ISMRM 2015 Course: Contrast by Body Part: How & Why?

# General Tools to Address Fat, Motion and Inhomogeneity

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## Outline

## I. Introduction

There are several sources of artifacts in MRI that can degrade image quality and reduce the diagnostic utility of the scan. One general category of artifact can be attributed to a violation of the basic assumption in MRI that the measured signal source is consistent, either with respect to time or with respect to frequency. Example deviations from this assumption include motion, fat, and inhomogeneities, due to hardware imperfections or magnetic susceptibility differences. This talk will review this general category of artifact in detail, describing the source of artifacts and their impact on MR data as well as highlighting conventional and emerging strategies for addressing these artifacts.

## II. Types of Artifacts

a. Motion artifacts
b. Fat artifacts
c. Inhomogeneity artifacts

## III. Motion Artifacts

a. Types of motion encountered during MRI
    i. Physiological sources of motion: cardiac, breathing, bulk patient motion, peristalsis, blood flow, CSF flow, fetal motion
    ii. Classes of motion: translation, rotation, non-rigid-body; 6 degrees of freedom in 3D space
b. Impact of motion on MRI data
    i. Fourier shift and rotation properties
    ii. Interview motion – motion occurring *between* views (data acquisition segments); amplitude and/or phase change can cause blurring and/or ghosting, depending on periodicity of motion
    iii. Intraview motion – motion occurring *within* a view, can cause dephasing and ghosting, e.g. blood flow
    iv. Other

c. Conventional Motion Detection and Correction Strategies
Several strategies have been developed to minimize the impact of motion on MR data. These methods can be categorized by those that require motion measurement, and those that do not.

    i. <u>Methods Requiring No Motion Measurement:</u>
        1. Immobilization – breath-holding, physical restraints, sedation, glucagon
        2. Averaging – increase the number of signal averages to average out artifact intensity
        3. Saturation bands – e.g. to reduce artifacts from blood flow or swallowing
        4. Gradient moment nulling to reduce flow dephasing
        5. Swap frequency/phase direction
        6. Alternative k-space trajectories for improved motion robustness – e.g. radial, spiral, cones
        7. Fast pulse sequences – minimize time over which motion can occur, e.g. single-shot fast spin echo

ii. Methods Requiring Motion Measurement:
    1. Triggering/gating – synchronize acquisition to a particular event to effectively "freeze" motion, e.g. cardiac gating and respiratory triggering; both prospective and retrospective
    2. View ordering techniques, e.g. ROPE (1) and EXORCIST (2), to minimize impact of motion
    3. MR-based motion measurements: interleaved "navigator" echoes (3), pencil-beam navigators, slice/slab tracking, spherical (4) and orbital (5) navigators, cloverleaf (Van der Kouwe et al. ISMRM 2004), low-resolution image-based navigators
    4. PROPELLER (7) – combination of non-Cartesian k-space trajectory and navigator information
    5. Algorithms for extracting motion from navigator data (6)

d. Advanced Motion Detection/Correction Techniques
New approaches to detect and correct for motion have emerged in recent years.
    i. 3D Motion correction
    ii. Self-gating methods – use motion information inherent in data itself: e.g. radial, DC detection, butterfly
    iii. Model-based motion estimation/prediction methods
    iv. Novel hardware methods to detect motion
    v. Optical detection methods
    vi. Snapshot imaging

## IV. Fat Artifacts

a. Source of artifact
Molecular structure differences between water and fat lead to different Larmor frequencies. This difference is known as chemical shift, quoted in parts per million (ppm) and is independent of field strength. We can calculate the frequency difference by multiplying the chemical shift in ppm by the resonant frequency in MHz of protons at particular field strength. E.g. 3.5ppm chemical shift → at 1.5T the water-fat frequency difference is 220Hz.

