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Diffusion MRI of Human Brain: Key Points and Innovations

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Abstract

MRI-based investigations represent, to date, very powerful approaches for the study of the brain. One set of tools, provided by diffusion MRI, allows the non-invasive analysis of structural aspects of gray and white matter, by analyzing how water molecules diffuse within the brain. Although number of clinical studies employing diffusion MRI has grown in last years, some aspects still result poorly known or poorly understood by unfamiliar researchers and clinicians, due to their technical complexity. The main goal of the present work is to resume the main landmarks of diffusion MRI investigation and to show the current state as well as future perspectives of related methodologies.

Index terms— magnetic resonance imaging, diffusionweighted imaging, diffusion models, diffusion tensor imaging, constrained spherical deconvolution, tractography.

1 I. Introduction

iffusion MRI (dMRI) represents nowadays a powerful tool for the non-invasive investigation of the brain. It allows to perform both qualitative and quantitative evaluation of brain features as well as of its alterations, with particular regards to white matter ones. All diffusion-based techniques are dedicated to the analysis of signals provided by the diffusion process of water molecules within brain tissues. Goal of this manuscript is two-fold: firstly, we want to provide a summary of the state of the art for researchers unfamiliar with dMRI models and related techniques; secondly, we want to address some of future perspectives in the field.

2 II. Diffusion Models

Diffusion models consist in a set of algorithms attempting to estimate how water molecules diffuse within each voxel (imaging unit). The mostly known model is diffusion tensor, which is the basis of Diffusion Tensor Imaging (DTI) (Basser et al., 2000); however a cohort of other models which overperform DTI have been developed over the years, such as Q-ball imaging (QBI) (Tuch, 2004), Diffusion Spectrum Imaging (Wedeen et al., 2008), Constrained Spherical Deconvolution (CSD) (Tournier et al., 2007), multi-compartments models (see for instance Panagiotaki et al., 2012). All above mentioned techniques return back a geometrical object (e.g. the tensor for DTI) which encodes diffusion process for each analyzed voxel; the sensitivity as well as the type of information which can be extracted from such objects vary according to the algorithm/model used. Based on these objects, qualitative and quantitative analyses can be performed. a) Qualitative analysis One of the most explored applications of diffusion MRI is tractography (Soares et al., 2013), i.e. the reconstruction of the path followed by a given white matter bundle. This can be achieved by means of both deterministic (one direction assigned for each voxel) and probabilistic (the most probable path obtained after a given number of attempts) tractographic algorithms (Soares et al., 2013;Behrens et al., 2007). Tractography reconstruction outcomes strongly rely on the underlying diffusion model used In this context, several issues can affect the reliability of tractographic results, e.g. the presence of voxels with multiple fiber directions (Farquharson et al., 2013). DTI cannot handle multiple fiber directions, as it can only provide a unique diffusion direction. This is the reason why other more advanced approaches outperform DTI based tractography, like CSD (Tournier et al., 2008;Farquharson et al., 2013). An exemplificative case showing how tractographic output can be different according to the model used, namely

DTI and CSD, is shown in Figure 1, where corticospinal tract and optic radiations were reconstructed with both methods. FA measures level of anisotropy in the voxel: the higher this number, the higher the probability that a single predominant fiber direction is appearing in that voxel. It has to be noticed however that (Jeurissen et al., 2013), if we were to compare FA values obtained by averaging within voxels sampled by means ofCSDbased tractographic reconstruction with the same average performed on the basis of DTI tractography, we would observe a FA reduction. This happens because, with CSD, voxels with multiple dominant fiber directions are involved; as result, water diffusion anisotropy is spread across different directions, and tensor model is), as previously described, tractographic output strongly depends on the algorithm used for diffusion signal modelling (Farquharson et al., 2013).Several inaccuracies caused by possible artefactual effects as well as false positive tracts should be also taken into account (Jones and Cercignani, 2010). Furthermore, since tractography represents the reconstruction of white matter paths provided by a mathematical computation (deterministic or probabilistic), it is often criticized by declaring that dissection is preferable due to its ability to definitely assess the real existence of a given connection. However, a number of studies have validated DTI tractographic output through histological investigations (Seehaus et al., 2013;Gao et al., 2013;Seehaus et al., 2015). The adoption of more advanced algorithms have allowed a better detection of white matter bundles; those techniques have obtained histological validations as well **??**Dirby et al., 2007;Azadbakht et al., 2015). Recently, in vivo neurite orientation dispersion and density imaging (NODDI) (Zhang et al., 2012) was proposed: this technique allows a multi-compartmental analysis of the brain, i.e. separately considering glial, axonal and extracellular components, thus restituting a detailed profile of brain microstructure. Although technical requirement are not easily reachable, this represents a promising investigative technique for a deeper study of the brain both in healthy and pathological conditions.

3 D

Interesting future perspectives will be to make more feasible these innovative approaches for clinical settings as well as to integrate them with other investigative techniques, such as electrophysiology and transcranial magnetic stimulation.

