Large and Medium Phantom Test Guidance
for the

MRI
Accreditation
Program

Large and Medium Phantom Test Guidance for the ACR MRI Accreditation Program

Contents

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0.0 INTRODUCTION

0.1 Overview and Purpose

This document provides information about the Large and Medium phantom tests that are part of the American College of Radiology (ACR) Magnetic Resonance Imaging Accreditation Program. The primary purpose of this document is to enable facilities to understand the appropriate phantom to use for submission to the ACR for accreditation of whole body MR scanners and the accreditation pass/fail criteria for the Large and Medium phantoms. This document will be useful to facilities wishing to determine whether or not they will pass the phantom tests prior to data submission. In addition, this document will assist sites that have failed the phantom tests to understand the significance of the failure, the recommended steps to correct it, and to determine whether or not their corrective actions have been successful. Sites are strongly encouraged to use these procedures to evaluate their phantom images in order to identify and correct problems in advance of submitting their images to the ACR for accreditation.

The pass/fail criteria are indicative of a minimum level of performance that one reasonably can expect from a well-functioning MRI system. On the other hand, being minimum levels of performance, these criteria should not be construed as indicators of typical or optimum levels of performance. Additional information on this topic can be found in the ACR MRI Quality Control Manual.

We begin with an introduction to describe the Large and Medium phantoms and the required image data, to introduce terminology used to refer to the images, and to list the tests that constitute the phantom assessment portion of the accreditation process. Following the introduction, the procedure and acceptance criteria for each test are described, along with common causes of failure and possible corrective actions.

0.2 The Phantoms

The Large ACR MRI phantom has been part of the MRI Accreditation Program (MRAP) since its inception. At the time the MRAP program was implemented, the available head coils on MR scanners were quadrature coils of sufficient size to accommodate the large phantom. Since then, phased array coils have become much more common in MR imaging than quadrature coils.

In mid-2021, the Medium ACR MRI phantom was approved for accreditation. This phantom was developed specifically for use in modern phased array head coils which typically have smaller open volumes than quadrature head coils. The Medium ACR MRI phantom enables sites to acquire phantom images for accreditation and for quality control (QC) with the same coil that is used to acquire most clinical brain images. This also eliminates the extra handling of MR coils in order to conduct required technologist QC.

Now that both phantoms are approved for accreditation of MR scanners in the modular Magnetic Resonance Accreditation Program (MRAP), sites must submit phantom images acquired using a head coil that is routinely used for clinical brain imaging on the scanner, and must use the largest phantom that fits inside that head coil. Facilities with scanners that do not have a head coil and/or do not routinely perform brain imaging should use the small phantom in the knee coil to obtain phantom images for accreditation review.

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The ACR Large and Medium MRI phantoms are hollow cylinders of acrylic plastic closed at both ends. Both phantoms are filled with 10 mM $NiCl_2$, 75 mM NaCl. The internal (signal producing) phantom dimensions are displayed in **Table 1**. Both phantoms contain resolution test objects consisting of either three or four patterns. Future large phantoms will include four resolution patterns. The outside of each phantom has the words "NOSE" and "CHIN" etched into it as an aid to orienting the phantom for scanning, as if it were a head.

Table 1: Large and Medium Phantom resolution patterns and internal (signal producing) dimensions

Phantom	Head Coil	Resolution Pattern (mm)	Internal Length (mm)	Internal Diameter (mm)
Large	Head coils large enough to fit the large phantom	1.1, 1.0, 0.9	148	190
Medium	Smaller phased-array head coils	1.1, 1.0, 0.9, 0.8	134	165

Inside the phantoms are several structures designed to facilitate a variety of tests of scanner performance. A description of each structure is included in the relevant test section. The methods for making the measurements are generally the same for both phantoms. However, the limits and ROI sizes differ for certain tests.

0.3 The Required Images

For both the large and medium phantoms, the phantom portion of the MRAP requires the acquisition of a sagittal localizer and four axial series of images. The same set of 11 slice locations within the phantom is acquired in each of the four axial series. These images are acquired using the scanner's routine clinical head coil using the largest ACR phantom that fits inside that coil. The scan parameters and approximate scan times for the sagittal localizer and the first 2 axial series of images are in **Table 2**. These three series are referred to as the **ACR sequences** or **series.** The third and fourth series of axial images are based on the site's own clinical brain protocols, and are referred to as the **site sequences** or **site series**.

> **Note:** MRI systems require that a weight be entered in order to scan the phantom; the ACR recommends that your site enter a weight of 200 pounds. For some 3T scanners, using a weight of 200 lbs will cause the ACR T1 series scan time to double from 2:16 to over 4 minutes. The scan time doubles in order to meet head SAR model restrictions. You could reduce the entered weight to approximately 50 lbs to maintain the 2:16 acquisition time. The image quality should not be affected. Note that this is only a workaround for phantom scans. For patient scans the actual patient we ight should always be used to ensure patient safety.

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The localizer is a sagittal spin-echo acquisition through the center of the phantom, that is referred to as the Sagittal **localizer**. In mid-2021 the thickness was reduced to 10mm. However, sites may continue to use 20mm slice thickness if they prefer.

The first axial series is a spin-echo acquisition with ACR-specified scan parameters that are typical of T1-weighted acquisitions. This series is called the **ACR T1** series.

Prior to mid-2021, the second axial series was a double spin-echo acquisition with ACR-specified scan parameters that were typical of proton density/T2-weighted acquisitions common at the time the MRAP began. Since the double-echo sequence is rarely used in modern imaging, starting in mid-2021 the ACR T2 series has been changed to a single echo spin echo with the same TR and TE as the double echo T2. For the **ACR T2** series, sites are encouraged to switch to a single echo spin echo, but still have the option of submitting the double echo series. When analyzing data from a double-echo acquisition, only the second-echo images (TE=80) are evaluated.

The third and fourth axial series are based on the scan parameters the site normally uses in its clinical protocols for axial T1- and T2-weighted brain, respectively. These series are called the **site T1** and **site T2** series. Sites should scan the phantom using their clinical protocols, but change the number of slices, thickness and gap to the values in **Table 2.**

It has come to our attention that some manufacturers of MRI systems have sent "sample" or "recommended" phantom site scanning protocols to their users. Please be aware that the requirement for MRI accreditation is that for the site T1 and site T2 series, facilities must use the same protocol (with appropriate modifications) for the phantom that the facility uses for routine T1 and T2 brain imaging. Failure to comply with this requirement could result in failure to achieve accreditation.

Table 2: Large and Medium Phantom scan parameters and approximate scan times. If scan times are significantly different, check scan parameters to ensure they are correct.

Series	Pulse Sequence	TR / TE (ms)	FOV (mm) (frequency)	FOV (mm) (phase)	# Slices	Slice Thickness mm)	Slice Gap (mm)	# Avgs	Matrix (frequency)	Matrix (phase)	Scan Time (min:sec)
*ACR Sag localizer	Spin echo	200 / 20	250	250	1	10*	n/a	1	256	256	0:56
ACR Axial T1	Spin echo	500 / 20	250	250	11	5	5	1	256	256	2:16
ACR Axial T2	**Spin echo	2000 / 80	250	250	11	5	5	1	256	256	8:56
***Site Axial T1 Brain					11	5	5				
***Site Axial T2 Brain					11	5	5				

*For the ACR Sag localizer 10mm slice thickness is preferred, but 20mm is acceptable.

For the ACR T2 series single echo spin echo is preferred, but double echo spin echo (TR 2000, TE 20/80) is acceptable. Fast/Turbo spin echo must **not be used.

***Blank fields indicate where to use the site's clinical parameters from routine brain protocols.

Each axial series has 11 required slice locations. The locations are numbered starting at the inferior end of the phantom; so, slice location 1 is at the end of the phantom labeled "CHIN." The phantom should be scanned inferior to superior. However, even if the images are acquired in reverse order, this document will refer to them by their series name and slice location number. For example, ACR T1 slice 7 is the image at slice location 7 of the ACR Axial T1-weighted acquisition.

For all 4 axial series, the required slice thickness is 5 mm and the slice gap is 5 mm. Thus, the set of 11 slices spans a distance of 100 mm from the center of the first slice to the center of the last slice.
Figure 1 shows sagittal localizers of the large and medium phantoms with the 11 axial slice locations cross-referenced. There are two pairs of crossed 45° wedges lying in the central sagittal plane of the phantom: one pair at each end of the phantom. Slice 1 is prescribed to be centered on the vertex of the angle formed by the crossed wedges at the inferior end of the phantom. The vertices of the wedge pairs are separated by 100 mm, and therefore slice 11 falls on the vertex at the superior end of the phantom.

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The phantom image data must be electronically uploaded to the ACR in uncompressed or lossless compressed DICOM format. Do not upload images in lossy compressed format. Detailed submission information can be found here: [Testing Package and Image Submission: Overview]

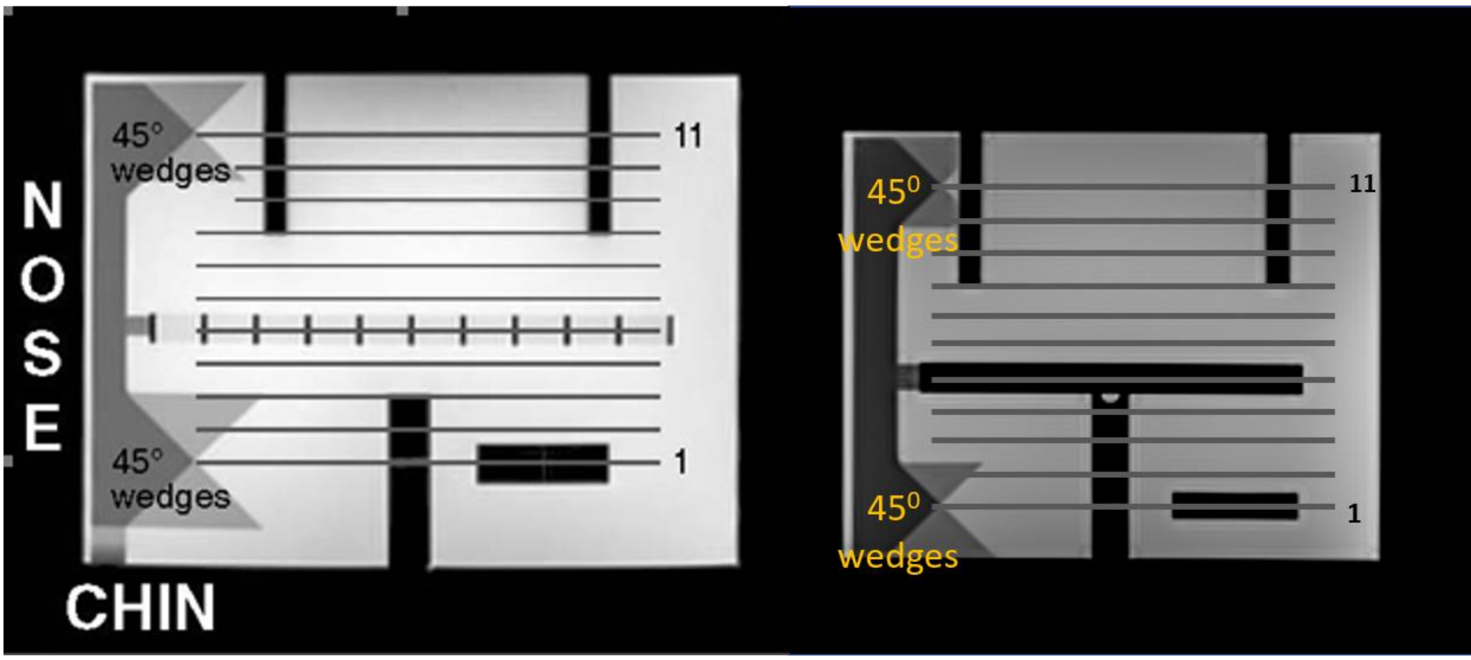

Figure 1: Sagittal localizers of the Large (left) and Medium (right) phantoms showing the 11 required axial slice locations and the paired 45^0 wedges. The words "CHIN" and "NOSE" indicate where those words are etched into the phantoms as an aid to orienting them for scanning as if they were a head.

