Impact of tissue porosity in DCE-MRI: a numerical simulation study

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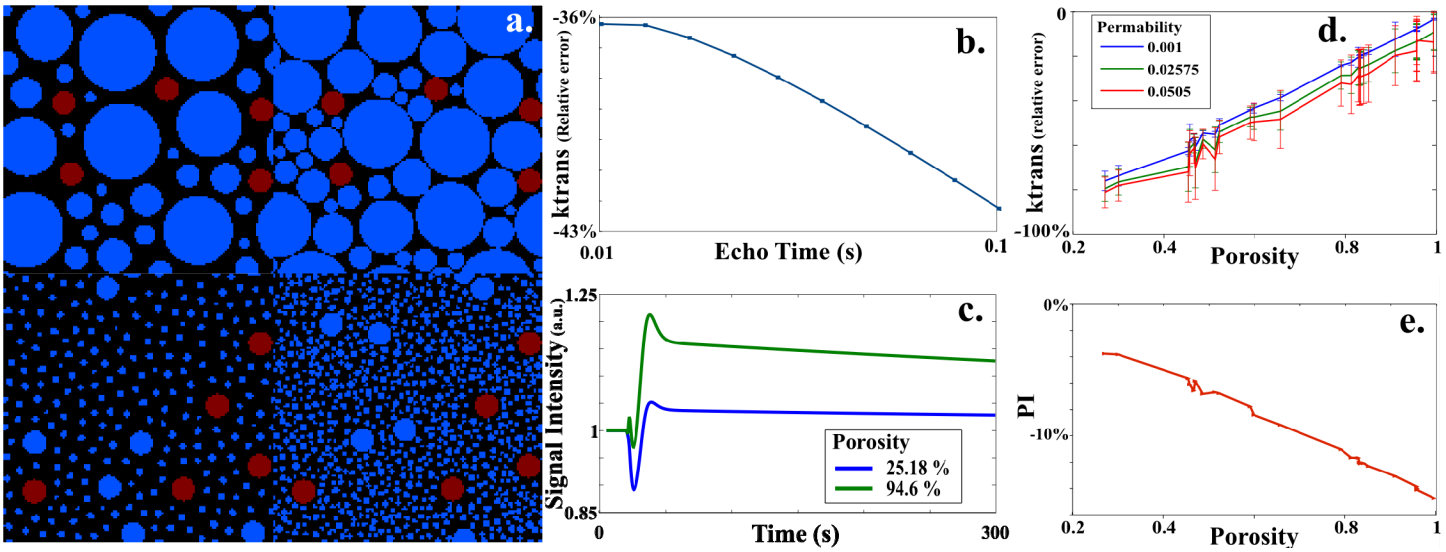
Introduction: The vascular permeability (ktrans) may be characterized with Dynamic Contrast Enhanced MRI (DCE-MRI). This technique relies on a monitoring of the change in voxel T1 over time following the injection of a diffusible contrast agent. To minimize the impact of change in transverse relaxations (either T2 or T2*), one generally uses a short echo time in DCE-MRI. The use of longer echo-times could however provide additional information. In this study, we evaluate using numerical simulations how the choice of echo-time and tissue porosity – the free space between cells fraction – impact ktrans. Moreover, we propose a strategy to simultaneously estimate the permeability and the porosity in tissue using multiple echo times. Imaging tissue porosity could be of high interest to characterize cancer tissue.

Materials and Methods: We simulated DCE-MRI experiments using the tool developed by *Pannetier et al.*[1]. Briefly, this tool uses a Fourier based approach to compute the magnetic field distribution inside a virtual voxel and a deterministic approach to account for relaxation and diffusion processes of water and of contrast agent (Gd-DOTA in this study). General parameters of the simulation: Time step of the simulation=0,5 ms, B0=4,7 T. Duration of the DCE experiment= 5min (baseline duration= 20s). TR=500 ms. First, vessels (n=5, radius=3µm, blood-volume = 3%) then circular cells with variable radii (1 to 10µm) were randomly distributed within the virtual voxel to obtain the requested porosity. Three vascular geometries and 3 cellular geometries were generated and associated to produce a total of 9 different geometries per condition. A total of 200 conditions were explored: 5 permeabilities (ktrans between 0.001 and 0.1 s-1),10 porosities (between 27% and 97% free space; 97% correspond to no cell), 2 minimum cells interspace, and 2 different MRI sequences i) Multi-gradient echo sequence: 10 TEs between 5 and 50 ms, flip angle= 90° and ii) Multi-spin echo: 10 TEs between 10 and 100 ms. Eventually, a modified Kety model (two compartment model) was fitted to the collected MR signal using the same arterial input function as the one used in the simulation to obtain a simulated ktrans ($ktrans_{simu}$).
To obtain a porosity indicator (PI), we computed a difference between two ratios: first, the ratio between spin-echo signals (TE=100 ms) collected before and five minute after contrast agent, and second the same ratio but using TE=10 ms.

Results: Fig. a. illustrates 4 geometries used in this study (vessels in red, cells in blue). Fig. b. shows the error on ktrans as a function on the spin-echo time and for a porosity of 60%. It can be observed that even with a short spin-echo time, the relative error on ktrans is -36%. Fig. c. shows two spin-echo DCE-MRI experiments (TE=100 ms) obtained for two different tissue porosities. The impact of porosity can readily be observed on the data. Fig. d. shows the difference between ktrans and $ktrans_{simu}$ as a function of the tissue porosity for three different ktrans and when measured with a spin-echo DCE-MRI experiment (TE=100 ms). Error bars correspond to the variability arising from the different voxel geometries.
To simultaneously derive the permeability and the porosity, one explore the gradient echo and spin echo signals as a function of the porosity. The most sensitive MR signal to porosity is the spin-echo. Fig. e. show the PI as a function of porosity. It can be observed that PI varies from -4 to -15%, values which could be measured in vivo.



Conclusions: Using numerical simulations, we observe that tissue porosity has a strong impact on ktrans estimates derived with DCE-MRI. While the use of a single short echo time can be used to minimize the error on ktrans, multiple spin echoes could be used to obtain improved estimates of ktrans and of tissue porosity.

Reference: 1. Pannetier et al. *PLoS ONE* **8,** e57636 (2013).