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Fiche Synthétique

PlasDiff

UNIVERSITÉ TOULOUSE III PAUL SABATIER — Université de Toulouse

Titre de l'étude

Etude méthodologique de l'imagerie de la plasticité synaptique par IRM de diffusion

Auteurs/PI/Institution/Labo

Nicolas RENAUD[a,b,c], Hélène GROS-DAGNAC[a], Florent AUBRY[a], Pierre CELSIS[a]

[a] ToNIC, Universite de Toulouse, Inserm, UPS, France

[b] INCIA, UMR5287, Bordeaux 2, CNRS, France

[c] ARCANI, N°SIRET :803 234 715 000 16, Bordeaux , France

Contexte/Objectif de l'étude

Mettre au point une méthodologie et une base de données en IRM de diffusion multimodale permettant d'évaluer la plasticité synaptique par IRM de diffusion chez des sujets sains jeunes et agés.

Prestation du Plateau Technique

Séquences :

3D T1 : 1*1*1 mm, 4mn23

DWI_IVIM : 2*2*2.1 mm, 11b (0 à 1500) 9mn54

DfMRI : 3*3*4mm, 5b (1500, 1000, 500, 250, 0)

EPI : 3*3*4mm, TR/TE= 2000/35ms

Matériel :

- Antenne 8 CX
- NNL googles

Période : juillet 2010 – octobre 2012

Publication (2017)

Magnetic Resonance Imaging 39 (2017) 123–131

Contents lists available at ScienceDirect

Magnetic Resonance Imaging

journal homepage: www.mrijournal.com

Original contribution

Comparison of BOLD, diffusion-weighted fMRI and ADC-fMRI for stimulation of the primary visual system with a block paradigm

R Nicolas [a,b,c,*], H Gros-Dagnac [a], F Aubry [a], P Celsis [a]

[a] Imagerie cérébrale et handicaps neurologiques, INSERM Université de Toulouse (UMR 825), F-31059 Toulouse, France

[b] Aquitaine Institute for Cognitive and Integrative Neuroscience (INCIA), CNRS Université Bordeaux 2 (UMR 5287), F-33400 Talence, France

[c] ARCANI, 27, rue fonfrède (N° SIRET: 803 234 715 00016), F-33800 Bordeaux, France

ARTICLE INFO

Article history:
Received 4 July 2016
Received in revised form 30 January 2017
Accepted 31 January 2017
Available online xxxx

Keywords:
Diffusion-weighted functional MRI
BOLD
ADC
Primary visual system V1
Block stimulation paradigm
IVIM
Cytoarchitecture
Cytoarchitectonic
Grey matter

ABSTRACT

The blood oxygen level-dependent (BOLD) effect is extensively used for functional MRI (fMRI) but presents some limitations. Diffusion-weighted fMRI (DfMRI) has been proposed as a method more tightly linked to neuronal activity. This work proposes a protocol of DfMRI acquired for several b-values and diffusion directions that is compared to gradient-echo BOLD (GE-BOLD) and to repeated spin-echo BOLD (SE-BOLD, acquisitions performed with $b = 0$ s/mm^2), which was also used to ensure the reproducibility of the response.

A block stimulation paradigm of the primary visual system (V1) was performed in 12 healthy subjects with checkerboard alternations (2 Hz frequency). DfMRI was performed at 3 T with 5 b-values ($b = 1500$, 1000, 500, 250, 0 s/mm^2) with TR/TE = 1004/93 ms, $\Delta/\delta = 45.4$ ms/30 ms, and 6 spatial directions for diffusion measures. GE-BOLD was performed with a similar block stimulation design timing. Apparent Diffusion Coefficient (ADC)-fMRI was computed with all b-values used. An identical Z-score level was used for all fMRI modalities for the comparison of volumes of activation. ADC-fMRI and SE-BOLD fMRI activation locations were compared in a voxel-based analysis to a cytoarchitectural probability map of V1.

SE-BOLD activation volumes represented only 55% of the GE-BOLD activation volumes ($P < 0.0001$). DfMRI activation volumes averaged for all b-values acquired represented only 12% of GE-BOLD ($P < 0.0001$) and only 22% of SE-BOLD activation volumes ($P < 0.005$). Compared to SE-BOLD-fMRI, ADC-fMRI activations showed fewer pixels outside of V1 and a higher average probability of belonging to V1.