0.4 The Image Analysis

To analyze the images, display them on a workstation or PC with DICOM viewing software capable of these basic image manipulation functions: window and level adjustment, magnification (zoom), mean signal measurement within a region-of-interest (ROI), and distance measurement. In most cases the most convenient place for a facility to evaluate its own data will be the scanner console or an associated image review station. However, prior to submission it is strongly recommended to review the images on an independent PC with DICOM viewing software in the form in which they will be submitted in order to check that data transfer can be completed and to replicate the way the data will be analyzed by the ACR reviewers.

The images and testing data will be used to assess:

1. Geometric accuracy
2. High-contrast spatial resolution

3. Slice thickness accuracy
4. Slice position accuracy
5. Image intensity uniformity
6. Ghosting ratio
7. Low-contrast object detectability
8. Artifact assessment

Each of these tests will be described in the sections below. The sections are numbered to correspond with the numbering of the tests in this list.

1.0 GEOMETRIC ACCURACY

1.1 What It Is

The geometric accuracy test assesses the accuracy with which the image represents true dimensions of the imaged subject. It consists of making phantom length and diameter measurements, between readily identified locations in the phantom, and comparing the results with the known phantom dimensions. A failure means that measured dimensions differ from the true dimensions substantially more than is usual for a properly functioning scanner.

Geometric accuracy is evaluated using the ACR Sagittal localizer image and slices 1 and 5 of the ACR Axial T1 series. The material used to construct the insert in slice 5 differs depending on the date the phantom was manufactured. For older Large ACR phantoms slice 5 will consist of a grid. Medium Phantom and newer Large Phantoms will have an acrylic insert with equally spaced holes. The function of both inserts is identical, to guide the measurements.

1.2 What Measurements Are Made

Seven phantom measurements are made using the distance measurement tool. The display window and level settings affect this measurement, so it is important to set them properly. For that purpose, a separate ancillary procedure for adjusting the display window and level settings is provided following the measurement procedure.

Geometric accuracy measurement procedure:

1. Display the ACR sagittal localizer image. Adjust the display window and level as described below.
2. Measure the superior to inferior (head to foot) length of the phantom along a line close to the middle of the phantom as shown in **Figure 2**.
3. Display slice 1 of the ACR T1 series. Adjust the display window and level as described below.

4. Measure the diameter of the phantom in 2 directions: top-to-bottom and left-to-right **(Figure 2).**
5. Determine the window level setting to measure slice 5 of the ACR T1 series, as described below. Display slice 5 with that window and level.
6. Measure the diameter of the phantom in 4 directions: top-to-bottom, left-to-right, and both diagonals **(Figure 3)**.

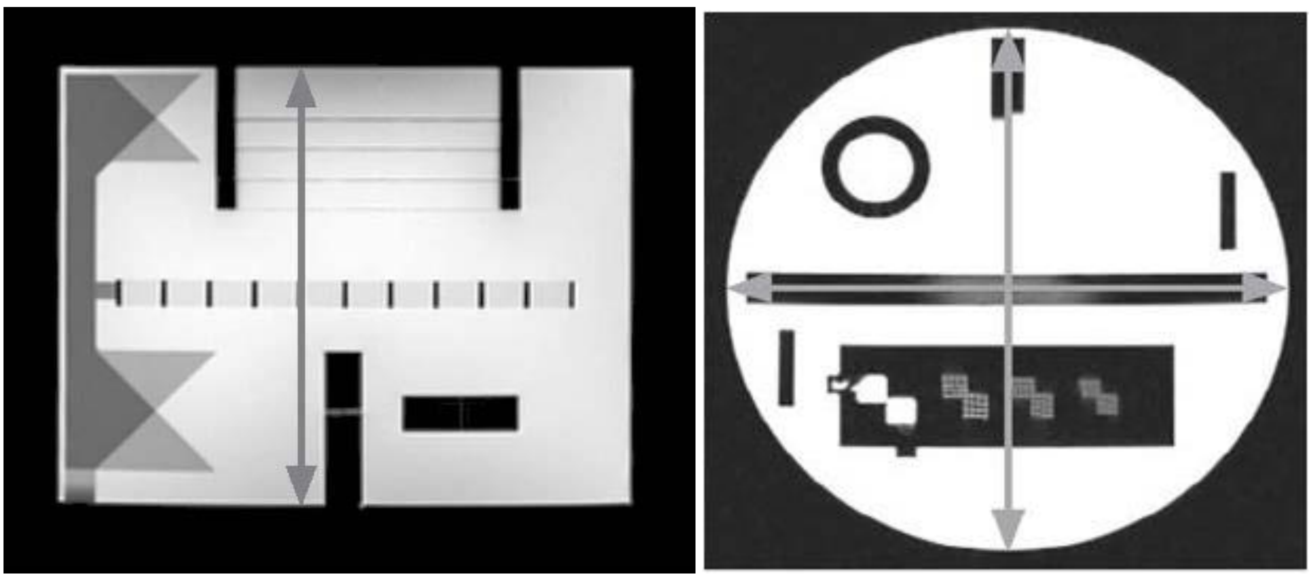

Figure 2: Localizer with superior to inferior length measurement illustrated (left). Axial slice 1 showing the diameter measurements (right).

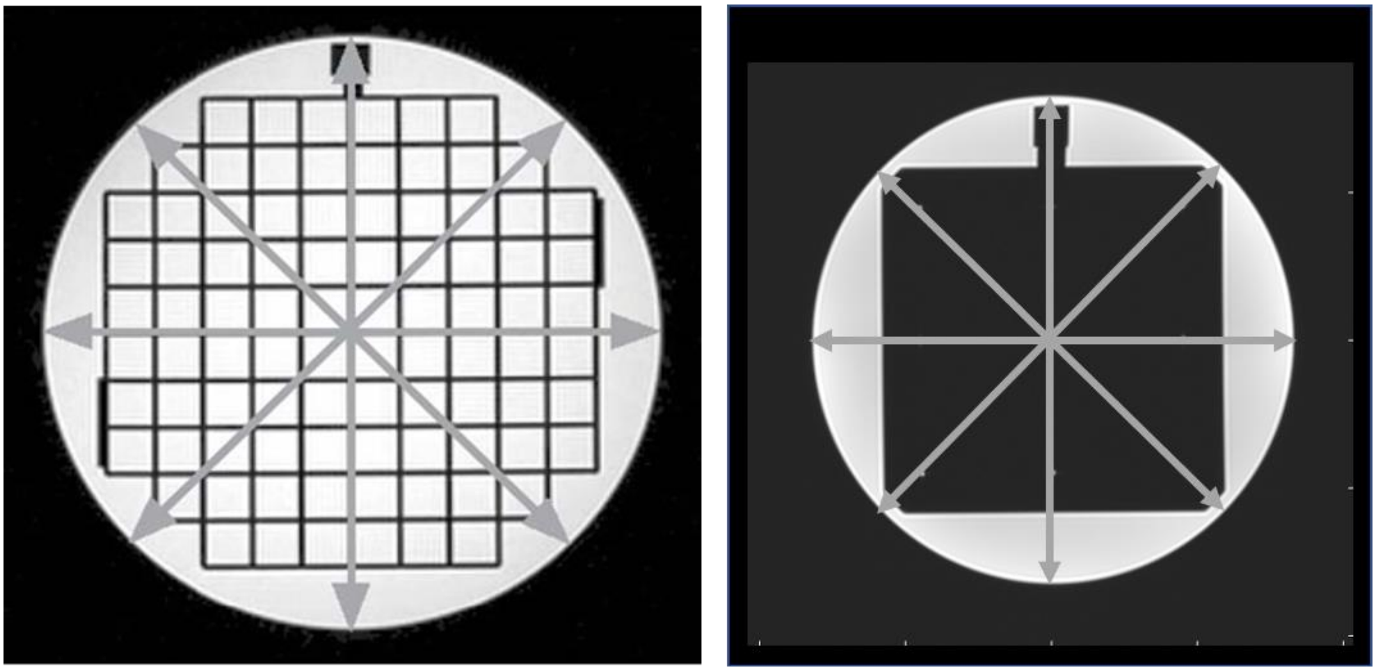

Figure 3: Slice 5 of the Large (left) and Medium (right) phantoms with diameter measurements illustrated (arrows).

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The display window and level settings affect the apparent location of the edges of the phantom and therefore can cause length measurement errors. To avoid this, the measurements should be made with the display window width set to the mean signal value and the level set to a value equal to half the mean signal value of the water-only regions of the image.

On most scanners the following procedure can be used for setting the display window and level:

1. Adjust the window to its narrowest setting, which is 0 or 1 on most scanners.
2. Observe the regions of the phantom that have only water, i.e., the regions with the highest signal that do not contain internal phantom structures. Lower the display level until the signal in these water-only regions is all white.
3. Raise the display level until about half of the total area of the water-only regions has turned dark. This is illustrated in **Figure 4**. The level is now set to a numerical value approximating the mean signal of the water-only regions; note this value. (This is really estimating the median signal, but that will be sufficiently close to the mean for our purpose.)
4. Lower the level setting to half of the mean signal value found in step 3. Increase the window width setting to equal the mean signal value.
5. For phantoms where slice 5 is a solid acrylic insert instead of a grid, use uniform slice 6 to determine the appropriate window/level setting, then display slice 5 with that setting before measuring diameters on slice 5.

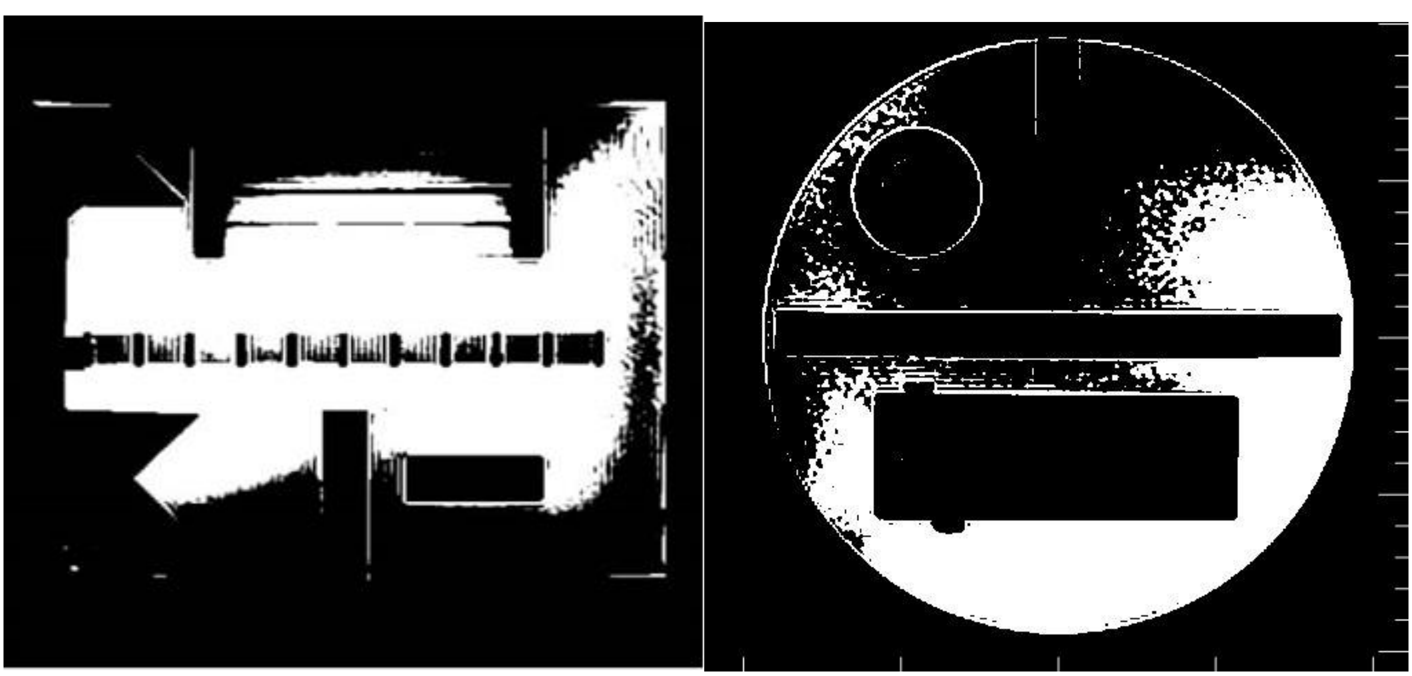


Figure 4: Sagittal locator (left) and Slice 1 of the Large phantom displayed with the window set to zero and level adjusted to approximate the mean signal.

