Characterization of Thermochemical Ablation Injections using ^{23}Na MRI

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Target Audience

Interventionalists interested in ablation therapies, in particular thermochemical ablation and scientists interested in ^{23}Na MRI.

Purpose

Thermochemical ablation (TCA) provides a novel concept in minimally invasive ablative procedures in which two reactive solutions[1], such as acetic acid and sodium hydroxide, release heat as they react prior to entering the tissue as sodium acetate (NaOAc) solution. Thermal damage results in surrounding tissue via the released thermal energy and additional damage is caused by the hyperosmolar environment after injection. A fast chemical shift imaging (fCSI) pulse sequence was proposed to assess NaOAc distributions and temperature[2,3] using autoregressive moving average modeling[4] for post-processing. However, the molar concentrations of NaOAc are difficult to quantify but important for damage prediction. Sub-molar concentrations are expected at the lesion margin but nevertheless have been shown to be cytotoxic in cell culture with only a few hours of exposure. In this work, ^{23}Na MRI is used to image NaOAc distributions to provide more detailed insight for effective delivery to advance the understanding of TCA towards clinical translation.

Methods

All experiments were performed on a 7 T whole-body MR system (Magnetom 7 T, Siemens Healthcare, Erlangen, Germany) using a double-resonant ^{1}H / ^{23}Na birdcage coil (Rapid Biomed, Würzburg, Germany). A density adapted 3D radial pulse sequence[5] was used for ^{23}Na MRI: TE = 0.25 ms, TR = 20 ms, $\alpha = 45°$, projections = 15000, $\Delta x^3 = 1$ mm^3, matrix = 192^3, T_{acq} = 5:00 min. ^{1}H images were acquired using an MP-RAGE pulse sequence with the same spatial resolution.

A phantom with eight vials containing NaOAc solutions (molar concentrations: 100 mM - 800 mM) was used to measure the apparent signal-to-noise ratio (SNR) of ^{23}Na MRI and examine feasibility of concentration quantification. Additionally, an *ex vivo* bovine liver was embedded into agarose gel next to a reference tube with NaOAc solution with a molar concentration of 1 M. During the experiment, NaOAc solution (1 ml, 2.5 M) was injected into the liver using a syringe. ^{23}Na MRI was performed after the injection to assess the distribution of NaOAc inside the tissue.

Results

Fig. 1 shows an image of the eight vials. The apparent SNRs decreased from 8.3 for 800 mM to 1.1 for 100 mM. The SNR for 400 mM was 3.9. The normalized signal intensities were 840 ± 61 for 800 mM, 399 ± 53 for 400 mM, and 206 ± 50 for 200 mM. Fig. 3 shows an image acquired after injection into tissue. A volume of 1.6 ml with a normalized signal intensity ≥ 400 was measured inside the liver. Using a signal threshold of 250 to exclude noise completely and assuming the normalized signal to be quantitative, $2.38 \cdot 10^{-3}$ mol were measured (injected: $2.50 \cdot 10^{-3}$ mol).

Discussion

While ^{23}Na MRI suffers from low SNR and spatial resolution due to its low concentration in tissue (< 100 mM), TCA involves very high molar concentration levels of NaOAc and, thus, allows for high resolution at acceptable measurement times. This initial assessment indicates that ^{23}Na MRI can be used to get a more detailed insight into TCA and provides additional information to complement fCSI. Quantification seems to be feasible in small phantoms with the proposed setup. T_1 correction for short TRs and coil sensitivity maps will be incorporated to increase accuracy.

Conclusion

^{23}Na MRI of TCA injections will facilitate a platform for the design and optimization of applicators as well as development and validation of computational models, and progress towards clinical translation.

References

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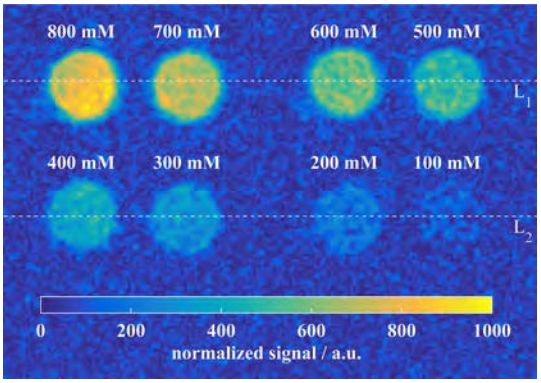

Fig. 1 Slice of 3D ^{23}Na MR image of eight vials with sodium acetate solutions (800 mM to 100 mM). White lines mark positions of line plots shown in Fig. 2.

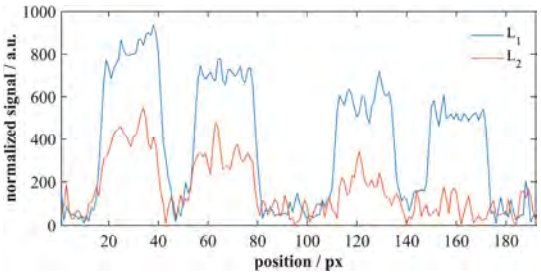

Fig. 2 Line plots of first (blue) and second row (red) of vials (cf. Fig. 1).

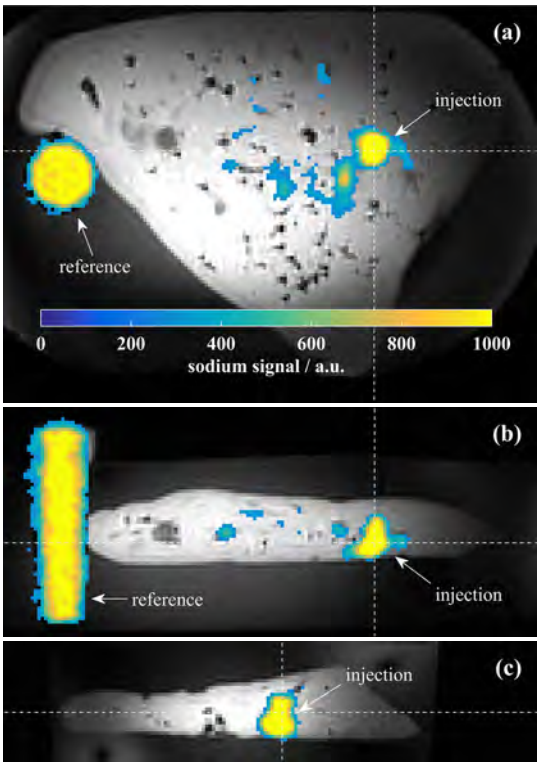

Fig. 3 Sodium acetate injection into *ex vivo* bovine liver embedded into agarose gel. Cropped perpendicular slices of a 3D ^{1}H image overlaid with the corresponding ^{23}Na image (transparent for signal values below 250). Intersection of slices at dashed white lines.