Mapping tissue components and dynamic processes in the brain using MRI

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Microscopic scale changes in brain tissue take place during normal and abnormal brain development, and following mild to severe traumatic brain injury (TBI). In addition, brain tissue is heterogeneous in nature; an imaging volume will contain an ensemble of different cells and extracellular matrix components. At the microscopic level, these components would vastly differ in their molecular composition, as well as in their microstructure. As a result, the water that resides within the tissue will also interact with different chemical and physical microenvironments. By probing these water interactions using magnetic resonance imaging (MRI) one can, theoretically, overcome the limited spatial resolution (~ 1mm^3) and noninvasively detect and distinguish between the different microenvironments within a voxel. However, to date, computational instabilities and vast data requirements, leading to clinically infeasible scan times, have mostly relegated these type of measurements to nuclear magnetic resonance (NMR) applications, and prevented them from being widely and successfully used in conjunction with imaging.

I have recently developed a novel experimental design, data acquisition, and signal processing framework, termed MADCO, which allows to combine various spectroscopic NMR experiments with imaging in reasonable scanning times and with excellent prospects for clinical applications. Using these tools one can measure, map, and render 3D images of the dynamics of water protons in a model-free and direct manner, making no assumptions about the underlying microstructure of the tissue. Here I will present two new, and complementary, MADCO-based MR imaging framework: (1) Magnetic resonance microdynamic imaging (MRMI), which permits the simultaneous noninvasive and model-free quantification of the volume fraction of multiple subcellular, cellular, and interstitial tissue components within a voxel (e.g., axons, neurons, glia, interstitial space, and myelin in brain tissue). (2) Accelerated diffusion exchange spectroscopic imaging (ADEXSI), which is able to noninvasively map dynamic migration of water from one
microenvironment to another (e.g., molecular exchange rate of water between intra- and extracellular spaces).

Apart from its known biological and clinical applications, MR is routinely used by chemists and biochemists to quantitatively describe materials with sub-molecular resolution; it is used by physicists to quantify flow and velocity in microscopic capillaries to measure mass transport; and it is used by geologists as logging tools for in situ oil, gas, and water underground reservoir evaluation. Integrating, migrating, and translating these approaches and methods from a broad range of scientific fields is what I believe can help us to better understand such a complex system as the human brain.

About the speaker
Dan Benjamini is a postdoctoral fellow at the Section on Quantitative Imaging and Tissue Sciences in the National Institutes of Health (NIH, Peter Basser's group). He holds a B.Sc. and a M.Sc. degrees in Biomedical Engineering from Tel Aviv University. Dan completed his Ph.D. in Biomedical Engineering as part of the Graduate Partnerships Program (GPP), a collaborative effort between Tel Aviv University and the NIH. He is a recipient of the 2016 Giulio Cesare Borgia Prize for Young Researchers and the 2018 NIH Fellows Award for Research Excellence (FARE).