

# Simultaneous Acquisition of Water and Metabolites Using Multi-Coil Sensitivities for Proton Chemical Shift Imaging Thermometry

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## Introduction

<sup>1</sup>H chemical shift imaging (CSI) can be used as a method of non-invasive temperature mapping by probing the resonant frequency difference between water and reference metabolites such as N-acetyl-aspartate (NAA) [1,2]. When water and metabolite signals are measured separately, the total scan time increases. When both signals are measured simultaneously by non-water-suppressed measurements, on the other hand, metabolite signals are contaminated by the frequency modulation sideband artifacts of the water signal [3]. We have proposed a method of simultaneously acquiring water and metabolites using multi-coil sensitivities named SENSitivity Decomposition of water and metabolites (SEND) [4-6] to reduce the scan time and separate the sideband artifacts from metabolite signals. This method can simultaneously acquire water and metabolites signals without increasing the scan time and the sideband artifacts. In this study, we applied the SEND method to CSI thermometry and we present the results obtained from phantom experiments.

## Method

**Measurement** The SEND method is implemented in a 2D CSI sequence with three CHEMical Shift Selective (CHESS) pulses. Only the polarity of water magnetization is alternately reversed in k-space according to phase encoding steps using three CHESS pulses (Fig. 1(a)) [4-6]. Only the water signal is modulated in k-space, while the signal from the metabolites is unaffected. Therefore, only the water signal is shifted to the four corners of the field-of-view (FOV) on an image after Fourier reconstruction (Fig. 1(b)). Multiple datasets are acquired simultaneously by using multiple receiver coils with different spatial sensitivities.

**Processing** The signal received by the  $k$ -th coil is given by:

$$s(k, f, r) = C(k, r) \cdot m(f, r) + C_{sft}(k, r) \cdot w_{sft}(f, r) \quad (1)$$

where  $f$  denotes the spectral sampling point,  $r$  denotes the coordinates of the voxel,  $m$  denotes the magnitude of the metabolite, and  $w_{sft}$  denotes the magnitude of the water signal shifted to the four corners of FOV on the image. The  $C$  and  $C_{sft}$  denote the sensitivity maps corresponding to  $m$  and  $w_{sft}$ , respectively. As shown in Eq. (1),  $m$  and  $w_{sft}$  can be separated by using the inversion of the sensitivity matrix, which consists of  $C$  and  $C_{sft}$ , if the sensitivity matrix is not ill-conditioned (Fig. 1(c) and (d)). Then,  $w_{sft}$  is corrected to the original position from the four corners of FOV on the image.

**Experiments** 2D Point-RESolved Spectroscopy (PRESS)-CSI with SEND was used to measure the phantom, which was cooled in a refrigerator for more than 24 hours. The phantom consisted of a round-bottomed flask (17 cm in diameter) filled with 12.5 mM of NAA, 10 mM of creatine, 3.0 mM of choline, 50 mM of potassium phosphate monobasic, 0.1% of sodium azide, and 0.1% of Gd-DTPA. All the experiments were performed on a 1.5T MRI scanner (non-product software version, Echelon Vega, Hitachi Medical Corporation, Japan) equipped with an 8-channel phased-array coil positioned around the phantom on the x-y plane. The main parameters for the CSI measurements with SEND were as follows: TR/TE = 1500/35 ms, 2048 points, BW: 2 kHz, number of voxels: 12 x 12, FOV: 180 mm, volume-of-interest (VOI): 90 mm, thickness: 15 mm, and a scan time of 3.6 min. The scan time was not increased even though water and metabolite were both acquired. The cooled phantom was wrapped in towels and continuously measured throughout the in CSI measurements with SEND. After about 50 minutes the towels on the upper side of phantom were removed, and the cooled phantom was continuously measured for 180 minutes. The room temperatures (RTs) before and after the experiment were 22.9 °C and 27.0 °C. The phantom's temperature periodically measured with an optical fiber probe during the CSI measurements (the probe position is shown in Fig. 3(a)). The water and NAA resonant frequencies were estimated by a standard frequency domain analysis of the line shape. FIDs of the CSI data were zero filled to 4096 complex data points, phase corrected using the separated water signal [7], and Fourier transformed. The water and NAA resonant peaks were separately modeled as Lorentzian line shapes and the frequencies were estimated.

