Temperature and fixation correction for postmortem MRI of the brain

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Target audience

Basic scientists with interest in relaxometry and scientists with interest in postmortem MRI.

Purpose

Postmortem MRI is increasingly applied in neuroscience research because of its high potential of gaining more detailed insights into the microstructure of the underlying tissue. However, formaldehyde fixation substantially changes the relaxation behavior and the magnetic susceptibility of the tissue by cross-linking of the macromolecules and by reducing the water content. [1-2] In addition, postmortem MRI is usually done at room temperature which further affects T_1, T_2 and T_2* relaxation. [3] Consequently, MRI of formaldehyde fixed brains cannot serve for quantitative comparisons with in vivo conditions and conclusions drawn about pathophysiological origins of signal intensity changes remain pure qualitatively. The goal of our work therefore was to develop a correction scheme to translate relaxation times of postmortem brain samples and make them comparable with in vivo conditions.

Methods

Central 10-mm-thick brain slices from five deceased subjects were imaged twice at 3T, directly after autopsy (unfixed) and after 150 days of formaldehyde immersion (fixed). Temperature dependency of the relaxation times T_1, T_2 and T_2* (in unfixed and fixed condition) were measured by a linear regression model in a range from 4°C to 37°C using a temperature stabilized water bath coupled to an optical thermometer. The temperature dependent regression models of the unfixed and fixed relaxation times then were combined to develop following correction scheme: $T_{unfixed}(37°C) = \psi + T_{C,fixed} * \vartheta - T_{fixed}$, where ψ is the tissue specific correction factor (including slope and offset of the unfixed regression model and the offset of the fixed regression model), $T_{C,fixed}$ the temperature coefficient, ϑ the temperature of the sample in °C and T_{fixed} the measured relaxation time of the fixed sample.

Results

The correction factors and temperature coefficients for different brain regions are summarized in Table 1. All relaxation times were markedly decreased after formaldehyde fixation. T_1 and T_2* temperature coefficients were decreased and T_2 temperature coefficient increased after formaldehyde fixation as shown in Figure 1. The effect of the formaldehyde fixation on the reduction of the relaxation times was stronger than the effect of the temperature. Most interestingly, the underlying tissue type additionally impacted on the magnitude of coefficient changes, e.g. it was less pronounced in white matter than in the cortex or basal ganglia. The significant change in T_2 relaxation time and the T_2 temperature coefficient caused by formaldehyde fixation is shown in Figure 1. For validation we used reported relaxation time values of normal appearing white matter of fixed brain tissue (T_1 = 377 ms and T_2 = 61 ms) from literature [4] and translated these values to in vivo conditions with the proposed correction scheme. The calculated values found here (T_1 = 700 ms and T_2 = 83 ms) were in excellent agreement with the reported values of the corresponding unfixed tissue (T_1 = 668 ms and T_2 = 81 ms). [4]

Table 1: Relaxation time reference values for postmortem image correction

		ψ	$T_{C,fixed}$
White Matter	T_1 (ms)	1052.2 ± 137.7	1.1 ± 0.7
	T_2 (ms)	142.2 ± 38.4	0.1 ± 0.2
	T_2* (ms)	65.1 ± 15.0	0.1 ± 0.1
Cortex	T_1 (ms)	1838.5 ± 355.2	4.1 ± 2.5
	T_2 (ms)	204.3 ± 63.6	1.6 ± 0.7
	T_2* (ms)	72.7 ± 26.3	0.2 ± 0.2
Basal Ganglia	T_1 (ms)	1508.8 ± 253.1	3.1 ± 1.1
	T_2 (ms)	145.3 ± 46.1	1.1 ± 0.3
	T_2* (ms)	57.2 ± 21.4	0.3 ± 0.2

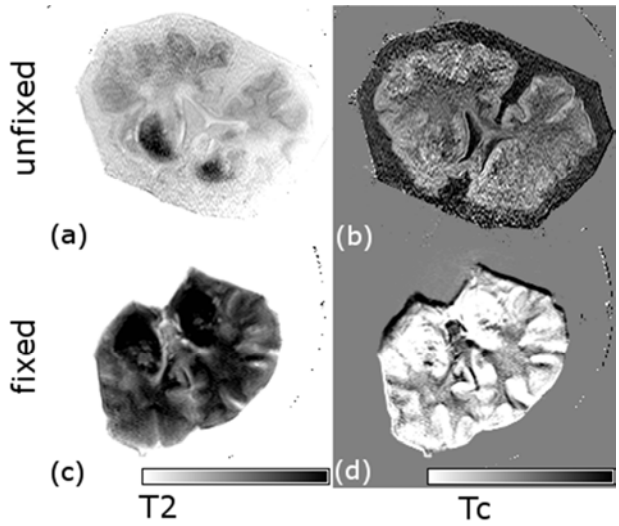

Figure 1: Comparison of T_2 (a) and temperature coefficient (b) before and T_2 (c) and temperature coefficient (d) after formaldehyde fixation.

Discussion and Conclusion

In this work, we suggest a correction scheme for the translation of postmortem MRI to in vivo conditions which accounts for the effects of temperature and of formaldehyde fixation. The model has been developed for normal brain tissue without pathologies and might need adaptation for diseased brains as e.g. relaxation times might change differently in neurodegenerative diseases compared to healthy brains. The provided correction scheme for relaxation times should serve to better relate quantitative postmortem MRI to in vivo conditions.

Reference

1. Schmierer K, Wheeler-Kingshott CA, Tozer DJ, et al. Quantitative magnetic resonance of postmortem multiple sclerosis brain before and after fixation. Magn Reson Med 2008;59:268–277.
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