Accelerated Mapping of T1 Relaxation Times using TAPIR

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Introduction
Fast and accurate T_1 mapping of the human brain provides many opportunities for diagnostic use. For example, it has been shown that T_1 values differ in the globus pallidus, the caudate nucleus, and the posterior limb of the internal capsule of patients suffering from hepatic encephalopathy, a liver disease with neuropsychiatric consequences [1]. The TAPIR sequence [2-5] is a distortion free and accurate method to acquire high resolution T_1 maps with an in-plane resolution of 1mm but without any acceleration it is too slow for clinical use for whole brain coverage. It has been shown that the accuracy of T_1 measurements using a Look-Locker sequence can be increased through the use of an adiabatic fast passage (AFP) inversion pulse [6].
TAPIR is an extremely flexible Look-Locker sequence that allows choices to be made regarding coverage and number of time points acquired on the recovery curve. We have implemented and investigated a more accurate and faster version of the TAPIR sequence using adiabatic fast passage inversion pulses, parallel imaging and a segmented EPI readout which is an integral feature of TAPIR.

Methods
All experiments were performed on a 3 Tesla Siemens Tim-Trio System using a body coil for transmission and a 12 channel head-array for reception of the signal (Siemens Medical, Erlangen, Germany). The inversion pulse is a hyperbolic secant and its amplitude and phase are modulated with $amp = \mathrm{sech}(\beta u)$ and $phase = \mu \log(amp)$ with $\beta = 4.5$ and $\mu = 5$. Further, parallel imaging was implemented with external acquisition of GRAPPA reference lines prior to the TAPIR sequence. GRAPPA reconstruction was performed using the standard software provided by the MR scanner. An inversion efficiency (IE) measurement, as needed when using rectangular inversion pulses, is not necessary when using the AFP pulse because it results in a very good inversion. [6]
The total acquisition time without acceleration for a T_1 map with volume coverage of 4 slices with a slice thickness of 4 mm is about 17 minutes (TR=12ms and 40 time points (TP), FA=25º, BW=720Hz/Px) and additional 4 minutes for an inversion efficiency measurement using an EPI factor of 5 (4 slices, TR=12ms, FA=25º BW=720Hz/Px). Using parallel imaging with an acceleration factor of 2 and an EPI-factor of 5 the total acquisition time can be reduced to 2 minutes. This results in an effective total acquisition time of 30 seconds per slice.
Increasing the number of slices to 7 and decreasing the number of time points to 25 results in nearly the same total acquisition time while the results do not suffer much from the lower number of time points [7]. This results in an effective total acquisition time of 17 seconds per slice.
The influence of adiabatic inversion as well as the acceleration of the acquisition (EPI and/or parallel imaging) was experimentally investigated. T_1 mapping was performed on a healthy volunteer and a so-called "revolver phantom" comprising 6 tubes filled with distilled water that was doped with different concentrations of GdCl3. For the phantom measurements, TAPIR results were compared to the gold standard spectroscopic inversion recovery measurements.

***In Vitro* Results**
As can be seen in Table 1, the T_1 values measured with an adiabatic fast passage inversion pulse are more accurate than the T_1 values measured with a rectangular inversion pulse. The parameters used were: single slice with a thickness of 4 mm, TR=12ms, 128 time points, BW=720Hz/Px, FA=25º.

SPECT T1 [ms]	T_1 using rect. inversion [ms]	T_1 using AFP [ms]	T_1 using AFP and EPI5 iPAT 2 [ms]
1349	1499 ± 87	1365 ± 55	1365 ± 59
838	828 ± 24	827 ± 16	824 ± 21
631	594 ± 12	601 ± 9	617 ± 13
490	489 ± 11	490 ± 7	493 ± 8
400	402 ± 9	405 ± 6	408 ± 7
339	329 ± 7	338 ± 4	340 ± 5

Table 1: Phantom results: spectroscopic T_1 measurements versus the different TAPIR results in six differently doped tubes

		Slice 1 T_1 [ms]	**Slice 4 T_1 [ms]**
rectangular	**WM**	824 ± 42	817 ± 41
	GM	1089 ± 113	1082 ± 117
AFP	**WM**	828 ± 37	815 ± 37
	GM	1095 ± 111	1081 ± 116
EPI5 iPAT2	**WM**	820 ± 34	815 ± 34
	GM	1093 ± 112	1083 ± 116

Table 2: In vivo results: T_1 values and the standard deviations of GM and WM of the human brain in different slices measured with the TAPIR sequence with a rectangular inversion pulse and an IE measurement compared with T_1 values measured with AFP and with accelerated methods in ms.

***In Vivo* Results**
The measured T_1 values for WM and GM of the human brain are listed in Table 2. In general, the segmented EPI readout and parallel imaging have little influence on the accuracy.

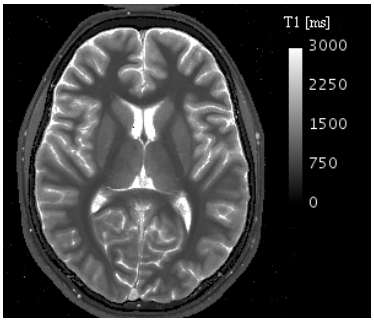

Figure 1: Representative T_1 map of a human brain in ms

Discussion and Conclusions
For a given set of parameters, it is possible to acquire high resolution T_1 maps with volume coverage of 4 slices in about 2 minutes instead of 21 minutes (17 minutes plus additional 4 minutes for the IE measurement) using an EPI readout and parallel imaging without a noticeable degradation of the T_1 results. We have demonstrated that the accuracy of the T_1 mapping procedure is increased when using an adiabatic fast passage inversion pulse instead of a rectangular pulse, even if we use an EPI factor of 5 and parallel imaging with an acceleration factor of 2. The standard deviations are between 1% and 5% which is in the same range as the ones for other methods described in the literature [6]. This technique offers the possibility to acquire accurate and distortion-free T_1 maps of the human brain in a short acquisition time.

References
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