## Results and Discussion

Figure 2 plots the correlation between water-NAA resonant frequency difference and the probe temperature. The probe temperature and resonant frequency data pairs were modeled with a linear equation. As can be seen from Fig. 2, The results demonstrate good linear regression fitting (large  $R^2$ ). The slope of the linear equation (-86.93°C/ppm) is different from those previously reported in studies on *in vivo* MRS brain temperature calibrations (-94.0 and -103.8 °C/ppm) [1,2]. This may have been caused by the difference in ionic strength, pH, protein concentration or other experimental conditions. Figure 3(b) plots the time variations in phantom temperature calculated with the linear equation shown in Fig. 2. The colors of the curves in Fig. 3(b) correspond to the positions of the voxels in Fig. 3(a). Figure 3(c) has the phantom temperature maps we calculated in the VOI for six durations. After the towels were removed, the calculated temperature of the voxels in upper side of the phantom increased, as can be seen in Figs. 3(b) and (c). It was assumed that the upper side of the phantom was warmed by RT. As these results indicate, CSI measurements with SEND may be acquired with *in vivo* brain temperature map without increasing the scan time and contaminating the sideband artifacts.

## Conclusion

We applied SEND method that simultaneously acquires water and metabolites to CSI thermometry. The results from phantom experiments revealed that CSI measurements with SEND may be useful for acquiring temperature map without increasing the scan time and the sideband artifacts.

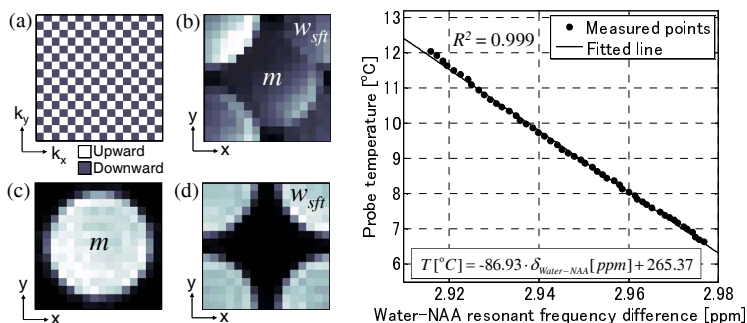


Fig. 1: (a) k-space data of CSI with SEND. (b)  $k$ -th channel image data before separation. (c) NAA image and (d) water image after separation.

Fig. 2: Correlation between water-NAA resonant frequency difference and probe temperature. Equation at bottom derives linear fitting result.

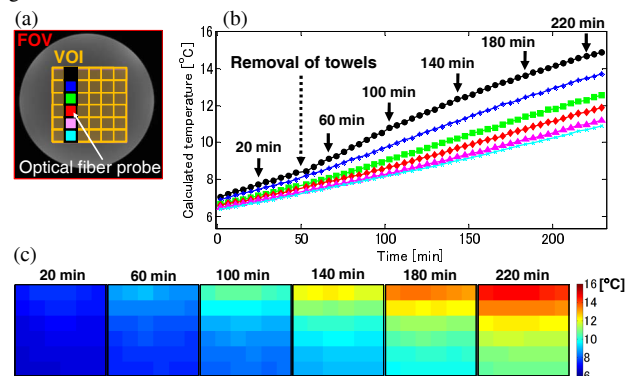


Fig. 3: (a) Location of FOV, VOI, and optical fiber probe. (b) Time variations in calculated temperature in voxels (colors of curve correspond to positions of voxels). (c) Calculated temperature maps in VOI for six durations.

## References

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