

# Sensitivity Decomposition of Water and Metabolites with Sensitivity Encoding for Unaliasing Lipid Contamination

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## Introduction

<sup>1</sup>H chemical shift imaging (CSI) is very useful for the clinical diagnosis of tumors. Although the water signal must usually be suppressed to acquire the high-quality metabolite signals, the non-water-suppressed (NWS) measurements have the following advantages. First, the water signal can be used as a reference signal for phase or eddy current corrections [1]. Second, it is possible to detect the resonant frequency difference between water and metabolites [2]. However, the addition of NWS measurement increases the scan time. To reduce the scan time, we have developed the technique for simultaneously acquiring water and metabolites using multi-coil sensitivities named SEND (Sensitivity Decomposition of water and metabolites) [3]. The CSI measurements also have a problem with subcutaneous lipid signal contamination aliasing into the field of view (FOV) caused by the displacement error due to chemical shift and/or the imperfection of the excitation profile of point-resolved spectroscopy (PRESS). To reduce the aliased lipid, a technique that applies sensitivity encoding (SENSE) has been proposed [4]. In this study, we have developed a technique that combines SEND with SENSE, in order to acquire the water and metabolites simultaneously and reduce aliased lipid contamination. Moreover, we have demonstrated the results of phantom and healthy volunteer experiments utilizing the proposed technique.

## Method

**Measurement** This technique is implemented in the 2D PRESS-CSI sequence. Prior to the use of the PRESS-CSI sequence, the polarity of water signals is alternately reversed by the three CHESSE pulses, the amplitudes of which are switched in accordance with the phase encoding steps [3]. Only water signal is modulated in the k-space, while the signal from the metabolites is unaffected. As a result, only the water signal is shifted to the four corners of the FOV reconstructed by a Fourier transformation (FT) from the k-space.

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

$$s(k, f, r) = \sum_{i=1}^4 C(k, r_i) \cdot m(f, r_i) + \sum_{i=1}^4 C_{sft}(k, r_i) \cdot w_{sft}(f, r_i) \quad (1)$$

where  $f$  denotes the spectral sampling point,  $r$  denotes the coordinates of the voxel, and  $r_i$  denotes the coordinates of the superimposed voxel.  $m$  denotes the magnitude of the metabolite,  $w_{sft}$  denotes the magnitude of the water signal shifted to the four corners of the FOV.  $C$  and  $C_{sft}$  denote the sensitivity maps of each coil corresponding to the positions of  $m$  and  $w_{sft}$ , respectively.  $m$ ,  $w_{sft}$ ,  $C$  and  $C_{sft}$  are the size of a two-fold FOV. As shown in Fig. 1(b), the metabolites sensitivity maps  $C$  can be calculated from the MR image of the same measurement position as CSI (Fig. 1(a)). On the other hand, the water sensitivity maps  $C_{sft}$  can be calculated by following procedure. First, the temporal sensitivity maps are calculated by cutting from the metabolites sensitivity maps  $C$  to the size of FOV. Next, the temporal sensitivity maps are shifted to the four corners of the FOV. Then, the water sensitivity maps  $C_{sft}$  are calculated by filling zero to the outside of the temporal sensitivity maps, which is the same size of the metabolites sensitivity maps  $C$  (Fig. 1(c)). As shown in Eq. (1),  $m$  and  $w_{sft}$  can be separated by using the inversion matrix of the sensitivity matrix, which consists of the  $C$  and  $C_{sft}$ , if the sensitivity matrix is not ill-conditioned. Then,  $m$  is corrected to the size of the FOV.  $w_{sft}$  is also corrected to the size of the FOV and the original position from the four corners of FOV. In this technique, the geometry ( $g$ ) factor can be defined as the following equation like the SENSE technique:

$$g_n = \sqrt{(S^H \Psi^{-1} S)_{n,n}^{-1} (S^H \Psi^{-1} S)_{n,n}} \quad (2)$$

where  $S$  denotes the sensitivity matrix consisted of the  $C$  and  $C_{sft}$ ,  $S^H$  denotes the complex conjugate transpose matrix of  $S$ ,  $\Psi$  denotes the noise correlation matrix, and  $n$  denotes a superimposed voxel. When  $n = 1, \dots, 4$ ,  $g_n$  shows  $g$  factor of metabolites. When  $n = 5, \dots, 8$ ,  $g_n$  shows  $g$  factor of water.

