Modeling focal cortical dysplasia lesions using diffusion of gadolinium-DTPA in gel phantoms

Quentin Duché[1,2], Giulio Gambarota[1,2], Isabelle Merlet[1,2], Oscar Acosta[1,2], and Hervé Saint-Jalmes[1,2]
[1]*Université de Rennes 1 - LTSI, Rennes, Bretagne, France,* [2]*INSERM, UMR 1099, Rennes, France*

Introduction: Many disorders such as multiple sclerosis or focal cortical dysplasia (FCD) require the use of MRI to detect and precisely delineate size-limited lesions. Optimizing MRI sequences to enhance the contrast between healthy and pathological tissues is necessary. In addition, improving brain images post-processing algorithms of pathological subjects where usual assumptions do not hold is an important task. Thus, it is of primary interest to develop test objects mimicking the aspect of some brain lesions. In this work, we propose a test object to address this problem. It is possible to model the aspect of lesions involving a contrast modification such as a blurring between two tissues. The size and the spreading of the lesion can be controlled. It relies on the diffusion of gadolinium-DTPA (Gd-DTPA). We also present numerical simulations of the test object by modeling the gadolinium with millions of particles evolving in a constrained space describing our phantom.

Material: Two agar (2.5%) gel layers of size 4.8*1.3*3.8cm^3 were prepared, one Gd-DTPA free and one with an adjusted concentration of Gd-DTPA to target a T1 of 1s. The gels were separated by an impermeable interface with two rows of small apertures. Each row contained three circular apertures of diameters 3.2, 5.5 and 7.5mm. They allowed the contrast agent to move across the gels by going through a constrained and controlled area. The thickness of the interface was estimated to be less than 10µm.

Methods: Experiment: The water gel was positioned on top of the Gd-DTPA gel. The spatiotemporal Gd-DTPA evolution was followed up with several scans during 24 hours.

Scans: MR experiments were performed on a 4.7T Bruker BioSpin scanner. The imaging protocol consisted in repeating the same sequences regularly to measure the gadolinium diffusion with time. Essentially, T1 maps were calculated with two successive 2D Spin Echo (SE) sequences (TR1=1s, TR2=5s, TE1=TE2=10ms). Concentration of Gd-DTPA maps were deduced from the T1 maps. The coefficient of diffusion of Gd-DTPA D was estimated with the experimental profiles through the apertures in these maps.

Simulations: The experiment was recreated by modeling Gd-DTPA with millions of particles. The particle positions were updated each with a given time step dt according to a 3D vector where each coordinate is the realization of a normal random variable of zero-mean and standard deviation $\sigma = \sqrt{2D\mathrm{t}}$.

Results: The measured T1 for the water gel and for the Gd-DTPA gel are respectively 3.2s and 0.8s before the diffusion starts. The relaxivity value of Gd-DTPA inside agar was estimated to be 3.9 s^{-1}mmol.L^{-1}. This is in good agreement with the value measured in [1] (3.4 s^{-1}mmol.L^{-1}). D was measured inside agar as 7.1*10^{-10}m^{2}s^{-1} after one hour of diffusion. In the simulations, at t=1h, D measured perpendicularly to the interface was 6*10^{-10}m^{2}s^{-1}. The simulation profiles obtained matched the experimental profiles. Our experimental D is underestimated as it is only measured perpendicularly to the interface while the particles also diffuse parallel to the interface (Fig. 1).

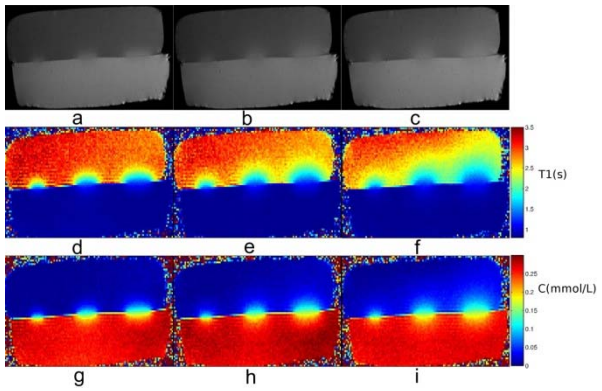

Fig. 1: SE MR images (TR=1s, TE=10ms) 1h (a), 5h (b), 21h (c) after the beginning of the diffusion. Corresponding T1 maps (d, e, f). Corresponding Gd-DTPA concentration maps (g, h, i).

Discussion: This phantom can be seen as an object mimicking a neuronal migration disorder. Indeed, one of the characteristic of FCDs is an unclear separation between gray matter (GM) and white matter (WM) (Fig. 2). This can be interpreted as a loss in the gradient of intensity between those two tissues in FCDs as compared to normal brain regions. The phantom models a change of T1 values throughout the apertures according to a spherical shape which leads to a similar aspect. This blurring effect is one of the features that is the most commonly used in the algorithms designed for FCD detection [2,3].

Conclusion: The physical phantom proposed in this study presents similar characteristics as the blurred GM/WM FCD. It can easily be reproduced and adjusted by varying parameters (object size, lesion size, diffusion time) to try enhancing contrast between healthy and pathological tissues as well as testing image processing algorithms.

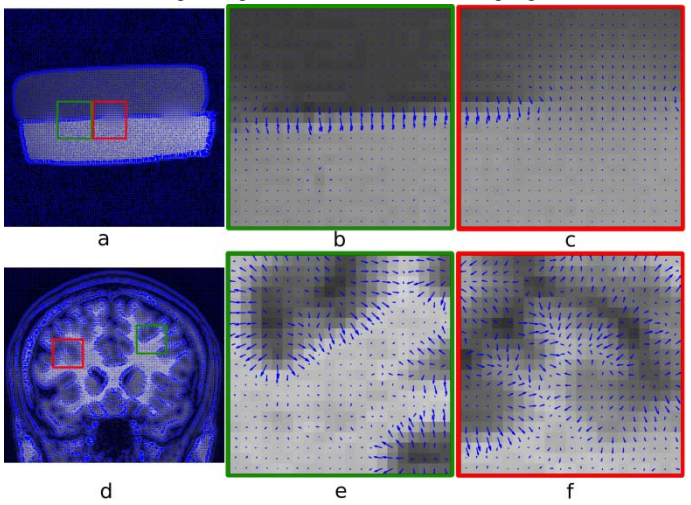

Fig. 2: Signal intensity gradient (arrows) in the physical phantom (a) and in an MRI of a patient with FCD (d). Similar aspect of the gradient in healthy tissues (b, e). A high norm corresponds to a normal transition between GM and WM. In the lesional tissue (c, f) a low gradient norm corresponds to an aggregation of neurons in the WM and results in a poorly contrasted cortical region.

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