Compartmental Sodium Quantification and Relaxometry in Multiple Quantum Filtered Sodium Imaging in Gliomatosis Cerebri

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Target audience:

Physicists, technologists and clinicians, who are interested in quantification and relaxation of sodium using triple quantum filtered MRI and its application to brain tumours.

Purpose:

Gliomatosis Cerebri (GC) is a rare kind of brain lesion, which manifests itself diffusely over entire regions of cerebral tissue and is spread over several lobes. Heterogeneity of the disease is high and a patient's prognosis is poor. Quantification of compartmental sodium and sodium relaxometry might provide an additional handle in the diagnostic process and has the potential to lead to an earlier and more accurate detection of the disease.

Methods:

Sodium relaxes mono- or biexponentially depending on its environment, with the former mainly occurring in case of unrestricted sodium (with T_{ex}), the latter (T_{2f}, T_{2s}) in the case of restricted sodium[1]. Restricted sodium can develop multiple quantum (MQ) coherences. Single (SQ) and triple quantum (TQ) coherences can be excited using three pulses, separated by a preparatory time, τ, and a mixing time, δ. Multiple, radial readouts after the first pulse can image total sodium distribution[2] and can be used to determine the fast relaxation time constant T_{2f}. The TQ filtered signal is obtained from multiple gradient echoes after the third pulse yielding T_{2f}, T_{2s} and relevant compartmental sodium concentrations. A single sequence suffices to populate tissue parameters such as intracellular volume fraction.

Measurements on a GC subject granting informed consent were performed on a custom 4T Siemens scanner with a dual tuned Na/H birdcage coil (Rapid Biomedical, Germany). 10mm isotropic resolution was achieved in a 320x240x120mm^3 field-of-view with a repetition time TR=150ms (8min acquisition time) and 12 step phase cycle. τ=7000µs allowed acquisition of 5 successive radial readouts with base resolution of 44 using DISCOBALL[3] at 1kHz/pixel bandwidth. TQ filtered images were acquired with δ=40µs using Cartesian sampling of gradient echoes after the third RF pulse at 120Hz/pixel bandwidth.

Segmentation of tumour tissue vs healthy tissue was achieved via localisation of FET-PET activity and simultaneously acquired proton FLAIR image acquired in a separate scan session on a Siemens 3T MRI/PET hybrid machine, which was co-registered to the sodium data. Healthy tissue was selected from normal appearing white matter in the temporal lobe, which was assumed to closely resemble the tissue affected by the lesion.

Results:

Decay curves for UTE, SQ and TQ signal can be seen in Fig.1. The images were segmented to isolate tumour from unaffected tissue. Changes in relaxation times T_{2s} (T_{2f}) of 21.9±2.5ms (7.2±2.0ms) are observed in the tumour region compared to 24.3±1.4ms (3.9±0.4ms) in brain tissue. Sodium tissue concentration (44.8±6.5mmol/L vs. 16.8±2.4mmol/L) and intracellular sodium concentration (33.9±2.2mmol/L and 13.9±1.3mmol/L) in the tumour region is more than doubled. Intracellular molar fraction is reduced from 0.81 to 0.68 in the selected region, intracellular volume fraction from 0.98 to 0.89 respectively.

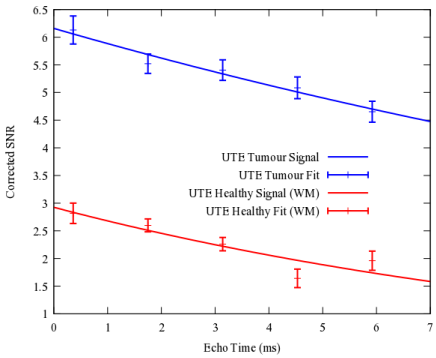
Discussion:

The UTE images show a hyperintensity in the ventricles, subarachnoid space and in the region of the lesion. SQ image delivers high signal in ventricles, subarachnoid space, and grey matter, signal is elevated in the region of the tumour. TQ image exhibit high signal in white matter and slightly lower signal in the region of the tumour and ventricles. Relaxation and intercellular sodium concentration is significantly altered in the region of the lesion.

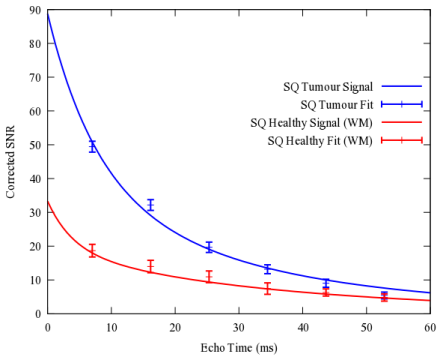
Conclusion:

Relaxometry of compartmental sodium reveal deviations in the relaxation behaviour in SQ, TQ and UTE images. Both total and intracellular sodium distribution are changed in the region affected by the lesion. Detection of these alterations might benefit successful diagnosis of pathology such as GC.

a) UTE image



b) SQ signal decay



c) TQ signal decay

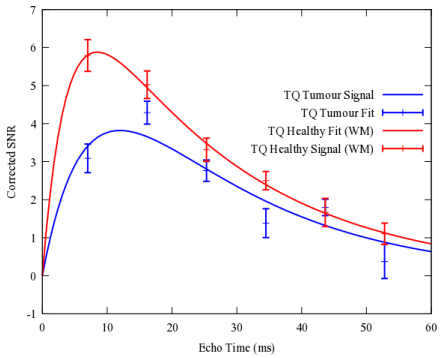


Fig 1: Echo amplitudes vs. TE for tissue affected by the lesion (blue) and normal appearing white matter (WM, red) for UTE, SQ and TQ images.

References: (1) Woessner DE, Concepts Magn Reson. 2001; 13(5):294–325. (2) Fiege DP et al., Magn Reson Med. 2013; 69:1691–1696. (3) Stirnberg R et al., Proc Int Soc Mag Reson Med. 2009; 17:3574.