Department of Electronics and
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BM 3121

Medical Imaging

MRI Quality Assurance

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1 Introduction to MRI

1.1 Basics of MRI

Magnetic Resonance Imaging is a non-ionizing imaging modality which is capable of three dimensional scanning at a higher resolution compared with Computed tomography. MRI signal is generated from the protons in water and lipid molecules in the body. Protons in powerful magnetic field resonates when an electromagnetic wave is introduced. This behaviour is used for MRI. Since MRI uses superconductors at 0K, the cost of MRI is too high and maintenance is a big responsibility. MRIs take more time than X-ray imaging. Thus the patient should be hold stationary throughout the scanning.

Figure 1: MRI machine

MRI technology was introduced in 1971. At the beginning it was known as Nuclear Magnetic Resonance Imaging (NMRI). But people were afraid to do imaging using this technology due to the misconceptions they had on the word nuclear. Then the "N" for nuclear was lopped off. So far MRI technology has developed a lot. In the beginning permanent magnets were used. Due to lack of magnetic field they were replaced by electromagnets.But due to their high power consumption superconductors were introduced to the MRI technology. To maintain superconductivity it is necessary to keep the temperature close to $0K$. Therefore the cooling system runs nonstop. When comparing with other imaging modalities this consumes more power but not more than the MRI which used non-superconductor electromagnets.

MRI is used in wide range of body scanning such as brain, cranium, heart, liver, pancreas, lungs, kidneys, abdomen and pelvic cavity. MRI is used in several imaging methods such as Neuroimaging, Cardiovascular imaging, Oncology, Functional MRI, Musculoskeletal imaging and Gastrointestinal Imaging.

Figure 2: MRI image of the head - Saggital plane

1.2 Importance of MRI

MRI is a popular imaging modality due to following reasons.

1. Ionizing radiation is not used
   X-ray, CT, PET modalities of imaging use ionizing radiation which is harmful for the organs. But in MRI ionizing radiation is not used. Therefore it is not harmful for the organs.

2. High soft tissue contrast
   Most of other imaging modalities do not possess this much soft tissue contrast. But due to different relaxation times of the different kind of soft tissues MRI can detect, and contrast between different soft tissues.

3. High spatial resolution
   In MRI spatial resolution can be around 1mm. By decreasing the the width of the slices, spatial resolution can be improved even more. But time used for the test gets increased.

4. Images can be 2D or 3D
   3D image can be taken on any part of the body from the MRI machine, but the slices(2D) has much high resolution.

5. Negligible penetration effects
   CT or X-ray uses a radiation source and passes the radiation through the body. But in MRI the relaxation generates EM radiation originated from the protons. Therefore the penetration effects are negligible.

6. Contrasts agents used are not harmful for the body
   Contrast agents used in X-ray or CT affects the body. But the the contrast agents used in MRI do not have such effect.

But there are several disadvantages also.

1. MRI systems are very expensive. Maintenance is a big responsibility.
2. People with metal implants can not use MRI for imaging.
3. MRI scans take a longer time for the image acquisition. Patients have to stay in the MRI machine for 30-40 minutes. People with Claustrophobia can not resist such a situation.
4. MRI systems are extremely complex and any small fault would cost millions of rupees.