1.3 How the Measurements Are Analyzed

The length measurements are compared with the known internal signal-producing dimensions of the phantom.

Table 3: Large and Medium phantom internal dimensions and geometric accuracy limits

Phantom	Sagittal length (mm)	Pass/Fail Limit (mm)	Axial diameter (mm)	Pass/Fail Limit (mm)
Large	148	148 +/- 3.0	190	190 +/- 3.0
Medium	134	134 +/- 2.0	165	165 +/- 2.0

1.4 Pass/Fail Criteria

Large Phantom: Images submitted for accreditation will fail if any measurement differs more than ± 3.0 mm from its true value.

Medium Phantom: All measured lengths must be within ± 2.0 mm of their true values to pass.

Note: Limits for the medium phantom are tighter because measurements are being made over a shorter distance and closer to isocenter where geometric accuracy is expected to be better.

1.5 Causes of Failure and Corrective Actions

Some MR vendors provide the ability to select gradient distortion correction at the operator console. For these systems be sure that the distortion correction option is turned on; leaving distortion correction off can cause geometric accuracy failure.

A common cause of failure of this test is miscalibration of one or more gradients. A mis-calibrated gradient causes its associated image dimension (x, y, or z) to appear longer or shorter than it really is. Mis-calibrated gradients also can cause slice position errors. It is normal for gradient calibration to drift over time and to require recalibration by the service engineer.

Another possible cause of failure is use of an excessively low acquisition bandwidth. It is common practice on low B_0 field scanners and at some facilities to reduce acquisition bandwidth, especially on long TE acquisitions, to increase signal-to-noise ratio (SNR). This can be pushed to the point that the normal inhomogeneities in B_0 manifest themselves as spatial distortions in the image. On most scanners the default bandwidth for T1-weighted acquisitions is set high enough to avoid this problem. If the geometric accuracy test measurements fail, and the ACR T1 series was acquired at low bandwidth, try acquiring that series again at a higher bandwidth to see if the problem is eliminated.

Abnormally high B_0 inhomogeneities can also cause significant dimensional errors in the phantom images. Such B_0 inhomogeneities may indicate the need for adjustment of gradient offsets, adjustment of passive or active magnet shims, or the presence of a ferromagnetic object in the magnet bore. The MRI physicist/scientist or the MRI service engineer can run diagnostic tests to determine the source of geometric errors.

2.0 HIGH-CONTRAST SPATIAL RESOLUTION

2.1 What It Is

The high-contrast spatial resolution test assesses the scanner's ability to resolve small objects when the contrast-to-noise ratio (CNR) is sufficiently high that it does not play a role in limiting that ability.

A failure of this test means that for a given field of view (FOV) and acquisition matrix the scanner is not resolving small details as well as normal for a properly functioning scanner. However, since clinical protocols are typically adjusted to optimize high contrast resolution, if the site fails resolution for either of the ACR series, this test is then applied to the site series. The submitted images must pass for one of either both ACR series or both site series.

2.2 What Measurements Are Made

High-contrast spatial resolution is evaluated by visually assessing whether individual small bright spots in arrays of closely spaced small holes are distinguishable. The hole sizes and spacing are provided in **Table 1**. These bright spots are water-filled holes drilled in a small block of plastic called the **resolution insert**, which appears in slice 1 **(Figure 5)**. Inside the insert are 3 or 4 pairs of not-quite-square arrays of holes. One pair of hole arrays is illustrated in **Figure 6.**

Note that each pair consists of an upper left (UL) hole array and a lower right (LR) hole array. Here right and left refer to the viewer's right and left. The UL and LR arrays share 1 hole in common at the corner where they meet. The UL array is used to assess resolution in the right-left or row direction, and the LR array is used to assess resolution in the top-bottom or column direction (anterior-posterior if this were a head).

The UL array is comprised of 4 rows of 4 holes each. The center-to-center hole separation within a row is twice the hole diameter. The center-to-center row separation is also twice the hole diameter. Each row is staggered slightly to the right of the one above, which is why the array is not quite square. The staggering ensures that the holes in at least one row will align exactly with the display matrix so that each hole in that row will be centered within a pixel. Holes that do not align with the display matrix will experience partial volume affects and appear to be blurred or irregularly shaped spots of signal.

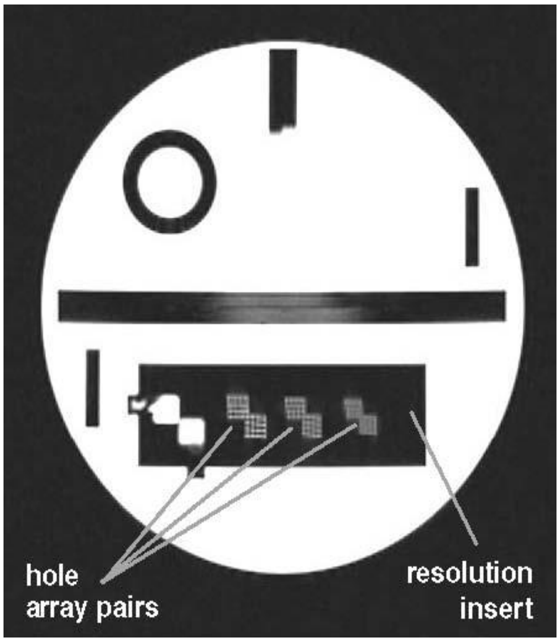


Figure 5: Axial slice 1 of the Large phantom showing the hole array pairs and resolution insert.

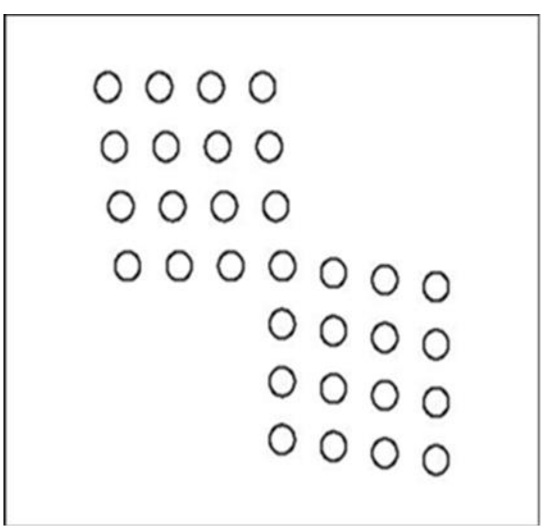
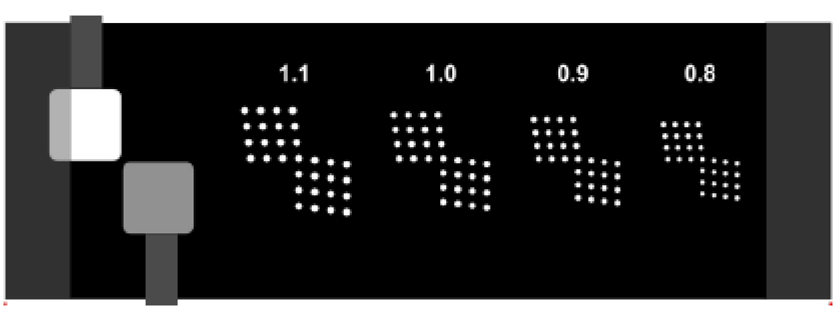


Figure 6: Illustration of one of the pairs of hole arrays in the resolution insert.

The LR array is comprised of 4 columns of 4 holes each. The center-to-center hole separation within each column and the center-to-center spacing between columns are twice the hole diameter. Each column is staggered slightly downward from the one to its left. As with the rows, staggering of columns ensures that the holes in at least one column will align exactly with the display matrix and not experience partial volume effects.

The hole diameter differs between the array pairs. Older, large phantoms will have three sets of arrays that are (from left to right) 1.1, 1.0, and 0.9 mm in hole size and spacing (**Figure 7).** Medium or newer large phantoms will have four sets of arrays that are (from left to right) 1.1, 1.0, 0.9 and 0.8 mm hole size and spacing. Using the inserts, one can determine the smallest resolvable hole size. Regardless of whether the phantom insert has three or four arrays, the minimum resolution limit required to pass is the same, 1.0 mm.

(a)



(b)

Figure 7:(a) Resolution insert of a large phantom with 3 arrays (1.1, 1.0 and 0.9 mm) (b) Schematic of a resolution insert with 4 arrays (1.1, 1.0, 0.9, and 0.8 mm)

For this test, resolution in slice 1 of each of the 2 ACR axial series is evaluated. The following procedure is repeated for each of those series, first to assess resolution in the right-left or row direction:

1. Display the slice 1 image.
2. Magnify the image by a factor of between 2 and 4, keeping the resolution insert visible in the display. This is illustrated in **Figure 8.**
3. Begin with the leftmost pair of hole arrays, which is the pair with the largest hole size, 1.1 mm.
4. Look at the rows of holes in the UL array, and adjust the display window and level to best show the holes as distinct from one another.
5. If all 4 holes in any single row are distinguishable from one another, score the image as resolved right-to-left at this particular hole size.

To be "distinguishable" or resolved, it is not necessary that image intensity drop to zero between the holes. To be distinguishable a single window and level setting can be found such that all 4 holes in at least one row are recognizable as points of brighter signal intensity than the spaces between them. **Figure 9a** shows the typical appearance of well-resolved holes.

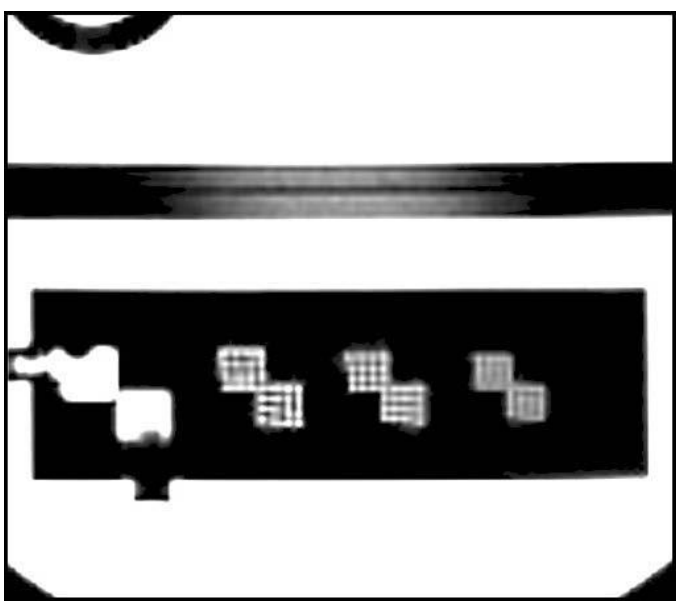


Figure 8: Magnified portion of slice 1 of the Large phantom displayed appropriately for visually assessing high-contrast resolution.

When the hole size is comparable to the resolution in the image, groups of two or more holes in a row or column may blur together and appear as a single irregularly shaped spot of signal. In this case the holes in that row are considered unresolved. An example of this is shown in row 1 of the UL array of **Figure 9b**.

Sometimes one or more holes which are distinguishable from their neighbors in their own row blur together with their neighbors in adjacent rows. This condition is acceptable and does not affect the scoring for the row. An example of this condition is shown in the second row of the UL array of **Figure 9b**, where the holes at each end of the row blur with their neighbors in adjacent rows.

To assess resolution in the top-bottom or column direction:

1. Look at the holes in the LR array and adjust the display window and level to best show the holes as distinct from one another.

2. If all 4 holes in any single column are distinguishable from one another, score the image as resolved top-to-bottom at that particular hole size. The remarks made in step 5 about distinguishability of holes within rows apply here to holes within columns.

