

Denoised diffusion spectrum imaging of white matter tracts in the brainstem

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Synopsis

High-angular resolution diffusion (HARDI) MRI, like diffusion spectrum imaging-DSI, provides an attractive tool to investigate the complex white matter structure in the brainstem. However, due to the application of high b-values in the HARDI acquisition, the raw images are SNR limited (SNR<10). In this study, we applied a novel denoising algorithm to low-SNR DSI data. Our results showed that Generalized Anisotropy maps and tractography seeding the periaqueductal grey matter, a small structure in the mesencephalon, match more accurately the underlying anatomy when applying the denoising algorithm.

Purpose:

The brainstem is a mixed grey-white matter structure, which plays a pivotal role in controlling consciousness, respiration, sleep, respiratory and cardiovascular function as well as sensory-motor communication between the brain and the spinal cord¹. Diffusion Magnetic Resonance Imaging (MRI) in the brainstem might help understanding in vivo physiology as well as pathophysiological mechanisms in neurological and neuropsychiatric diseases (i.e. multiple sclerosis², migraine³, stroke⁴ ect). DSI as other high angular resolution diffusion MRI techniques might be highly advantageous to study the complex white matter structure characterizing the brainstem. Yet, diffusion MRI in the brainstem is prone to susceptibility, motion artifacts due to cardiac pulsation and respiratory activity and is located in the area of lowest coil sensitivity⁵.

In this work, we applied a new non-local denoising method^{6,7} to diffusion spectrum imaging (DSI) data. Using denoised and original DSI data, we then evaluated the qualitative parametric and tractography appearance of large white matter bundles in the mesencephalon, pons and medulla oblongata.

Methods:

We retrospectively evaluated two DSI datasets obtained from a cohort of multiple sclerosis patients and healthy subjects (repetition time [TR]/echo time [TE]=8,600/144 msec, field of view [FOV]=212x212 mm, 48 slices, 2.2x2.2x3 mm resolution, 258 diffusion directions, $b=8,000$ s/mm²). Each subject was scanned at clinical 3T MRI (Magnetom Trio a TIM System, Siemens, Germany) using a 32 channel head-coil array. MP2RAGE uniform images (TR/TI1/TI2=5000/700/2500 ms, $vs=1.0x1.0x1.2$ mm³)⁸ were used for anatomical reference. A prototype of the non local spatial and angular block matching (NLSAM) technique was used to denoise the raw DSI data. Probabilistic Identification and Estimation of Noise (PIESNO)⁹ was used to automatically correct for the variable non-central Chi distributed noise and then NLSAM was performed with a spatial neighborhood of 3x3x3 and 5 angular q-space neighbors. Generalized fractional anisotropy (GFA) maps were calculated as in¹⁰. White matter tracts in the mesencephalon, pons and medulla oblongata of GFA maps from denoised and original volumes were qualitatively compared to the Duvernoy atlas of the brainstem¹¹.

The periaqueductal grey matter (PAG) was manually delineated based on the Duvernoy atlas (PAG is a gray matter structure located around the mesencephalic aqueduct, which extends for about 14mm and is approximately 4–5mm wide). PAG was used as seed to perform streamline tractography using trackvis (www.trackvis.org). Tractography-derived fibers trajectories from the PAG were qualitatively evaluated based on anatomical knowledge and previous studies¹².

Results and Discussion:

Figure 1 shows the comparison of GFA maps in the mesencephalon at the level of the PAG: GFA maps from denoised images evidenced the presence of the medial lemniscus and spinothalamic tract, which were not visible in the original maps. Figure 2 shows the comparison of GFA maps in the pons: also at this level, GFA maps from denoised data show the presence of the medial and lateral lemniscus, in addition to the pyramidal and spinothalamic tract that are evident also in the original images. No clear white matter tract differences were observed between the denoised and the original datasets in the medulla oblongata. Figure 3 shows the tractography result of seeding the PAG in the mesencephalon. The PAG is a key structure in the brainstem as it plays a major role in pain modulation, anxiety, reproductive behavior and in the integration of information from the periphery and the brain¹³. Therefore, the PAG is directly highly connected to the prefrontal and insular cortex, thalamus, hypothalamus, brainstem and deep layers of the spinal cord¹⁴. In addition, it is connected to the cerebellum through the inferior olive in the medulla oblongata. Figure 3 shows the tractographic appearance of PAG connection in denoised and original DSI data, highlighting the advantages of using denoised data to perform tractographic analysis of a small brainstem structure like the PAG.

Conclusion:

NLSAM applied to high-angular resolution diffusion DSI data provided clear advantages to visualize WM bundles in the brainstem using both GFA maps and streamline tractography. Future investigations in patients affected by pathologies alternating WM bundles in the brainstem will highly benefit of denoising techniques such NLSAM.

Acknowledgements

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Figures

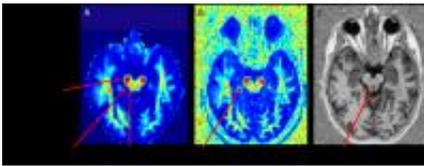


Figure 1: Mesencephalon: axial Generalized Fractional Anisotropy maps in denoised (A) and non-denoised DSI data (B). Axial T1-weighted MP2RAGE uniform image (C). Arrows indicate the medial lemniscus and the spinothalamic tract that appear better delineated in the denoised images and the periaqueductal grey matter in the uniform MP2RAGE image.

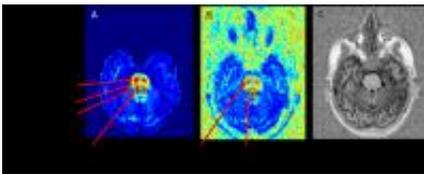


Figure 2: Pons: axial Generalized Fractional Anisotropy maps in denoised (A) and original DSI data (B). Axial T1-weighted MP2RAGE uniform image (C). Arrows indicate the medial and lateral lemniscus in A and the spinothalamic and pyramidal tract in A and B. All structures appear better delineated in denoised images.

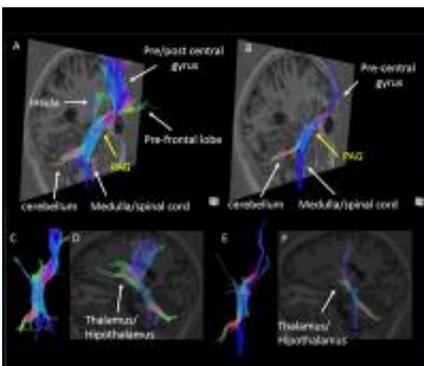


Figure 3: Tractography results obtained seeding from the PAG (violet ROI). A, C and D denoised PAG tractography and B, E and F PAG tractography on original DSI data.