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Technical Aspects of Quality Control in Magnetic Resonance Imaging

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Compliance Testing of MRI Systems

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Compliance Testing

Compliance testing for MRI is not mandated by any federal regulation or agency, however, the American College of Radiology accreditation program for MRI includes semi-annual tests.

State of Michigan certificate of need regulations, effective July 1997 for all new con's issued for either purchases of new MRI systems or upgrades to existing MRI systems exceeding $500,000 in a two year period, also includes compliance tests.

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ACR Semi-Annual Test Requirements

Review of Daily QC
Image uniformity
Spatial linearity.
Spatial resolution.
Slice thickness, location, and separation.

ACR STANDARD FOR
THE PERFORMANCE OF
MAGNETIC RESONANCE IMAGING

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ACR Accreditation Test Requirements

Geometric accuracy (spatial linearity).
High contrast (spatial) resolution.
Slice thickness
Slice position accuracy
Image Uniformity
Percent signal ghosting (phase stability)
Low contrast resolution.

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State of Michigan Compliance Test Requirements

Signal to noise ratio.
Spatial resolution.
Slice thickness, location, and separation.
Spatial linearity.
Field homogeneity and drift.
System calibration and stability.
Cryogen level and boil off rate.
Radio frequency power monitor

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Other Optional Tests

- Repeat tests for
  - Other Orientations
  - Other FOVs
  - Body or surface coils
- Field homogeneity.
- Display Monitor
- Cryogen Boil off

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Comparison of Compliance Testing in CT and MRI

Dose, Scatter Radiation	**Review of Daily QC**
Uniformity	**Image uniformity**
Pixel size calibration	**Spatial linearity.**
High contrast resolution	**Spatial resolution.**
Slice thickness, overlap	**Slice thickness, separation.**
Low contrast resolution	**Low contrast resolution**
CT number for water	**T_2 H_2O ?, Other?**
Contrast scale, linearity	
Noise level	**SNR**
	Slice Position Accuracy
	Percent Signal Ghosting

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Why No Accreditation SNR?

- System Variability
  - Hardware (eg maximum gradient amplitudes)
  - Software (pulse sequence differences/limitations)
- Field strength dependence
- Different measurement methods
- Differences in materials (T1, T2 etc)

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T_2 as Calibration Standard

- Sensitive to environmental Factors
  - Temperature
  - Concentration of Ions, O_2
- Function of System Characteristics
  - Field Strength, Homogeneity
  - Non-Ideal RF pulses
- Error in T_2 Calculation

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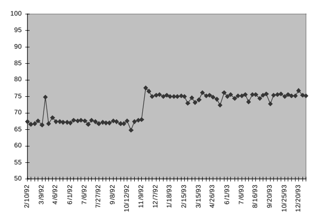
T_2 over 2 Year Period



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Standard Pulse Sequences

	T1 Weighted	*T2 Weighted*
TR	500	2000
TE	20msec	20/80 or 30/90
Matrix	128, 160, or 256	128, 160, or 256
Coil	Head	Head
#excitations	1	1
FOV	24or 25	24 or 25

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Image Uniformity

The degree to which MRI of a homogeneous test object results in a uniform image response across the FOV of the object.

- **An MR image acquired from any coil has some degree of non-uniformity This non-uniformity will be more or less evident depending on the window and level used to display the image.**
- **It is necessary therefore to use a criterion that is quantifiable and independent of the means used to display or print the image**.

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Uniformity Narrow vs. Wide Width

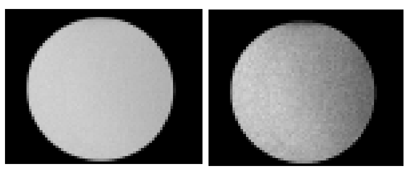

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Image Uniformity (cont.)

Image uniformity is influenced by
- Main magnetic field homogeneity
- RF non-uniformity
- Gradient linearity
- Eddy currents
- Pulse sequence type

Test objects also influence image uniformity
- Magnetic susceptibility
- RF penetration

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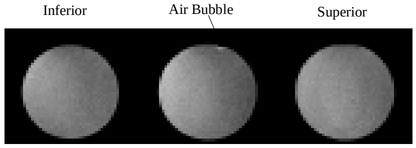
Comparison of Air Bubble and no Bubble SE Images

Inferior Air Bubble Superior



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Comparison of GRE and SE images

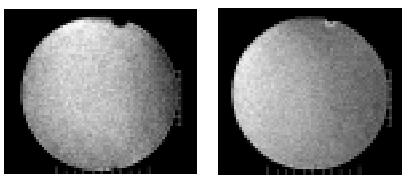

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Image Uniformity (cont)

RF penetration or incorrect nutation angle

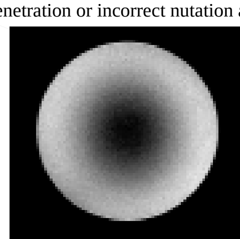

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Image uniformity (cont.)