1.3 Components and Implementation of MRI

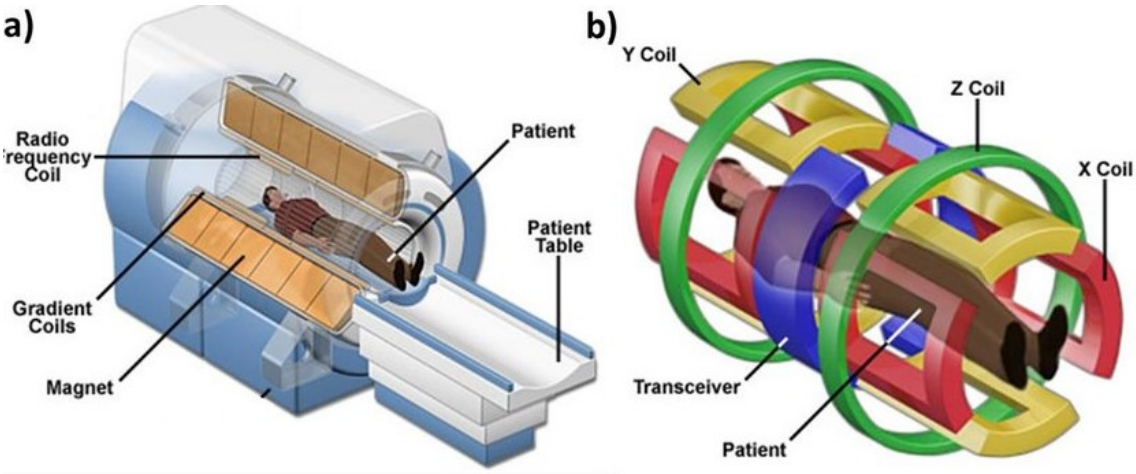

Figure 3: Main components of MRI system

Patient is entered through a hole in the machine. Around the patient there are several layers of different components.

Components of the MRI,

1. Powerful superconductor magnet - 1.5T / 3T / 6T
2. Gradient coils
3. Radio Frequency coils
4. Patient table
5. Shield
6. Computer system

2 Quality Assurance of MRI

The quality of the MRI system is very important in providing a better health service. The medical diagnosis based on magnetic resonance imaging depends on the fact that the image is sufficiently suitable to extract required information. Therefore quality assurance must be guaranteed. Otherwise diagnosis will be failed. The MRI system consists of many units as mentioned in above topic. Quality assurance of each part or section assures the quality of overall system.

Furthermore, due to powerful magnetic properties, it is necessary to implement rules and regulation when implementing a MRI system and when using the MRI system. As an example; no one can enter the MRI room with any metallic equipment. If those rules are not implemented, there can be severe damages to the people in the room even death. Furthermore there can be damages to the system which definitely cost lots of money to recover. Therefore to assure the quality those rules and regulations are important.

To assess the quality of MRI systems under the discussed aspects several parameters have been defined and agreed upon by the medical community internationally, regionally or institutionally. Regular tests should be done daily, weekly, monthly, quarterly or annually according to the requirement to identify and correct problems with MRI systems.

The quality assurance of MRI is responsibility of following people - Quality Assurance Committee.

1. Radiologists
2. MRI Technologists
3. Medical Physicists/MRI Scientists

This team should ensure that,

i. Every imaging procedure is necessary and appropriate to the clinical problem at hand

ii. The images generated contain information critical to the solution of the problem

iii. The recorded information is correctly interpreted and made available in a timely fashion to the patient's physician

iv. The examination results in the lowest possible risk, cost, and inconvenience to the patient consistent with objectives above

2.1 Radiologists' main responsibilities

i. Ensure that technologists have adequate training and continuing education in MRI.

ii. Provide an orientation program for technologists based on a carefully established procedures manual (see Section E).

iii. Ensure that an effective QC program exists for all MR imaging performed at the site. The supervising radiologist should provide motivation, oversight, and direction to all aspects of the QC program.

iv. Select the technologist to be the primary QC technologist, performing the prescribed QC tests.

v. Ensure that appropriate test equipment and materials are available to perform the technologist's QC tests.

vi. Arrange staffing and scheduling so that adequate time is available to carry out the QC tests and to record and interpret the results.

vii. Provide frequent and consistent positive and negative feedback to technologists about clinical image quality and QC procedures.

viii. Participate in the selection of a qualified medical physicist or MRI scientist who will administer the QC program and perform the physicist's tests.

ix. Review the technologist's test results at least every three months, or more frequently if consistency has not yet been achieved.

x. Review the results of the qualified medical physicist or MRI scientist annually, or more frequently when needed.

xi. Oversee or designate a qualified individual to oversee the MRI safety program for employees, patients, and other individuals in the surrounding area.

xii. Ensure that records concerning employee qualifications, MRI protocols, and procedures, QC, safety, and protection are properly maintained and updated in the MRI QA Procedures Manual

2.2 MRI technologists' main responsibilities

The MRI QC technologist's responsibilities revolve around image quality. More specifically, the functions performed by the technologist that affect image quality are patient positioning, image production, image archiving, and film processing.

Following figure shows the quality assurance methods followed by MRI technologists and the frequency they are executed.

Procedure	Minimum Frequency	Approx. Time (min)
Setup	Weekly	7*
Table Position Accuracy	Weekly	3
Center Frequency/Transmitter Gain or Attenuation	Weekly	1
Geometric Accuracy Measurements	Weekly	2*
High-Contrast Spatial Resolution	Weekly	1
Low-Contrast Detectability	Weekly	2
Artifact Evaluation	Weekly	1
Film Printer Quality Control (if applicable)	Weekly	10
Visual Checklist	Weekly	5

*Some measurement can be performed simultaneously.

