Specialty Area: Advanced Diffusion Acquisition

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Highlights

- 2D single-shot EPI is the most common diffusion acquisition method due to its speed and robustness against motion.
- 3D segmented diffusion acquisitions enable higher-spatial resolution, reduced distortions and higher SNR efficiency but suffer from longer scan times and motion-induced phase-offsets between k-space segments.
- Simultaneous multi-slice acquisitions can be thought of as a hybrid 2D/3D acquisition, providing some of the benefits of each approach.

TALK TITLE: 3D vs. 2D Acquisition

TARGET AUDIENCE: Scientists and Clinicians interested in optimizing diffusion MRI scans.

OUTCOME/OBJECTIVES: To become familiar with 3D and 2D diffusion MRI acquisition strategies and be able to identify the pros and cons of each approach.

PURPOSE: The encoding strategy of a diffusion MRI pulse sequence will influence the achievable ***spatial resolution***, ***acquisition speed*** and ***SNR efficiency***, as well as the vulnerability of the pulse sequence to ***image distortions*** and ***motion artifacts***. The purpose of this lecture is to highlight these trade-offs for different 3D and 2D diffusion MRI encoding strategies such that scientists and clinicians may optimize the acquisition of diffusion MRI data for specific applications.

METHODS: A 3D acquisition employs either a non-selective or slab-selective RF pulse and 3D k-space encoding. A 2D acquisition employs a slice-selective RF pulse and 2D k-space encoding. Many different 2D and 3D diffusion MRI acquisition strategies have been presented in the literature, however, the majority of diffusion data is still acquired using 2D single-shot EPI[1] due to its speed and robustness against motion artifacts. 3D diffusion MRI pulse sequences usually have a segmented read-out due to the increased encoding steps required to cover a 3 k-space[2]. Diffusion pulse sequences with 3D single-shot acquisitions[3] are less common but do exist and usually depend heavily on techniques such as reduced-FOV, parallel imaging and partial k-space to reduce encoding time. Likewise many of the more advanced 2D diffusion MRI pulse sequences have segmented read-outs[4-13]. A hybrid 2D-3D approach, that is becoming more frequently used for diffusion imaging is called simultaneous multi-slice (SMS)[14,15]. SMS uses an RF pulse and gradient waveform that simultaneously excites multiple slices. The signals from each of the simultaneously excited slices are then separated using parallel imaging methods.

RESULTS and DISCUSSION: We will frame our review of 2D and 3D diffusion acquisition methods in terms of the following five imaging considerations: spatial resolution, acquisition speed, SNR efficiency, image distortions and motion artifacts.

Spatial Resolution: The resolution of a 2D diffusion sequence is potentially limited by the accuracy with which a slice-selective RF pulse can isolate a very thin slice. For 2D single-shot imaging the resolution is also limited by the amount of data that can be acquired in a read-out that yields an acceptable level of distortion and before the signal decays away. The resolution of 3D diffusion pulse sequences is more likely limited by SNR and acquisition time considerations.

*Acquisition Speed: M*ost 3D acquisitions are slower than 2D acquisitions for two reasons. Firstly, most 3D acquisitions have a shorter segmented read-out that requires more excitations to encode the imaging volume. Secondly, since the entire imaging volume is excited with each excitation only one k-space segment may be acquired per TR, compared to multiple interleaved slices in a 2D acquisition. SMS methods speed up imaging time for a 2D acquisition even further by exciting and reading-out even more 2D slices per TR interval.

SNR Efficiency: Compared to sequential 2D slice-selective imaging of N sequential slices, 3D imaging using the same trajectory plus N diffusion-encoding steps in the third dimension will require the same scan time but have √N times better SNR because the entire volume (rather than one excited slice) contributes signal from each excitation. It is possible, however, to recover some SNR for 2D imaging by interleaving the slice-selection and using longer TRs. Since SMS does not under-sample the data like traditional in-plane parallel imaging, it therefore does not suffer the same √R SNR penalty that conventional parallel imaging does. As such, SMS gains in an increase in SNR efficiency compared to traditional single-slice excitation 2D imaging that is proportional to the number simultaneously excited slices.

Geometric Image Distortions: Off-resonance effects cause spins to accrue unexpected phase during the time they spend in the transverse plane between excitation and read-out. Since 3D acquisitions tend to have segmented read-outs that are usually shorter than a standard 2D single-shot read-out they tend to be more robust against off-resonance effects.

Motion Artifacts: Sensitivity of the MRI signal to short range diffusive motion is necessarily accompanied by sensitivity to other sources of motion. Just as diffusive motion is encoded in the phase of the magnetization, bulk and physiological motion creates a net phase offset that induces ghosting and/or signal drop-out if k-space data is acquired in multiple segments. Single-shot DWI acquisitions avoid this problem by acquiring all data required for an image in one continuous read-out. For segmented acquisitions motion effects can be mitigated by acquiring low-resolution but full field-of-view navigator image along with the acquisition of each k-space segment in order to characterize the phase-offsets between k-space segments and to correct for them[4,9,16-18]. In order to save time, the navigator image is often generated from central, overlapping part of each k-space segment (called "self-navigation")[8,10,11].

Unfortunately, for 3D acquisitions a 3D navigator is needed in order to accurately estimate phase-offsets between k-space segments[19] and the time it takes to acquire a 3D navigator along with each k-space segment is prohibitively long. If a disproportionate amount of time is spent acquiring the navigator data compared to the associated k-space segment the pulse sequence will become highly inefficient. Despite this several approaches to 3D navigated diffusion MRI have been presented[5,20-23]. Another alternative approach is to use 3D radial k-space trajectories that have been shown to be more robust against motion artifacts[24,25]. Real-time optical motion correction is also becoming an increasingly favoured approach for many different types of diffusion imaging[26,27].

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