T1-independent vessel size imaging with multi-gradient- and spin-echo EPI

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Introduction Vessel size imaging (VSI) is a relatively new MRI technique that relates the contrast agent-induced changes of transverse relaxation rates, R_2 and R_2^*, to each other [1,2] to obtain an index that provides information about the size of vessels within a voxel of interrogation. Ideally, such measurements require the simultaneous acquisition of multiple gradient-echo (GE) and a spin-echo (SE) signals. However, limiting the acquisition to just one GE and SE induces T_1-related errors in the estimation of the vessel size [1]. This problem can be solved by acquiring multiple GE/SE-signals (Fig.1), from which one can derive T_1-independent estimates of R_2 and R_2^* from before and during contrast-agent passage. The parameter estimates can then be used to improve accuracy in VSI.

Theory and Methods A spin-and gradient-echo (SAGE) echo-planar imaging (EPI) pulse sequence [3] with parallel imaging was used for bolus-perfusion measurements with the capabilities to detect R_2 and R_2^*, as well as ΔR_2 and ΔR_2^*, the bolus-induced changes in these values. Assuming static dephasing for ΔR_2^* determination [4] and slow-diffusion approximation for ΔR_2 [5], the vessel size index can be calculated according to [1,2] via:

(1) $$R = 0.867 \cdot \sqrt{\zeta \cdot D} \cdot \frac{\Delta R_2{}^*}{\Delta R_2{}^{3/2}}$$

Both the diffusion coefficient D and the volume fraction of blood in tissue ζ are spatially varying and should ideally be included for accurate calculation of the VSI. In this study, we used relative cerebral blood volume (CBV) maps determined from the underlying bolus-perfusion experiment as an approximation for ζ:

(2) $$\zeta = k \cdot \mathrm{rCBV} = \frac{k}{TR} \int \left(R_2(t) - \overline{R_{2,pre-bolus}} \right) dt$$

Here, k is a correction factor that is necessary to relate rCBV to the absolute volume fraction of blood. With dynamic susceptibility-contrast perfusion weighted imaging (DSC-PWI), an absolute value for k cannot be determined; therefore all the calculations in this study are based on relative values. Moreover, we used the simplified assumption of a constant D across the brain. Changes in R_2 and R_2^* were calculated as follows:

(3) $$\Delta R_2 = \frac{1}{TR} \int \left(R_2(t) - \overline{R_{2,pre-bolus}} \right) dt \quad \text{and} \quad \Delta R_2^* = \frac{1}{TR} \int \left(R_2^*(t) - \overline{R_{2,pre-bolus}^*} \right) dt$$

From the substitution of ΔR_2 and ΔR_2^* in Eq. (1) by Eq. (3) follows:

(4) $$R = 0.867 \cdot \sqrt{D \cdot k} \cdot \frac{\Delta R_2^*}{\Delta R_2} \propto \frac{\Delta R_2^*}{\Delta R_2}$$

$R_2(t)/R_2^*(t)$ were calculated through least-squares fit of the characteristic signal equations [6]:

(5) $$S(t) = S_0^I \cdot e^{-t \cdot R2^*} \qquad 0 < t < TE/2$$
$$S(t) = S_0^{II} \cdot e^{-TE \cdot (R2^* - R2)} \cdot e^{-t \cdot (2 \cdot R2 - R2^*)} \qquad TE/2 < t \le TE$$

with S(t) measured at 4 different TEs using the SAGE-EPI sequence. This method has the advantage of inherently T_1-insensitive R_2^* estimations (same as the non-EPI measurements in [1] performed in animals measured in steady-state, but opposed to the single gradient-echo EPI acquisitions in [2] that cannot reveal an absolute measure of R_2^*). Also, R_2 is free from T_1-biases as opposed to the two-point techniques for ΔR_2-estimation used in [1,2].