3. Move on to the pair of arrays with the next smaller hole size, and evaluate as in steps 4 through 7. Continue until the smallest resolvable hole sizes have been found for the right-to-left and top-to-bottom directions.

4. Record the smallest hole size resolved in each direction; that is the measured resolution for that direction.

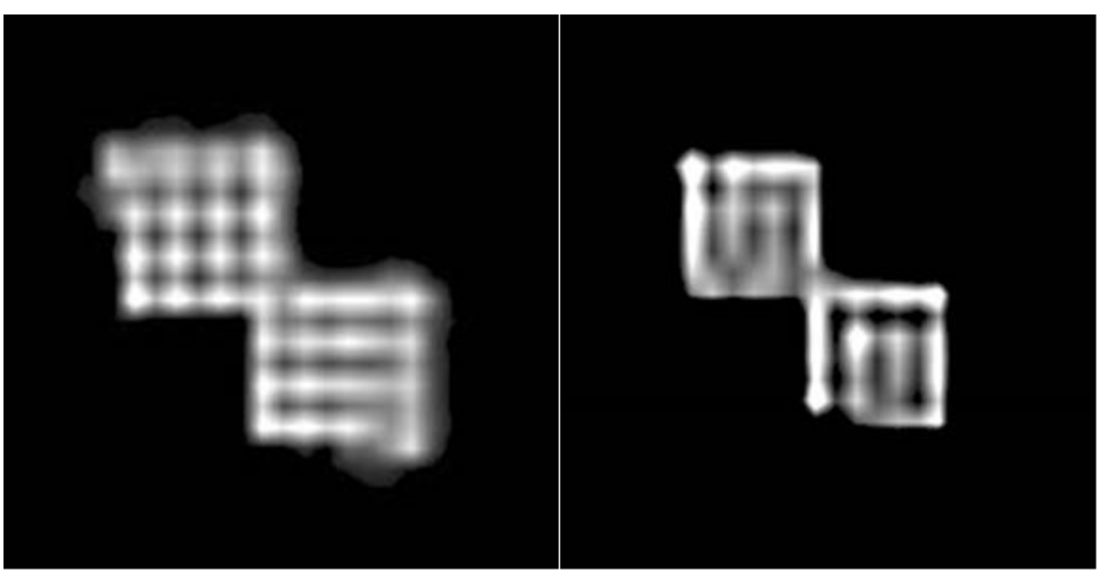


Figure 9:

(Left) Typical appearance of well-resolved holes. Rows 2 through 4 of the UL array are resolved, and columns 1 through 3 of the LR array are resolved. (Rows and columns are numbered starting from the upper left corner of each array.)

(Right) Example of barely resolved rows and unresolved columns. Row 2 of the UL array is resolved because all 4 holes are discernible from each other, even though the holes at either end of the row blur together vertically with their neighbors in the row below. So, the horizontal direction would be scored as resolved at this hole size. None of the columns of the LR array show more than 3 discernible spots within the column, so the vertical direction is not resolved at this hole size.

2.3 How the Measurements Are Analyzed

Record the measured resolution in both directions for both ACR T1 and ACR T2 axial series and compare to the pass/fail criteria.

2.4 Pass/Fail Criteria

For both phantoms, the FOV and matrix for the axial ACR series are chosen to yield a pixel size of 1.0 mm in both directions. The measured resolution of both axial ACR series must be 1.0 mm or smaller in both directions. If the resolution score for either of the ACR series is more than 1.0 mm, then evaluate the site series. If both site series can resolve 1.0 mm or smaller, then the scanner passes this test. A scanner must pass on both the ACR T1 and T2 series, or on both the site T1 and T2 series. A scanner cannot pass on just one of the ACR series and one of the site series. The resolution measurement procedure and limits for the Large and Medium phantoms are identical.

2.5 Causes of Failure and Corrective Actions

Application of filters can either improve image sharpness or detract from it. Many types of filtering that are used to make the images appear less noisy also smooth the image, which blurs small structures. A site that has failed the high-contrast resolution test should check that any user-selectable image filtering is either turned off, or set to the low end of the available filter settings. Certain vendor-specific options, e.g., Low SAR or slice uniformity, can also impact resolution scores.

Resolution can also fail if the phantom is rotated in the axial plane so that the holes in the resolution pattern do not align with the image matrix.

Poor eddy current compensation can cause failure. The scanner's service engineer should check and adjust the eddy current compensation if this problem is suspected.

Excessive ghosting can cause failure. The presence of excessive ghosting will be evident elsewhere in the images if it is sufficient to cause failure of the high-contrast resolution test. Ghosting is a very nonspecific symptom of a hardware problem. In general, it is caused by instability of the measured signal from pulse cycle to pulse cycle, which can have its origin in the receiver, transmitter, or gradient subsystems. Motion of the phantom can also cause ghosting. Make sure the phantom is stable in the head coil and not free to move or vibrate. Having ruled out phantom motion, it will usually be necessary to ask the service engineer to track down and correct the cause of ghosting.

Geometric errors from gradient miscalibration, B0 inhomogeneity and too-low acquisition bandwidth can cause failure of this test. However, it is unusual for the geometric errors to be large enough to do that. In such cases the image will usually be obviously misshapen, e.g., the circular phantom may appear elliptical or egg-shaped. If the scanner passes the geometric accuracy test, it is unlikely that geometric error could be the cause of failure of the high-contrast spatial resolution test. On the other hand, if the scanner fails the geometric accuracy test by a large margin, then the failure of this test and the geometric accuracy test may have a common cause. Refer to section 1.5 of the geometric accuracy test for discussion of causes and corrective actions for geometric error.

3.0 SLICE THICKNESS ACCURACY

3.1 What It Is

The slice thickness accuracy test assesses the accuracy with which a slice of specified thickness is achieved. The prescribed slice thickness is compared with the measured slice thickness.

A failure of this test means that the scanner is producing slices of substantially different thickness from the prescribed thickness. This problem will generally not occur in isolation since the scanner deficiencies that can cause it may also cause other image problems. Therefore, the implications of a failure are not just that the slices are too thick or thin, but can also result in poor image contrast and low SNR.

3.2 What Measurements Are Made

For this test the lengths of two signal ramps in slice 1 are measured for both axial series.

The ramps appear in a structure called **the slice thickness** insert. **Figure 10** shows an image of slice 1 with the slice thickness insert and signal ramps identified. The two ramps are crossed: one has a negative slope and the other a positive slope with respect to the plane of slice 1. They are produced by cutting 1 mm wide slots in a block of plastic. The slots are open to the interior of the phantom and are filled with the same solution that fills the bulk of the phantom.

The signal ramps have a slope of 10 to 1 with respect to the plane of slice 1, which is an angle of about 5.71°. Therefore, the signal ramps will appear in the image of slice 1 with a length that is 10 times the thickness of the slice. If the phantom is misaligned from right-left, one ramp will appear longer than the other. The crossed ramps allow for correction of the error introduced by right-left misalignment, and the slice thickness formula takes that into account.

For each axial series, the lengths of the signal ramps in slice 1 are measured according to the following procedure:

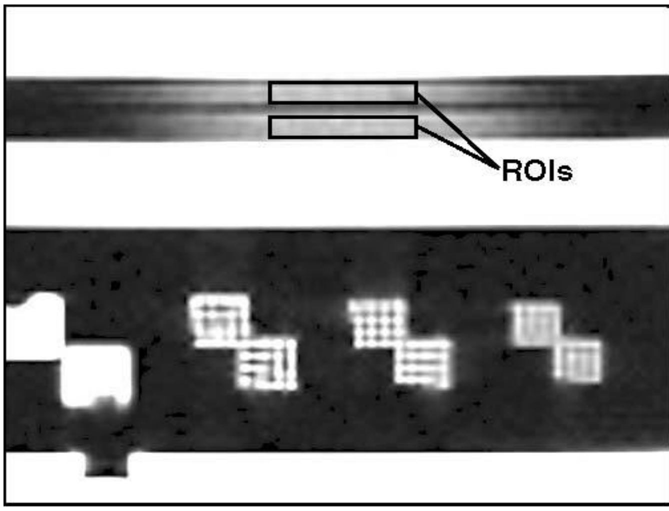
1. Display slice 1, and magnify the image by a factor of 2 to 4, keeping the slice thickness insert fully

visible on the screen.

2. Adjust the display level so that the signal ramps are well visualized.
    - The ramp signal is much lower than that of surrounding water, so usually it will be necessary to lower the display level substantially and narrow the window.

3. Place a rectangular ROI at the middle of each ramp as shown below in **Figure 11.**
    - Note the mean signal values for each of these two ROIs and then average those values.
    - The result is a number approximating the mean signal in the middle of the ramps.
    - An elliptical ROI may be used if a rectangular one is unavailable.
4. Lower the display level to half of the average ramp signal calculated in **step 3.**
    - Leave the display window set to its minimum.

NOTE: When making these measurements, be careful to fully cover the widths of the ramp with the ROIs in the top-bottom direction, but not to allow the ROIs to stray outside the ramps into adjacent high- or low-signal regions. If there is a large difference, (that is, more than 20%), between the signal values obtained for the ROIs, it is often due to one or both of the ROIs including regions outside the ramps.



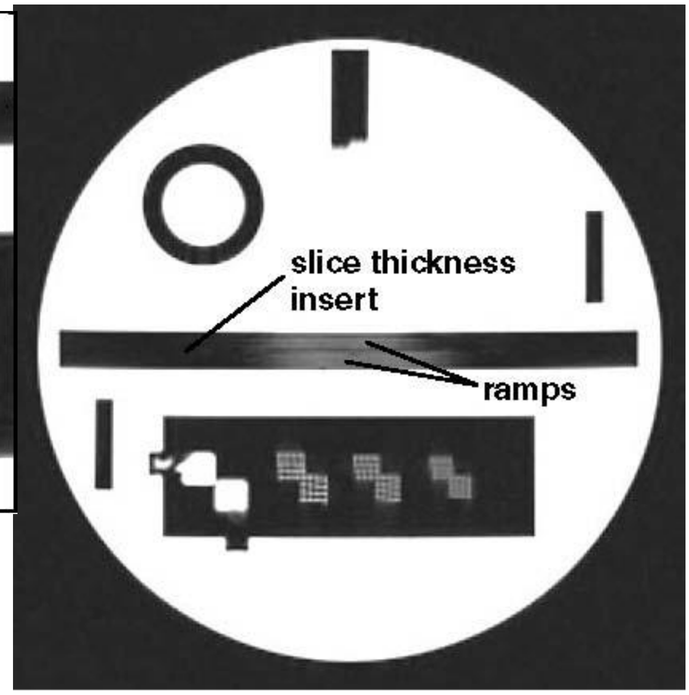


Figure 10: Slice 1 of the Large phantom with the slice thickness insert and signal ramps indicated.

Figure 11: Magnified region of slice 1 showing slice thickness signal ramps with ROIs placed for measuring average signal in the ramps.

5. Use the on-screen distance measurement tool to measure the lengths of the top and bottom ramps. This is illustrated below in **Figure 12**. Record these lengths and compare to the action limits.

   Often there are horizontal striations in the signal intensity of the ramps that cause the ends to appear scalloped or ragged. The striations are a manifestation of truncation (Gibbs) artifact, and are normal. In this case one must estimate the average locations of the ends of the ramps in order to measure the ramp lengths. **Figure 12** is an example of how the measurements should be made. Estimating the ends of the ramps introduces a source of error, but a millimeter of error in the ramp length measurement corresponds to only a tenth of a millimeter error in the slice thickness, so the errors introduced are small in effect.

