Seeing is believing: Magnetic Resonance Imaging at ultra short echo time

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Authors: G. Liney, A. Xing, L. Holloway, B. Schmidt; LIVERPOOL/AU
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Aim

Magnetic resonance imaging conventionally operates with an echo time (TE) of between 4 ms (short) and 200 ms (long) which means tissues and materials with extremely short T2 relaxation times, such as cortical bone and plastics, are invisible on routine clinical images.

Recently developed ultra-short echo time (UTE) sequences are able to achieve the shortest possible TE from the MRI scanner, limited only by transmit/receive switching times and gradient performance, with no additional hardware requirements. These sequences typically acquire signal immediately after the RF pulse using ramp sampling of the gradients or even with the gradients already on. 3D radial acquisition and reconstruction is also employed.

UTE sequences may offer the following advantages for MR-based radiotherapy planning:

1. the increased visualisation of cortical bone should improve registration of bony anatomy in MR-CT planning,
2. improved mapping of this highly attenuating material should improve dosimetric accuracy for MR-only planning, and
3. on real-time MR-Linac systems it may be crucial to identify the RF coil present in the beam path so that its attenuation may be accounted for.

The aim of this work was to evaluate two new UTE research sequences (called UTE and PETRA) and demonstrate their proposed use for RT planning.

Methods and materials

All imaging was performed on our dedicated MR-simulator which is a 3.0 Tesla wide bore Skyra system (Siemens) located in the Liverpool cancer therapy centre and used exclusively for radiotherapy patients and associated research. This is a 64 channel system with XQ gradients.

Two new 3D isotropic sequences were tested; ultra short echo time (UTE) and point-wise encoding time reduction with radial acquisition (PETRA). The PETRA sequence offers shorter encoding times compared to UTE. The shortest TE used for both sequences was 40 µs, which in the case of UTE was achieved by altering the RF duration and delay times. Other parameters of interest were the number of radial views and number
of compressed channels, both of which effect the image quality but also the amount of data reconstruction.

A quality assurance phantom was constructed in order to evaluate image quality over the range of ultrashort TEs (40 µs up to 1 ms). This consisted of small samples of material expected to produce rapidly decaying signal: concentrated NiCl₂ solution, gadoteric acid and adhesive putty.

Next, a porcine specimen was cut in half and imaged using a 20 channel head & neck RF coil to examine the appearance of cortical bone. Subtraction of a second short echo (4.9 ms) was employed to reduce long T₂ signal in the other soft-tissues.

Finally, a cylindrical doped-water phantom was imaged using a 4 channel flexible coil with a large FOV in order to include any signal from the coil housing and assess the ability to demonstrate its position.

Image quality in all cases was assessed in terms of SNR, visualisation of the examined structures and presence of any artefacts.

**Results**

Example images acquired as part of the study are shown in Figures 1-6.

In Figure 1, a set of UTE images acquired using the quality assurance phantom are shown with TEs ranging from 0.04 ms (40 µs) to 3.8 ms. Three small samples of materials can be seen on top of a cylindrical test object. These materials exhibit signal which decays quickly and has vanished by the 4th, 5th and 6th images which correspond to (left to right) gadolinium, adhesive putty and concentrated NiCl₂ respectively. A cod liver oil marker is present in all these images. Figure 2 shows images of the same phantom acquired with the PETRA sequence. At TE = 0.04 ms there was significant edge blurring, loss of signal and presence of artefacts which were completely resolved (right) by increasing the TE to 0.06 ms.

An example taken from the porcine bone imaging is shown in Figure 3. The subtracted image shows the structures of cortical bone, endosteum and periosteum with SNR= 38 in the cortical bone.
Figures 4-6 demonstrate the ability of UTE to visualise the RF coil with SNR >13. Acquisition time for these two images was 4 minutes (Figure 4) and 6 mins 42 s (Figure 6) according to the different number of radial spokes. In Figure 6 the signal from the coil has been segmented and rendered in 3D so that the positions of the individual coil elements can now be seen.

**Images for this section:**

![Fig. 1: (left to right, top to bottom) Images of the UTE QA phantom acquired at TE= 0.04, 0.08, 0.2, 0.5, 1 & 3.8 ms.](image-url)
Fig. 2: Example of artefacts seen with PETRA at TE = 0.04 ms (left) that were not present at 0.06 ms (right).

Fig. 3: Porcine bone specimen (left to right) at TE = 0.04 ms, 4.9 ms and the subtracted image.
**Fig. 4:** Phantom and RF coil imaged at TE = 0.06 ms with 0.9 mm isotropic resolution and 25,000 radial views.
Fig. 5: Image with TE = 0.04 ms, 1.4 mm resolution and 40,000 radial views.
**Fig. 6:** 3D rendering of the post-processed data from Figure 4 in which the water phantom has been removed.
Conclusion

This study demonstrates the feasibility of using ultrashort TE imaging to visualize both cortical bone and the RF coils used in the image acquisition. This may have significant benefit in MR based radiotherapy planning and warrants further investigation in vivo.

Initial results have shown that the PETRA sequence is prone to more artefacts, especially at 40 µs. This may be related to the switching interval required by the RF coil, although these issues were not observed with the UTE sequence and the same coil.

We have recently been granted local ethics approval to conduct volunteer studies which will begin later this year.

Personal information

References
