Diffusion Weighted Imaging (DWI)

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Introduction to DWI

Diffusion weighted imaging (DWI) is an MR imaging method which provides information on the Brownian motion of water molecules in each imaging voxel. Specifically, DWI enables measurement of tissue cellularity and integrity of cell membranes, with the compact nature of the extracellular space in highly cellular tissues leading to "restricted" diffusion. In contrast, fluid filled tissues exhibit "free" diffusion. DWI is typically acquired through the application of bipolar gradients which dephase and rephase water molecule spins in the tissue of interest. The gradients are characterized by the b-value (s/mm^2) which incorporates factors such as gradient amplitude, gradient duration and the time between the gradient lobes. Water molecules which have moved between the application of the gradient lobes will not be completely rephased causing signal attenuation. Generally signal attenuation increases with increasing b-value. A linear fit of the logarithm of signal intensity with increasing b-value generates a measure of the apparent diffusion coefficient (ADC). For intravoxel incoherent motion (IVIM) methods several low b-values (<200 s/mm^2) are acquired to capture capillary perfusion and higher b-values capture molecular diffusion. A biexponentional model fit provides values for perfusion fraction (f), diffusion (D) and perfusion (D*). DWI methods are available on most clinical MR systems and do not require specialized equipment[1].

When and how to use DWI

DWI is predominantly employed for oncology purposes notably lesion detection and characterization and evaluating treatment response, however DWI is also potentially useful in chronic liver disease, where it has been utilized to stage liver fibrosis. As liver fibrosis severity increases, ADC values have been shown to decrease signifying increased diffusion restriction at higher fibrosis stages, though some studies report conflicting results. DWI is most commonly performed using a fat suppressed, single-shot, spin-echo echo-planar imaging (SE-EPI) sequence. Imaging may be performed over a single or multiple breath holds, or as a free breathing acquisition with multiple signal acquisitions and the capability to include respiratory and cardiac triggering. Breath hold acquisitions reduce motion artifacts however the constrained acquisition time reduces image signal-noise-ratio (SNR) and limits the spectrum of b-values acquired. Free breathing DWI with multiple signal averages necessitates longer scan duration (3-6 minutes) but provides increased SNR and greater flexibility in b-value acquisition. There is little consensus in the community on b-value selection however increasing the number of b-values reduces the error when estimating ADC, with a minimum of 3 b-values recommended for liver acquisitions of the order 0, 50-100 and 400-1000 s/mm^2 depending on the desired application.

Accuracy of DWI

DWI has been shown to have variable accuracy in the staging of liver fibrosis. A recent meta-analysis reported an area under the receiver operating characteristic curve (AUC) of 0.86 for detecting liver fibrosis stage ≥F1 (12 studies), 0.88 for ≥F2 (16 studies), 0.88 for ≥F3 (18 studies) and 0.86 for F4 (12 studies)[2]. In the same study, the authors report a significantly higher accuracy in detecting fibrosis stages ≥F2 and ≥F3 using maximum b-values ≥800 s/mm^2 compared to maximum b-value ≤800 s/mm^2. Despite the reported accuracy of DWI, it has been shown to be inferior to magnetic resonance elastography (MRE) for staging liver fibrosis, particularly for detection of advanced fibrosis and cirrhosis[3].

Limitations of DWI

One of the primary limitations of DWI is the lack of standardization in choice of b-values in the scientific community. Measured ADC is determined by the b-values acquired leading to difficulty in comparing measurements between studies. DWI is affected by the inherent sensitivity of the SE-EPI sequence to ghosting and distortions, however the widespread use of multichannel coils and presence of higher performing imaging gradients and advanced software has reduced these effects. In addition, DWI is less reliable in the presence of hepatic steatosis and iron deposition[4].

References:

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