Figure 4: Minimum Frequencies of Performing Technologist's QC Tests

2.3 Medical Physicists/MRI Scientists' main responsibilities

The responsibilities of the qualified medical physicist or MRI scientist relate to equipment performance, including image quality and patient safety.

Following figure shows the the quality assurance methods to be followed by MRI scientists.

	Performance Tests (Those in italics indicate tests that can be performed by scanning the ACR MRI Phantom)	Technologist QC (Weekly)	Medical Physicist/ MR Scientist (Annually)
1	Setup and Table Position Accuracy	X	X
2	Center Frequency	X	X
3	Transmitter Gain or Attenuation	X	X
4	*Geometric Accuracy Measurements*	X	X
5	*High-Contrast Spatial Resolution*	X	X
6	*Low-Contrast Detectability*	X	X
7	Artifact Evaluation	X	X
8	Film Printer Quality Control (if applicable)	X	X
9	Visual Checklist	X	X
10	Magnetic Field Homogeneity		X
11	*Slice-Position Accuracy*		X
12	*Slice-Thickness Accuracy*		X
13	Radiofrequency Coil Checks		X
	a. SNR		X
	b. Percent Image Uniformity (PIU)		X
	c. Percent Signal Ghosting (PSG)		X
14	Soft-Copy (Monitor) Quality Control		X
15	MR Safety Program Assessment		X

Figure 5: Specific Required Tests Required for Annual MRI System

3 Main Quality Assurance Methods of MRI

3.1 Visual Checklist

This is the basic method to find flaws in the system and it should be done in every week. Following list of equipment is inspected visually to find any missing part or any malfunction. This verifies whether the MRI system working properly electrically and mechanically.

1. Patient Transport and Gantry
   (a) Table position and other displays
   (b) Alignment lights
   (c) Horizontal smoothness of motion and stability
   (d) Vertical motion smoothness and stability
2. Filming Viewing
   (a) Laser camera
   (b) Light boxes
3. RF Integrity and Control Room
   (a) RF door contacts
   (b) RF window-screen integrity
   (c) Operator console switches/lights/meters
   (d) Patient monitor and intercom
   (e) Room temperature and humidity
4. Facility Safety
   (a) Emergency cart
   (b) Safety warning signage
   (c) Door indicator switch
   (d) Cryogen level indicator

If any of this fails, it should be repaired or replaced as soon as possible even before carrying out other quality assurance protocols.

MRI Accreditation Program Visual Checklist

MRI Facility Name: MRI Scanner Identifier:

	Date:
Patient Transport and Gantry	Table position and other displays
	Alignment lights
	Horizontal smoothness of motion and stability
	Vertical motion smoothness and stability
Filming Viewing	Laser camera
	Light boxes
RF Integrity and Control Room	RF door contacts
	RF window-screen integrity
	Operator console switches/lights/meters
	Patient monitor (if present)
	Patient intercom
	Room temperature/room humidity
Facility Safety	Emergency cart
	Safety warning signage
	Door indicator switch (if installed)
	Cryogen level indicator
	Pass = ☑ Fail =F Does Not Apply = NA
	Technologist Initials:

Reviewed by: ______________________ Date of Review: ______________

Qualified Medical Physicist/MRI Scientist

MR Weekly QC Forms_6-12-15 (2)

Figure 6: Visual checklist for MRI

3.2 Setup and Table Position Accuracy Test

Setup and Table Position Accuracy is a method used to determine that the MRI machine performs patient setup, data entry and prescan tasks properly. And this should be done once a week. For this QA test a MRI phantom is used. Method of using the phantom is shown in the following figure. If the positioning laser is calibrated properly and the table is positioned properly this test is passed.

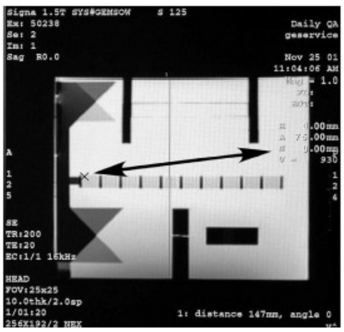

Figure 7: An example taken from a scanner where a square ROI has been placed with its center on the anterior/superior edge of the grid

