# The Impact of Motion on Data Consistency and Image Quality in MRI

*Jim Pipe, Ph.D., Barrow Neurological Institute, Phoenix, Arizona, USA*

Conventional reconstruction of MRI data collection makes an implicit assumption that data are collected from a static source. Motion of that source results in data changes that will produce an artifactual image of the source, if not corrected for. The resulting image artifacts depend highly on (1) the type of motion, (2) the type (weighting) of the image, (3) the data collection trajectory, and (4) the reconstruction used. An illustrative set of examples are shown of a variety of these combinations. They are listed below and ordered, roughly, from the easiest to correct to the most difficult to correct. In most cases, the effects on standard Cartesian, radial, and spiral trajectories are shown to illustrate effects from linear, angular, and radial inconsistencies in the k-space data, respectively.

1. **Rigid-body (in-plane) Displacement**. Bulk translation and rotation produce linear phase shifts and concomitant rotation of the k-space data, respectively. These two effects can be completely decoupled. The effects of such motion will be demonstrated for Cartesian, radial, and spiral trajectories for both random and correlated motion.

2. **Velocity (and higher order motion)**. Between spin excitation and signal readout, motion of spins in the direction of the applied gradients (and along a patient-induced gradient) can produce phase shifts which adds to the imposed (desired) Fourier encoding phase related to position. If this motion-related phase varies between shots, this can confound the Fourier data to produce well-known motion "motion artifacts". Motion during the measurement period can be analyzed by gradient moment analysis. While gradient moments can be nulled in the center of k-space, they cannot be nulled throughout k-space, and thus velocity will always have some effect on the final image. The effects of such motion will be demonstrated for Cartesian, radial, and spiral trajectories for both random and constant velocity.

3. **Through-plane motion**. For 2D imaging, the movement of spins in and out of the imaging plane disturbs the spin steady state, and excites spins out of the intended imaging plane. This is most problematic for retrospective 2D motion correction. A simple example of effects for Cartesian, radial, and spiral trajectories will be given.

4. **Susceptibility effects**. The $B_0$ field in a patient is altered by the morphology of tissue susceptibility. As the patient moves, the $B_0$ field is altered, which can create significant changes in the data, particularly for T2*-weighted imaging. The effects of such motion will be demonstrated for Cartesian, radial, and spiral trajectories for both random and correlated motion.

5. **Diffusion-weighted imaging**. Diffusion Weighted Imaging has (at least) three additional challenges regarding motion. First, motion during the application of the diffusion-weighting gradients creates data inconsistency, which is very challenging for multi-shot methods, but exists even for single-shot methods. Second, motion between data collection using different diffusion weightings can lead to inconsistencies in synthesized images (e.g. ADC maps, FA maps, etc.). Third, diffusion measurements are applied in well-defined directions relative to the scanner, and conventional post-processing methods for correcting motion do not account for the shifts of these DW directions relative to the moving patient.

6. **$B_1$ coils effects (receive phase array)**. For fixed coils, patient motion has minimal effect on the coils, with the possible exception of some differences in sensitivity due to loading effects. For most motion-correction schemes (prospective, retrospective, data-based, or tracking external markers), correction of the data for patient motion results in variable B1 sensitivity from TR to TR. Combining data from all coils prior to motion correction may help to eliminate the shading, but is typically done in image space, which requires that k-space data from different trajectories be added together prior to motion correction. This effect will be illustrated, and the impact on the final image will be demonstrated for Cartesian, radial, and spiral trajectories for both random and correlated motion.

7. **Non-Rigid body motion**. Non-rigid body motion can be considered as piece-wise-continous rigid body motion, given the linear nature of the Fourier encoding inherent in the MRI signal. The complex

nature of general patient motion, as well as the fact that data are (literally) complex, make this a complicated problem.