Sensitivity Decomposition of Water and Metabolites with Sensitivity Encoding for Reducing Scan Time

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Introduction

In ^{1}H-chemical shift imaging (CSI), although the water signal must be suppressed sufficiently to acquire high-quality spectra by water suppressed (WS) measurement, acquiring this signal by the additional non-water-suppressed (NWS) measurement has 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, it is clinically desired that the additional NWS measurement does not increase the scan time. To reduce the scan time, we developed a method for simultaneously acquiring water and metabolites with multi-coil sensitivities called "sensitivity decomposition" (SEND) [3]. In this study, to further reduce the scan time to half, we propose a method that combines SEND with sensitivity encoding (SENSE) [4]. Moreover, we demonstrate the results of using the proposed method in experiments with a healthy volunteer.

Method

Measurement The proposed method is implemented in the 2D PRESS-CSI sequence with three CHESS pulses. In the y direction of k-space, only the polarity of a water signal is alternately reversed in accordance with the phase encoding steps by three CHESS pulses [3]. Only the water signal is modulated in the k-space, while the signal from the metabolites is unaffected. Only the water signal is shifted to a half of field-of-view (FOV/2) on an image by Fourier reconstruction (1D-SEND), as shown in figure 1(a). In the x direction of k-space, the number of phase encoding steps is undersampled by the reduction factor R. The water and metabolite signals are aliased to the FOV/2 on the image by Fourier reconstruction (1D-SEND with 1D-SENSE), as shown in figure 1(b). By using multiple receiver coils with different spatial sensitivities, multiple datasets are acquired simultaneously.

Fig. 1: Diagram of (a) fully sampled 1D-SEND and (b) undersampled 1D-SEND with 1D-SENSE.

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

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

where f denotes the spectral sampling point, r denotes the position of the superimposed voxel, and r_i denotes the original position of the each voxel. R denotes the reduction factor of the spatial sample points of the image, m denotes the magnitude of the metabolite, and w_{sft} denotes the magnitude of the water signal shifted to the FOV/2 on the image. C and C_{sft} denote the sensitivity maps of m and w_{sft}, respectively. As shown in figure 2(b), the metabolite sensitivity maps C can be calculated from the MR images of the position as a CSI measurement [Fig. 2(a)]. The water sensitivity maps C_{sft} can be calculated by shifting the metabolite sensitivity maps C to the FOV/2 on the maps in the y direction [Fig. 2(c)]. 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. Then, w_{sft} is corrected to the original position from the FOV/2 on the image. In this method, the theoretical signal-to-noise ratio (SNR) can be defined like that in SENSE [4].

Fig. 2: (a) Reference image, (b) metabolite sensitivity map C and (c) water sensitivity map C_{sft}. Orange box shows VOI.

Experiments The proposed method was applied to the measurements of a healthy volunteer, who was a 28-year-old male. All the experiments were performed on a 1.5T MR scanner (Echelon Vega, Hitachi Medical Corporation, Japan) equipped with an 8-channel phased-array coil positioned around the head. In this study, we measured the datasets of 1D-SEND with the 1D-SENSE and 2D-SENSE methods to which NWS measurement was added, to make a comparison between both methods. The scan time of both methods was reduced to one-fourth of the fully sampled CSI, to which NWS measurement was added. The common parameters of both methods were: TR/TE = 1500/35 ms, 2048 points, BW: 2 kHz, volume of interest (VOI): 90 × 90 mm, thickness: 15 mm. In 1D-SEND with 1D-SENSE, the water signal was shifted to the FOV/2 on the image in the y direction, and the dataset was undersampled by the factor R = 2 in the x direction. FOV: 90 × 180 mm, number of voxels: 6 × 12, and scan time: 1.8 min. In 2D-SENSE, the dataset was undersampled by the factor R_x = 2 in the x direction and the factor R_y = 2 in the y direction. As a result, the total reduction factor R = R_x × R_y = 4. FOV: 90 × 90 mm, number of voxels: 6 × 6, and the total scan time of the sum of the WS and NWS measurements: 0.9 + 0.9 = 1.8min. The reduced FOV and the number of voxels were reconstructed to 180 × 180 mm and 12 × 12 by both methods, respectively.

