Course: Methods En Vogue-How Have They Fared Over Time?

Ultra-short Echo Time (UTE) imaging

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Highlights:

- UTE helps to visualize signal which is usually invisible in conventional MRI
- Many interesting research applications are conceivable, but UTE is not really clinical yet

Target audience: – MR engineers, scientist and physicians with interest in learning more about basic UTE MRI

Outcome/Objectives: To be able to understand the basic principle of ultra-short TE imaging, its problems and limitations but also its prospects for the future and the needs to prove.

Purpose: The shortest possible echo time in conventional MRI is limited to the millisecond range. Therefore, conventional clinical MRI is blind to fast T2 relaxing species. Ultra-short TE (UTE) imaging is a class of MRI techniques aiming at the direct imaging of these signals to obtain new diagnostic information.

Methods & Results:

Protons in highly ordered structures like muscular-skeletal tissue and protons attached or bound to proteins or solids, like bone, teeth, etc. show very short T2 relaxation times down to less than hundred microseconds (1). Usually, these types of tissues appear as signal voids in conventional MR imaging and are not directly visible. UTE imaging is a new and promising approach that allows detection of those short-T2 signal components.

As every MR experiment, which comprises of signal generation, signal evolution and signal detection in UTE imaging all three are made very short and signal evolution which is in conventional MRI the phase encoding step is merged with the signal detection. Therefore, in UTE only two basic blocks have to be considered (signal excitation and signal detection).

Signal excitation -RF excitation pulses act differently on very short and long T2 components. While a given RF pulse affects magnetisation for long T2 components, very short components are quickly loosing coherence (T2 relaxation) and are not sufficiently excited (2) resulting in a signal loss for these components already from the beginning. This means that each RF pulse applied to a spin system exhibits a certain filter characteristic for the T2 components to be imaged (3). Therefore, to obtain signal from very short T2 components very short RF pulses (in the order of the shortest T2) should be used. This is often feasible in 3D imaging, employing a non-selective block excitation RF pulse but more complicated in slice selection for 2D imaging. Pauly et al. (4) proposed to split a usual slice selective Sinc-shaped RF pulse into two halves, each applied in two separate experiments using a selection gradient of opposite sign and adding the resulting MR data. Thus, slice selection is achieved without the need of a slice refocusing gradient facilitating short TE sampling. However, due to gradient system imperfections and timing issues these RF pulses are very demanding and extensive trimming is often necessary.

Signal sampling -UTE imaging is usually performed by acquiring the free-induction decay (FID) signal shortly after RF excitation. No phase encoding gradient, as used in conventional Fourier imaging, is applied to keep T2 related signal decay as small as possible. Thus, k-space is traversed on radial or short spiral trajectories in a centre-out mode. If applied in combination with slice selective UTE excitation (4) 2D imaging can be performed. More common is 3D UTE imaging and there are, among others, two basic approaches in broader use employing 3D radial FID sampling yielding isotropic spatial resolution (5,6). In the first, the read-out gradient is switched almost immediately after the RF pulse and sampling is performed already during read-out gradient ramping (7) while in the other, the read-out gradient is already present while RF is applied (8). The latter approach samples more time efficiently but might have a missing data problem in the centre of k-space due to finite transmit/receive switching, which can be solved by algebraic reconstruction or other means. Due the reduced gradient switching needs, this scheme can be interesting for silent MRI applications. In all these schemes fast switching of the RF system and short acquisition-windows are essential for imaging short-T2 components. A long sampling window in conjunction with a low sampling bandwidth usually helps to maximise the SNR. However, due to the T2 signal decay during sampling signal blurring occurs which spoils the spatial resolution for the fast relaxing components (7).

Contrast manipulations -The signal T2 relaxation during RF pulses has also implications for all kind of magnetisation preparations to tailor contrast. Complete spin inversion for short components is difficult to achieve using conventional RF pulses. Different magnetisation preparation approaches have been proposed for long T2 suppression to selectively visualise the ultra-short components (3). A multi-echo acquisition, subtracting short-TE and long-TE (water/fat in-phase) signals appropriately could be an alternative.

Discussions:
UTE is currently used in many diverse fields of MR research. In muscular-skeletal approaches one tries to characterise ligaments, bones, parts of the cartilage and surgery outcome. Those applications are among all the others closest to potential clinical use, but did not make it yet there. Bone visualisation might potentially become also important in radiation therapy treatment planning and PET/MR attenuation correction to estimate photon attenuation. Other related areas are also of very investigational nature like the imaging of teeth. UTE has been applied to study the brain in particular demyelisation. Other body parts including the lungs, neglected in the past, are getting more into research focus.

Conclusions:
However, UTE did not really make it into clinical practice yet, although focussing on the more robust 3D approaches. More effort, work and robustness are needed to make this happen.

References:
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