Experience using Novel Multidimensional Diffusion Magnetic Resonance Imaging for Characterization of Tissue Microstructure in various Brain Pathologies

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RANDOM WALK IMAGING

CARING

MAHAJAN IMAGING
From X-Rays to Molecular Imaging

1 TEACHING ACTIVITY

At the conclusion of this activity, participants will be able to:

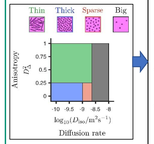
- Understand how DTD Provides better discrimination of the average rate, microscopic anisotropy, and orientation of diffusion within microscopic tissue environments
- Understand how DTD allows separation of tissue-specific diffusion profiles of the main brain components, e.g., white matter(WM), grey matter (GM), cerebrospinal fluid (CSF) and pathological tissue environments such as edema through 'bins', namely the 'thin', 'thick', 'big', and the 'sparse' bin.
- Identify key differential diagnostic points in different brain indications
- Learn the Pros and cons of the sequence.

2 BACKGROUND

- Conventional diffusion MRI measurements are based on Stejskal-Tanner pulse sequences yielding single diffusion encoding (SDE) that allows for estimation of the mean diffusivity and fractional anisotropy. These parameters are sensitive to microstructural tissue changes, and lack specificity in depicting the cause of these changes, especially in heterogeneous voxel contents featuring complex WM fiber crossings.
- MDD-MRI is a novel diffusion imaging technique relying on optimized gradient waveforms to capture the features of the diffusion process via the b-tensor.
- The acquisition of planar and/or spherical b-tensors provides complementary information enabling better discrimination of the average rate, anisotropy, and orientation of diffusion within microscopic tissue environments.

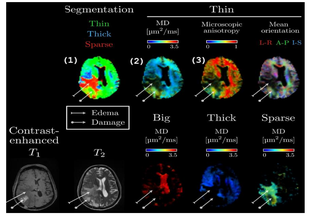
3 INTERPRETATION OF THE DTD BINS

- DTD imaging allows for separation of tissue-specific diffusion profiles through so-called "bins". In addition to the routinely visualized "thin", "thick" and "big" bins, we introduce a fourth bin, dubbed "sparse", that isolates signal fractions arising from pathological tissue environments such as edema.
- DTD "bins", encapsulate tissue-specific diffusion patterns based on their diffusion rate and anisotropy.



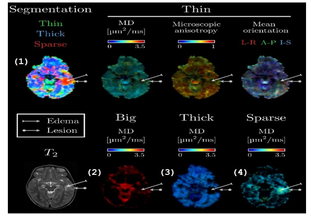
- **Thin bin**: captures elongated cells(e.g., WM fiber bundles, certain brain tumors).
- **Big bin**: captures free water (e.g., CSF in the ventricles).
- **Thick bin**: captures densely packed round cells (e.g., GM).
- **Sparse bin**: captures low cell-density diffusion environments (e.g., edema).

4 Evaluation of MDD in Radiation damage



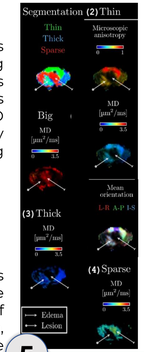
(1) The bin-segmentation map (SegM) highlights the presence of edema (sparse bin) surrounding a damage area containing fiber populations (thin bin). **(2 & 3)** Thin-bin resolved maps indicate that the damage area has a higher MD and a lower microscopic anisotropy than healthy WM, which may indicate ongoing neurodegeneration.

Evaluation of MDD in Neurocysticercosis



(1) The SegM highlights that the lesion is captured by the thin bin (green), indicating the presence of elongated cells at the site of infection. This site is surrounded by edema, captured by the sparse bin (red)**.(2, 3 & 4)** The bin resolved MD maps tease apart the contributions of CSF **(2)**, healthy grey matter **(3)** and edema **(4)** around the site of infection. Colors indicate the expected tissue-specific ranges of MD values.

MDD sequence in Tuberculoma



(1) The SegM highlights edema from the sparse bin (red) surrounding the tuberculoma lesion captured by both the thin and thick bins **(2)** The thin-bin resolved microscopic anisotropy map suggests that the lesion consists of elongated cells exhibiting lower microscopic anisotropy (yellow) compared to the highly anisotropic nerve fibers entering the cerebellum (red/orange).**(3)** The thick-bin resolved MD map suggests that the lesion has additional densely packed round cells within its outer layer (blue).**(4)** The sparse-bin resolved MD map informs on the severity of the edema around the lesion, increasing from low MD (green) to high MD (yellow).

5 FUTURE DIRECTION AND RECOMMENDATION

Distortion artefacts could be corrected upon acquiring a reverse phase-encoding b0 image.

6 ADVANTAGES

- Allows acquisition of b-tensors with varying shape.
- Efficient gradient waveform design can deliver the required b-tensors in a clinically feasible acquisition time
- Enables estimation of voxel-resolved nonparametric DTD maps of microstructural tissue heterogeneity, which is not accessible with conventional diffusion MRI methods.
- Binning of the DTDs allows for tissue-specific quantitative parameter maps isolating the diffusion properties of the main brain components.
- Microscopic anisotropy is not confounded by cell alignment over the voxel scale, unlike conventional FA.

7 CHALLENGES

- Long processing time.
- longer TE imposes a lower image resolution(3x3 mm^2) .
- MDD analysis methods can suffer from detrimental noise sensitivity, given the typically lower signal levels yielded by planarly and spherically encoded diffusion sequences.

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