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Mapping Iron Content in the Brain with Magnetic Resonance Imaging and Machine Learning

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Abstract : Iron deposition in the brain has been linked with a host of neurological disorders such as Alzheimer's, Parkinson's, and Multiple Sclerosis. While some treatment options exist, there are no objective measurement tools that allow for the monitoring of iron levels in the brain in vivo. An emerging Magnetic Resonance Imaging (MRI) method has been recently proposed to deduce iron concentration through quantitative measurement of magnetic susceptibility. This is a multi-step process that involves repeated modeling of physical processes via approximate numerical solutions. For example, the last two steps of this Quantitative Susceptibility Mapping (QSM) method involve I) mapping magnetic field into magnetic susceptibility and II) mapping magnetic susceptibility into iron concentration. Process I involves solving an ill-posed inverse problem by using regularization via injection of prior belief. The end result from Process II highly depends on the model used to describe the molecular content of each voxel (type of iron, water fraction, etc.) Due to these factors, the accuracy and repeatability of QSM have been an active area of research in the MRI and medical imaging community. This work aims to estimate iron concentration in the brain via a single step. A synthetic numerical model of the human head was created by automatically and manually segmenting the human head on a high-resolution grid (640x640x640, 0.4mm^3) yielding detailed structures such as microvasculature and subcortical regions as well as bone, soft tissue, Cerebral Spinal Fluid, sinuses, arteries, and eyes. Each segmented region was then assigned tissue properties such as relaxation rates, proton density, electromagnetic tissue properties and iron concentration. These tissue property values were randomly selected from a Probability Distribution Function derived from a thorough literature review. In addition to having unique tissue property values, different synthetic head realizations also possess unique structural geometry created by morphing the boundary regions of different areas within normal physical constraints. This model of the human brain is then used to create synthetic MRI measurements. This is repeated thousands of times, for different head shapes, volume, tissue properties and noise realizations. Collectively, this constitutes a training-set that is similar to in vivo data, but larger than datasets available from clinical measurements. This 3D convolutional U-Net neural network architecture was used to train data-driven Deep Learning models to solve for iron concentrations from raw MRI measurements. The performance was then tested on both synthetic data not used in training as well as real in vivo data. Results showed that the model trained on synthetic MRI measurements is able to directly learn iron concentrations in areas of interest more effectively than other existing QSM reconstruction methods. For comparison, models trained on random geometric shapes (as proposed in the Deep QSM method) are less effective than models trained on realistic synthetic head models. Such an accurate method for the quantitative measurement of iron deposits in the brain would be of important value in clinical studies aiming to understand the role of iron in neurological disease.

Keywords : magnetic resonance imaging, MRI, iron deposition, machine learning, quantitative susceptibility mapping
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