Fig. 3: Results of human brain experiment of SEND with SENSE. (a) NAA image before separation, (b) after separation. (c) Water image after separation.

Fig. 4: Spectra of the voxels shown as Fig. 3(b) red box. (a) 1D-SEND with 1D-SENSE and (b) 2D-SEND.

Results and Discussion

As shown in figure 3, the NAA and water images were sufficiently separated by SEND with SENSE, in spite of the short echo time measurement of which the water signal becomes large. Figure 4(a) shows that several metabolite peaks could be detected. Figure 5 shows that the g factor map was equal to 1D-SEND with 1D-SENSE and 2D-SENSE. This is the reason that the separation of the water and metabolite signals in SEND with SENSE is equivalent to the separation of the superimposed signal in the y direction in 2D-SENSE. The theoretical SNR was proportional to the inversion of $g\sqrt{R}$ [4]. Therefore, the SNR of metabolites in both methods depends on only the reduction factor R. The total factor $R = 2$ in 1D-SEND with 1D-SENSE, and the total factor $R = 4$ in 2D-SENSE. Furthermore, NWS measurement in 2D-SENSE did not contributed to SNR of metabolite. Therefore, the SNR of the metabolites in 1D-SEND with 1D-SENSE was $\sqrt{2}$ times higher than that of the metabolites in 2D-SENSE, although the scan time was equal in both methods. The results of the spectra as shown in figure 4 agree well with the discussion above. In 1D-SEND with 1D-SENSE, the scan time could be reduced 2R-fold relative to the fully sampled CSI, to which NWS measurement was added, although the SNR of the metabolites decreased by the factors R and g. Therefore, the 1D-SEND with 1D-SENSE method may also be useful for acquiring water and metabolites simultaneously to reduce the scan time. In addition, the 1D-SEND with 1D-SENSE method is made further useful by using multiple coils that have larger coil sensitivity differences, which reduces the g factor, and/or by applying a higher field MR scanner to increase the SNR.

Fig. 5: g factor map of metabolites. (a) 1D-SEND with 1D-SENSE and (b) 2D-SENSE.

Conclusion

We proposed a method that combines SEND with SENSE for simultaneously acquiring water and metabolites to reduce the scan time. The results from an experiment with a healthy volunteer showed that the proposed method reduces the scan time to one-fourth of the fully sampled CSI, to which NWS measurement was added. It may also be useful for acquiring water and metabolite signals simultaneously in a short 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]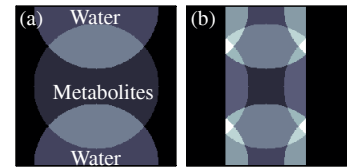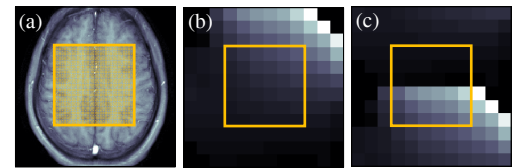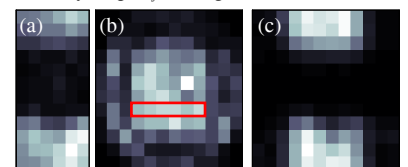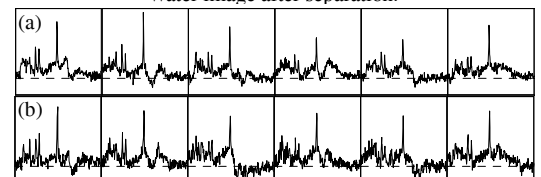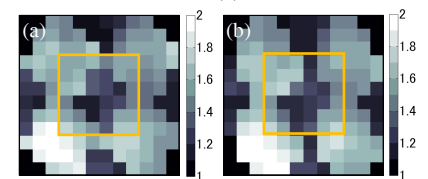 U. Dydak et al., MRM, **46**, 713, 2001.