Title of Session: MR Physics & Techniques for Clinicians
Title: Gradient Echo Imaging
Target Audience: Clinicians interested in the physics and applications of gradient echo imaging.
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Highlights:
- Gradient echo (GRE) imaging has a wide range of clinically useful applications.
- GRE imaging can produce proton-density, T_1-, or T_2*-weighted images.
- GRE imaging has emerging applications for quantitative tissue characterization.

Gradient echo (GRE) imaging has a wide range of clinically useful applications. In particular, GRE imaging is frequently used in the clinic for anatomical/structural imaging and imaging dynamics for diseases that span all organ systems and many pathologies. In general, GRE imaging is regarded as fast owing to the generally short repetition times (TRs). As a consequence, GRE imaging is useful for: T_1-weighted and T_2*-weighted imaging, capturing physiologic motion, real time imaging, and for true 3D imaging. This talk will also provide context by succinctly comparing and contrasting spin echo and GRE imaging. The basic GRE pulse sequence components consist of image contrast preparation pulses, slice selection, phase encoding, readout, and spoiling.

Image Contrast Preparation – Like many MRI sequences, GRE image contrast can be further manipulated through the use of inversion, saturation, T_2-prep, fat-saturation, and magnetization transfer pulses, which precede phase and frequency encoding.

Slice Selection – The combination of an RF pulse and a slice-selection gradient allows us to excite, in principle, a thin plane of spins. This must, however, be followed by a slice-selection refocusing gradient to rephase spins in the through-plane direction, thereby significantly increase the overall echo amplitude. The correct choice of flip angle is important for achieving the best image quality. For spoiled steady-state GRE imaging (i.e. FLASH, SPGR, or T1- FFE) there exists an optimal flip angle, called the Ernst angle, which can be calculated from the TR and T_1 of interest.

Phase Encoding – GRE imaging can be either 2D or 3D. In 2D imaging phase and frequency encoding along two orthogonal directions is used to encode image information within an excited slice. In 3D imaging the phase encoding is performed along two orthogonal axes and frequency encoding is performed along a third mutually orthogonal axis. GRE imaging is particularly amendable to 3D imaging due to the typically short TRs, whereas spin echo imaging typically has longer TRs. 3D imaging can have an SNR advantage and it also permits acquiring higher spatial resolution and/or thinner slices than is achievable with 2D imaging.

Frequency Encoding – The frequency encoding gradient consists of a gradient prephasing lobe followed by a frequency encoding gradient. The echo signal is recording during the readout gradient and contains information (spatial location and contrast) about the object being imaged. Importantly, the magnitude of the readout gradient controls the speed of the *k-space* traversal. If the gradient has a large amplitude, then *k-space* is traversed quickly, therefore we need to sample more quickly (increase the bandwidth) to acquire the same number of *k-space* points. Because we acquired the data quickly (i.e. at high bandwidth) the data has a lower SNR. High bandwidth, however, also permits a shorter TE and TR because the frequency encoding gradient is shorter.

Spoiling – Spoiling is a technique that permits the use of very short TRs. Gradient spoiling is a technique that uses a gradient pulse at the end of the TR to hasten dephasing of the transverse magnetization (M_{xy}) so that the net M_{xy} is very nearly zero at the end of the TR. Alterations of the slice-selective RF pulse's phase can also be used to promote signal spoiling.

Image Contrast – GRE image acquisition can be adjusted to achieve proton density-weighting, T_1- weighting, or T_2*-weighting. This is easily accomplished by using a spoiled steady-state

GRE sequence. Tissues with a higher proton density are brighter on proton density-weighted images, which can be obtained with a long TR (>100ms), short TE (<5ms), and small FA (<10°). Tissues with a short T_1 are bright in T_1-weighted images and are achieved with short TRs (<50ms), short TEs (<5ms), and a large FA (>30°). In distinction, tissues with a short T_2* are dark on T_2*-weighted images and are achieved with a long TR (>100ms), a long TE (>20ms), and a small FA (<10°). T_2* reflects both the intrinsic T_2 spin-spin relaxation and an additional T2'($\propto 1/\Delta B0$) component that further hastens signal dephasing due to intravoxel field heterogeneities (B_0-field inhomogeneity and susceptibility variations). This means that T_2*-weighted GRE is more sensitive than spin echo imaging to the presence of hemorrhage due to the iron in blood products.

Flow Sensitivity – A unique attribute of GRE imaging is the ability to encode the velocity of flowing spins in the phase of the NMR signal. With proper correction for background off-resonance, eddy currents, Maxwell terms, and chemical shift effects phase contrast MRI (PC-MRI) becomes a useful quantitative imaging tool for measuring peak and average velocities, flow rates, and total flows. To make a GRE imaging sequence quantitatively sensitive to flow we need to add flow encoding gradients, which extended both the TE and TR. This, combined with the need to acquire two measurements, means the temporal resolution of PC-MRI is typically lower than other time-resolved GRE imaging sequences.

Quantitative Imaging – GRE imaging can also be used to perform quantitative T_1-mapping, T_2*-mapping, and fat-fraction mapping. These are emerging techniques that hold tremendous clinical promise for tissue characterization.

As with many imaging sequence in MRI, GRE imaging is amenable to a great deal of modifications, which provides both a unique strength and complexity.