# Simulation of Artificial Delayed Hyperenhancement Resulting from Signal Modulation in the Phase Encoding Direction

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**Abstract:** An artificial mid-spetal hyperenhancement often appears on the inversion recovery prepared interleaved segmented gradient recalled echo (IRISGRE) sequence with a low-high phase encoding order. In this simulation we studied the imaging artifacts resulting due to the signal modulation across the phase encode direction in the IRISGRE sequence. These hyperenhancement artifacts capable of leading to the spurious diagnosis of myocardial scarring, can be avoided by using liner phase encoding order.

**Introduction:** Typically an ECG-gated 2D inversion recovery prepared, interleaved k-space segmented gradient recalled echo (IRISGRE) sequence acquired in a single breath-hold is employed for the assessment of myocardial viability through delayed enhancement. The modulations of the recovering signals from various tissues over the k-space of IRISGRE sequence influence the point spread function (PSF) and the tissue contrast. The signal modulation over the k-space of IRISGRE sequence depends on: 1) approach to steady state; 2) readout duration for each shot; and 3) phase encoding order (PEO); apart from other factors like, varying time of inversion (TI) for patients with variable heart rate. In order to avoid oscillatory approach to steady state on the order of several T1s the IRISGRE scan is commenced with a lower flip angle which is increased for successive excitations, up to the angle specified. Attempt is made to acquire as many k-lines in each shot to keep the breath-hold time short. Thus, the varying flip angle over the relatively longer shot duration modulates the recovering signal in addition to the inversion recovery. The PEO directly affects the distribution of this modulated recovering signal over the k-space and thus directly influences the PSF. Purpose of this experiment is to study the effect of this signal modulation during readout onto the image reconstruction through simulation.

**Materials and Methods:** All IRISGRE imaging was performed on a 1.5T, Philips Intera clinical scanner, on five vials containing different concentrations of Gd-DTPA in water, using a synthetic vector-cardiographic (VCG) signal for gating. The optimal time of inversion for central vial was determined using a Look-Locker sequence and phase encoding gradient was turned off to measure the signal magnitude at each phase encoding step. Specific acquisition parameters were: GRE, TR/TE/flip: 5 msec/2 msec/15$^o$; acquired and reconstructed spatial resolution: 1x1x8 mm$^3$. Images were acquired for shot durations of 110 and 210 msec (13 and 25 k-space lines per R-R) using the low-high PEO (from ky=0 outwards to +/- Kymax) and the linear PEO (from - kymax to +Kymax). The heart (ventricles, myocardium, scar and pericardial fluid) phantom image was constructed using ellipses. The acquired signal magnitudes were used as the modulation transfer functions for blood, myocardium, scar, and pericardial fluid and image reconstruction through Fourier transform is treated as a linear system.

**Results:** Representative images depicting the signal modulation along phase encoding direction, corresponding normalized PSF, and reconstructed image for linear and low-high PEO are shown in Figure 1.

**Discussion:** The readout for the low-high PEO begins at the TI of the vial to be nulled and continues for the complete shot duration, while the readout for linear PEO begins half the shot duration before the TI. Although linear PEO reads the pre-TI negative signal the IRISGRE readout is commenced with a lower flip angle and thus suppress signal at the higher -ky values. The low-high PEO allows twice the time for post-TI recovery thus having high signal at the periphery of the ky. Thus, low-high PEO has significant oscillatory lobes in the ky direction resulting in ringing in the phase encoding direction. The ringing effect increases with the shot duration leading to mid-septal artificial hyperenhancement. The difference in modulation of the signals between linear and low-high PEO also results into better contrast between shorter-T1 tissue and the tissue being nulled as can be observed from the signal values at ky=0.

**Conclusion:** The results of this study show that the ringing artifact and tissue contrast is significantly influenced by the choice of the PEO. Low-high PEO with IRISGRE artificially creates a mid-myocardial septal hyperenhancement. Linear PEO suppresses the ringing which caused these artifacts and further improves the tissue contrast. Accordingly, linear PEO should be used for IRISGRE in delayed enhancement studies for assessment of myocardial viability.

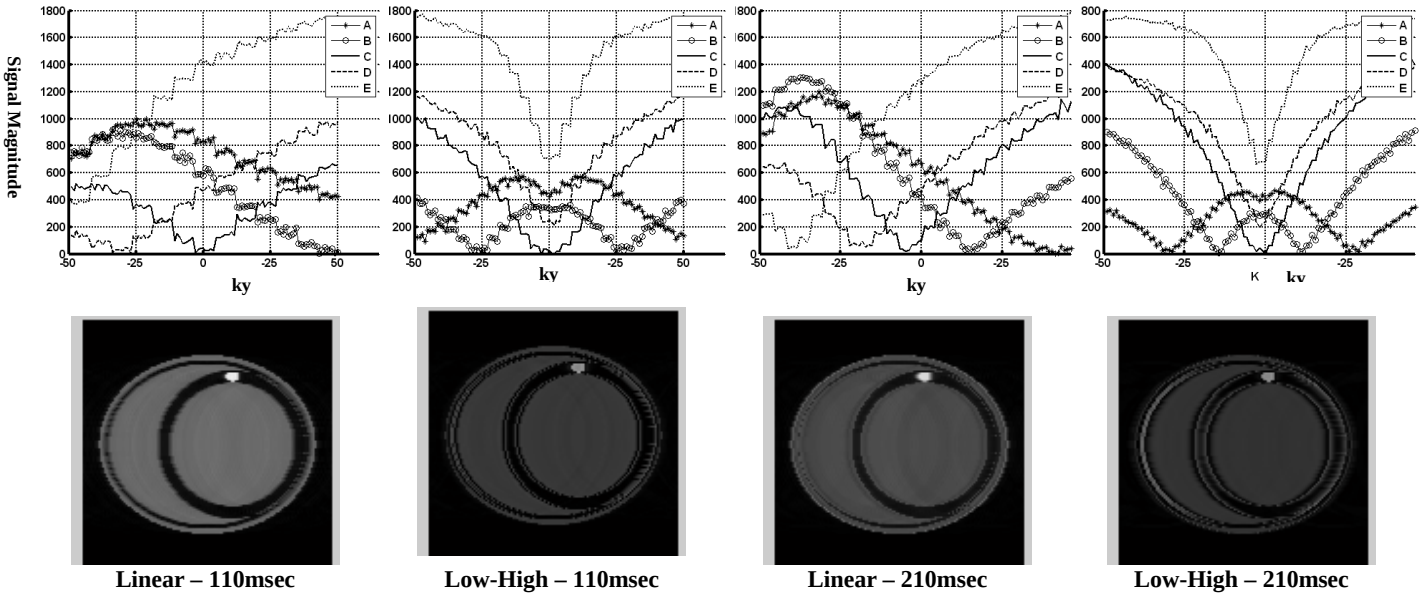


Figure 1: The signal modulation along phase encoding direction, and corresponding reconstructed images for linear and low-high PEO.