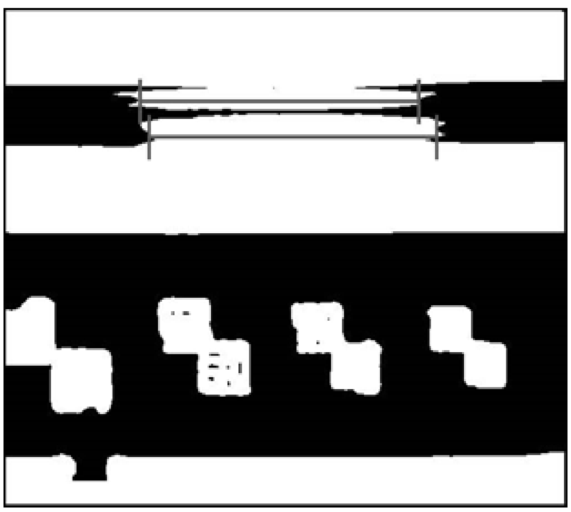


Figure 12: Magnified region of slice 1 showing slice thickness signal ramps. The display window is zero and the level is half the average signal level of the ramps. The length measurements of the ramps are shown on the image.

3.3 How the Measurements Are Analyzed

The slice thickness is calculated using the following formula:

$$\text{Slice thickness} = 0.2 \times (\text{top} \times \text{bottom})/(\text{top} + \text{bottom})$$

In the formula above, the top and bottom are the measured lengths of the top and bottom signal ramps.

Note: 0.2 is a unitless factor that corrects for rotation of the phantom about the vertical (y) axis.

For example, if the top signal ramp were 59.5mm long and the bottom ramp were 47.2mm long, then the calculated slice thickness would be:

$$\text{Slice thickness} = 0.2 \times (59.5\text{mm} \times 47.2\text{mm})/(59.5\text{mm} + 47.2\text{mm}) = 5.26\text{ mm.}$$

3.4 Pass/Fail Criteria

For both the ACR T1 and T2 series, the measured slice thickness should be 5.0 mm ± 0.7 mm. Errors greater than +/-1.0 mm fail. If the thickness error for either series is greater than +/-1.0 mm, the user should evaluate the site series. If slice thickness for both site series is 5.0 mm +/-1.0 mm, then the scanner passes this test. The slice thickness measurement procedure and limits for the Large and Medium phantoms are identical.

3.5 Causes of Failure and Corrective Actions

Radiofrequency (RF) amplifier nonlinearity can cause distorted RF pulse shapes and failure of this test. A mis-calibration could possibly cause failure of this test. On many scanners, the service engineer must empirically calibrate the RF power amplifier for linearity.

Distorted RF pulse shapes can also arise from malfunctions anywhere in the high-power RF portion of the transmitter, for example, in the RF power amplifier, the cables and RF switches that convey power from the amplifier to the transmitter coil, or in the transmitter coil itself.

Extremely poor gradient calibration or poor gradient switching performance can also cause failure of this test.

All of these possible causes for failure require corrective action by the service engineer.

4.0 SLICE POSITION ACCURACY

4.1 What It Is

The slice position accuracy test assesses the accuracy with which slices can be prescribed at specific locations utilizing the localizer image for positional reference.

A failure of this test means that the actual locations of acquired slices differ from their prescribed locations by substantially more than is normal for a well-functioning scanner.

4.2 What Measurements Are Made

For this test, the differences between the prescribed and actual positions of slices 1 and 11 are measured for the ACR T1 and T2 series.

As described in the introduction, slices 1 and 11 are prescribed to be aligned with the vertices of the crossed 45° wedges at the inferior and superior ends of the phantom respectively **(Figure 1)**. On axial slices 1 and 11 the crossed wedges appear as a pair of adjacent, dark, vertical bars at the top (anterior side) of the phantom **(Figure 13)**.

For both slice 1 and slice 11, if the slice is exactly aligned with the vertex of the crossed wedges, then the wedges will appear as dark bars of equal length on the image. By design of the wedges, if the slice is displaced superiorly with respect to the vertex, the bar on the observer's right (anatomical left) will be longer (**Figure 14a**). If the slice is displaced inferiorly with respect to the vertex, the bar on the left will be longer (**Figure 14b**).

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For both size phantoms, measurements are made for slices 1 and 11 of the ACR T1 and ACR T2 series. Use the following procedure for each image:

1. Display the slice. Magnify the image by a factor of 2 to 4, keeping the vertical bars of the crossed wedges within the displayed portion of the magnified image.

2. Adjust the display window to be very narrow so that the ends of the vertical bars are sharp and well defined. The display level setting is not critical, but should be set to a level roughly half that of the signal in the bright, all-water portions of the phantom.

3. Use the on-screen length measurement tool to measure the difference in length between the left and right bars. The length to measure is indicated by the arrows in **Figure 14.** If the left bar is longer, then assign a negative sign to the length. For example, if the bar length difference is 5.0 mm and the left bar is longer, then record the measurement as -5.0 mm.

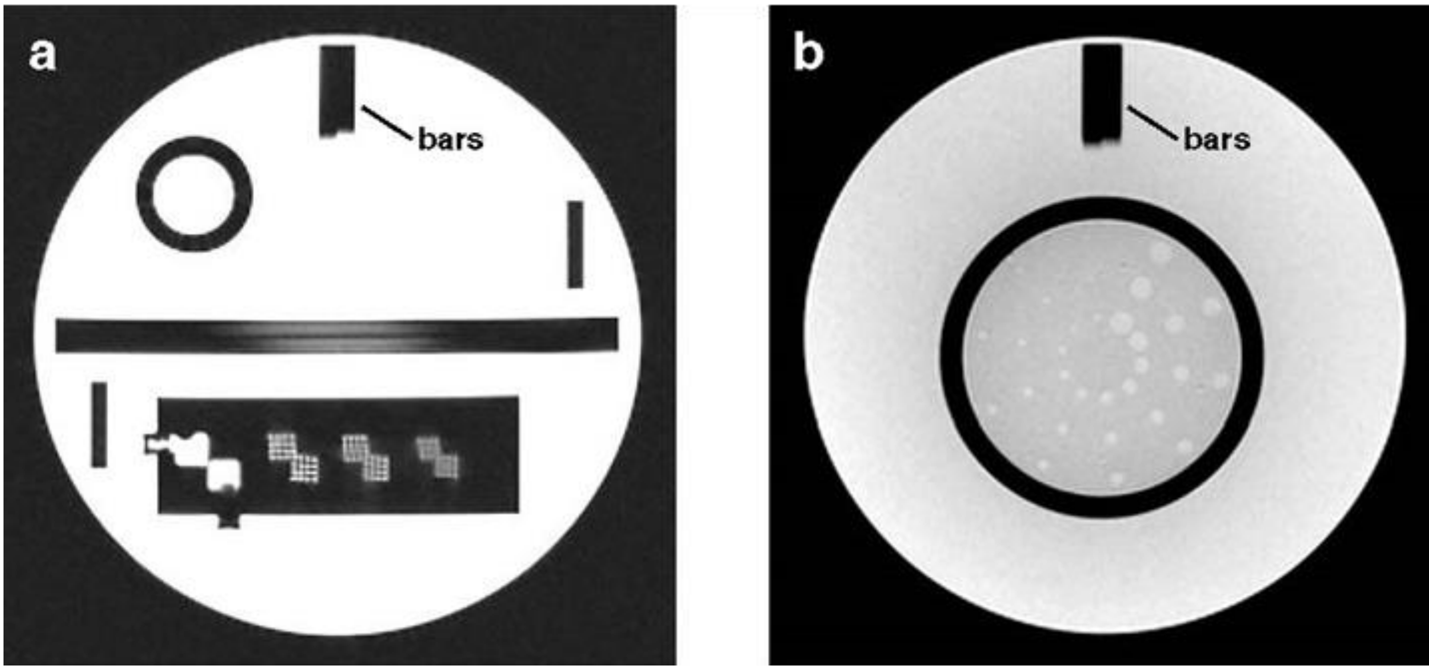


Figure 13: Images of slice 1 (a) and slice 11 (b) with the pairs of vertical bars from the 45^0 crossed wedges indicated. On these images the length difference between the right and left bars is small and typical of well-positioned slices.

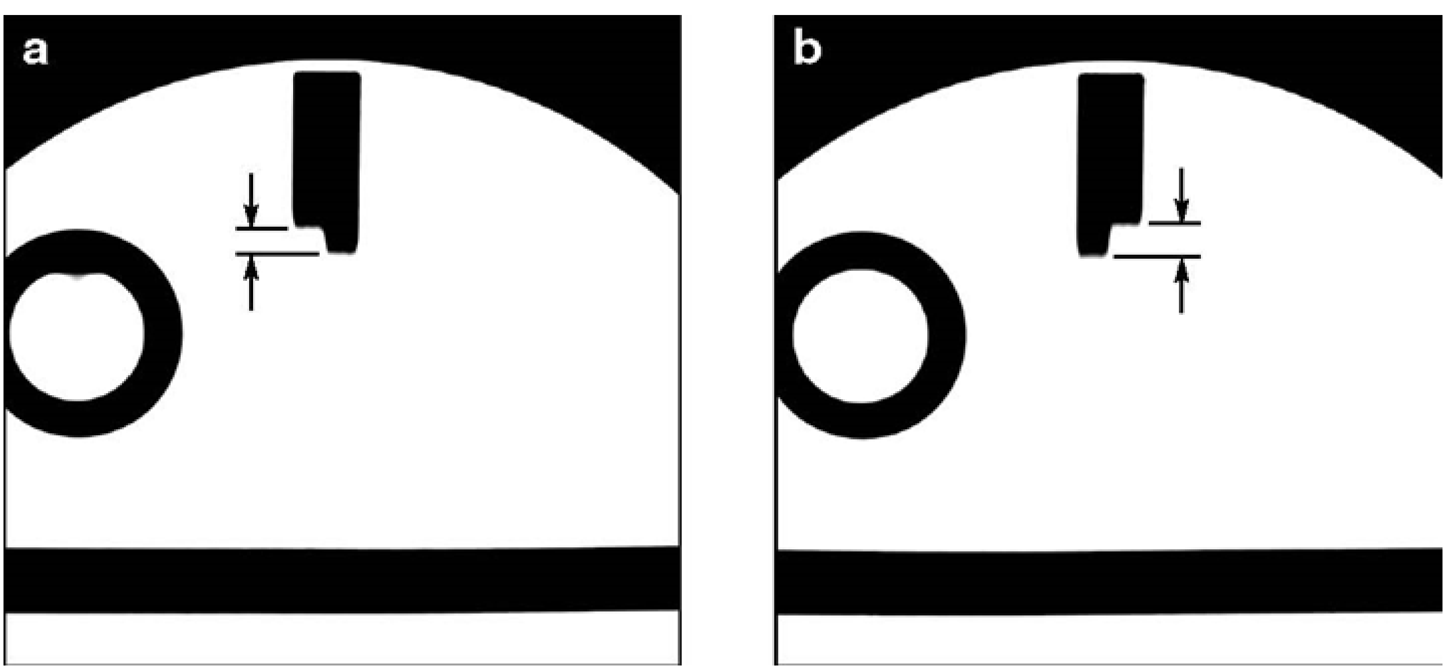


Figure 14: Images of slice 1 illustrating measurement of slice position error. The arrows indicate the bar length difference measurement. **(a)** The bar on the right is longer, meaning the slice is mis-positioned superiorly; this bar length difference is assigned a positive value. **(b)** The bar on the left is longer, meaning the slice is mis-positioned

inferiorly; this bar length difference is assigned a negative value.

4.3 How the Measurements Are Analyzed

Record the bar length difference measurements for the ACR T1 and ACR T2 series. The action criteria are specified in terms of limits on the bar length difference measurements. Because the crossed wedges have 45° slopes; the bar length difference is twice the actual slice displacement error. For example, a bar length difference of –5.0 mm implies the slice is displaced inferiorly by 2.5 mm from the vertex of the crossed wedges.

4.4 Pass/Fail Criteria

The absolute bar length difference should be 5 mm or less, but up to 7 mm is acceptable. However, as explained in section 7.5, a bar length difference of more than 4 mm for slice 11 will adversely affect the low-contrast object detectability (LCD) score. Although 5 mm is acceptable for this test, it is advisable to keep the bar length difference to 4 mm or less. The slice position accuracy measurement procedure and limits for the Large and Medium phantoms are identical.