4 IV. Conclusion

In this paper the main key points of diffusion MRI investigations have been neatly described. We wanted to provide a brief and simplified description of the complex methodological aspects, in order to offer necessary pills for better understanding diffusion-based studies.

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Figure 1: Figure 1 :

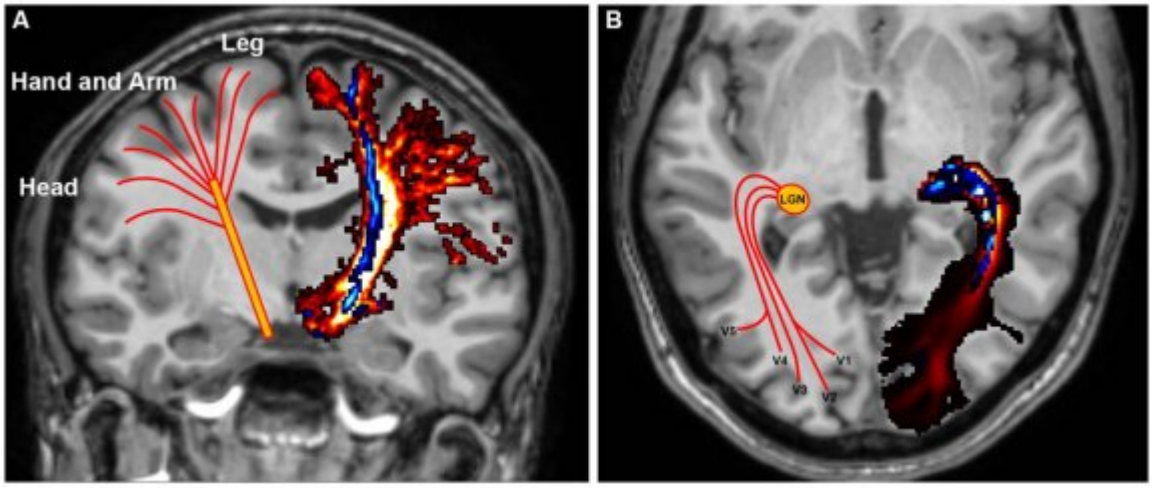

Figure 2:

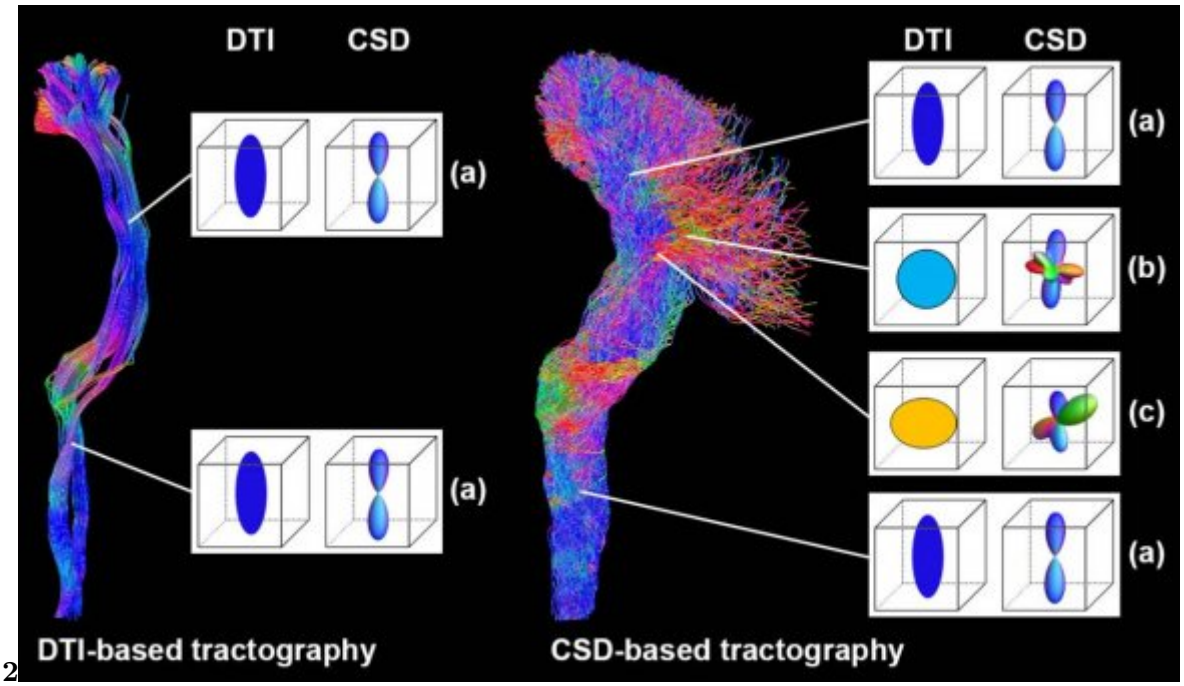

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Figure 3: Figure 2 :

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