Electrical conductivity imaging of brain tumours.

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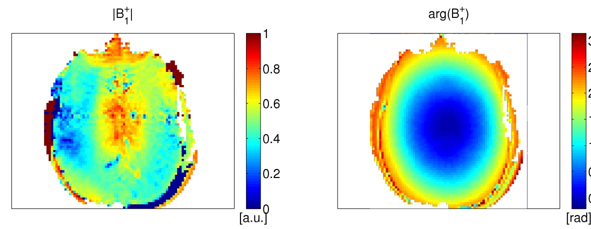
Introduction: Electrical conductivity mapping is a new technique to generate MRI contrast. [1,2]. Over the last years, the theory and practical implementation of the method has been shown, and measurements of phantoms and healthy volunteers were presented. Here we present for the first time conductivity mapping in brain tumour patients. As tumours may have a distinctly different conductivity than healthy tissue [3], we have used conductivity mapping for additional *in vivo* characterization of neoplastic tissue in the brain.

Method: To explore the potential of electrical conductivity mapping of brain tumours, two patients were scanned at a 7T (Philips Healthcare) one day prior to surgery (informed consent obtained). Patient 1 (46y male) had a grade IV astrocytoma (glioblastoma multiforme), patient 2 (62y male) a grade II astrocytoma (gliomatosis cerebri); both proven by a post-operative pathology exam. Reconstruction of the electrical conductivity is based on the Helmholtz equation of the B_1^+ field (Eq. 1 and 2). This requires a measurement of the B_1^+ amplitude and phase (Eq. 3) [2].

The B_1^+ amplitude map was acquired using a Bloch-Siegert shift ($\omega_{\text{off.res.}}$ = 1.5kHz, 8ms Fermi pulse) [4], the B_1^+ phase was measured using two interleaved GRE measurements with different echo times (TE_1 = 1.41 ms, TE_2 = 2.41 ms) [2]; all scans had a 2.5x2.5x5mm resolution. Kernel size for calculation of the Laplacian was 7 by 7 pixels in-plane and 5 pixels through-plane. Along with the electrical conductivity map, a FLAIR [5] and a conventional post-contrast 3T T1W image were obtained and matched with the electrical conductivity map.



a b

Figure 1: *Typical examples of a) $|B_1^+|$ map and b) $\arg(B_1^+)$ map, needed as input for electrical conductivity mapping.*

$$\frac{\nabla^2 B_1^+}{B_1^+} = -k^2 \text{ where } k^2 = \mu\varepsilon\omega^2 + i\mu\sigma\omega \quad (1)$$

$$-Im\left(\frac{\nabla^2 B_1^+}{B_1^+}\right)\frac{1}{\mu\omega} = \sigma \quad (2)$$

$$B_1^+ = |B_1^+|\exp\left(i\arg(B_1^+)\right) \quad (3)$$

Results and discussion: For patient 1, the electrical conductivity map (Fig. 2a), FLAIR (Fig. 2b) and T1W image (Fig. 2c) show a tumour with a spherical shape in the right temporal lobe. In the T1W image as well as in the conductivity map, show a large amount of heterogeneity in the tumour.

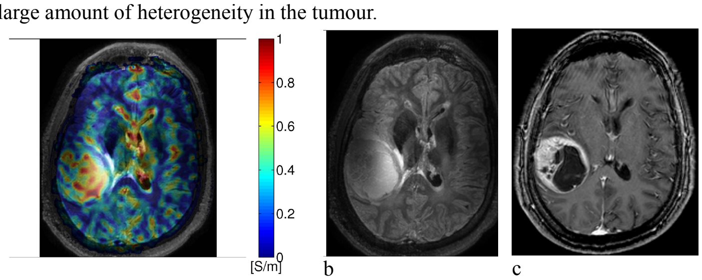


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Figure 2: *Patient 1: grade IV astrocytoma a) Reconstructed conductivity map overlaid on a FLAIR image. b) FLAIR c) post-contrast 3T T1W*

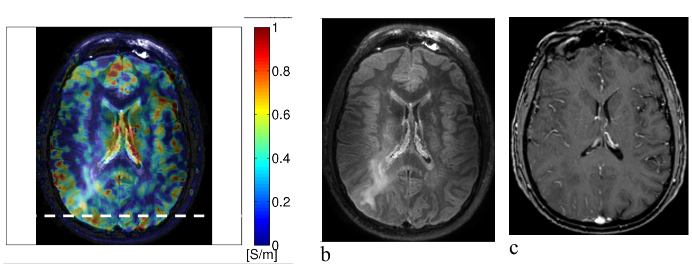

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Figure 3: *Patient 2: grade II astrocytoma a) Reconstructed conductivity map overlayed on a FLAIR image b) FLAIR c) post-contrast 3T T1W*

The medial portion, with low contrast uptake, has a high conductivity; in the lateral portion the characteristics are opposite. The electrical conductivity in medial portion of the tumour is 1.77 S/m ± 0.45 S/m is comparable to the conductivity in of the ventricles (1.61 S/m ± 0.45 S/m). For patient 2, the conductivity map shows a left/right asymmetry (Fig. 3a), i.e. the right parietal lobe exhibits an increased conductivity compared to the left lobe (see also Fig. 4). In the FLAIR image, the right parietal lobe shows a hyperintensity region. In the T1W image, the contrast between white and gray matter is deprived in the parietal lobe.

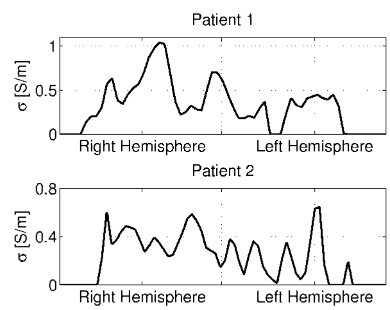

Figure 4: *Profile (RL) of the electrical conductivity over the tumour. (see dashed lines Fig 2a and 3a)*

Conclusion: For the first time, electrical conductivity mapping is shown for patients with a histologically proven lesion. The electrical conductivity maps vary considerably between the two patients. For patient 1 with a high grade tumour, the tumour itself and even structures within the tumour can be observed in the electrical conductivity map. For patient 2 with a low grade tumour, only subtle variations of the electrical conductivity were observed in the tumour area. In the near future, more patients will be included in this study to investigate the potential of electrical conductivity mapping for tumour detection, characterization and staging.

[1] Katscher et *al.*, IEEE Trans Med Imag 28:1365-7, *2009* [2] Van Lier et *al.*, Proc. ISMRM p.2864, *2010* [3] Lu et *al.*, Int. J. Hyperthermia, 8:755-760, *1992* [4] Sacolick et *al.*, MRM 63:1315-22, *2010* [5] Visser et *al.*, MRM 64:194-202, *2010.*