4.5 Causes of Failure and Corrective Actions

The most common cause of failure of this test is an error by the scanner operator in the prescription of the slice locations. This type of error will be evident when the axial images are cross-referenced on the sagittal localizer: slices 1 and 11 will not be aligned with the crossed-wedge vertices on the localizer image. It is important to prescribe the slices as carefully as possible since errors introduced here can cause other measurements, such as low-contrast detectability, to fail.

Many scanners shift the patient table position in the inferior-superior direction to place the center of a prescribed stack of images at gradient isocenter. This table shift occurs after the localizer is made, and thus error in the table positioning mechanism leads to slice position error. If the bar length difference for slices 1 and slice 11 are the same in sign and similar in magnitude, this type of table positioning error may be the cause.

Poor gradient calibration or poor B_0 homogeneity can cause failure of this test. In either case, the problem will typically be apparent as a failure or near failure of the geometric accuracy test.

Sometimes a failure of this test is an unfortunate combination of two or three of the problems mentioned above— that is, inaccurate slice prescription, error in the table positioning mechanism, and/or poor gradient calibration or B_0 homogeneity—with none of the problems in itself being sufficiently bad to cause a failure on its own. If no one thing seems to be responsible for causing a failure of this test, try having the service engineer do the following: (1) check the laser alignment lights and shim B_0; (2) recalibrate the gradients; and (3) check the table positioning mechanism for excessive play. Then acquire a new image dataset prescribing the slices as carefully as possible.

5.0 IMAGE INTENSITY UNIFORMITY

5.1 What It Is

The image intensity uniformity test measures the uniformity of the image intensity over a large water-only region of the phantom near the middle of the imaged volume which is typically near the center of the head coil.

Head coils tend to have fairly uniform spatial sensitivity near the center of the coil when loaded as typical for a human head. However, signal distribution varies with coil design. Phased array coils naturally produce brighter signal immediately adjacent to the smaller coil elements at the periphery and therefore require the application of intensity or uniformity correction to pass this test.

Since the ACR MRAP phantom is filled with a conductive solution, at field strengths of 3 Tesla and higher, the dielectric effect is prominent. This artifact occurs because, as B_0 increases, the radiofrequency wavelengths decrease until they approach the size of the phantom. Standing E-waves converging on the phantom from different directions can create a pattern of destructive interference and constructive interference in different regions of the phantom. Often this manifests as central brightening in high-conductivity phantoms. Because of dielectric effect, it is recommended that the phantom images are acquired with the same intensity non-uniformity correction method used for clinical images.

Failure of the uniformity test means that the scanner/coil combination has significantly greater variation in image intensity than is normal for a properly functioning system. Lack of image intensity uniformity may indicate the following: (1) that the intensity non-uniformity correction was not used; (2) a deficiency in the scanner; (3) a defective head coil; and/or (4) a problem in the radio-frequency subsystems.

5.2 What Measurements Are Made

For this test, the high and low signal levels within a large, uniform, water-only region of the phantom are measured for the ACR T1 and T2 series. The measurements are used to calculate Percent Integral Uniformity (PIU).

For each series, the measurements are made according to the following procedure:

1. Display slice location 7.
2. Place a large, circular region-of-interest (ROI) on the image as shown in **Figure 15.**
    - The area of the ROI depends on whether the large (200 cm^2) or medium (160 cm^2) phantom was scanned **(Table 4).**
    - This large ROI defines the boundary of the region in which the image uniformity is measured.

- Although the mean pixel intensity inside this ROI is not needed for the uniformity test, it is used in the percent signal ghosting test (section 6.0), so it should be noted.

3. Set the display window to its minimum, and lower the level until the entire area inside the large ROI is white.
   - The goal now is to raise the level slowly until a small, roughly 1 cm^2 region of dark pixels develops inside the ROI. This is the region of lowest signal in the large ROI.
   - Sometimes more than one region of dark pixels will appear. In that case, focus attention on the largest dark region.
   - In some cases, rather than having a well-defined dark region, one or more wide, poorly defined dark areas or areas of mixed black and white pixels are apparent.
   - In that case, make a visual estimate of the location of the darkest 1 cm^2 portion of the largest dark area should be made.

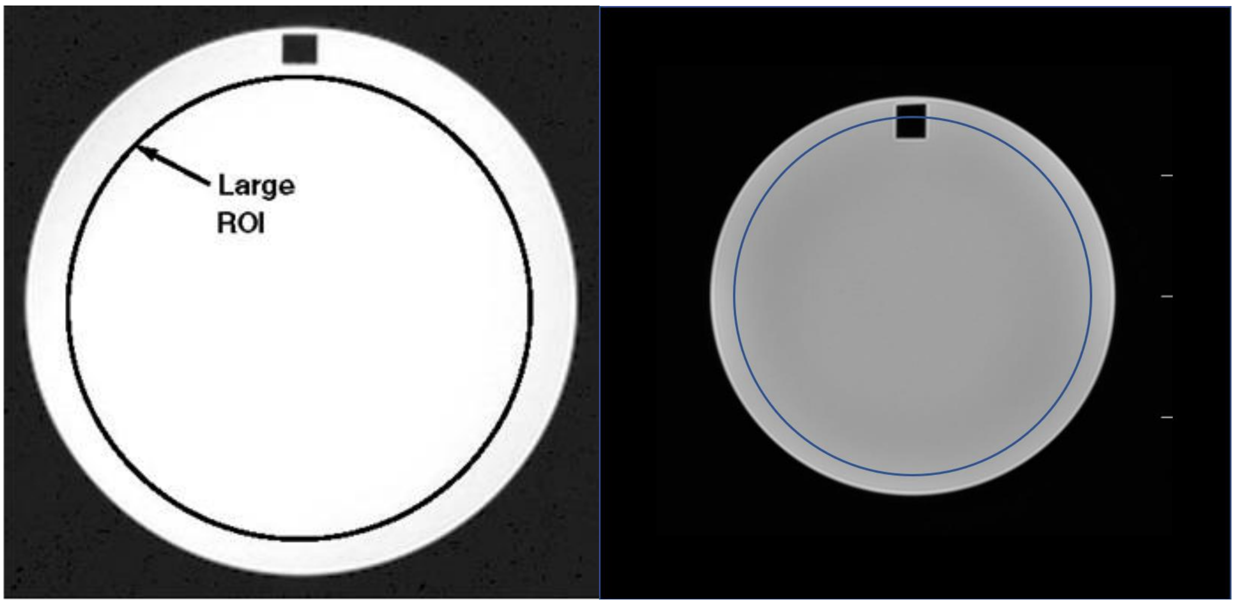
4. Place a 1 cm^2 circular ROI on the low-signal region identified in step 3.
   - If measuring in the Medium phantom be sure that this ROI does not include any of the notch at the top of the phantom.
   - **Figures 16a and 17a** show what typical Large and Medium phantom images look like at this point.
   - Record the mean pixel value for this 1 cm^2 ROI. This is the measured low-signal value.
   - If there is uncertainty about where to place the ROI because there is no single obviously darkest location, try several locations and select the one having the lowest mean pixel value.

5. Raise the level until all but a small, roughly 1 cm^2 region of white pixels remains inside the large ROI.
   - This is the region of highest signal.

Table 4: ROI sizes for PIU measurement. Passing PIU limits for both ACR T1 and ACR T2 series are listed by field strength.

Phantom	Large ROI (cm^2)	Small ROI (cm^2)	PIU Limit (%) < 3T	PIU Limit (%) 3T
Large	195-205 (200)	1.0	≥85	≥80

Medium	155-165 (160)	1.0	≥90	≥85



(a) (b)

Figure 15: Image of slice 7 illustrating size and placement of the large ROI that defines the outer boundary for image uniformity measurements. (a) 200 cm^2 ROI in the Large phantom and (b) 160 cm^2 ROI in the Medium phantom. Note that the large ROI when centered will include the notch at the top of the Medium phantom.

- Sometimes more than 1 region of white pixels will remain. In that case, focus attention on the largest white region.
- In some cases, rather than having a well-defined white region, there can be one or more diffuse areas of mixed black and white pixels. In that case, a best estimate of the location of the brightest 1 cm^2 portion of the largest bright area should be made.

6. Place a 1 cm^2 circular ROI on the high signal region identified in step 5.

- **Figures 16b and 17b** show what typical Large and Medium phantom images look like at this point.
- Record the average pixel value for this 1 cm^2 ROI. This is the measured high signal value.
- If there is uncertainty about where to place the ROI because there is no single obviously brightest location, try several locations and select the one having the highest mean pixel value.

NOTE: Some workstations have ROI tools that report the maximum and minimum pixel values within an ROI. It is tempting to use these as high and low signal values. However, these values should not be used to determine PIU. Due to the presence of noise in the image, using the maximum and minimum pixel values introduces systematic overestimation of the high signal and underestimation of the low signal. This systematic error can be significant, and biases the test toward failure.

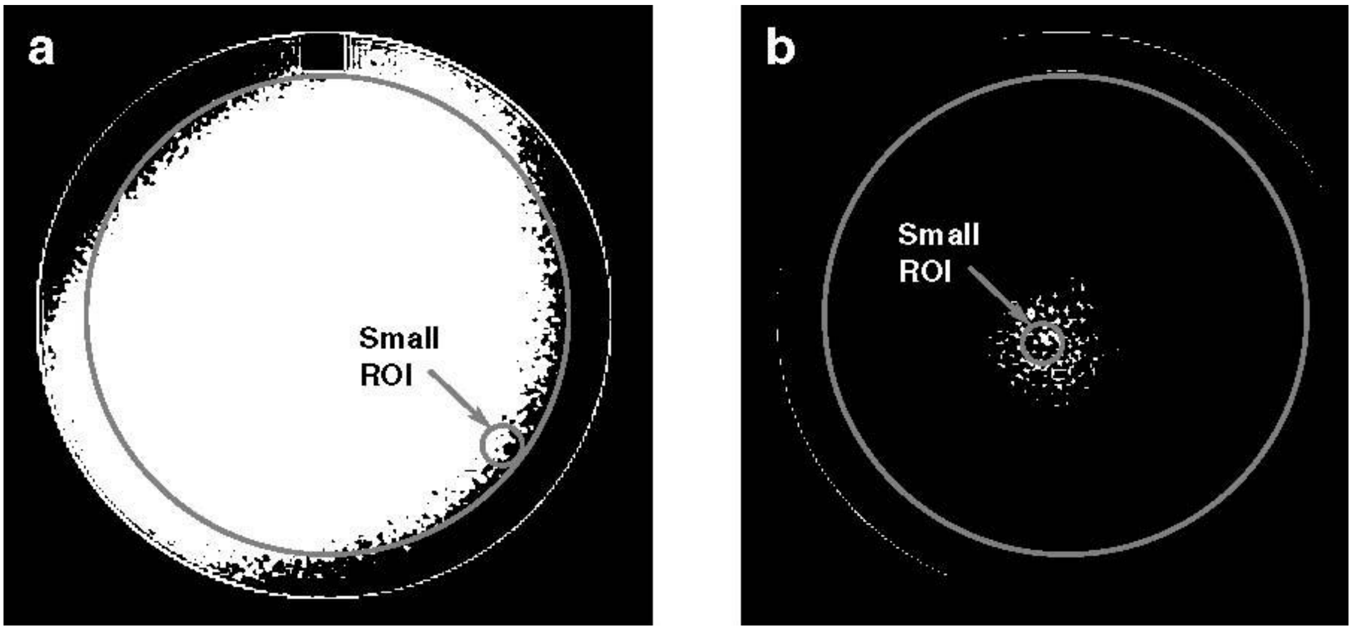


Figure 16: Image of slice 7 of the Large phantom showing windowing of the image and placement of small, 1 cm^2 ROIs for (a) low and (b) high signal measurements.

