Image Resolution and SNR in 2D Radial Ultrashort TE Imaging

M. Bydder[1], J. Du[1], A. Takahashi[2], M. D. Robson[3], and G. Bydder[1]

[1]Radiology, University of California, San Diego, CA, United States, [2]GE Healthcare, Menlo Park, CA, United States, [3]Oxford University, United Kingdom

Introduction With radial sampling the nominal pixel size Δr is inversely dependent on the sampled radius of k-space, $\pm k_{max}$ rad m^{-1}, and may be calculated from the gradient G and the readout acquisition time T_{AQ},

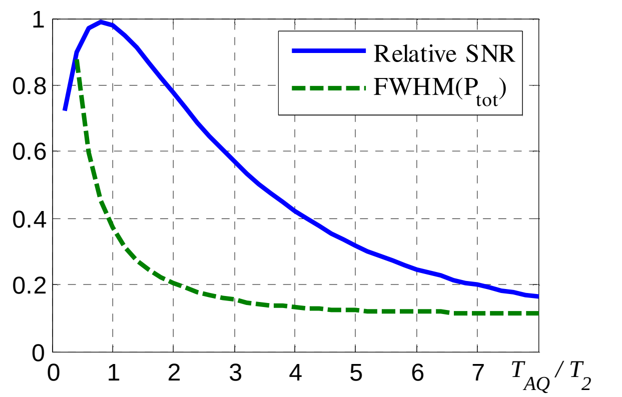
$$\Delta r = 2\pi / \gamma G T_{AQ} \text{ m} \quad [1]$$

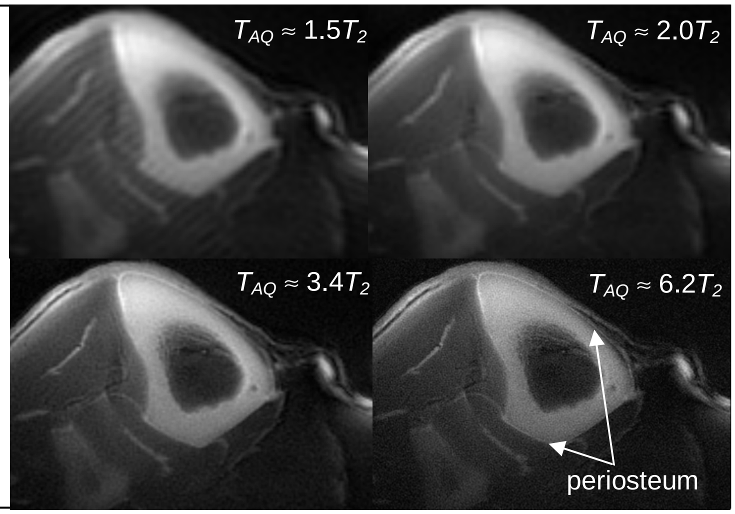
where gyromagnetic ratio $\gamma = 2.675 \times 10^8$ rad s^{-1} T^{-1} for proton (1). Although Δr defines the unit length in the image, it is only as an indicator of the resolution as other factors also contribute, such as the trajectory used to sample k-space and T_2 decay during the acquisition. 2D center-out radial sampling gives rise to a sinc-like PSF (P_{sv}) with a FWHM of 1.41 and T_2 decay gives rise to a Lorentzian-like PSF (P_{dec}) with a FWHM of 0.49 T_{AQ}/T_2, where units are in Δr (2). The total PSF (P_{tot}) is the convolution $P_{sv} \otimes P_{dec}$.

$$P_{sv} = 2\, J_1(k_{\max} r)/k_{\max} r \quad \text{and} \quad P_{dec} = 2\left(T_2/T_{AQ}\right)^2 \Big/ \left(1 + \left(k_{\max} r\, T_2/T_{AQ}\right)^2\right)^{\frac{3}{2}} \quad [2]$$

For a fixed k_{max} the standard deviation of the measurement noise is inversely proportional to sqrt(T_{AQ}). Thus an elegant measure of the SNR can be defined by the product of the peak amplitude of P_{tot} and sqrt(T_{AQ}) (2). Figure 1 shows that this SNR measure passes through a maximum at $T_{AQ} = 0.81 T_2$.

Fig 1: Relative SNR and pixel resolution *vs* T_{AQ}
Fig 2: Bone ($T_2 \approx 365\mu s$) images at different T_{AQ}





However, because the maximum gradient amplitude is limited by hardware, the attainable resolution is also limited. With $G = 40 \times 10^{-3}$ T m^{-1} and $T_{AQ} = 0.81 T_2$, the nominal resolution can be calculated from Eq 1.

$$\Delta r \approx 0.72 \times 10^{-6} / T_2 \text{ m} \quad [3]$$

The actual resolution is given by FWHM(P_{tot}) $\approx 1.1 \times 10^{-6} / T_2$ m. This is 3.8 times the theoretical minimum imposed by T_2 - induced blurring, i.e. FWHM(P_{dec}) . With a T_2 of 500 µs the actual resolution is more than 2 mm, which is significant compared to the structures of clinical interest for ultrashort TE (UTE) imaging (3).

To attain better resolution the acquisition time must be increased by increasing k_{max} in proportion to T_{AQ}. Different criteria can be used to choose k_{max} and T_{AQ}; a simple heuristic is to require that FWHM(P_{dec}) = FWHM(P_{sv}), which entails $T_{AQ} = 2.88 T_2$. Here the SNR is 0.6 times the maximum and FWHM(P_{tot}) is 1.4 times the theoretical minimum. Alternatively, maximizing the product of SNR and FWHM(P_{tot}) leads to $T_{AQ} = 1.50 T_2$. Here the SNR is 0.9 times the theoretical maximum and FWHM(P_{tot}) is 2.3 times the theoretical minimum. Deciding upon a suitable T_{AQ} is challenging in clinical imaging. The trade-off between SNR and resolution is illustrated in Figure 2, which shows UTE images acquired on a GE Twinspeed 3T scanner at various T_{AQ}. A TE of 8 µs, bandwidth 31 kHz, matrix of 512^2 and 891 radial spokes were used.

Discussion The readout duration and gradient amplitude control the trade-off between SNR and resolution in UTE imaging. The optimal SNR is obtained with short T_{AQ} however this also restricts the attainable resolution. Increasing T_{AQ} may be necessary to depict thin structures such as the periosteum.

Refs (1) McRobbie, Moore, Graves, Prince. In: MRI From Picture to Proton. Cambridge University Press 2003 pp. 212 **(2)** Rahmer, Bornert, Groen, Bos. Three-Dimensional Radial Ultrashort Echo-Time Imaging with T2 Adapted Sampling. *Magn Reson Med* 2006;55:1075 **(3)** Robson, Gatehouse, Bydder, Bydder. Magnetic Resonance: An Introduction to Ultrashort Echo-Time Imaging. *J Comput Assist Tomogr* 2003;27:825