b. Types of fat artifacts
    i. Chemical shift artifact – apparent position of fat is shifted by a number of pixels. Severity depends on receive bandwidth.
    ii. Chemical shift artifact of the $2^{nd}$ kind, also known as black line or cancellation artifact, occurs with certain TE's in voxels containing both water and fat
    iii. Other

c. Strategies to address fat artifacts
    i. Parameter selection (BW, TE)
    ii. RF pulse design: selective excitation and saturation, tissue nulling
    iii. Pulse sequence and reconstruction design: multi-point water-fat separation methods

## V. Inhomogeneity artifacts

a. Source of artifacts – hardware imperfections and susceptibility effects within the body (air-tissue interfaces), different species (water/fat). Any field variation beyond the applied linear encoding gradients causes spins to be encoded at the wrong position, leading to image distortion.

b. Types of artifacts
    i. Signal loss
    ii. Distortion
    iii. Banding
    iv. Inhomogeneous signal

c. Strategies to address

i. Shim
ii. RF pulse design
iii. Sequence design
    1. bSSFP: parameter selection, phase cycling, alternating TR
    2. Multi-spectral imaging
    3. Other

## VI. Summary

A good understanding of the source and nature of this type of image artifact is necessary in order to design and apply effective artifact mitigation strategies.

## References


1. Bailes DR, Gilderdale DJ, Bydder GM, Collins AG, Firmin DN. Respiratory ordered phase encoding (ROPE): a method for reducing respiratory motion artefacts in MR imaging. J Comput Assist Tomogr. 1985 Jul-Aug;9(4):835-8.
2. Glover GH, Pelc NJ, inventors; Method of reducing image artifacts due to periodic signal variances in NMR imaging. U.S. Patent. 1988.
3.Ehman RL, Felmlee JP. Adaptive technique for high-definition MR imaging of moving structures. Radiology. 1989 Oct;173(1):255-63.
4. Welch EB, Manduca A, Grimm RC, Ward HA, Jack CR, Jr. Spherical navigator echoes for full 3D rigid body motion measurement in MRI. Magn Reson Med. 2002 Jan;47(1):32-41.
5. Fu ZW, Wang Y, Grimm RC, Rossman PJ, Felmlee JP, Riederer SJ, Ehman RL. Orbital navigator echoes for motion measurements in magnetic resonance imaging. Magn Reson Med. 1995 Nov;34(5):746-53.
6. Wang Y, Grimm RC, Felmlee JP, Riederer SJ, Ehman RL. Algorithms for extracting motion information from navigator echoes. Magn Reson Med. 1996 Jul;36(1):117-23.
7. Pipe JG. Motion correction with PROPELLER MRI: application to head motion and free-breathing cardiac imaging. Magn Reson Med. 1999 Nov;42(5):963-9.
8. Larson AC, White RD, Laub G, McVeigh ER, Li D, Simonetti O. Self-gated cardiac cine MRI. Magn Reson Med. 2004;51:93-102.
9. Brau AC, Brittain JH. Generalized self-navigated motion detection technique: Preliminary investigation in abdominal imaging. Magn Reson Med. 2006 Feb;55(2):263-70.
10. Odille F, Cindea N, Mandry D, Pasquier C, Vuissoz PA, Felblinger J. Generalized MRI reconstruction including elastic physiological motion and coil sensitivity encoding. Magn Reson Med. 2008 Jun;59(6):1401-11.
11. Odille F, Vuissoz PA, Marie PY, Felblinger J. Generalized reconstruction by inversion of coupled systems (GRICS) applied to free-breathing MRI. Magn Reson Med. 2008 Jul;60(1):146-57.
12. W.T. Dixon. Simple proton spectroscopic imaging. Radiology 153: 189, 1984.
E.M. Haacke, J.L. Patrick, G.W. Lenz and T. Parrish. The separation of water and lipid components in the presence of field inhomogeneities. Rev. Magn. Med. 1: 123, 1986.
13. D. A. Yablonskiy and E.M. Haacke. Theory of NMR signal behavior in magnetically inhomogenous tissues: the static dephasing regime. Magn. Reson. Med, 32: 749, 1994.