Session: Imaging Acquisition & Reconstruction

Title: Gradients - Spatial Encoding, Contrast Manipulation, and Artifact Management

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Highlights:

- Gradient fields are used for spatial encoding, motion encoding and sensitizing, and signal and contrast manipulation.
- Undesirable effects from gradient fields include Eddy currents and concomitant field effects.
- Biological effects from the gradient fields include primarily Peripheral Neuro Stimulation (PNS) and acoustic noise.

Target audience:

This talk is for those who are interested in basic MR physics, particularly in the image formation and contrast manipulation through utilization of linear gradient fields.

Outcome/Objectives:

Following the talk, attendees should be able to understand

(1) the fundamental principles of spatial encoding using magnetic field gradients
(2) the motion encoding and motion sensitizing mechanism
(3) the ways to introduce or enhance contrast and avoid artifacts using gradients

Methods & Results:

The gradient system in MRI provides a spatially linear magnetic field in all three dimensions. For spins at a given spatial location, the gradient allows the association of that location with the Larmor frequency which is proportional to the superposition of the static magnetic field (B0) and the gradient fields. Through this association, the spatial information is encoded into the frequency or the phase of the magnetization. Spatial localization is achieved by decoding the magnetization via a Fourier transformation of the time domain signal. This spatial encoding process is the primary function of the gradient system.

In order to spatially encode the signal, the gradient fields G_x, G_y, and G_z are typically controlled independently to play out time-varying waveforms in a pre-designed sequence. This allows the frequency and phase of one-dimensional time-domain signals to be manipulated to yield 2 or 3 dimensional images.

Slice Selecting - The gradient is played out simultaneously with a slice selecting RF pulse that has the excitation bandwidth matching the desired location and thickness. In this case the transverse magnetization is generated only from the spins within that slice/slab, typically perpendicular to the direction of the selection gradient. This transverse magnetization can be further processed either for signal detection or suppression.

Frequency and Phase encoding - After spatially selective excitation is completed, the signal can be acquired with the presence of more gradient fields which embed the spatial location in the phase and/or frequency of the signal at different time points. The history of the effects from the gradient, or the time integral of the scalar product of the gradient fields and the spatial coordinates, determines the trajectory of the data acquisition in k-space, either in 2D or 3D. In the traditional 2D/3D Cartesian acquisition, the phase encoding gradient is applied in incremental steps prior to the frequency encoding gradient. In the non-Cartesian acquisition such as spiral or radial acquisitions, gradients along different axes are applied simultaneously during data collection.

Motion encoding and sensitization – The gradient waveforms have different effects on the stationary spins and the moving spins. The difference is caused by the different phase accumulation of these spins and can be used to visualize or even quantify the movement of the spins, as used in Phase Contrast (PC) imaging, Diffusion Weighted imaging (DWI), Diffusion Tensor Imaging (DTI), and more recently MR Elastography (MRE). Typically the smaller the scale the motion occurs, the higher the gradient fields are needed to detect or encode the motion. Gradient fields can also be used to reduce artifacts that are induced by specific moving components.

Spoiling – In general MR signal from the transverse magnetization undergoes de-phasing in the presence of magnetic field inhomogeneity, which includes those induced by the gradient fields. In certain situations, the gradient fields are used in such a way to suppress or spoil the residual signals either to enhance the image contrast or to avoid image degradation caused by unwanted magnetization.

Undesirable gradient effects – Rapidly switching gradient fields can induce electric currents, or so-called eddy currents which can in turn produce perturbing magnetic field causing adverse effects on the final images. Hardware solutions including pre-emphasis can be used to compensate for this effect. Concomitant field effects (also known as Maxwell terms) that are due to the fundamental physics also need to be taken into account in order to ensure better image quality and data accuracy.

Physiological Effects and Sound - The gradient field switches at high rate and this can induce electric field that can provoke peripheral nerve stimulation. This unpleasant sensation limits the maximal slew rates and amplitudes in most of the modern MRI systems. The switching gradient field also induces mechanical vibration in the form of acoustic noise.

Discussion & Conclusion:

Gradient system plays a vital role in MR imaging. While methods such as parallel imaging and parallel excitation can provide spatial information based on the sensitivity of the coil elements, spatial encoding using linear gradient fields will remain a versatile and indispensable method in the foreseeable future.

Reference:

1. Bernstein MA, King KF, Zhou XJ. Handbook of MRI Pulse Sequences, Chapter 7-10. Elsevier Academic Press 2004