Imaging parameters were chosen as follows: field strength = 3T, 4 EPI echo trains (R = 3) were acquired with TE = 16.8, 38.3, 87.2, and 107 ms; TR = 1800 ms, 14 slices with 5 mm slice thickness; in-plane resolution = 96x96, FOV = 24 cm; 60 dynamic time-points. 19 ml Gd-DTPA were injected into the right hand of a tumor patient at a flow rate of 5 ml/s, followed by 25 ml saline flush.

Results and Discussion Fig.2 shows R_2 and R_2^* maps in a tumor patient after surgical treatment. Fig.3 gives a glance at the relative cerebral blood volume (rCBV), as well as the vessel size index VSI. We were able to acquire a qualitative measure of the mean vessel size per voxel with multi-echo SAGE-EPI, with R_2 and R_2^* being estimations of relaxation rates free of T_1-biases.

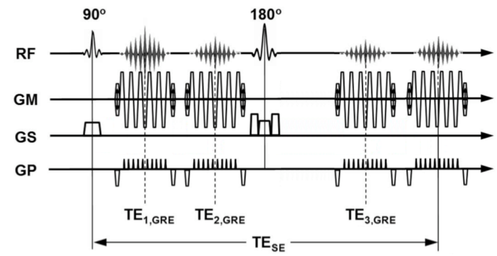

Fig. 1: Spin- and gradient-echo (SAGE) EPI sequence [3] used in this study for T1-independent estimation of R_2 and R_2^*

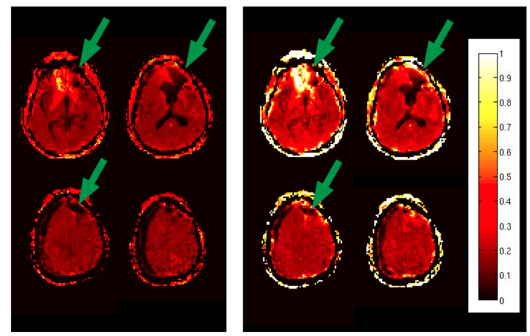

Fig. 2: Comparison of R2 (left) and R2 (right) in a brain-tumor patient. The scale on the right is in ms^{-1}. R_2 and R_2^* were calculated using the characteristic signal equations (Eq. 5).*

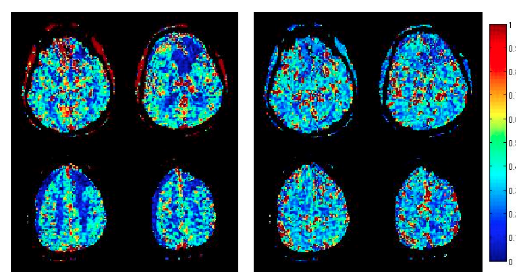

Fig. 3: Cerebral blood volume (left) and vessel size index (right). Both maps show relative number numbers indicated on the scale on the right.

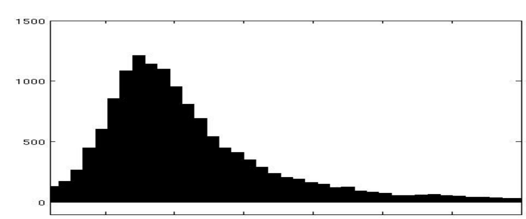

Fig.4: Histogram of the vessel size index for the slices shown in Fig.3.

References [1] Troprès, *et al.* MRM 45, 397–408 (2001), [2] Kiselev, et al. MRM 53: 553-563 (2005), [3] Newbould, *et al*. Proc. ISMRM 2007, #1451, [4] Yablonskiy, *et al.* MRM 32:749-763 (1994), [5] Kiselev, *et al.* MRM 41:499–509 (1999), [6] MA *et al.* J MR B 111:61-69 (1996) – **Acknowledgements** Supported in part by NIH (1R01EB008706, 5R01EB002711, 1R01EB006526, 1R21EB006860, P41RR09784), Lucas and Oak Foundations