# In vivo conductivity mapping using double spin echo for flow effect removal

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***Introduction*** Imaging the electric conductivity of tissues can potentially provide new contrast for the diagnosis of various diseases [1]. The electric properties tomography (EPT) is used to evaluate tissue conductivity *in vivo* by analyzing B1 map. The B1 map, however, can be hampered by attenuation of signal amplitude from flow components which include capillary, vessel, and even cerebrospinal fluid (CSF) flow within a voxel. This study focuses on the reconstruction of *in vivo* conductivity map using flow compensated double spin echo signals. The double spin echo sequence effectively reduces the signal loss by flow. This approach is validated in *in-vivo* experiments.

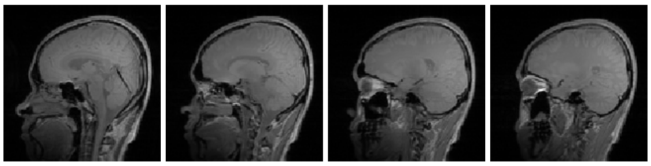
***Methods*** Conductivity can be estimated using the active magnetic RF field component $H^+$ [2]. The amplitude of the $H^+$ is determined by means of B1 mapping using double angle method (DAM) [3], and the phase of the H+ is determined from phase information of a spin echo image. The phase information of the $H^+$ is dominant factor to estimate the conductivity. However, phase information is frequently distorted due to the flow. A method for evaluating conductivity includes the Laplacian operation defined as the inner product of two gradient operations, which makes the method sensitive to fluctuation of signal and noise. Hence, the phase distortion by flow becomes propagated and significantly degrades the result. Therefore it is needed to precondition the phase perturbation from flow to get a conductivity map without flow effects. Since the motion due to both vessel and capillary flow is coherent, phase cancellation occurs at even echoes due to spin rephasing [4]. Therefore, double spin echo sequence is proposed in this study. We can use the standard B1 mapping method such as DAM in the case of double echoes. Two images are acquired with different flip angles $\alpha_1$ ($I_1(r)$) and $\alpha_2 = 2\alpha_1$ ($I_2(r)$), where the ratio of the resulting magnitude images satisfies equation (1).

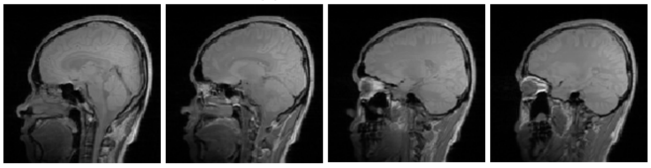
$$I_2(r)/I_1(r) = \sin\alpha_2(r)f_2(T1,TR)/\sin\alpha_1(r)f1(T1,TR) \qquad (1) \qquad\qquad \sigma(r) = \mathrm{real}(\nabla^2 H^+(r)/i\omega\mu H^+(r)) \qquad (2)$$

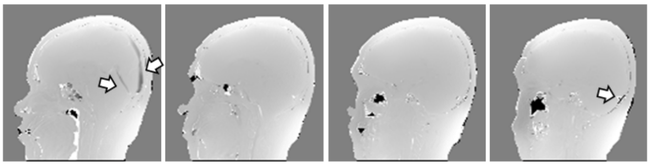
Here, f (T1, TR) is a signal function of T1 dependence. B1 map, i.e., $H^+$ is determined from (1), and conductivity can be estimated by (2).

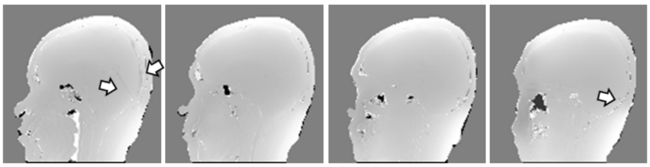
Sagittal images of a healthy volunteer were acquired on a 3.0T Siemens Tim Trio MRI scanner using a head coil. For $B1^+$ magnitude mapping, two consecutive scans are performed with $\alpha_1 = 60°$, $\alpha_2 = 120°$ and 180° for all of the refocusing pulses. 4 slices were obtained in 2D acquisition mode with resolution 2.0x2.0x5.0 mm$^3$. The double spin echo sequence with TR = 2000 ms, TE1 = 8.8 ms, TE2 = 17.6 ms (twice of TE1), FOV = 256 mm, NEX = 4 was used, leading to a total scan time of 17min at each scan.