Test object

- Diameter ≥ 80% of routine FOV used for RF coil.
- Conductivity such that RF penetration similar to tissue.

Coils: Head, Body

Example imaging parameters

- Std. T1 Weighted
- Single echo, single 10mm slice
- Single excitation
- FOV > 80% of coil dimension or largest used clinically

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Image uniformity (cont.)

Procedure

- Uniform Spherical Phantom
  - Acquire image in all three orientations centered at isocenter in the magnet.
- ACR Phantom Slice #7 - Axial Plane only
- Measure mean, σ, S_{max}, and S_{min} from an ROI centered on and enclosing at least 75% of the image
  - Exclude regions near boundaries of the test object
  - Inspect for evidence of air bubbles. Avoid placing ROI near air bubbles.

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Image uniformity (cont.)

Calculate the percent integral uniformity:

$$PIU = \left[1 - \frac{S_{max} - S_{min}}{S_{max} + S_{min}}\right] \times 100\%$$

Action level

- Should meet manufacturer's specifications > 90%

If test fails

- Examine ROI for hot spots and repeat analysis using ACR accreditation recommended procedure

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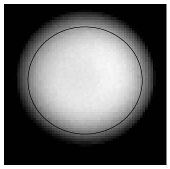
Uniformity Results at 1.0T



Coil		Mean	σ	S_{min}	S_{max}	PIU
Head						
	Axial	[illegible]	21.6	920	1034	94.17
	Sagittal	983.2	16.7	923	[illegible]	94.81
	Coronal	985.3	[illegible]	930	[illegible]	94.80
Body						
	Axial	[illegible]	18.6	869	1002	92.89
	Sagittal	943.4	25.0	[illegible]	1013	91.48
	Coronal	942.5	26.2	845	1012	91.00

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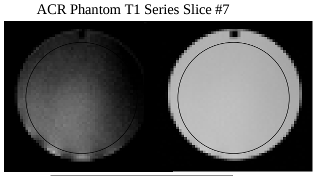
Uniformity Results at 1.0T

ACR Phantom T1 Series Slice #7



ROI Max	ROI Min	PIU
1581	1296	90.1%

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Spatial Linearity

The degree to which the MR image response accurately reflects the spatial location from which the signal originated.

Factors which influence spatial linearity are those which modify B_{tot} and signal phase and frequency in any location in the FOV:

- Magnetic field homogeneity
- Magnetic susceptibility
- Gradient linearity

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Spatial linearity (cont.)

- Test object
  - Any object for which accurate dimensions are known, provided that magnetic susceptibility effects are minimal.
- Acquire standard T1 weighted image in
  - Each orthogonal plane
  - Optionally acquire images swapping phase and frequency directions.

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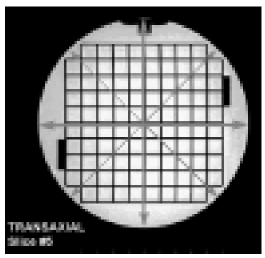
ACR Spatial Linearity Insert



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Spatial linearity (cont.)

- Measure distance of object in both inplane directions.
  - Procedure for determining object boundary
    - Method 1: If the computer possesses profile analysis, measure profile across entire test object and measure distance between FWHMs at each end.
    - Method 2: Determine the mean signal within an ROI containing ≈ 75% of test object and within adjacent outside area but not containing boundary pixels. Set window width to one and the window level to the midpoint between the these two values. Measure distance in this binary image.

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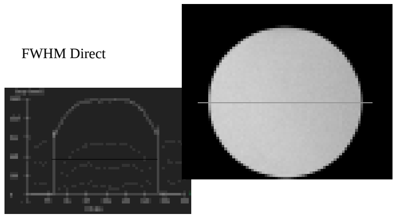
Spatial Linearity

FWHM Direct



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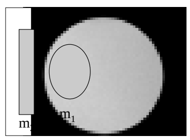
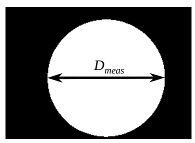
Spatial Linearity

FWHM Direct





$ww = 1$

$wl = m_2 + 0.5(m_1 - m_2)$

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Spatial linearity (cont.)

