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T₂*-mapping of the mouse brain at 7T with a 3D Multi Gradient Echo Sequence.

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Introduction

Quantitative T₂* MRI is commonly used in human for analysing iron deposition in the heart or liver and also in the brain after a stroke [1]. Measuring T₂* in mouse brains may therefore be of interest in assessing pathological models or innovative treatments directed against these pathologies. However, reproducibly T* mapping in small animal brains remains a challenge. Indeed, it is necessary to obtain parametric maps with high spatial resolution (<150µm) and in 3D. Acquisitions are generally carried out at high magnetic fields, which has the effect of increasing susceptibility and generating T₂* long acquisition times generate potential resonance frequency drift and hence artifacts on the parametric maps. The aim of our work is therefore to propose a Multi Gradient Echo (MGE) sequence combined with a robust fitting method to obtain highly resolved 3D T₂* maps on mouse models. Acquisitions were performed first ex vivo and then in vivo on C57Bl/6 and BALB/c models.

Methods

Materials: Experiments were performed on a 7T Bruker BioSpec system equipped with a volume resonator (75.4mm inner diameter, active length 70mm) for excitation, and a 4-element (2×2) phased surface cryoprobe for signal reception.

Ex vivo Brain images: Brains were extracted and incubated (N=5) or not with Gd-DOTA (3mM) (N=5), then placed in a plastic tube. The brain was installed at the center of the MR coil.

In vivo Brain images: Mice (N=5) were anesthetized with isoflurane (1.5-2% in air) and positioned with the brain at the center of the MR coil. Animal breathing and temperature were monitored during the scanning session and maintained at 60-90 resp/min and 37°C±0.8.

Sequence: A 3D monopolar Multi-Gradient-Echo sequence was used with parameters describe in Table.1. A drift compensation module was added every TR before the acquisition and enabled to reset the acquisition frequency in real-time.

T₂* mapping: The data were reconstructed with Julia using the package MRIReco.JI [2], Specific masks covering the whole brain were designed with 3D Slicer, For the T₂* calculation, 3 fitting models have been tested: the offset model, the truncation model and the second moment noise model (M²NCM) p]. The offset model adds a free parameter to the Bloch equation to represent the contribution from iron-poor species and noise. The truncation model tries to minimize the impact of the noise by fitting the data with high Intensity only: It consists of removing the last echo, one by one, until the R² Is high enough. The second moment noise model takes Into account the non-central chi distribution of the multichannel gaussian noise. All the curve fits were perform using a Levenberg-Marquardt optimization.

Results

Due to the intensive use of the magnetic field gradients (>75% gradient duty cycle), a frequency drift of the MRI can be observed after less than 5 minutes of acquisition, leading therefore to a displacement of the brain on the images, The use of the Drift Compensation module corrected this Issue (Fig. 1). Ex vivo acquisitions were used to compare the 3 fitting models. The M²NCM provides a more robust fitting and a better precision in the values than the two other models. Figure 2 shows the influence of the ETL (Echo Train Length) on the R² values of the T₂* decay fit and demonstrates that the ETL must be equal at least 1.5 times the T₂* measured. High-quality high-resolution 3D maps were obtained ex vivo, and in vivo, and T₂* values could be measured In each brain area. For example, ex vivo, T₂* of the cortex was equal to 23.9 ± 2.6 ms and 48.1 ± 3.6 ms for brain doped (Fig.3) or not (Fig.1) with Gd-DOTA, respectively. Figure 4 shows a representative T₂* map obtained in vivo at an intermediate (171

xl 56x156 μ m) spatial resolution in 12 min and at 115 μ m isotropic in 21 min. The R2 map is also shown in Fig,4 (last line). In vivo, T₂^{*} was equal to 33.1 ± 5.2 ms in the cortex and 25.75 ± 6.9 ms in the corpus callosum.

Conclusion

In conclusion, we developed a 3D T₂^{*} mapping method of the mouse brain at 7T. Maps can be obtained in less than 12 min with a spatial resolution of 150 μ m and 22 min for 115 μ m isotropic. The addition of the drift compensation module is mandatory to generate quality maps. The M²NCM method proved to be the most robust for data fitting. These preliminary results show that it is possible to generate 3D T₂^{*} mappings of the whole brain of mice at high magnetic fields. However, it will be necessary to test complementary approaches such as motion correction or respiratory synchronization to obtain reproducible maps. This will enable cohorts of animals to be compared with each other.