DfMRI and ADC-fMRI acquisition at 3 T could be easily post-processed with common neuro-imaging software. DfMRI and ADC-fMRI activation volumes were significantly smaller than those obtained with SE-BOLD. ADC-fMRI activations were more precisely localized in V1 than those of SE-BOLD-fMRI. This validated the increased capability of ADC-fMRI compared to BOLD to enhance the precision of localizing an fMRI activation in the cyto-architectural zone V1, thereby justifying the use of ADC-fMRI for neuro-scientific studies.

1. Introduction

The blood oxygen level-dependent (BOLD) signal [1] is extensively used in research and clinical practice to perform functional MRI (fMRI). BOLD is dependent on vascular processes presumably reflecting "brain activation" toward a hypothesized coupling process between neuronal activity, blood oxygenation and dynamics [2].

The BOLD effect is caused by a local decrease in magnetic susceptibility in tissue when paramagnetic deoxyhemoglobin is converted to diamagnetic oxyhemoglobin in brain vessels near activation. This is due to an increase in blood oxygen consumption and blood flow in brain vessels [1]. To ensure maximal sensitivity, BOLD is generally measured with gradient echo (GE) MRI pulse sequences, very sensitive to magnetic susceptibility [3]. Using spin echo (SE) pulse sequences instead of GE pulse sequences makes the BOLD signal insensitive to local T_2*-based relaxation [3] and therefore less intense.

As BOLD is a method sensitive to blood dynamics and oxygenation in large and small vessels [4–7] and not directly to neuronal activity, BOLD currently has some limitations [2]. However, two different types of novel fMRI imaging methods overcoming the limitations of BOLD and

Abbreviations: ADC, apparent diffusion coefficient; BOLD, blood oxygen level-dependent; CPMG, Carr-Purcell-Meiboom-Gill; DfMRI, diffusion-weighted fMRI; DW, diffusion-weighted; EDD, extra-vascular dynamic dephasing; ESD, extra-vascular static dephasing; FEAT, fMRI Expert Analysis Tool; FLAME, fMRI local analysis of mixed effects; fMRI, functional MRI; FWHM, full width at half maximum; GE, gradient-echo; GRF, Gaussian random field; ICA, independent component analysis; IDA, intra-vascular dynamic averaging; IFS, intra-vascular frequency shift; IVIM, intra-voxel incoherent motion; MFG, magnetic field gradients; MNI, Montreal Neurological Institute; MRI, Magnetic Resonance Imaging; SE, spin-echo; SPM, Statistical Parametric Mapping; VBA, voxel-based analysis; VOI, volume of interest.

* Corresponding author at: Imagerie cérébrale et handicaps neurologiques, INSERM Université de Toulouse (UMR 825), F-31059 Toulouse, France.

E-mail address: md.nicolas@gmail.com (R. Nicolas).

http://dx.doi.org/10.1016/j.mri.2017.01.022

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Publication 2 (2015)

Accuracies and Contrasts of Models of the Diffusion-Weighted-Dependent Attenuation of the MRI Signal at Intermediate *b*-values

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FREEDOM TO RESEARCH

Renaud Nicolas[1,2,4], Igor Sibon[2,3] and Bassem Hiba[1,2]

[1]Centre de Résonance Magnétique des Systèmes Biologiques (RMSB), UMR 5536, CNRS-Université Bordeaux, Bordeaux Cedex, France. [2]Aquitaine Institute for Cognitive and Integrative Neuroscience (INCIA), UMR 5287, CNRS-Université Bordeaux, Talence, France. [3]University Hospital (CHU) Bordeaux Pellegrin, NeuroVascular Unit, Bordeaux Cedex, France. [4]Ecole Pratique des Hautes Etudes (EPHE), Laboratoire de Neurobiologie Intégrative et Adaptative, Bordeaux Cedex, France.