**Experiments** The proposed method was applied to measurements of a phantom and a healthy volunteer. The phantom consisted of a round-bottom flask (17 cm diameter) filled with 12.5 mM of N-acetylaspartate (NAA), 10 mM of creatine, 3.0 mM of choline, 12.5 mM of glutamate, 7.5 mM of myo-inositol, 5.0 mM of lactate, 50 mM of potassium phosphate monobasic, 0.1% of sodium azide, and 0.1% of Gd-DTPA. The healthy volunteer was 28 years old (male). All the experiments were performed on a 1.5T MR imaging scanner (Echelon Vega, Hitachi Medical Corporation, Japan) equipped with an 8-channel phased-array coil positioned around the phantom and head on the x-y plane. The main parameters are as follows: <phantom> TR/TE = 1500/35 ms, 2048 points, bandwidth (BW): 2 kHz, number of voxels: 14 x 14, FOV: 140 mm, volume of interest (VOI): 80 mm, thickness: 20 mm, and acquisition time: 4.9 min. <healthy volunteer> TR/TE = 1500/35 ms, 2048 points, BW: 2 kHz, number of voxels: 12 x 12, FOV: 180 mm, VOI: 90 mm, thickness: 15 mm, and acquisition time: 3.6 min.

## Results and Discussion

As shown in Figures 2(a)-(c), the NAA was sufficiently separated from the water. As shown in figure 2(b), the lipid signal was unaliasing outside the FOV. As shown in figures 3(a)-(f), the lipid aliased into FOV was reduced by the proposed technique. As shown in figures 4(a)-(d), in the results of the healthy volunteer experiments, the NAA was sufficiently separated from the water and lipid signal was unaliasing, same as in the phantom experiments. Since the proposed technique uses the coil sensitivity difference such as the SENSE technique, theoretical SNR calculated by  $g$  factor is decreased. However, as shown in figure 4(e), since the maximum of  $g$  factor is about 1.1 in VOI, this results suggests that the decrease in SNR is small. Therefore, the proposed technique is very useful for acquiring water and metabolites simultaneously, and reducing aliased lipid contamination.

## Conclusion

We have proposed a technique in this study for simultaneously acquiring metabolites and water with SENSE for unaliasing lipid contamination in CSI. The results from phantom and healthy volunteer experiments showed that this technique reduces the aliased lipid signal while acquiring water and metabolites simultaneously without increasing scan time.

## References

[1] U. Klose, MRM, **14**, 26-30, 1990. [2] E. Cady et al., MRM, **33**, 862, 1995. [3] T. Shirai et al., ISMRM, **19**, 1430, 2011. [4] O. S. Esin et al., MRM, **55**, 1164, 2006.

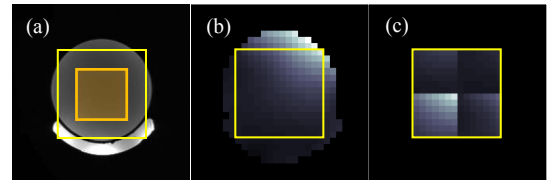


Fig. 1: (a)Reference image, (b)Sensitivity map of twofold FOV for metabolites C, and (c)water  $C_{sft}$ . Yellow box shows FOV and orange box shows VOI.

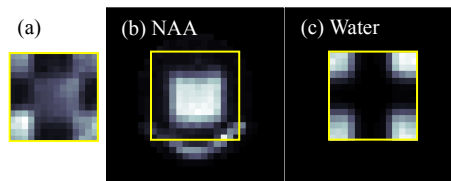


Fig. 2: Results of phantom experiment. (a)NAA image before separation, (b)after separation, (c)water image after separation.

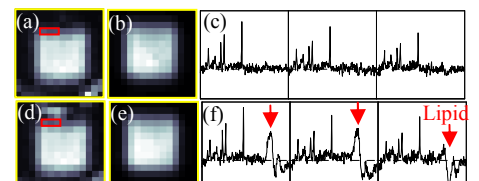


Fig. 3: Results of phantom experiment using SEND with SENSE (upper), without SENSE (lower). (a)(d) NAA images, (b)(e) water images, (c)(f) spectra of the voxel shown as NAA images (red box).

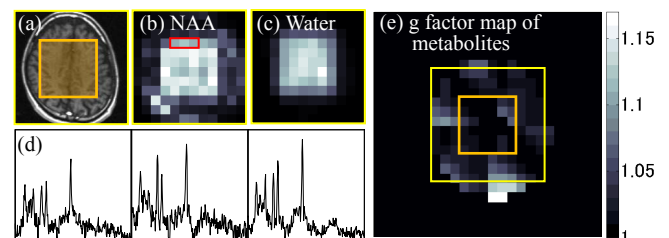


Fig. 4: Results of healthy volunteer experiment using SEND with SENSE. (a)Reference image, (b)NAA image, (c)water image, (d) spectra of the voxel shown as NAA images (red box), (e) geometry factor map of metabolites.