DIFFUSION IN REALISTIC BIOPHYSICAL SYSTEMS MAY LEAD TO ALIASING EFFECTS IN DIFFUSION SPECTRUM IMAGING

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TARGET AUDIENCE - This abstract is targeted for researchers and neuroscientists working with diffusion imaging.

PURPOSE – Diffusion Spectrum imaging [1] is a very demanding technique that requires extensive validation before it can be well established in clinical practice. Even though it has been successfully applied to resolve white matter crossings in the human brain, the accuracy of DSI in more complex microstructure environments has not been well characterized. In this study, we simulated different tissue configurations, sampling schemes and processing steps to evaluate the performance of DSI. Particularly, we also tested DSI reconstructions with partial volume effects and draw some conclusions on possible limitations and optimization of the technique for research and clinical purposes.

METHODS – An isotropic component was simulated with diffusivities ranging from $1x10^{-3}$ mm^2/s to $3x10^{-3}$ mm^2/s in $0.5x10^{-3}$ intervals. Additionally a single fibre configuration with Gaussian diffusion was simulated with a single tensor of constant trace - $2.1x10^{-3}$ mm^2 – axial diffusivities of [1.1, 1.3, 1.5, 1.7, 1.9] $x10^{-3}$ mm^2. Each configuration was simulated for a diffusion time (Δ) of 50ms, and three different acquisition schemes: an "ideal" DSI acquisition defined over a 63x63x63 Cartesian grid with a maximum b-value of 65000 s/mm^2 and two typically used acquisitions; a high resolution DSI acquisition with b-value of 8000 s/mm^2 and 11x11x11 grid yielding 515 sampling points and a medium resolution DSI acquisition with a max b-value of 4000 s/mm^2 with 7x7x7 and 123 sampling points. For each dataset the propagator was estimated and from it, with and without Hanning filtering [2], the ODF was derived by radial integration along a mesh of 10832 vertices, for better visualization. The main objective of this analysis was to evaluate how consistent DSI reconstructions were for each configuration, and for different simulated angles, when different diffusion parameters were used. We expected the amplitude of the ODFs to be constant, thus, we computed its amplitude for different angles, rotating the same fibre from 0° to 180°. We also evaluated the isotropic component in 180 directions along half-sphere, expecting to obtain a constant value.

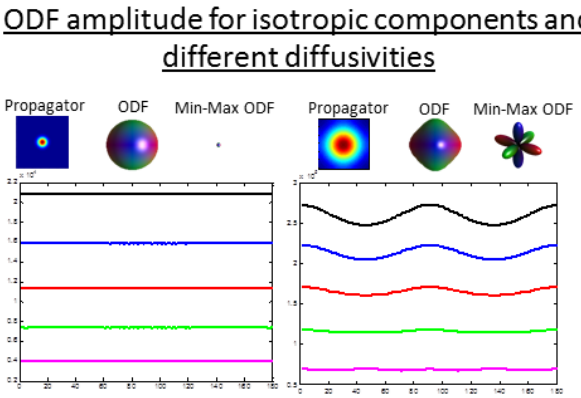

Fig 1 – Amplitude of the ODF measured in different angles for different diffusivities: from bottom to top - $1x10^{-3}$ mm^2/s to $3x10^{-3}$ mm^2/s in $0.5x10^{-3}$ intervals, for a b4000 s/mm^2 (Left) and an "ideal" (Right) DSI scheme. A propagator and ODF (with and without min-max normalization) are also shown for the $3x10^{-3}$ mm^2/s scenario for both diffusion schemes.

