Systematic Brain Tumor Conductivity Study with Optimized EPT Sequence and Reconstruction Algorithm

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Introduction: With electric properties tomography (EPT) [1] we are able to measure the electric conductivity of tissue as an additional parameter [2,3], which might improve the diagnostic of brain tumors and other diseases using standard MRI-sequences. Different conductivity for grey matter and white matter was already shown [1]. Differences between tumors and healthy brain tissue were shown up to now for 4 cases [2,3]. In this study we systematically examined 12 patients with intracerebral tumors in reference to the electrical conductivity of the tissue using a conventional MRI-sequence that has not been used for brain EPT so far.

Methods: Volumetric complex 3D SSFP images (FOV = 220 × 220 × 170mm³, resolution 1.2 × 1.1 × 2mm³, sagittal slices, ⟨=38°, TR/TE = 3.0/1.5 ms, 4 averages, total scan time ~3 min) have been acquired on clinical 1.5T and 3T scanners (Achieva, Philips Healthcare, The Netherlands) using 8-element head coils. This sequence has the advantage that unwanted phase effects from off-resonance and tissue eddy currents are negligible [4]. From the transceive phase $\varphi(\mathbf{r})$ of these scans, conductivity $\sigma(\mathbf{r})$ can be estimated quantitatively via $\sigma(\mathbf{r}) = (2\mu_0\omega)^{-1}\Delta\varphi(\mathbf{r})$ with Δ the Laplacian operator, μ_0 the magnetic permeability, and ω the Larmor frequency [1]. To speed up reconstruction time, reconstruction is performed in the Fourier domain (i.e., multiplication of phase and Laplacian) instead in the spatial domain (convolution of phase and Laplacian). Subsequently, a median filter was applied, which was locally restricted to voxels with comparable signal magnitude [5]. We examined 12 patients with primary brain tumor (6), metastases (4) and resected primary brain tumor (2). For further clinical analysis we defined multiple ROIs for the following locations: tumor (solid/cystic), edema, supraventricular white matter, basal ganglia and cerebellar white matter on the level of cerebellar peduncles - to quantitatively define conductivity values.

		Primary Brain Tumors				Metastases		
		healthy WM	Tumor	Edema		healthy WM	Tumor	Edema
Supra-tentorial	1	0.47 +/- 0.017	0.66 +/- 0.06	0.62 +/- 0.06	9	0.14 +/- 0.08	cystic: 0.79 +/- 0.5 solid: 0.1 +/- 0.1	0.63 +/- 0.41
	2	0.5 +/- 0.025	-	0.63 +/- 0.027				
	3	0.45 +/- 0.056	1.12 +/- 0.14	0.95 +/- 0.24	10	0.45 +/- 0.047	0.54 +/- 0.15	0.65 +/- 0.15
	4	0.4 +/- 0.055	1.22 +/- 0.29	-				
	5	0.48 +/- 0.013	0.66 +/- 0.11	0.65 +/- 0.1				
	6	0.33 +/- 0.37	cystic: 0.77 +/- 1.5 solid: 0.64 +/- 0.09	0.75 +/- 0.16				
	7	0.4 +/- 0.09	-	0.71 +/- 0.03				
Infra-tentorial	8	0.57 +/- 0.13	0.75 +/- 0.05	0.57 +/- 0.035	11	0.49 +/- 0.24	0.27 +/- 0.24	0.4 +/- 0.21
					12	0.48 +/- 0.18	0.4 +/- 0.1	0.42 +/- 0.085

Tab.1: conductivity values and standard deviation (WM= white matter)

Results: Supratentorial localized tumors always showed a different conductivity than the healthy supratentorial white matter. In detail all primary brain tumors show a higher conductivity for cystic as well as for solid parts of the tumor (figure 1) while metastases show lower as well as higher conductivities compared to healthy white matter. Infratentorial tumors showed lower or almost even conductivity values compared to infratentorial white matter. For perifocal edema we observed similar results. Supratentorial edema always showed a higher conductivity than the healthy supratentorial white matter, while infratentorial edema showed lower or almost even conductivity values compared to infratentorial white matter (table 1).
The analysis shows an interindividual difference for the electric conductivity of cerebral white matter (range: 0.12 S/m - 0.53 S/m, IQR: 0.16), basal ganglia (range: 0.42 S/m - 0.89 S/m, IQR: 0,14) and cerebellar white matter (range: 0.15 S/m - 0.68 S/m, IQR: 0,13). This also shows higher electric conductivity for phylogenetic older parts of the brain like basal ganglia and the cerebellum compared to the cerebrum as a phylogenetic newer part.
The color-coded conductivity map in most cases also allows a visual definition of the basal ganglia (figure 2).

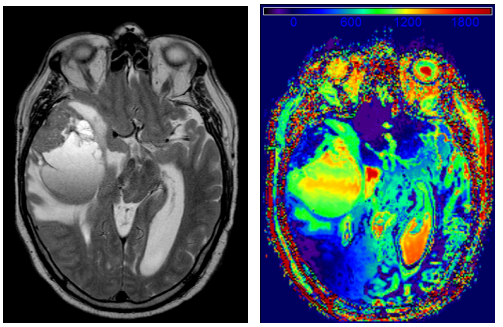

Fig. 1: T2w image and EPT-map of temporal glioblastoma (scale in mS/m)

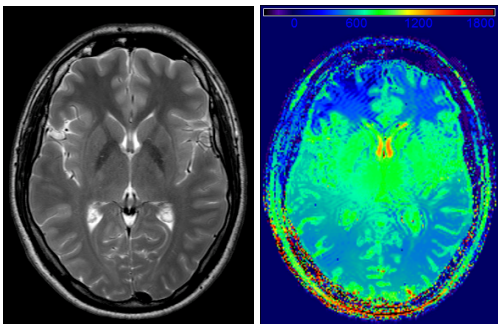

Fig. 2: T2w-image and EPT-map with visually definable brain-structures like basal ganglia and ventricles. (scale in mS/m)

Discussion: Even though the number of examined patients is too small to prove evidence, we observed unambigous trends for the electrical conductivity of different tissues in the human brain. By being able to visually define relatively small anatomic structures by their different conductivity values we show that the combination of dedicated sequence and reconstruction algorithm allows a spatial resolution that was not achieved in earlier studies [2,3]. The difference of conductivity for gray matter and white matter that was shown in the earlier studies with less patients was reproducible as well as differences for tumor and healthy tissue.

Conclusion: With the introduced method we are able to collect an additional parameter for radiological diagnostic needing little additional examination time of about 3 minutes. The consistency of the described findings and trends as well as the significance of the parameter electric conductivity needs to be proven in further studies.

References: [1] Voigt T et al, MRM 66 (2011) 456 [2] Voigt T et al., ISMRM 19 (2011) 127 [3] van Lier A et al., ISMRM 19 (2011) 4464 [4] Stehning C et al., ISMRM 19 (2011) 129 [5] Katscher U et al., ISMRM 20 (2012) 3482