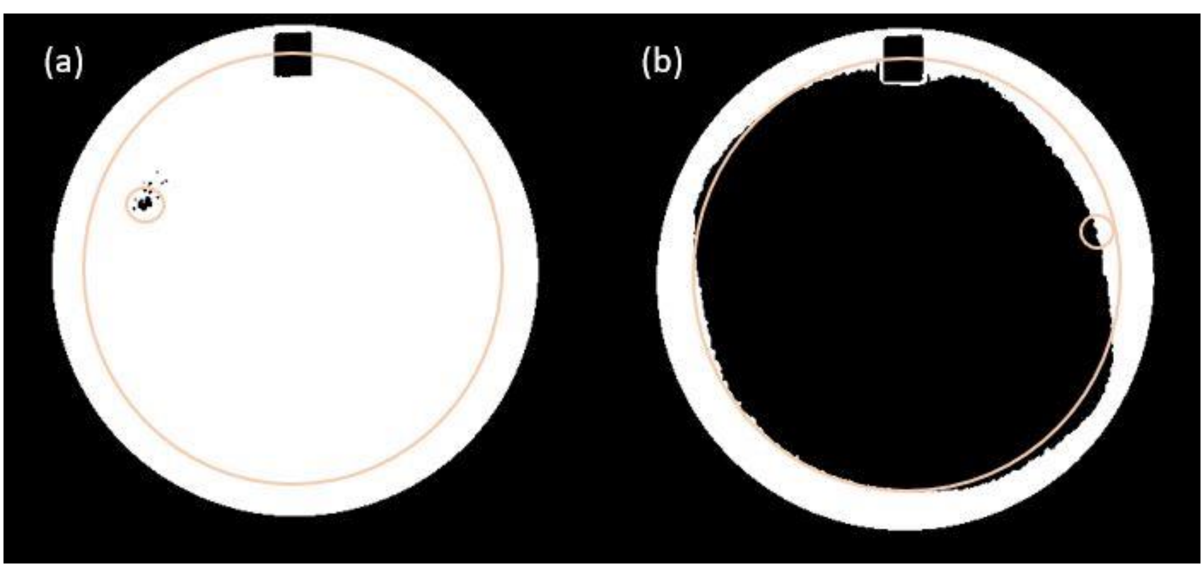


Figure 17: Image of slice 7 of the Medium phantom showing windowing of the image and placement of small, 1 cm^2 ROIs for (a) low and (b) high signal measurements. Placement of the small ROIs must avoid the notch.

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5.3 How the Measurements Are Analyzed

The measured high and low signal values for each of the ACR series are used to calculate PIU using the following formula:

$$PIU = 100 \times (1 - \{(high - low)/(high + low)\})$$

where "high" and "low" are the measured high and low signal values measured in the small ROIs as described above.

5.4 Pass/Fail Criteria

The PIU pass/fail limits for the Large and Medium phantoms are given in **Table 4**.

For images acquired using the large phantom on MRI systems with field strengths less than 3 Tesla, PIU should be greater than or equal to 87.5% and will fail if less than 85%. Large phantom PIU for 3T systems should be greater than or equal to 82% and will fail if PIU is less than 80%.

PIU limits for the Medium phantom are higher since uniformity is measured over a smaller region. For images acquired using the Medium phantom on MRI systems with field strengths less than 3 Tesla, Medium phantom PIU must be greater than or equal to 90%. Medium phantom PIU for 3T systems must be greater than or equal to 85%.

For images acquired using phased array coils and for images acquired on 3T systems, ensure that the vendor's intensity non-uniformity correction method has been applied.

5.5 Causes of Failure and Corrective Actions

When scanning the phantom, it is important to position it as close to the center of the head coil as possible. If the phantom is closer to one side of the head coil than another, uneven image intensities could potentially cause a failure of this test. This problem occurs most often with poor centering in the anterior-posterior (AP) direction. It may be necessary to remove some of the normal patient head support or add some cushioning, or both, to get the phantom centered AP. Poor centering may be evident in the images. Another indicator that centering may be a problem is the appearance of bright spots in the image where the phantom is too close to the coil's conducting elements. If the scanner seems to be working well, and producing ghost-free head images with typical levels of signal-to-noise (SNR) ratio, poor phantom-centering may be the cause of PIU failure.

Phased array head coils naturally produce images that are less uniform due to the smaller coil elements, as compared to quadrature coils. Be sure to apply the vendor's intensity correction to the ACR T1 and T2 series if they were acquired using a multi-channel phased array coil. The correction goes by different names depending on vendor (SCIC, PURE, CLEAR, Normalize, Pre-scan normalize, and B1 Filter are some examples).

Phased array coils can be scanned in different coil modes or configurations where some or all of the coil elements are activated. The coil configuration can have a significant impact on image uniformity. If uniformity fails, verify that the appropriate coil configuration was active during the scan.

Image ghosting can cause image intensity variations that also result in PIU failure. Ghosting sufficient to cause failure will be readily apparent in the image, and likely will also result in failure of the percent-signal ghosting test (section 6.0).

Degraded image intensity uniformity can result from failure of components in the head coil, and from failure of the mechanisms for inductive decoupling of the body coil from the head coil. In these cases, the images' SNR usually becomes noticeably lower, i.e., they usually appear grainier. A service engineer is required to diagnose and correct these problems.

6.0 PERCENT-SIGNAL GHOSTING

6.1 What It Is

The percent-signal ghosting test assesses the level of ghosting in the ACR T1 images. Ghosting is an artifact which presents faint copies (ghosts) of the imaged object superimposed on the image, and displaced from the true location. If there are many low-level ghosts they may not be recognizable as copies of the object but simply appear as a smear of signal emanating in the phase encode direction from the brighter regions of the true image. Ghosting is a consequence of signal instability between pulse cycle repetitions. For this test the ghost signal level is measured and reported as a percentage of the signal level in the true (primary) image.

Ghosting is most noticeable in the background areas of an image where there should be no signal, but ghosting overlays the main portions of the image as well, altering the true image intensities. A failure of this test means that there are ghosting artifacts at a level significantly higher than that observed in a properly functioning scanner.

6.2 What Measurements Are Made

For this test, measurements are made on slice 7 of the ACR T1 series. Using the workstation's ROI tool, five intensity measurements are made: the average intensity in the primary image of the phantom, and the average intensity in the background at four locations outside of the phantom. The ROIs are placed as shown in **Figure 18.**

For the sequences used for ACR phantom imaging, ghosting always occurs in the phase encoding direction. Since the background ROIs are placed along the four edges of the FOV, two will be in the phase encoding direction and sample the ghosting signal, and two will be free of ghosting signal. The two ghost-free background ROIs serve as a control on the mean background intensity, which can be affected by several factors, most notably noise.

The procedure for making these measurements is:

1. Display slice 7 of the ACR T1 series.
2. Place a large, circular ROI on the image as shown in **Figures 16 and 17**.

- The size of the large ROI will depend on whether the Large or Medium phantom was imaged **(Table 4).**
- For both phantoms, the ROI should be approximately centered on the phantom.
- For the Medium phantom, the ROI will include the notch at the top of the phantom, as described in section 5.

3. Record the mean pixel value for this ROI.
4. If the workstation cannot produce a circular ROI, a square ROI of approximately the same size may be used.

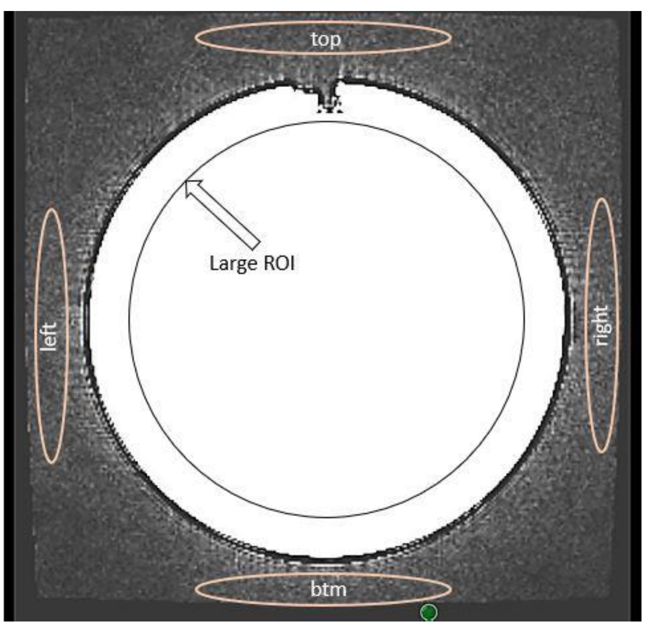

Figure 18: Image of slice 7 in the Large phantom illustrating ROI placement for percent signal ghosting measurement.

5. Adjust window and level settings to brighten the background of the image so that the edges of the image space are visible. Image space may be warped due to gradient nonlinearity corrections.
   - Place elliptical or rectangular ROIs so that they are fully within the background noise, as shown in **Figure 19**.
   - For both phantoms, the ROIs should have a length-to-width ratio of about 4:1, and a total area of about 10 cm^2 (1000 mm^2).

- We will refer to these ROIs as they are labeled in **Figure 19**: top, bottom, left, and right.

6. Record the mean pixel value for each ROI, keeping track of which value goes with which ROI.
    - It is important not to place the background ROIs against the edges of the phantom or against the edges of the FOV, but centered between the edges of the phantom and FOV. If the phantom is off center in the FOV, it may be necessary to reduce the width of some of the ROIs in order to fit them between the phantom and the edge of the FOV.
    - Reduce the ROI width as necessary to fit, and increase the length to maintain an approximately 10 cm^2 area; the top and right ROIs in **Figure 17** are examples of this.
    - If the workstation cannot produce an elliptical ROI, a rectangular ROI of approximately the same size may be used.

6.3 How the Measurements Are Analyzed

Ghosting ratio, as a fraction of the primary signal, is calculated using the following formula:

$$\text{ghosting ratio} = \left| ((\text{top} + \text{btm}) - (\text{left} + \text{right}))/(2 \times (\text{large ROI})) \right|$$

where top, bottom, left, right, and large ROI are the average pixel values for the ROIs of the same names. The vertical bars indicate absolute value. Percent signal ghosting is the ghosting ratio expressed as a percentage. To calculate PSG, multiply ghosting ratio by 100%.

6.4 Pass/Fail Criteria

For both phantoms, images submitted for accreditation will fail if the ratio exceeds 0.030 (3.0%). However, this limit is very generous and only applies to ghosting measured on ACR T1 slice 7. If ghosting is very visible on either the ACR T1 or T2 series, those images could still fail the artifacts test. See the Artifacts Assessment section for more information.

6.5 Causes of Failure and Corrective Actions

Ghosting can be caused by motion or vibration of the phantom during the acquisition. Make sure the phantom is securely positioned in the head coil and not free to move.

Ghosting is a nonspecific symptom of a potential hardware problem. In general, it is caused by instabilities of the measured signal from pulse cycle to pulse cycle, which can have its origin in the receiver, transmitter, or gradient subsystems. Having ruled out phantom motion, it will usually be necessary to ask the service engineer to track down and correct the cause of ghosting.

7.0 LOW-CONTRAST OBJECT DETECTABILITY

7.1 What It Is

The low-contrast object detectability (LCD) test assesses the extent to which objects of low contrast are discernible in the images. For this purpose, the phantom has four sections with low contrast objects of varying size and contrast.

The ability to detect low contrast objects is primarily determined by SNR and the contrast-to-noise ratio (CNR) achieved in the image, and may be degraded by the presence of artifacts such as ghosting.

CNR performance is strongly influenced by field strength. Clinical protocols are typically adjusted to take this into account. Therefore, if the ACR T1 and T2 series fail low-contrast object detectability, the test is applied to the site series. Most scanners can pass the test on the ACR series, but it is sufficient for a scanner to pass on both site series.

A failure of this test means the images produced by the scanner show significantly fewer low-contrast objects than most properly functioning clinical scanners. Generally, a failure indicates low SNR. But sometimes artifacts, such as ghosting, can contribute.

7.2 What Measurements Are Made

LCD measurements are made for the ACR T1 and T2 series. The low contrast objects are present in four sections of the phantom: slices 8 through 11. In each slice the low-contrast objects appear as rows of small disks, with the rows radiating from the center of a circle like spokes in a wheel. Each spoke is made up of three disks, and there are 10 spokes in each slice. **Figure 19** shows slice 11 of the Large phantom with 10 visible spokes.