References

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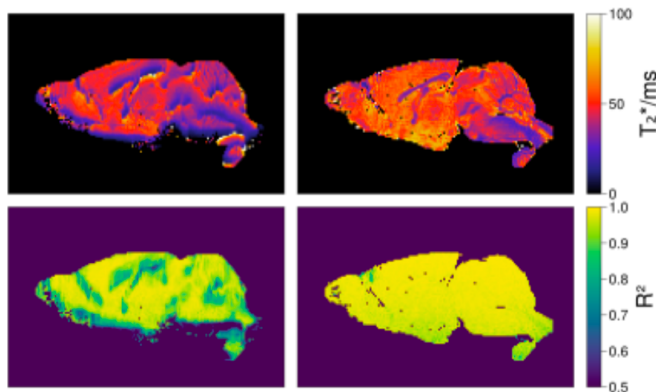


Figure 1. Sagittal view of a 3D T₂^{*} map of an ex vivo mouse brain and the corresponding R² map. Images were obtained with a 3D Multi Gradient Echo sequence without (left column) and with the drift compensation module (right column).

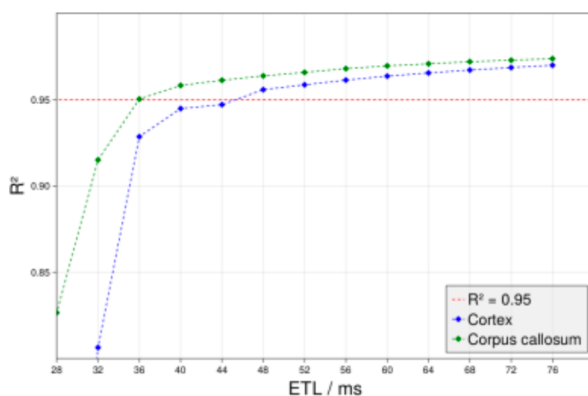


Figure 2. R² of the T₂^{*} decay fit for 2 regions (cortex and corpus callosum) in the mouse brain in vivo with respect to the number of echoes (echo spacing 2 ms).

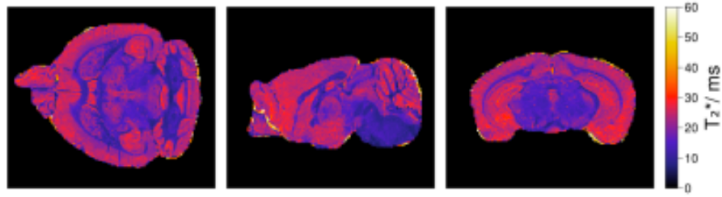


Figure 3. Coronal, sagittal and axial views of a T_2^* map of an ex vivo mouse brain (spatial resolution: $96 \times 96 \times 96 \mu\text{m}$)

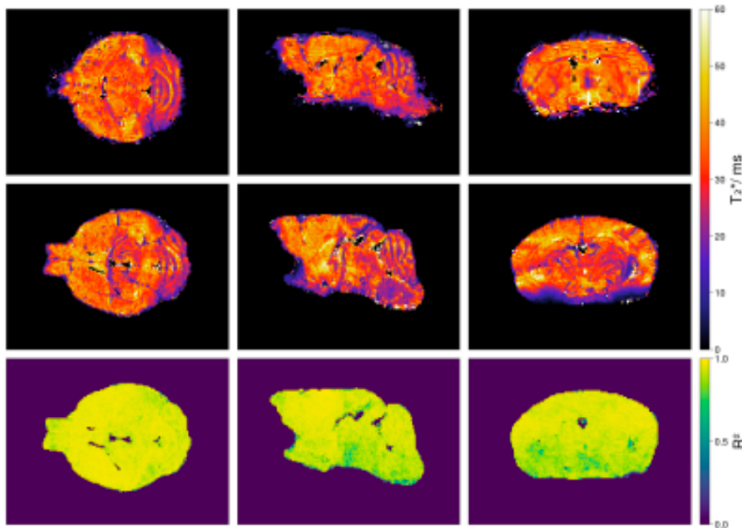


Figure 4. Coronal, sagittal and axial views extracted from an in vivo mouse brain T_2^* map. The maps shown in the first row were acquired at $171 \times 156 \times 156 \mu\text{m}$ spatial resolution. The maps in the second row were acquired at $114 \times 117 \times 117 \mu\text{m}$ spatial resolution. The bottom row shows the corresponding R^2 -map.

	TR (ms)	TE (ms)	Echo Spacing (ms)	Number of Echo	FOV (mm)	Matrix	Spatial resolution (μm)	Total Acquisition Time (min)
Ex vivo	100	2	2	38	20 x 12 x 12	128 x 128 x 96	153 x 96 x 128	20.48
	80	2	2	25	24 x 12 x 12	256 x 128 x 128	96 x 96 x 96	21.8
In vivo	80	2	2	38	22 x 15 x 15	192 x 128 x 128	114 x 117 x 117	21.8
	80	2	2	25	22 x 15 x 15	128 x 96 x 96	171 x 156 x 156	12.3
	80	2.5	2.5	25	22 x 15 x 15	192 x 128 x 128	114 x 117 x 117	21.8

Table 1. Parameters of the different acquisitions performed ex vivo and in vivo on the mouse brain.