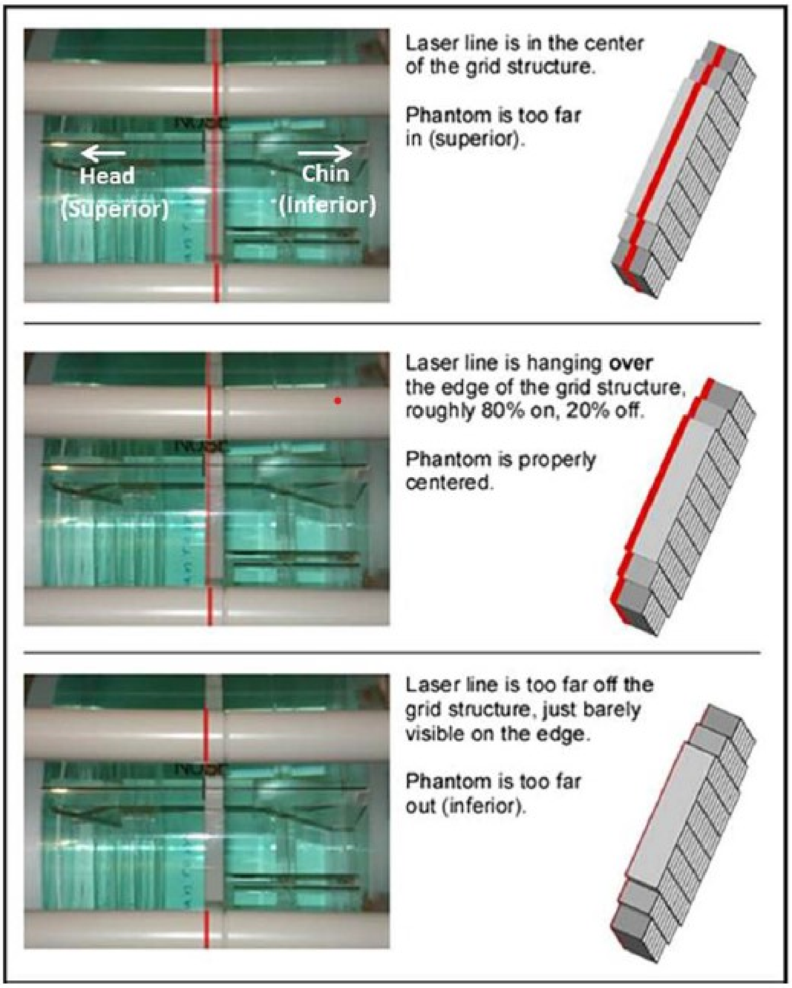

Figure 8: Illustration of the use of the central grid structure for alignment of the large phantom

3.3 Center Frequency Test

The resonance frequency is the RF frequency that matches with the magnetic field intensity B(Tesla)

$$f = \frac{\gamma}{2\pi} \times B$$

MRI system manufacturers provides specific automated protocols for resonance frequency adjustments. Using the phantom at the center of the magnetic field RF frequency us adjusted. Working the system off the frequency reduces the SNR value and the quality of the image. A MRI phantom is used for this test. This test has to be done weekly. If the recorded center frequency value does not match with value established by the qualified medical physicist or MRI scientist, the test should be repeated. If the test proved to be correct by the second test, re correction need to be done for the RF frequency before other QA protocols are executed.

3.4 Transmitter Gain or Attenuation Test

Transmitter Gain or Attenuation Test is protocol followed once a week. If there are any fluctuations in transmitter Gain or Attenuation there are problems associated with the RF chain. This test is done after tuning the resonance frequency and it acquires several signal while varying the transmitter gain. If the changes measured in Transmitter attenuation or gain exceeds the limits MRI system should be subjected to repair. This is very important since transmitter gain is directly related to SNR value.

3.5 Geometric Accuracy Measurement Test

Geometric Accuracy Measurement test is carried out with a MRI accreditation phantom and frequency of the test is once in a week. Objective of this test is to verify that the image taken from the system(outcome) has the similar dimensions with the body part.

$$GD\% = \frac{true_dimension - observed_dimension}{true_dimension} \times 100$$

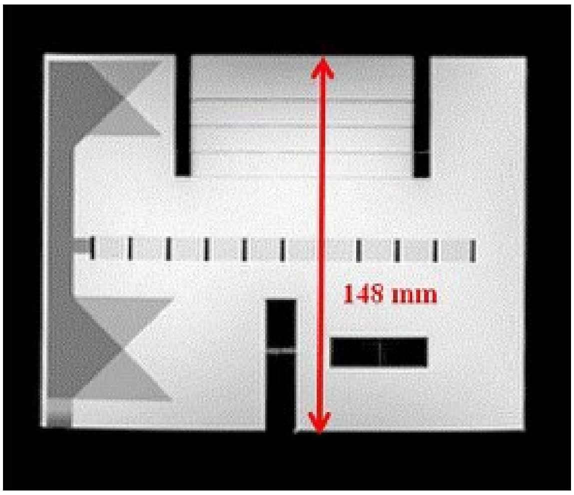

Figure 9: Positioning of length measurement on ACR MR accreditation phantom.

