Diffusion MRI: Past, Present, and Future

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The measurement of the translational diffusion of water in tissue via MRI provides unique biological and clinical information about its microstructure, and architectural organization non-invasively and without exogenous contrast agents.

Erwin Hahn first described the effect of molecular diffusion on the NMR signal (1). Carr and Purcell then (2) employed Hahn's NMR spin echo (1) in the presence of a static magnetic field gradient (2) to make the first NMR measurements of the self-diffusivity of water protons. Their work also established the non-perturbing and highly accurate NMR measurement of the self-diffusion coefficient of water and other solvents as a "gold standard". Torrey later incorporated diffusion of spins explicitly into the Bloch equations (3) as another NMR relaxation mechanism (4). Analytical solutions followed for freely diffusing species during a spin echo experiment (5) and later, for restricted geometries (e.g., see (6-8)).

Stejskal and Tanner's pulsed-field gradient NMR (9) method then allowed the diffusion time and the lengthscale probed to be varied independently (7). Their proposed Fourier relationship between the NMR signal attenuation and the conditional displacement distribution became the basis of q-space NMR (10,11). Tanner's definition of the "apparent diffusion coefficient" (ADC) (12) was useful to describe diffusion in complex media, like tissue.

Following a decade of NMR measurements of diffusion properties in muscle and nerve tissue, MRI was invented by Lauterbur in 1973 (13). Although he suggested it, diffusion MRI was not realized until 1984 by Wesbey, Moseley and Ehman (14,15), whose ADC maps were shown to be useful in following a stroke in progress (16). Diffusion MRI, however, failed to describe anisotropic diffusion in brain white matter. Diffusion Tensor MRI (DTI) was invented in the early '90s, providing a more comprehensive and accurate description of diffusion in such heterogeneous, anisotropic tissue (17).

In the past decade, several non-parametric displacement MRI methods have been proposed to characterize features of restricted diffusion observed in nerve axons or anomalous diffusion observed in complex, hierarchically organized tissues. The future appears bright to continue developing displacement MRI methods to measure key microstructural and architectural features of living tissues.

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