ABSTRACT: The diffusion-weighted-dependent attenuation of the MRI signal $E(b)$ is extremely sensitive to microstructural features. The aim of this study was to determine which mathematical model of the $E(b)$ signal most accurately describes it in the brain. The models compared were the monoexponential model, the stretched exponential model, the truncated cumulant expansion (TCE) model, the biexponential model, and the triexponential model. Acquisition was performed with nine b-values up to 2500 s/mm² in 12 healthy volunteers. The goodness-of-fit was studied with F-tests and with the Akaike information criterion. Tissue contrasts were differentiated with a multiple comparison corrected nonparametric analysis of variance. F-test showed that the TCE model was better than the biexponential model in gray and white matter. Corrected Akaike information criterion showed that the TCE model has the best accuracy and produced the most reliable contrasts in white matter among all models studied. In conclusion, the TCE model was found to be the best model to infer the microstructural properties of brain tissue.

KEYWORDS: diffusion MRI, model accuracy, kurtosis, cumulant expansion, Akaike information criterion, brain, IVIM

CITATION: Nicolas et al. Accuracies and Contrasts of Models of the Diffusion-Weighted-Dependent Attenuation of the MRI Signal at Intermediate *b*-values. *Magnetic Resonance Insights* 2015:8 11–21 doi:10.4137/MRI.S25301.

RECEIVED: February 25, 2015. **RESUBMITTED:** April 23, 2015. **ACCEPTED FOR PUBLICATION:** April 26, 2015.

ACADEMIC EDITOR: Sendhil Velan, Editor in Chief

TYPE: Original Research

FUNDING: This work was supported by the LECMA (Ligue Européenne Contre la Maladie d'Alzheimer), the EPHE (École Pratique des Hautes Études), and by the 2013 joint fellowship of the SNFV (Société Française de NeuroVasculaire) and France AVC, dedicated to fundamental stroke research. The authors confirm that the funder had no influence over the study design, content of the article, or selection of this journal.

COMPETING INTERESTS: Authors disclose no potential conflict of interest.

CORRESPONDENCE: rnd.nicolas@gmail.com

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Introduction

Diffusion MRI (dMRI) is a powerful *in vivo* method for exploring biological microstructures.[1] The contrast of diffusion-weighted (DW) images is dependent on the magnitude of the diffusion-weighting factor (b-value). In clinical practice, especially for fast and early detection of ischemic stroke, DW images are generally acquired with a unique b-value ($b = 1000$ s/mm²). The geometric mean of DW images over three spatial directions is then used to calculate apparent diffusion coefficient (ADC) maps[2] with the help of a monoexponential model (MEM) formalism. As it uses the same limited range of b-values but is acquired for 6–60 spatial directions,[3] diffusion tensor imaging is also an MEM that includes the effect of water diffusion anisotropy[3] and leads to the calculation of a rotationally invariant form of the ADC, the mean diffusivity.

On the other hand, the higher the b-value, the more sensitive the DW images are to smaller absolute random displacements of water molecules, and therefore to the microscopic structures of brain tissue.[1] Therefore, high b-value dMRI consists of recording series of DW images with successively increasing b-values up to relatively high values (b ~2500 to ~12,000 s/mm²). The number of spatial direction measures acquired is adapted depending on the time constraints. The DW-dependent attenuation of the MRI signal obtained in each image pixel is related by Fourier transformation to the water displacement probability distribution (q-space method). In brain tissue, the standard deviation of this distribution has a characteristic length scale of tenths of µm,[4,5] making it possible to investigate some microstructural changes related to cerebral insults.[5] However, Fourier transformation of the DW-dependent attenuation of the MRI signal (q-space) requires experimentally challenging conditions, whereas signal modeling is more flexible. Indeed, the DW-dependent attenuation of the MRI signal (designed as $E(b)$) acquired with intermediate or high b-values needs to be modeled numerically with a mathematical function describing its non-exponential decay, which is relevant to the postulated properties of the microscopic structures present in brain tissues.[4,6–8] High b-value dMRI modeling and q-space are very sensitive to microscopic water displacements, highlighting white matter (WM) structures[7,8] or cerebral insults in animals[9–12] and in human brains,[5,13] and thus having a potential clinical interest.

Two types of models are needed for the study of diffusion imaging. The first (signal models) describes empirically how the $E(b)$ signal decays, whereas the second (tissue models) describes how the signal relates to the underlying tissue

Publication 3

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