If the MRI is not properly calibrated or the faults in the gradient scaling factors which may produce a non homogeneous magnetic field, this test might not pass. If the test is failed it is better find out which of the above problem caused it.

3.6 High-Contrast Spatial Resolution Test

High-contrast Spatial Resolution Test; also known as "Limiting spatial resolution" measures the ability of MRI system to resolve small objects. When the scanner has the ability to resolve small details of a object it has a good spatial resolution. This test is also done by a MRI accreditation phantom.

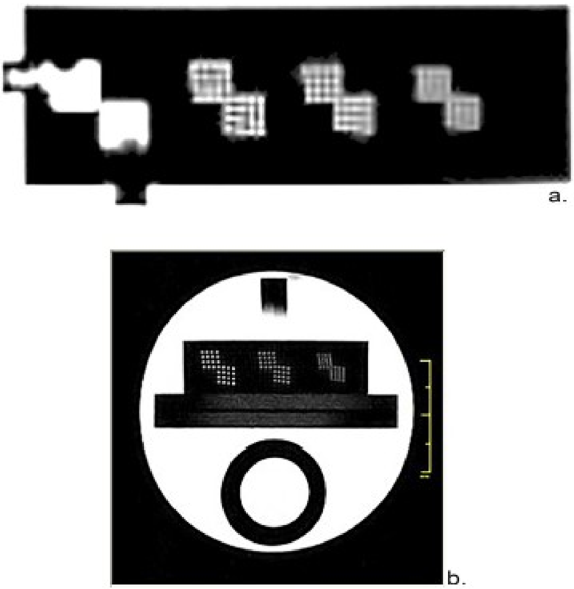

Figure 10: a) Large phantom high-contrast resolution insert from slice 1 of an axial series shows three sets of two arrays of holes. Hole sizes and spacing: from left, 1.1 mm, 1.0 mm, and 0.9 mm. b) Small phantom high-contrast resolution insert from slice 1. Hole sizes and spacing: from left, 0.9 mm, 0.8 mm, and 0.7 mm.

3.7 Low-Contrast Detectability Test

The low-contrast detectability (LCD) test measures the extent to which objects of low contrast are discernible in the images. For this purpose the MRI accreditation phantom is used which contains contrast objects of varying size and contrast. The detection of a low-contrast object is primarily determined by the contrast-to-noise ratio achieved in the image, and may be reduced due to the presence of artifacts such as ghosting. It should be carried out weekly.

Following figure shows the difference of the Low-contrast detectability of two different MRI machines of 1.5T scanner (left) and 0.3T scanner (right).

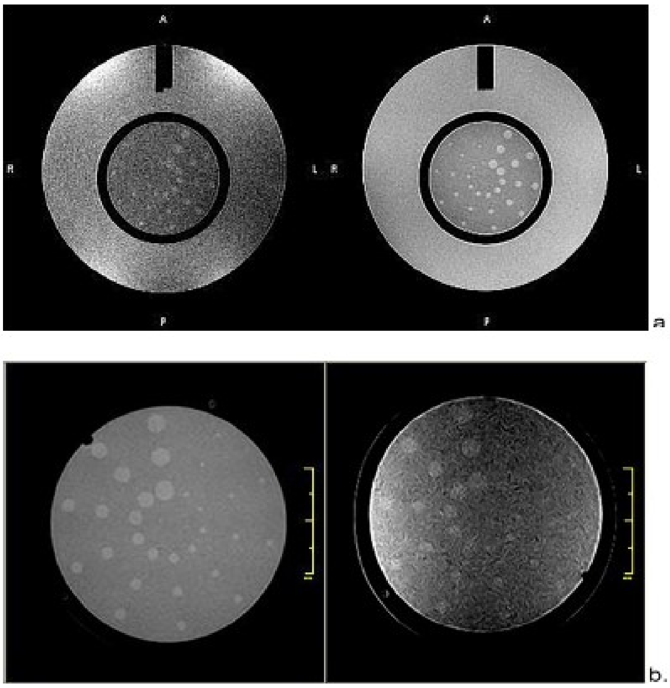

Figure 11: Phantom images of low-contrast detectability (LCD) inserts.

