Multi-Channel Line-Sharing for Rapid T1 Mapping: Application to TAPIR

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INTRODUCTION: T_1 mapping with partial inversion recovery (TAPIR) is a novel sequence which enables high-resolution, multislice T_1 relaxation-time mapping [1-3]. TAPIR is a Look-Locker-based T_1 mapping approach based on a partial inversion recovery scheme which is typically faster than traditional inversion recovery based methods. The accuracy and precision of TAPIR to measure T_1 are high, but a reduction in the acquisition time is required to allow for T_1 mapping in clinically acceptable measurement times. Therefore, a scheme termed multi-channel, line-sharing is introduced here as modification of the traditional full *k*-space sampling scheme in TAPIR. In the new approach, the central *k*-space region (the keyhole) is fully sampled whereas the high-frequency *k*-space region in the phase-encode direction is undersampled. In order to avoid fold-over artefacts, missing *k*-space lines are reconstructed using linear interpolation of the corresponding lines acquired for the neighbouring time-points on the T_1 relaxation curve. The method is generally applicable to any mapping scheme acquiring the full *k*-space and is fully compatible with parallel imaging.

METHODS: *In vivo* data of a single healthy volunteer were acquired on a 4T system using TAPIR. The sequence parameters were: TR=15 ms, TE=2.5 ms, BW=700 Hz/Px, τ=2000 ms, α=40°, TI=10 ms, 14 slices, slice thickness=2 mm, FOV=256 mm x 256 mm, EPI factor=1 and time-points=20. The matrix size was 256x256. An 8-channel phased-array receive coil was used and the *in vivo* data were acquired from each of the 8 channels. The multi-channel, line-sharing method was performed in using Matlab for each of the single-channel *k*-spaces as follows: the high frequency part of *k*-space was undersampled by omitting every second line while fully sampling the keyhole which comprises one-eighth of the full *k*-space. As multiple time-points on the T_1 relaxation curve are sampled in TAPIR, omission of lines is performed in an interleaved way. For odd time-points (1, 3, …), even lines (2, 4, …) of *k*-space were omitted whereas that scheme was reversed for even time-points (see Fig. 1) i.e., lines 1,3,5, .. were sampled for the first acquired time-point on the relaxation curve while lines 2, 4, 6, .. were acquired for the second time-point. For each time-point, except the first and the last, the complex valued *k*-space data for the omitted lines were linearly interpolated using the complex-valued data of the corresponding lines from the preceding time-point and the succeeding time-point as shown in Figure 1. The omitted lines of the last time-point were substituted from the corresponding lines of the second last time-point. Correspondingly, omitted lines at the first time-point were substituted from the corresponding lines of the second time-point. The resulting data from each of the 8 channels were Fourier transformed resulting in the reconstruction of so called line-shared images. For each time-point, the line-shared images from each of the 8 channels were combined by using the sum-of-squares algorithm. Those were used to calculate the line-shared T_1 map. There were no visible fold-over artefacts in the combined line-shared images and line-shared T_1 map. In addition, the original T_1 map was reconstructed using the original data without line-sharing. All T_1 maps were obtained using an in-house tool based on the Levenberg-Marquardt algorithm. The relative difference between the original T_1 map and the line-shared T_1 map was calculated. Based on the relative difference image, average difference values for different ranges of T_1 were determined.

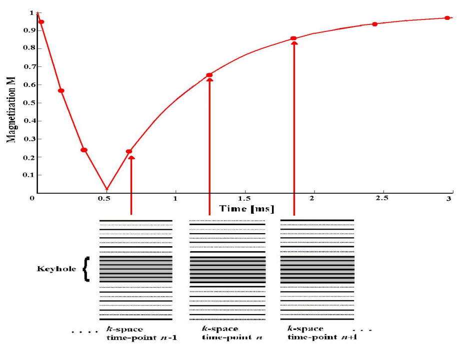

Fig.1.

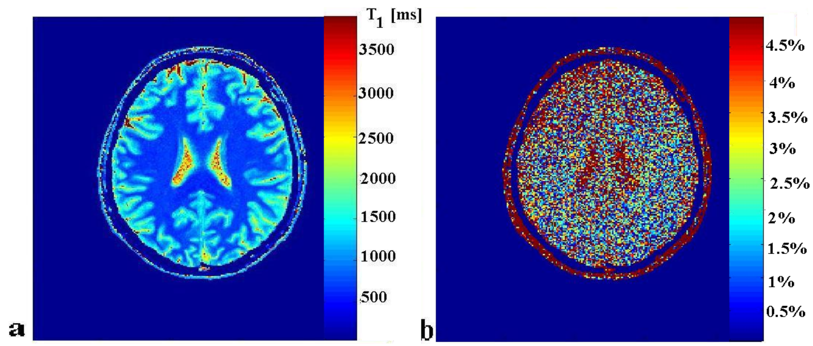

Fig.2.

Fig.1. Schematic representation of the line-sharing concept. The skipped phase-encode lines are shown as thin lines whereas the acquired phase-encode lines are shown as thick lines at the time-points n-1, n and n+1.

Fig.2. a: A representative line-shared *in vivo* T_1 map. b: Relative difference map between the line-shared T_1 map and the original T_1 map of the same slice as shown in (a) Average differences values higher than 5% were clamped to 5%.

RESULTS: A representative line-shared T_1 map of a slice is shown in Figure 2a. The relative difference between line-shared T_1 map and original T_1 map is shown in Figure 2b. For most voxels, the relative difference remains below 3%, with the exception of the ventricles. This is also confirmed by the results shown in Table 1 which demonstrates that the relative systematic error of T_1 due to the line-sharing approach is well below 1% for grey and white matter even at 4T.

DISCUSSION and CONCLUSIONS: The proposed trajectory inherently samples the centre of *k*-space densely at each time-point such that the central *k*-space, the keyhole, satisfies the Nyquist sampling rate. The rest of the *k*-space is sparsely sampled. The skipped *k*-space lines are linearly interpolated by using the preceding and succeeding time-points. This method has the potential to reduce the total acquisition time by 40%. The reconstructed line-shared T_1 maps exhibit high quality without visible artefacts. As the additional systematic error for most brain tissue (i.e. grey and white matter) remains significantly below 1%, the proposed line-sharing approach offers the possibility to significantly accelerate the measurement without introducing additionally significant error components. The method is generally applicable to relaxation time mapping techniques be they T_1, T_2, or T_2*. Further, given the acquisition of a keyhole, the line-sharing method is fully compatible with parallel imaging whereby a further reduction in the number of peripheral lines could be achieved. The precision of the method for T_1 mapping is expected to increase with increasing field (longer T_1), where the interval of highest variation – and thus highest error for interpolation - on the relaxation curves is sampled with a larger number of points.

Range of T_1 Values (ms)	Percentage Difference (%)
$500 \le T_1 < 1000$	0.26
$1000 \le T_1 < 1500$	0.32
$1500 \le T_1 < 2000$	0.36
$2000 \le T_1 < 2500$	2.81
$2500 \le T_1 < 3000$	1.22

Table.1. Average difference between line-shared and original T_1 map for different T_1 ranges.

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