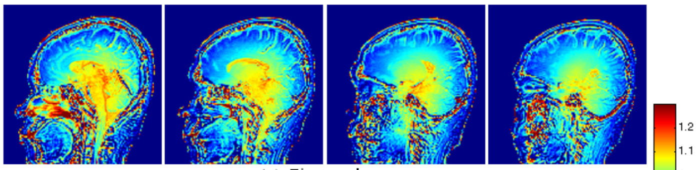
***Result and Discussion*** The magnitude and phase images are shown in Fig. 1 and Fig. 2, respectively. (a) represents the first echo images and (b) shows the second echo images. Signal intensity become restoration between the cerebrum and the cerebellum. The increased intensity of the second echo's magnitude image compared to the first echo image is caused by addition of stimulated echoes. This induces higher SNR without distortion of the phase information, which is an added benefit of using double spin echo. Fig. 3 represents magnitude of B1 map (Scale: [0.7, 1.3]). The pattern shows that using second echo is better in estimating the B1 even though a relatively short TR was used. White arrows show distorted regions by the signal attenuation caused by flow. The reconstructed conductivity is shown in Fig. 4 (Scale: [0, 2.5] S/m). Comparing (a) and (b), (b) shows better geometry of brain especially near the CSF.


(a) First echoes

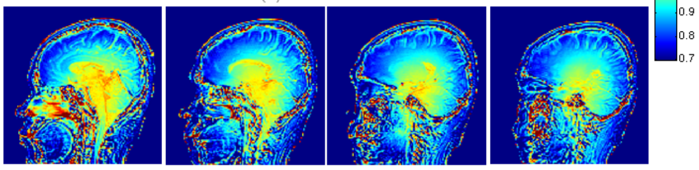

(b) Second echoes
Figure 1. Magnitude image

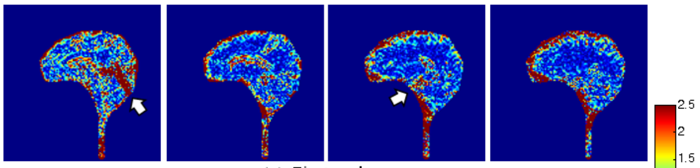

(a) First echoes


(b) Second echoes
Figure 2. Phase image

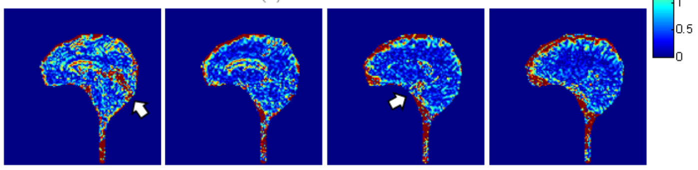


(a) First echoes


(b) Second echoes
Figure 3. B1 map



(a) First echoes


(b) Second echoes
Figure 4. Conductivity map

***Conclusion*** We have shown that using double spin echo can be an effective method for *in vivo* conductivity mapping. The method provides first moment nulling thereby excluding flow related phase accrual (vessel, capillary, and CSF) which can severely degrade the conductivity map. An added benefit is the increased SNR due to the addition of stimulated echoes.

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***References:*** [1] William T. Joines, et al., Med. Phys. 21(4), 1994 [2] H. Wen, et al., SPIE, 5030, 2003, [3] Charles H. Cunningham, et al., MRM, 55:1326-1333, 2006. [4] C. B. Ahn, et al., Med. Phys. 14(1), 1987.