Calculate the percent geometric distortion.

$$GD = \frac{D_{tr} - D_{meas}}{D_{tr}} \times 100\%$$

Action level:

GD should be < 5% across the FOV, and generally < 2%.

Alternatively, if using the ACR phantom, measured lengths should be within ±2 mm of their published values.

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Spatial Resolution

The ability of the MR system to resolve high SNR and CNR objects depends on:

- Gradient strength
- Data sampling strategy (matrix)
- Reconstruction algorithm, signal processing

Minimum resolution is pixel limited, i.e. minimum object size = pixel size.

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Spatial Resolution (cont.)

Spatial resolution is most completely characterized by the point spread function, however, determination of the PSF can be time consuming. Measure spatial resolution analogous to CT ,i.e., visual evaluation of test objects.

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Spatial Resolution (cont.)

Analogous to CT the high contrast resolution insert consists of a regular array of alternating holes and spaces of varying diameters. In this case 3 blocks of holes with spaces equal to the respective hole diameters of 0.9, 1.00, 1.1 mm, were drilled in a 11mm thick bar. Holes were drilled in two orthogonal directions in the test object to permit simultaneous estimation of resolution in both frequency and phase encoding directions.

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Spatial Resolution (cont.)

Test object positioning
- Position insert at isocenter
- Line reference guides to insure axis of phantom is perpendicular to scan plane.

Procedure
- Utilize ACR Accreditation T1 and T2 Series Slice #1
- Magnify image 2-4 times
- Record smallest hole pattern visible in both directions using predetermined window level and width method.

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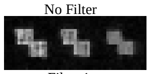
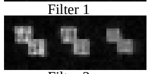
High Contrast Resolution

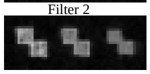
Resolution Insert
No Filter



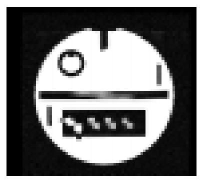
Filter 1



Filter 2



ACR Phantom Slice #1



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Slice Thickness

In MRI, the slice thickness depends on
- gradient strength and linearity
- magnetic field homogeneity
- RF homogeneity
- pulse sequence type (e.g. 2DFT vs. 3DFT)

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Slice thickness (cont.)

- Two methods for slice thickness measurement
  - Measure slice profile directly by applying slice and frequency gradients in slice direction
    - Profile across image directly measures slice thickness
  - Image a ramp oriented perpendicular to scan plane

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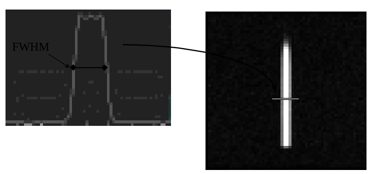
Direct image of Slice Profile



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Slice Thickness (cont)

- Method 2 ramp angled wrt image plane
- Scan parameters
  - ACR T1 Series, Slice #1
  - ACR T2 Series, Slice #1
- Scan test object position
  - Center of slice at isocenter, making sure that phantom is aligned in all three dimensions.

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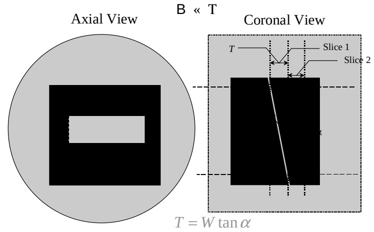
Slice Thickness

B « T



$T = W \tan \alpha$

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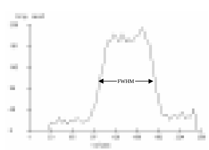
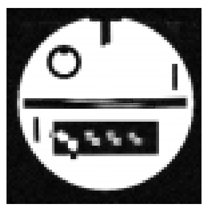
Slice Thickness Measurement

Draw ROI through each bar including background
Plot histogram for each ROI
Estimate or calculate FWHM





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Slice Thickness (cont.)

Procedure

- Acquire multi-slice data either with zero gap or interleaved
- Either measure profile across the apparent width
- Or measure maximum signal level in bar, mean value of adjacent background
- Subtract background from maximum value and determine midpoint
- Set window width to 1 and level to midpoint
- Measure distance for each ramp

$Thk = 0.2 \times (top \times bottom) / (top + bottom)$

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Slice Separation

Using the multi-slice image set acquired for slice thickness, add adjacent slices.

Image of bar should be twice the width of a single slice.

Note any gaps or central region of double signal intensity.

Action level: gap, or overlap should be 1 mm or less.