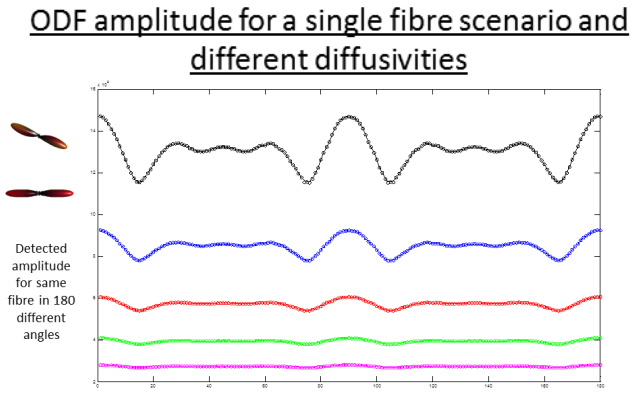

Fig 2, left – Example of two ODFs reconstructed with the b8000 s/mm^2 high resolution DSI scheme in 45° (upper row) and 0° (medium row) degrees. Fig 2, right - Amplitude of the ODF measured in different angles for different diffusivities: from bottom to top – $1.1x10^{-3}$ mm^2/s, $1.3x10^{-3}$ mm^2/s, $1.5x10^{-3}$ mm^2/s, $1.7x10^{-3}$ mm^2/s and $1.9x10^{-3}$ mm^2/s for a for a b8000 s/mm^2 DSI scheme.

RESULTS AND DISCUSSION – Figure 1 depicts the maximum amplitude of the ODF (without min-max normalization) for different diffusivities, at different angles, for an isotropic scenario and different diffusion schemes. On the left-hand side of figure 1, as expected, it is visible that for an "ideal" scenario, independently of which diffusivity we are considering, the amplitude of the ODF is constant for all analysed angles, which is consistent with the spherical profile of the ODF. However, on the right hand-side of figure 1, the amplitude of the ODF is no longer constant for all diffusivities. For the b8000 (not shown) and particularly b4000 DSI schemes, it is visible in the propagator that the displacement of water molecules goes beyond the field of view, which causes aliasing on the reconstruction and subsequently changes the real amplitude of the ODF. It can also be seen that the aliasing effect leads to artefactual fibre reconstructions when standard processing, specifically min-max normalization, is performed (Fig 1, right). This effect is more pronounced with higher diffusivities and is therefore expected to be particularly problematic in voxels containing (or exhibiting partial volume contamination with) Cerebrospinal Fluid (CSF) or Oedema in pathological tissue. The limit when aliasing is detected depends on the capability of the acquisition, as we need to sample as far as twice the maximum displacement present in the diffusion propagator, which gives us a good indication for future optimization of DSI acquisition schemes [3]. This limitation of DSI is further extended in a single fibre analysis, depicted in Figure 2. In this figure we once again show the maximum amplitude of the ODF for different diffusivities and a diffusion time of 50ms as generated from different angles (0° to 180°). The general trend that was observable in the isotropic component scenario remains, but we can depict specific angles where the aliasing effects are more pronounced. This seems to be an effect deriving from the Cartesian acquisition scheme that is used in DSI which causes some ODFs to lose their symmetric profile. In both Figure 1 and Figure 2, the computed ODF were generated from a propagator without Hanning Filtering. Similar results were also observed with Hanning filtering, i.e., the presence of aliasing in the diffusion propagator. Finally, simulations conducted with different diffusion times, showed that the use of smaller diffusion times led to a decrease of aliasing in the propagator whilst using longer diffusion times amplified this effect.

CONCLUSION – With this study we were able to demonstrate an inherent limitation of Diffusion Spectrum Imaging, namely the inability to deal with fast diffusion components, which causes aliasing on the diffusion propagator reconstruction, using traditional acquisition protocols. This effect can eventually lead to artefactual peaks in the presence of partial volume contamination. These limitations should be dealt with, particularly for the use of DSI-based analyses in clinical environments. Future directions include optimizing the current acquisition schemes based on the maximum biological displacement that can be probed without artifacts, and also exploring other diffusion imaging techniques capable of retrieving information about the diffusion propagator [4,5].

[1] Wedeen, V. J. et al, MRM 2005, 54(6), 1377–86; [2] Paquette, M. Et al ISMRM 2014; [3] Qiyuan, T. et al, ISMRM 2014; [4] Özarslan, E. et al, ISMRM 2009; [5] Özarslan, E. et al, NeuroImage 2013, 78, 16–32;