$. The resulting effects of signal amplitude loss on I(**r**) from Dec(**k**) are shown in Figure 1A, for a ring of D_{out} = 3.0cm and D_{in}=1.0cm (roughly approximating the cross sectional dimensions of human tibia bone), with gradient parameters *slew* = 70 T/m/s and gmax = 40 mT/m. As demonstrated by the I(**r**) plots, for decreasing T2 values there is increasing signal amplitude loss in the final image of the ring. The amount of signal loss is quantified in Figure 1B, where *M* is plotted versus *T2* for the parameters used in figure 1A.

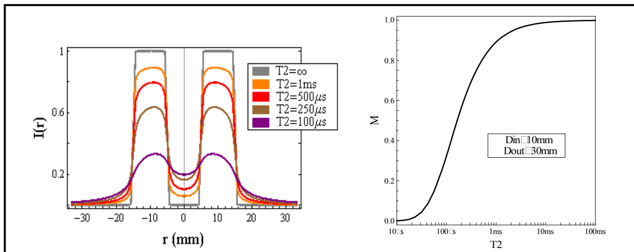

Figure 1- Signal amplitude loss in a 2D ring due to T2 decay during UTE k-space readout. A) Cross sectional plots of I(**r**) for a 2D ring with D_{out}=3cm and D_{in}=1cm at selected T2 values, with gradient parameters *slew* = 70 T/m/s, gmax = 40 mT/m. B) The amplitude *M* is plotted across a range of T2 values. Steep signal loss is observed for T2 less than 1ms, with highest contrast (slope) at T2 ~ 100µs.

To investigate how changes in shape and size affect the readout T2 decay dependent signal amplitude relationship, we examined *M* for rings of varying D_{in} from 0 to 4cm while keeping D_{out} fixed at 5cm. The resulting differences in the *M* curves are shown in figure 2A. For any given value of T2, increasing D_{in} (resulting in a lower total surface area of the ring) leads to decreased signal *M*. Highest signal amplitude is observed for D_{in} = 0cm (i.e. essentially a 2D disk with diameter 5cm), and also serves as a comparison of signal between a 2D disk with 2D rings of identical outer diameters. In figure 2B, we plot the ratio $M/M_{Din=0cm}$, i.e. the signal amplitude ratio of each ring compared to the disk with D_{in} = 0cm. This demonstrates significant amplitude differences between the various objects, including greater than 70% difference between D_{in} = 0cm and the smallest ring of D_{in} = 4cm. In figures 2C and 2D, we compare rings of varying D_{out} between 2 to 5cm, while keeping D_{in} constant at 1cm. Again, we observe significant differences in the signal amplitude *M* curves between rings of differing D_{out}, including greater than 80% amplitude difference between the ring with smallest D_{out} of 2cm and the ring of largest D_{out} at 5cm.

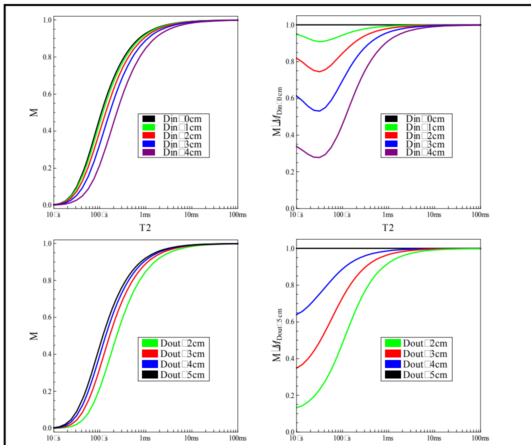

Figure 2 – Dependence of signal amplitude *M* on object shape and size illustrated by 2D rings of varying D_{in} and D_{out}. A-B) *M* and $M/M_{Din=0cm}$ versus T2 are plotted for D_{in} between 0 to 4cm and fixed D_{out} = 5cm. C-D) *M* and $M/M_{Dout=5cm}$ versus T2 are plotted for D_{in} fixed at 1cm and D_{out} between 2 to 5cm.

Conclusions: T2 decay during UTE radial k-space readout leads to significant signal amplitude dependence on T2, as evaluated above for 2D rings. Important differences are observed between rings of varying inner and outer diameters, as well as comparison to a 2D disk with similar outer diameter. These results expand previous findings of signal amplitude dependence on size in 2D disks [4], and demonstrate a general dependence on object shape and size. Additionally, the results obtained provide a quantitative model of expected T2 dependent signal amplitude relationships when imaging tubular bones in cross-section.

References: [1] Tyler, et. al., JMRI. 25:279-289 (2007) [2] Rahmer, et. al. MRM. 55:1075–1082 (2006) [3] Carl, et. al. MRM. 64:481-90 (2010) [4] Chiang, et. al. ISMRM 18:5127 (2010); [5] Techawiboonwong, et. al. Radiology. 248:824-33 (2008); [6] Du, et. al., JMR.207:304-11 (2010).

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