Dealing with Motion: Gating, Triggering & Sampling

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Many types of motion produce artifacts in MR images. The most common examples of motion sources include blood flow, the beating heart, respiratory motion, and bulk motion due to failure of patients to stay still. Other sources of motion include movement of cerebral spinal fluid and gastrointestinal motility. All of these types of motions can degrade the quality of MR images, and various motion-compensation strategies have been developed to minimize image artifacts.

Blood flow during the time between radiofrequency excitation and data readout causes a shift in the phase of the acquired signal, and this phase shift creates image artifacts. This effect can occur due to both in-plane flow or through-plane flow. Gradient waveforms designed to both provide spatial encoding and eliminate phase shifts due to velocity (a technique called gradient moment nulling or flow compensation) are very effective at reducing artifacts resulting from blood flow. This method has the slight disadvantage of increasing the echo time. Nonetheless, flow compensation with gradient moment nulling is widely used and very effective.

For MRI of the cardiovascular system, triggering the image acquisition to be synchronous with the heartbeat is a widely used and very effective method to minimize artifact from cardiac motion and to reconstruct time-resolved images that depict the motion of the heart and flowing blood. For this method, the electrocardiogram (ECG) is monitored during imaging. The ECG R-wave is detected by the scanner, and it is used to synchronize MRI data acquisition with the heartbeat. Either prospective triggering or retrospective gating can be employed. The retrospective gating method has advantages in reconstructing images that depict the entire cardiac cycle, whereas prospective triggering is advantageous in the setting of irregular cardiac rhythms. Newer methods for cardiac imaging utilize self-gating or real-time imaging, and do not require monitoring the ECG.

The effects of respiratory motion can be dealt with by monitoring respiration with an external bellows system, and respiratory gating can be employed in a manner similar to ECG gating. However, this method has not been very successful due to variation in breathing patterns. A more popular and successful approach has been navigator gating, where the MRI signal from the right hemidiaphragm is monitored during MR image acquisition, and image data are accepted or rejected depending upon the position of the diaphragm. This approach has seen reasonably good success, as this method has produced some of the best MR images of the coronary arteries. While navigator gating can be successful, it has limitations including low data acquisition efficiency (and, accordingly, long scan times) as well as poor image quality when breathing patterns vary during the course of a scan. Newer approaches use image-based navigators to accept or reject data, and the most recent methods use iterative reconstructions that motion-correct more of the raw data, with the goal of highly efficient acquisitions that utilize most of all of the raw data. Motion compensation methods continue to evolve and remain an intense and important area of MRI research.

Suggested reading:

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