BOLD-based characterization of relative oxygen extraction fraction in patients with ischemia

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Introduction: Hypoxia plays an important role in ischemic diseases. Recently, a new method – based on the quantitative BOLD effect [1] and independent measurement of T2, T2* and CBV – was proposed for qualitative mapping of a relative oxygen extraction fraction (rOEF) [2]. Here, we applied this new method in patients with stroke or severe arterial stenosis. Purpose of this study was to evaluate whether a protocol with separate quantification of T2, T2*and CBV could provide diagnostically valuable rOEF maps for improved penumbra estimation, in comparison to the established method of the DWI/PWI mismatch concept [3, 4].

Subjects and Methods: 27 patients (63 ± 16 y; 14 males) with suspected ischemia or severe carotid artery stenosis were examined on a 3T Philips Achieva scanner. Quantitative measurements of T2 (multi-echo GRASE: EPI-factor 7, SENSE-factor 2, 8 echoes, ΔTE = 16ms, TR = 8547 ms) and T2* (multi-GE: 12 echoes (TE1 = 6 ms, ΔTE = 5 ms), TR = 1950 ms, α = 30° including correction for macroscopic susceptibility gradients [5, 6] and motion [7]) were performed in 3.5 min covering 20 slices with a voxel size of 2x2x3mm^3. CBV was derived from the routine DSC PWI protocol (40 dynamic single-shot EPI scans during CA bolus application). For assessment of hypoxic areas, rOEF = R2‘/(c·rCBV) was calculated with R2‘ = (1/T2*) - (1/T2), relative rCBV and c = $4/3 \cdot \pi \cdot \gamma \cdot \Delta\chi \cdot B_0$ = 317Hz at 3T [2]. rOEF maps were compared to FLAIR, ADC, TTP and CBV maps by two independent experts and correlated to the clinical outcome in order to evaluate its prognostic value and validity for therapeutic implications. VOI evaluations were performed on ADC, TTP and rOEF lesions using Brainlab. Values from unaffected tissue were obtained from mirrored lesion VOIs.

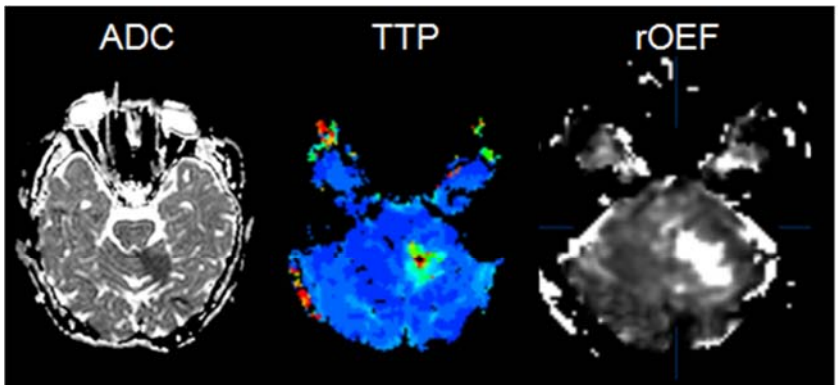

Figure 1. Image example of a patient with hyperacute ischemic stroke. Supposedly hypoxic areas with decreased ADC and increased TTP appear bright in the rOEF map.

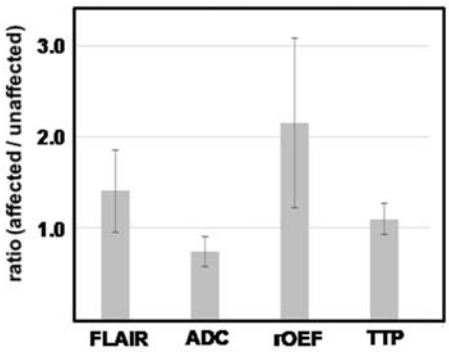

Figure 2. Ratio of FLAIR, ADC, rOEF and TTP values (affected vs. unaffected side) in patients with stroke.

Results: 17 patients (12 with acute, 2 with subacute ischemia and 3 with severe arterial stenosis) showed areas of prolonged TTP (> 4s) and/or diffusion restriction. Figure 1 shows a selected slice from a patient with hyperacute stroke where rOEF is increased in an extended area overlapping with areas of decreased ADC and increased TTP. Generally, the localization of rOEF lesion was correlated with TTP lesion ($p<0.05$). Figure 2 summarizes the result of the VOI evaluation comparing the lesion vs. a mirrored VOI at the unaffected side. Patients with stroke show clear differences between the lesion VOI and a mirrored VOI in the unaffected hemisphere. rOEF shows the strongest relative changes. In areas with prolonged TTP but without diffusion restriction, rOEF presented an increase to 1.44 ± 0.85 compared to 0.59 ± 0.19 in healthy appearing tissue ($p=0.077$). In regions with diffusion restriction this effect was less pronounced (1.03 ± 0.62, $p=0.082$).

Discussion: Measurement of rOEF allows to identify ischemic areas and detects differences in rOEF between ischemic core and surrounding tissue. rOEF values correlate with perfusion prolongation. We assume that areas with rOEF increase outside the ischemic core represent tissue with potentially reversible metabolic function. Further work is needed to delineate the utility of rOEF for the penumbra concept.

References:

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