Real-Time Conductivity Mapping using Balanced SSFP and Phase-Based Reconstruction

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Introduction

MR-based Electric Properties Tomography (EPT) provides a noninvasive means to assess electric tissue properties, such as conductivity and permittivity, and provides a framework for an accurate determination of local SAR [1]. Furthermore, it may provide a diagnostic parameter in oncology and cardiology. Recently, simplified EPT reconstruction methods based on the pure image phase information were introduced [2,3]. In these studies, spin echo (SE) sequences were employed due to their low susceptibility to B0 variations, or a B0 map was measured. However, these scans are very time consuming. In the present study, we have employed a fast balanced SSFP sequence, which has similar properties as SE in terms of a B0-independend phase accuracy, but provides sufficient speed for imaging of dynamic processes. First real-time conductivity scans in phantoms are shown, in which salt was added during the scan.

Methods

Phantom experiments were conducted on a clinical 1.5T scanner (Achieva, Philips Healthcare) using a birdcage head coil. Three cylindrical phantoms were used, two of which contained phantom fluid (water, 2-Propanol, Magnevist, and NaCl) with known conductivity (0.41 S/m and 1.48 S/m at 64MHz), and one cylinder with warm tab water (0.03 S/m), to which salt was added at two time points during the scan. For real-time imaging, a series of volumetric SSFP images were acquired (FOV = 230 x 162 x 90mm³, isotropic resolution 2.4 x 2.5 x 2.5mm³, coronal slices, nonselective block RF pulse, α=60°, TR/TE = 2.3 / 1.13 ms). A smooth 3D phase encoding order was employed to reduce eddy currents [4]. The temporal resolution was 4s per frame, and 24 frames were acquired. A reconstruction method based on the image phase [2] was employed, and the resulting conductivity maps were reformatted into a transversal view to visualize the laminar layers of fluid in the water phantom. Prior to real-time imaging, a 3D SE scan as described in [2] was performed to provide a reference. Furthermore, an SSFP pre-scan was performed, where a constant gradient was used to provoke banding artefacts and to interrogate the SSFP offresonance frequency response.

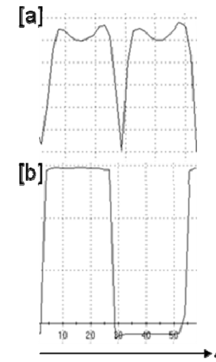

Fig. 1 SSFP frequency response in the presence of a linear gradient ([a] magnitude, [b] phase). The phase plateaus between the periodic wraps

Results and Discussion

The SSFP frequency response (measured profile across the water phantom in the presence of a linear gradient) is shown in Fig. 1. While the magnitude plot shows a residual dip between the dark bands, the phase plot perfectly plateaus between the periodic wraps. Color-coded coronal conductivity maps of the three cylindrical phantoms acquired with SE and SSFP are shown in Fig. 2 [a] and [b], respectively. The resulting conductivity values (mean ± standard deviation) are summarized in table 1. A good agreement between the conductivity values obtained with SE and SSFP were observed, although SSFP revealed a higher standard deviation. Selected transversal conductivity maps of the real-time SSFP series are shown in Fig. 3. After adding salt to the water phantom, the formation of laminar layers with different salt content and conductivity is clearly visualized [d-f], which disappear after stirring [g]. No significant motion or flow artifacts were observed.

Conclusion

The SSFP frequency response measured using a linear gradient revealed a constant plateau of the phase between the periodic phase wraps at 1/TR. Hence, a low susceptibility of the SSFP image phase to B0 variations (within the bandwidth 1/TR) is an asset which makes SSFP particularly useful for phase based EPT mapping. It overcomes the need to employ time-consuming spin echo sequences or the acquisition of a B0 map. The variation of the measured conductivity is considerably higher with SSFP. However, this may in part be attributed to the increased spatial resolution of the SSFP scan. Furthermore, the scan time can be reduced from the order of minutes to four seconds with SSFP, which enables real-time conductivity imaging for the visualization of dynamic processes.

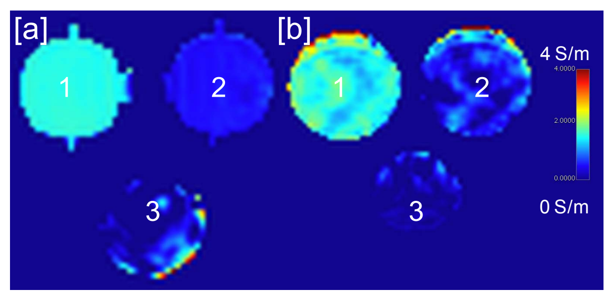

Fig. 2 Color-coded coronal conductivity maps acquired with SE [a] and SSFP [b]. Three samples with phantom fluid (1, 2), and tab water (3) were used.

Table 1 Measured conductivity values (mean ± standard deviation) in phantom samples versus reference values

sample	1	2	3
ref value	1.48 S/m	0.41 S/m	0.03 S/m
SE scan	1.59 ± 0.03 S/m	0.52 ± 0.04 S/m	0.04 ± 0.64 S/m
SSFP scan	1.39 ± 0.15 S/m	0.53 ± 0.28 S/m	0.04 ± 0.25 S/m

References:
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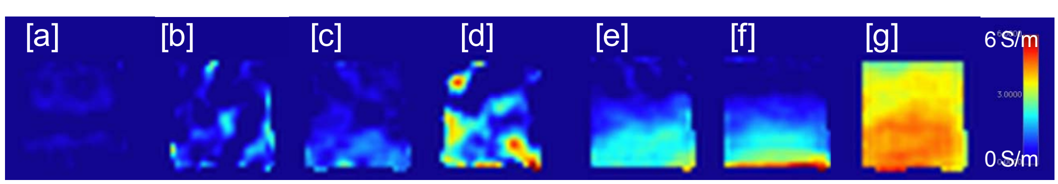

Fig. 3 Series of SSFP real-time conductivity maps in tab water. [a] initial condition, [b, c, d] during addition of salt, [e,f] at three minutes intervals, [g] after stirring.