Rapid 3D T1 Mapping

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Introduction
The measurement of T_1 values remains an important technique in clinical MRI research. In particular there is current interest in changes in T_1 in multiple sclerosis (MS) and clot formation in vascular disease. Both require T_1 maps with high spatial resolution, the data for which must be acquired within a short enough duration to make clinical scanning practical. Current fast T_1 mapping techniques involve rapid acquisition of multi-slice 2D images and mostly utilize slice selective inversion or saturation recovery pulse sequences. Such multi-slice 2D techniques are limited by -

1. A larger voxel dimension in the through-slice direction compared to in-slice resolution.

2. Imperfect slice excitation profiles. These affect both T_1 values and cause partial volume effects in the through-slice direction.

3. Slice-selective inversion RF pulses. In- and out-flow from a slice, from blood and to a lesser extent CSF, will affect T_1 values if slice selective RF inversion pulses are used, especially for longer inversion times (TI). Non-selective inversion pulses overcome the majority of inflow effects as flowing blood is inverted outside as well as in the slice, but do not lend themselves to traditional rapid 2D multislice acquisitions.

A rapid 3D FLASH sequence utilizing a non-selective RF inversion pulse has been developed and implemented to overcome these problems. Cubic voxels may be obtained with effectively 'square' slice profiles. As only one thick slice is excited, all partitions within it effectively experience the same TI from the non-selective inversion pulse, which in turn reduces the effects of flow. The accuracy of T_1 values calculated was checked using a calibrated phantom. It has been successfully used to measure T_1 maps on 30 MS patients to date.

Methods
The rapid 3D FLASH sequence was implemented on a 1·5 T Siemens Vision MR scanner. For each through-plane phase encoding line, a non slice-selective adiabatic RF inversion pulse was applied followed by a TI delay and then all the in-plane phase encoding slice-selective FLASH readout lines. After a TR delay, the process was repeated for the next through-plane phase encoding line. The in-plane phase encoding lines were centrically reordered, acquiring the centre of k-space first. This reduces the T_1 effects of repeated FLASH lines on the inversion recovery curve[1] and helps to ensure that the contrast in the image depends mainly on the actual TI set. It also allows images with shorter TI's to be acquired compared to non-centrically reordered FLASH. In-plane phase encoding was performed most rapidly as it usually contains more steps than through-plane phase encoding. Therefore, the total acquisition time depends primarily on the number of 3D partitions.

The sequence parameters were 256x256 matrix, TR (per FLASH line) 5·8 ms, TE 3·0 ms, bandwidth per pixel 488 Hz, flip angle 10°. For MS patients, data were acquired in the brain with 1x1x4 mm voxels, 24 3D partitions and a TR (per 3D partition) of 5000 ms, resulting in a total acquisition time of two minutes. This was repeated with seven different TI values and volume T_1 maps calculated using non-linear Marquardtian curve fitting.

3D volumes were also acquired through the neck of a patient with a clot in their carotid artery using a receive-only neck RF coil. The same imaging parameters were used except that the voxel dimensions were 1x1x1 mm.

A calibrated T_1 phantom (TO5, MagNet, Imperial College, London, UK) was imaged using this technique. T_1 values in the phantom ranged between 300 and 1500 ms.

Results
T_1 maps of the calibrated TO5 phantom were calculated using the 3D sequence, with a mean absolute difference of 2·8% (standard deviation 2·8%) from the calibrated values. Routine high quality volume T_1 maps of the brains of MS patients were acquired in 15 minutes and are currently the subject of further analysis. A typical slice from a T_1 map of the brain is shown in Figure 1. Figure 2 shows an axial T_1 map through a patient's neck. Low T_1 is seen in the clot in the patient's right carotid artery (arrowed, on the left of the image) adjacent to high T_1 blood.

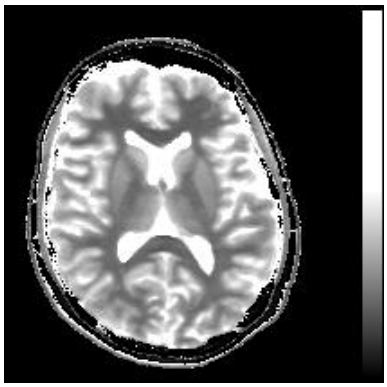

Figure 1. Typical T_1 map of the brain produced using the 3D sequence. The grey scale bar spans T_1 values from 20 to 3000 ms.

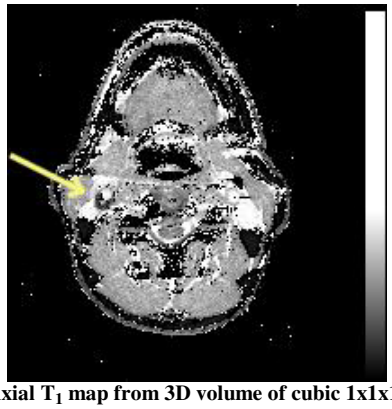

Figure 2. Axial T_1 map from 3D volume of cubic 1x1x1 mm voxels showing short T_1 signal from clot in the patient's right carotid artery (arrow). Grey scale bar spans T_1 values from 20 to 3000 ms.

Discussion
A rapid, centrically reordered 3D FLASH sequence utilizing a non-slice-selective inversion pulse has been implemented to acquire data for high quality volume T_1 maps on a clinical scanner. The total acquisition time depends on the number of 3D partitions acquired. The sequence design removes the problems associated with most other 2D multi-slice T_1 mapping techniques, such as in-flow and slice profile effects, and as such does not require complex post-processing to calculate accurate T_1 values.

References
1. A.Jivan *et al.* J. Magn. Reson. **127**:65-72. (1997)