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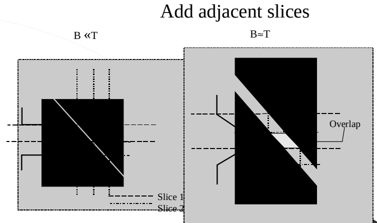
Slice Separation

Add adjacent slices



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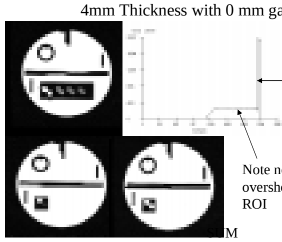
Summed Separation Images

4mm Thickness with 0 mm gap

Slice 1

Slice 2



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Phase Stability

All current MRI imaging methods use phase information for spatial localization. Some techniques employ additional phase shifts to encode other information into the MR signal (e.g. phase contrast angiography).

From conventional 2 DFT to single shot EPI, MR imaging methods require multiple data samples in which the phase is incremented in a precise fashion.

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Phase Stability

The reconstruction algorithm assumes that the phase is stable between samples and that any phase shifts are accounted for.

Unwanted phase shifts produce spatial misregistration which appear as faint copies of the image displaced along the PE axis. These phase shifts may be produced by tissue motion during application of gradient pulses, or may be due to drift or failures in RF or gradient subsystems.

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Phase stability (cont.)

Method 1: Percent Signal Ghosting

Use ACR Phantom Slice #7, T1 Series

Draw large ROI (> 200 cm^2) in center

Draw 4 ROIs in phase and frequency noise regions

Record mean signals. Ghost Ratio is

$$GR = \left| \frac{(top + bot) - (left + right)}{2 \times LROI} \right|$$

Action Level: G.R. ≤ 0.025

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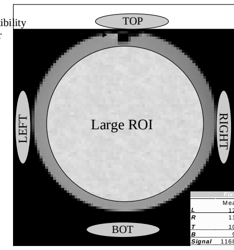
Ghost Ratio

Susceptibility from air bubble



ACR T1 Series
Slice #7

ROIs for Ghost Ratio measurement

Ghost Ratio for 3 Systems

	Fixed 11.5T		Fixed 2 1.5T		Mobile 1.0 T	
	Mean	σ	Mean	σ	Mean	σ
L	12.08	5.82	11.22	5.87	20.96	11.77
R	11.18	6.87	10.59	6.15	22.59	10.40
T	10.42	5.13	9.93	5.07	20.28	10.18
B	9.04	4.41	10.47	5.14	19.14	10.04
Signal	1168.00	50.35	1407.19	40.32	1451.46	50.00
GR	0.001627		0.000501		0.001423	

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Phase stability (cont.)

Method 2

Test object

- Uniform sphere or cylinder, diameter < 0.5 FOV.

Position

- Displaced from isocenter in both frequency and phase encoding directions

Pulse sequence

- Multislice TR 2000, TE 20,80
- – One excitation

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Phase stability (cont.)

- Acquire multiecho, multislice data
- Inspect all slices and echoes for evidence of ghosts
- Record image number, position, of image with maximum intensity ghosts
- Measure mean value from an identical ROI in original image and ghost image
- PE = $(Mean_G / Mean_O) \times 100\%$
- Action level
  - Mean signal from ghosts should be less than 2% of original image signal.

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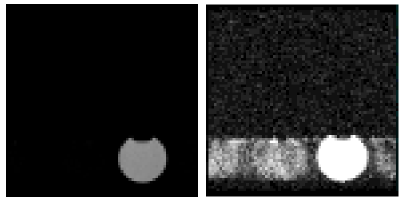
Phase Stability



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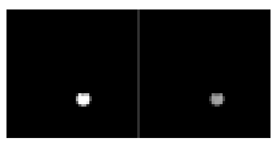
Phase stability (cont.)

Optionally repeat procedure for each orthogonal plane.

Repeat measurement using body coil.



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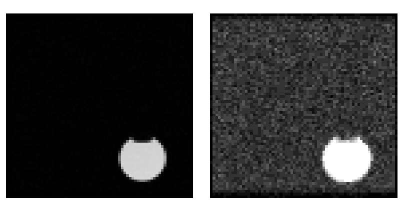
Phase Stability

After Head Coil was replaced



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Summary

Compliance test result influenced by

- Test Object , Pulse Sequence, Anatomic Plane

Measure relative changes, not absolute limits

Optional methods for

- Data Acquisition
- Data Analysis

Total imaging time 1-1.5 hours if using several phantoms and/or multiple planes

Analysis time in addition to image acquisition