Advanced Diffusion Acquisition: Targeted Methods

Diffusion-Weighted Imaging of the Spinal Cord and Nerve Roots

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Objectives:

- to understand the challenges of diffusion-weighted imaging in the spinal cord, e.g. the small size of the cord and its inner structure, susceptibility differences in the cord's vicinity, and cord motion
- to know methods that improve diffusion-weighted imaging, e.g. reduced field-of-view techniques, multi-shot acquisitions, and non-echo-planar pulse sequences, and their advantages and limitations

Background:

Diffusion-weighted imaging (DWI) has become an important tool to gain information about the tissue structure, e.g., to estimate cell or axon diameters, to identify and track white matter nerve fibres, or to detect cytotoxic edema in the very early stage of stroke. While the brain has been studied extensively with DWI, its application in the spinal cord is not very common although it can be expected to deliver valuable information for biomedical research and clinical medicine. Reasons for this are the additional challenges DWI faces in the spinal cord.

Problems:

The most important problems are related to the small diameter of the cord, its position in the body in the vicinity of susceptibility inhomogeneities, and the displacements it may exhibit due to physiological motion:

- because of the small diameter of the cord and the tiny size of the grey matter structure in it, a high spatial resolution is required, at least in the cross-sectional direction(s), to demark the cord from surrounding cerebrospinal fluid and distinguish grey and white matter reliably
- located close to the vertebrae and the vertebral disks and, in some sections, not too far away from air-filled organs (lung, trachea, esophagus) and the body surface, the susceptibility differences between bone, tissue, and air cause inhomogeneities of the magnetic flux density; they can degrade the image quality in the cord significantly and can distort the diffusion weighting applied
- the spinal cord is not fixed and can move within the spinal channel, not only during head or body motion but also due to physiological motion like breathing, swallowing, or the flow of cerebrospinal fluid that changes over the cardiac cycle; the corresponding displacements of the cord can cause signal reductions and dropout when occurring during the diffusion weighting

As a consequence, the usefulness of protocols and pulse sequences that are well established for brain DWI, is often limited in the spinal cord. In particular, conventional slice-selective echo-planar imaging that is used in most brain DWI studies, can suffer from limited spatial resolution and significant artifacts like geometric distortions, image blurring, and signal losses.

Solutions:

These problems of DWI in the spinal cord can be addressed with different approaches:

- reduced field-of-view techniques, e.g. based on cross-sectional or tilted RF excitations, 2D-selective RF excitations, outer volume suppression, or line scan imaging, that allow to shorten the acquisition without aliasing artifacts in the phase-encoding direction; thus, image artifacts, e.g. geometric distortions and image blurring in echo-planar imaging, can be reduced and the spatial resolution improved
- multi-shot echo-planar imaging, e.g. with readout, phase-encoding, or PROPELLER-like segmentation, or alternative pulse sequence like fast spin echo imaging can be used; they are not or less sensitive to artifacts related to susceptibility differences and can provide a higher spatial resolution
- flow-compensated diffusion weighting can be applied and ECG-gating can be performed in order to acquire data solely during a cardiac phase with only minor spinal cord motion; both approaches reduce motion artifacts

Conclusion:

With appropriate methods and dedicated protocols, DWI becomes feasible to assess tissue structure in the spinal cord for biomedical or neuroscientific research and clinical medicine.