Gradient Echo Imaging

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Introduction

In general, pulse sequences without a spin echo are called gradient echo sequences. Although the term "gradient echo" refers to a point where the cumulative gradient area refocuses the magnetization, (also the "centre of k-space") gradient echo imaging is generally used to describe a broad range of pulse sequences.

Contrast in gradient echo sequences is affected by (1) Excitation timing and flip angle, (2) Spoiling techniques, and (3) Contrast preparation. Although there are numerous different combinations of these, the basic principles are straightforward.

Excitation Timing and Flip Angle

In gradient echo sequences, the repetition time falls into three categories [1-4]:

TR much greater than T1: In this case, the sequences begins with full magnetization on each TR, and contrast is proton-density weighted.

TR comparable to T1 but much greater than T2: Only a partial recovery of longitudinal magnetization occurs, and magnetization reaches a steady state with T1 contrast, that can be adjusted with the flip angle.

TR is short compared to both T1 and T2: Both longitudinal and transverse magnetization reach a steady state. Contrast depends strongly on both flip angle and spoiling techniques and is a function of T1 or T2/T1.

Spoiling Techniques

When TR is short compared to both T1 and T2, the transverse magnetization cannot be neglected. Two different spoiling techniques, RF spoiling and gradient spoiling are often used, or spoiling may be removed.

RF Spoiling: (SPGR, FLASH, T1-FFE) By "randomizing" the phase of successive excitations, it is possible to create a case where the remaining transverse magnetization can be neglected after each TR. This enables pure T1 contrast, commonly used for 3D contrast-enhanced scanning. In practice the phase of both the excitation and the received data are incremented with quadratic phase, and gradient spoiling is included so smooth signal fluctuations [5,6].

Gradient Spoiling: (GRE, GRASS, FISP, T2-FFE) Simply adding an unbalanced gradient at the end of the sequence dephases transverse magnetization. However this does not eliminate signal, as after several repetitions this signal is refocused [7]. The gradient spoiler has the effect of smoothing different magnetization states within a voxel to avoid variations with background frequency (next section), and creates a contrast that is a function of the ration T2/T1.

No Spoiling: (TrueFISP, FIESTA, Balanced FFE) When all gradients are fully-rewound, "balanced SSFP", a steady state forms as a function of T1, T2, flip angle and the precession angle [8,9]. The latter is dominated by off-resonance, and can cause significant signal variations resulting in "dark bands." Balanced SSFP produces a contrast also based on T2/T1, but with a higher signal than GRE at the expense of sensitivity to off-resonance.

Contrast Preparation

Contrast preparation or magnetization preparation techniques are often applied prior to the excitation in gradient echo sequences to alter the image contrast. There are many examples, frequently used in combination with all types of timing and spoiling already described. In most cases, the effect is to scale the longitudinal magnetization prior to imaging.

Fat Saturation: A spectrally-selective 90° pulse may be applied to fat, followed by a dephaser. Ideally, this results in no magnetization from fat.

Inversion Recovery: A 180° pulse followed by an inversion time (TI) can produce T1-nulling to suppress fat (STIR), to suppress long-T1 tissue such as cerebrospinal fluid in FLAIR imaging, or for arterial spin labeling (ASL) perfusion imaging.

Double IR: Two 180° pulses, with different spatial selectivity can be used for dark-blood imaging or for background-suppressed inflow-enhanced imaging.

T2-Prep: By tipping magnetization into the transverse plane for some duration, then returning it to the longitudinal axis, T2 contrast can be generated. This is often combined with a rapid imaging readout such as EPI, spiral or MP-RAGE.

Magnetization Transfer (MT): Exciting off-resonance "short T2" macromolecules suppresses the signal in certain tissues such as muscle or cartilage.

Spatial Saturation: In order to avoid aliasing or wrap into the FOV, slabs at the edges of the FOV may be excited and dephased.

Summary

The combination of timing, spoiling and magnetization preparation techniques offers a wide variety of pulse sequences used for gradient echo imaging.

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