All the disks on a given slice have the same level of contrast. In order, from slice 8 to slice 11, the contrast values are 1.4%, 2.5%, 3.6%, and 5.1%. All the disks in a given spoke have the same diameter. Starting at the 12 o'clock position and moving clockwise, the disk diameter decreases progressively from 7.0 mm at the first spoke to 1.5 mm at the tenth spoke.

The low contrast disks are actually holes drilled in thin sheets of plastic mounted in the phantom at the locations of the four slices. Since the contrast is derived from the displacement of solution from the slices by the plastic sheets, the contrast is independent of pulse sequence, TR, flip angle, and field strength.

The measurements for this test consist of counting the number of complete spokes visible in each of the four LCD sections in the ACR T1 and T2 series.

Use the following procedure to score the number of complete spokes visible in a slice:

1. Display slice 11, which has the highest contrast objects. Adjust the display window width and level settings for best visibility of the low contrast objects. This will usually require a fairly narrow window width and careful adjustment of the level to best distinguish the objects from the background.

2. Count the number of complete spokes. Begin counting with the spoke having the largest diameter disks; this spoke is at 12 o'clock or slightly to the right of 12 o'clock, and is referred to as spoke 1. Count clockwise from spoke 1 until a spoke is reached where one or more of the disks is not discernible from the background. A spoke is complete only if all three disks are discernible. Count complete spokes, not individual disks.
3. The score for this slice is the number of complete spokes. Record the score.
4. Repeat the procedure to determine the number of visible spokes for the remaining LCD images.

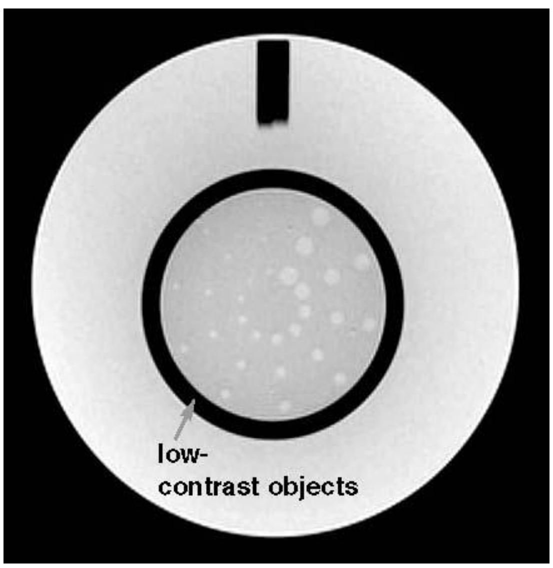

Figure 19: Image of slice 11 of the Large phantom showing ten spokes of low-contrast objects.

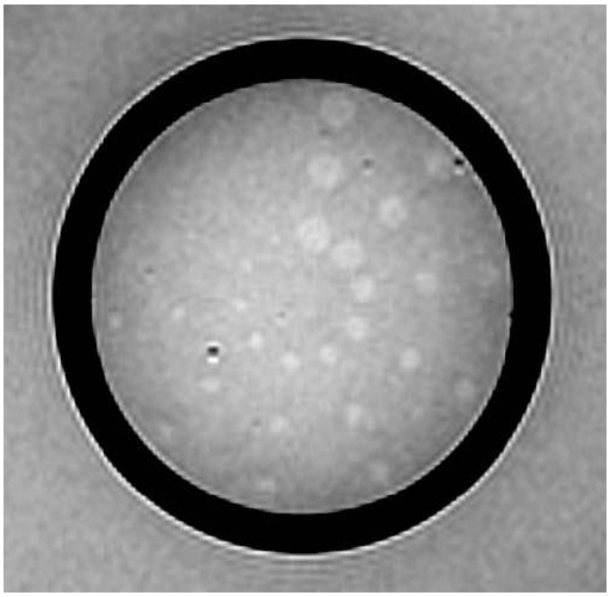

Figure 20: Image of slice 8, magnified and cropped, showing the circle of low-contrast objects. This image would be scored as showing 9 spokes.

As an example, **Figure 20** shows an image of slice 8 on which less than all 10 spokes are visible. The score for this image is 9 complete spokes.

Sometimes there will be a complete spoke of smaller size following a spoke that is not complete. Do not count it. Stop counting at the first incomplete spoke.

Disks on the threshold of discernibility can present a difficult scoring decision. Disks do not need to be perfectly circular in order to count. It is acceptable if they appear ragged or misshapen. The question is whether or not there is some sort of smudge or spot at the known location of the disk which is different enough from the background that one can say with a reasonable degree of confidence that there is something really there. In making this decision it can be helpful to look at areas where there are no disks in order to gauge the fluctuations in intensity from noise and artifacts that might mimic a barely discernible disk. A disk that looks no different than the brighter background noise fluctuations would not be counted as visible.

Most scanners meet or exceed the minimum passing score given in the action criteria section below. In most cases it isn't necessary to spend time pondering difficult decisions on barely visible disks; just score the test conservatively and revisit the scoring if the final score is below the passing limit.

If the ACR T1 or ACR T2 series fail this test, score the LCD sections of the Site T1 and Site T2 series. The LCD test can pass if both the Site T1 and Site T2 series pass.

7.3 How the Measurements Are Analyzed

For each series, record the number of complete spokes visible on each slice, then sum the values for all four slices to determine the total LCD score. For example, if the ACR T2 series scored 3 spokes in slice 8, 5 spokes in slice 9, 9 spokes in slice 10, and 10 spokes in slice 11; the total score for the ACR T2 series would be 3 + 5 + 9 + 10 = 27.

7.4 Pass/Fail Criteria

Table 5: Passing criteria for the low contrast detectability test by field strength. Limits apply to both the Large and Medium phantoms.

Nominal Field Strength	ACR T1 LCD Limit (total spokes)	ACR T2 LCD Limit (total spokes)
<1.5T	≥7	≥7
1.5T - <3T	≥30	≥25
3T	≥37	≥37

For scanners with field strength of less than 1.5T, both ACR series should have a total score of 9 spokes, but must have at least 7 to pass. If either ACR series fails this test, then evaluate the site series. If the LCD score for both site series is at least 7, then the scanner passes this test.

Beginning mid-2021 the LCD limits for 1.5T - <3T scanners were raised. The ACR T1 axial series must have a total LCD score of at least 30 to pass and the ACR T2 series must score at least 25 to pass If either ACR series fails, the site can pass if the site T1 series total LCD score is at least 30 and the site T2 score is at least 25.

For 3T scanners, both ACR axial series must have a total score of 37 spokes to pass. If the score for either ACR series fails, then evaluate the site series. If the score for both site series is at least 37, then the scanner passes this test.

A scanner must pass on both the ACR T1 and T2 series, or on both the site T1 and T2 series. A scanner cannot pass on just one of the ACR series and one of the site series.

7.5 Causes of Failure and Corrective Actions

The most frequent cause of failure is incorrectly positioned slices. In order to maximize contrast slices 8 through 11 must be aligned closely with the LCD sections, which consist of thin plastic sheets. If a slice is mispositioned by more than 2 mm there will be substantial reduction in the contrast of the low-contrast objects in that slice. The easiest way to check if this is a problem is to look at slice 11. Recall from section 4.0

(Slice Position Accuracy) that the bar length difference of the crossed 45° wedges on slice 11 is twice the slice position error. Verify that the slice 11 bar length difference is less than 4.0 mm. If it is not, reacquire the images after adjusting the slice prescription as needed to bring the crossed-wedge bar length difference in slice 11 to less than 4.0 mm.

Failure of this test can also be caused by phantom mispositioning. Tilting of the phantom shifts a portion of the slices out of their proper locations leading to the same sort of problem as described for incorrectly positioned slices. In this regard, rotation of the phantom in the axial plane is not a problem, but tilt in the sagittal plane or rotation in the coronal plane can be. Tilt in the sagittal plane will be readily apparent on the sagittal localizer. If the phantom doesn't look square relative to the edges of the FOV on the localizer, it should be repositioned before re-acquiring data. A non-ferromagnetic level can be used to verify that the phantom is not tilted. Rotation in the coronal plane can be viewed on a 3-plane localizer and it may be detected as right-to-left fade of structures across an axial slice. The best way to avoid this is to carefully align the phantom squarely in the head coil. Use of a 3-plane localizer is useful prior to acquiring the required sagittal and axial series in order to verify correct phantom positioning in all three planes. The alignment lights may be helpful for positioning, if they are accurately aligned.

Ghosting artifacts can affect the ability to see low-contrast objects and cause failure. Make sure the phantom is stable and can't move or vibrate during image acquisition. If ghosting is still a problem, then the service engineer should be asked to find and correct the cause. On some scanners, a small but noticeable amount of ghosting is normal on conventional T2 spin-echo acquisitions and fast spin-echo acquisitions. If in doubt whether the level of ghosting is normal, ask the service engineer to perform the manufacturer's diagnostic tests that relate to signal stability and ghosting.

If the images are free of ghosts, and the slices are positioned accurately, then a failure of this test is most likely due to inadequate SNR. Low SNR can be caused by a faulty coil, poor coil connections or inactive phased array coil elements. Verify that the appropriate coil elements were active during the scan. Since SNR is also affected by the receive bandwidth, verify that an appropriate bandwidth was used. The service engineer can also perform testing to determine if the scanner and coil SNR performance are within manufacturer specifications.

8.0 ARTIFACT ASSESSMENT

Artifacts that could have an adverse effect on diagnostic accuracy, and artifacts suggestive of system problems may result in a failure for accreditation even though the system passes the quantitative tests. Phantom image reviewers will assess the submitted ACR Sagittal, ACR T1 and ACR T2 phantom images for the presence of artifacts and record which artifacts are observed and if they are considered to be unacceptable. If it is necessary for the reviewer to evaluate the Site series, the reviewer may comment on artifacts observed in those series, particularly if they indicate a potential system issue.

Some artifacts are common in MR images or common with certain MR manufacturers and considered to be acceptable. For example, Gibbs ringing (truncation artifacts) (if not severe), mild ghosting, or DC offset. Other artifacts indicate a MR system or scanner environment issue that needs to be resolved, such as spike noise or RF interference. Severe artifacts may be marked as excessive and unacceptable by the reviewers and result in an overall a failure even if all other measurements pass.

9.0 RECOMMENDATIONS

Make sure the service engineer has a few weeks of warning to check the system and make everything right before acquiring images for accreditation. Many sites schedule quarterly preventive maintenance testing before accreditation tests are performed.

Position the phantom as close to the center of the head coil as possible. This may not be where the patient head normally rests. Line up the center mark etched on the phantom with the center of the coil along the inferior-superior direction. Also make sure the phantom is centered in the coil right-left and anterior-posterior.

Use blank paper (without toner, which can cause susceptibility artifacts) or clean cushioning as necessary to stabilize the phantom against motion to avoid ghosting artifacts.

As explained in section 7.5, it is important to make sure that slices 8 through 11 align as closely as possible to the LCD sections of the phantom, and that the phantom be aligned with the three principal axes, i.e., not tilted or rotated. A 3-plane localizer can be very useful to determine if the phantom is correctly positioned before beginning acquisition of the required images.

If acquiring a double echo sequence for the ACR T2 series, be sure to evaluate the second echo images with TE of 80 msec (or similar). Depending on how the second echo images are grouped and numbered in a double echo series, it is easy to mistakenly make the measurements on the first echo images.

A small bubble of a few cubic centimeters may be present in the phantom. Avoid shaking the phantom as it causes the bubble to break up into smaller bubbles which may adhere to structures within the phantom where they may interfere with making the measurements. If the bubble is large enough to interfere with geometric accuracy measurements in the A/P direction on slice locations 1 and 5 as described in section 1.2, please follow the phantom manufacturer's instructions for refilling the phantom prior to acquiring images for accreditation. Note that it is not acceptable to cool the phantom before scanning to improve SNR.

The ACR strongly recommends performing the measurements described in this document prior to uploading to Acredit. After uploading, verify that all five required ACR and Site series uploaded completely and that the images are not in Lossy Compressed format. Lossless or uncompressed DICOM format is required. Please only submit the required series. Instructions for image submission are provided in the *Accreditation Testing* section of Complete Accreditation Information: MRI