Fast clinically feasible MR sequences to map electrical tissue conductivity for improved accuracy in hyperthermia treatment planning (HTP)

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Fast clinically feasible MR sequences to map electrical tissue conductivity for improved accuracy in hyperthermia treatment planning (HTP)

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INTRODUCTION

- Electrical properties for hyperthermia treatment planning (**HTP**) are measureable MRI using Electrical Property Tomography (**EPT**)[1–4].
- EPT-based patient-specific conductivity σ values:
  - have a significant impact on reliability of HTP[4].
  - are based on transceive phase ($\Phi^{\pm}$) measurement, typically measured with a **time-consuming** spin-echo (**SE**) sequence[1]

Purpose: To investigate faster alternatives for $\Phi^{\pm}$-mapping

Study design: **bSSFP**[5] sequence and **PLANET**[6], an ellipse fitting approach on phase-cycled bSSFP data are compared to SE, based on precision, acquisition speed and quality of reconstructed conductivity maps in a phantom and a healthy brain.

METHODS

MR measurements
- 3T (Philips Ingenia, The Netherlands)
- Transmit: body coil
- Receive: 15-channel head coil
- Cylindrical phantom content: H_2O + 5.1 g/L NaCl + 2% agar with σ = 0.80 S/m
- *In vivo*: brain of a healthy volunteer.

Analysis on transceive phase
- Precision → SD($\Phi^{\pm}$) in ROI. SD($\Phi^{\pm}$) corresponds to RMSE of 2D parabolic fitting to measured $\Phi^{\pm}$.[7]
- Efficiency → 1 / (SD($\Phi^{\pm}$) · scan duration)

Conductivity reconstruction[2]
- "phase-only EPT"
- transceive phase assumption

Analysis on conductivity
- Accuracy → Mean(σ) in ROI.
- Precision → SD(σ) in ROI.

	SE					PLANET					bSSFP				
FOV (mm³)	240 x 240 x 60					240 x 240 x 60					240 x 240 x 60				
Imaging mode	2D Multi-slice					3D					3D				
Phase-cycling scheme	N.A.					bSSFP with 8 cycles, phase increment = 45°					N.A.				
Imaging flip angle (°)	90					25					25				
Resolution (mm)	1.5	1.88	2.5	3	3.75	1.5	1.88	2.5	3	3.75	1.5	1.88	2.5	3	3.75
TE (ms)	5.2					2.3					2.3				
TR (ms)	1000	850	675	615	615	4.6					4.6				
Scan duration (min:sec)	10:52	7:26	4:28	3:25	2:46	7:43	4:53	2:46	2:00	1:13	00:58	00:37	00:21	00:15	00:09

Table1: *Sequence settings for phantom and in vivo MR measurements. Isotropic resolutions used.*

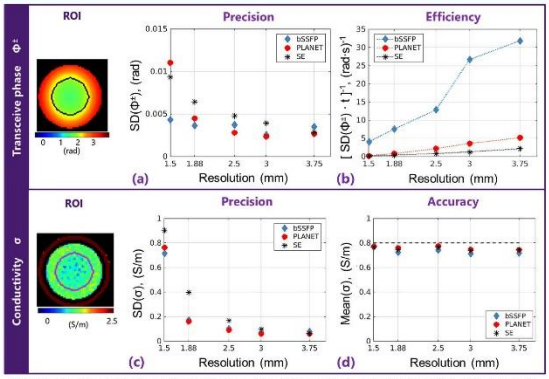

Figure 1: *Analysis results on transceive phase and conductivity for SE, bSSFP and PLANET.* ***(a)*** *Precision of the transceive phase* ***(b)*** *Sequence efficiency* ***(c)*** *Precision of the conductivity* ***(d)*** *Accuracy of the conductivity*

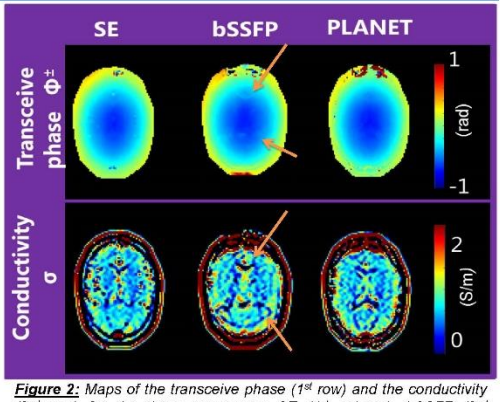

Figure 2: *Maps of the transceive phase (1st row) and the conductivity (2nd row) for the three sequences: SE (1st column), bSSFP (2nd column) and PLANET (3rd column). Isotropic resolution: 2.5 mm .*

RESULTS

All three techniques had similar precision performances with respect to $\Phi^{\pm}$ (***Fig. 1a***). However, **bSSFP** was the most time-efficient technique (***Fig. 1b***) (14-24 times more efficient than SE). **PLANET** was 1.2-2.8 times more efficient than **SE**.

Mean conductivity values were slightly biased from the true values, as expected when a "phase-only" EPT reconstruction is used (***Fig. 1d***). The greatest bias of 10% was found for **bSSFP**-based conductivity. Precision in conductivity was comparable for **bSSFP** and **PLANET** for all resolutions (***Fig. 1c***). For the resolution typically used in EPT, i.e. 2.5 mm, the precision in the conductivity approximated 12% of the true value for **bSSFP** and **PLANET** and almost 24% for **SE**. Standard deviation values for all the techniques doubled when the resolution was increased from 2.5 mm to 1.88 mm.

In vivo results are based on 2.5 mm resolution scans for all techniques (***Fig. 2***).

The **bSSFP** $\Phi^{\pm}$-map was mildly corrupted by local B_0 field variations, that were amplified in the reconstructed σ-map (see orange arrows in ***Fig. 2***)

PLANET showed less sensitivity to these variations and was faster than **SE**. Moreover, **PLANET**-based σ resembled the σ reconstructed on **SE** data.

DISCUSSION

bSSFP is the most time-efficient method for conductivity mapping (***Fig. 1***) but small local B_0 field variations affecting its phase pattern in the brain altered the apparent brain conductivity distribution (***Fig. 2***).

PLANET intrinsically corrected for these local field variations and the **PLANET**-based conductivity resembled the conductivity obtained with **SE** in the brain. **PLANET** was also increasingly faster than **SE** when resolution was increased. For an isotropic resolution of 2 mm, typically used for **HTP**, the standard deviation of the conductivity reconstructed on **SE** data was ~50% of the true conductivity value, versus ~25% when conductivity was obtained from **bSSFP** and **PLANET** acquisitions (with shorter scan durations).

CONCLUSION

PLANET showed to be a good candidate to image brain conductivity and could potentially replace **SE** in the imaging protocol for MR-based **HTP**. As a bonus, **PLANET** reconstructs simultaneously quantitative T_1, T_2, B_0 maps[6].

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