a) Large phantom LCD insert images. Slice 11 (5.1% contrast) acquired on two different scanners, each with proper slice positioning. The left image is from a 1.5T scanner where all 10 spokes (each spoke consisting of three test objects) are visible. Right image is from slice 11 of a 0.3T scanner where only seven complete spokes are visible. The qualified medical physicist or MRI scientist should designate the specific MRI phantom image slice that is most appropriate to assess for weekly

b) Small phantom LCD insert images. The left image is slice 7 (5.1% contrast) from a 1T scanner, where all 10 spokes are visible. The right image is also slice 7, but from a 0.3T scanner, where 7 spokes are visible. One or two objects in the eighth spoke are seen, but the outermost object is no more apparent than background noise, so the eighth spoke is not counted, nor are any spokes beyond the eighth spoke.

3.8 Artifact Evaluation Test

Artifact Evaluation test is a artifact analysis procedure. This could be a early measurement of declining system performance. This test is done in every week with the use of a phantom. Following scenarios should be true if the system performs normal during the test.

i. Phantom appears circular, not distorted

ii. No ghost images appears over the phantom or in the background

iii. There are no bright/dark spots or streaks

iv. There no unusual new feature in the image

3.9 Film Printer Quality Control Test

This test assures that the films produced are artefact free and and consistent with gray levels. This test should be done as necessary when a change happens in the film system. Ex: change of chemicals/film type. There is no specific time for this test. Equipments used for this tests are,

i. Densitometer

ii. Film printer QC chart

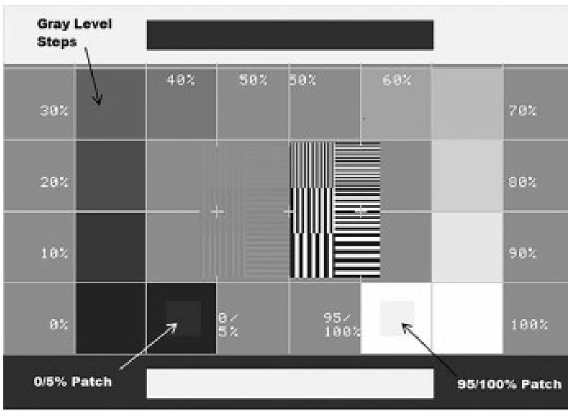

Figure 12: The central portion of the test pattern

If the gray levels on the film matches with the gray levels on the display the Film system qualified to proceed from this test.

3.10 Magnetic Field Homogeneity Test

Homogeneity of the main magnetic field in the designated volume is one of the most important condition in MRI systems. Magnetic field inhomogeneity is usually specified in parts per million (ppm) of the magnetic field strength over a spherical volume. Inhomogeneities contributes to difficulty in obtaining fat suppression and geometrical distortions of images.

When comparing with other Quality assurance methods this procedure might be the hardest one. This test must be carried out annually. There are 4 methods for this test. They are,

i. Spectral peak method

ii. Bandwidth-difference method

iii. Phase-map method

iv. Phase-difference method

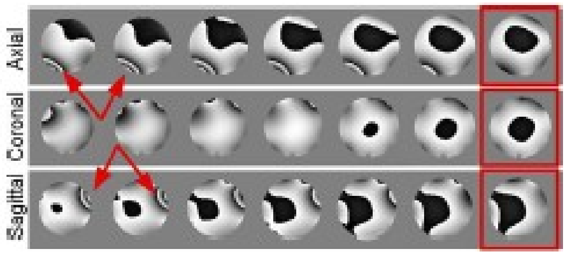

Figure 13: Boxes in the right appears to be completely normal while, inhomogeneities are appeared to be in the left by the arrows which was caused due to a bobby pin under the magnet bore

3.11 Slice-Position Accuracy Test

Slice Position Accuracy test assures the accuracy of the axial slices which are positioned at specific locations. It helps to determine whether the actual locations of acquired slices differ from their position in the image. Following procedure has to done to each image in this test.

i. Display the slice magnified on the monitor by a factor of two to four.

ii. Adjust the display window so that the ends of the vertical bars are not fuzzy using a narrow window width.

iii. Use the viewer's length measurement tool to determine the difference in length between the left and right bars.

iv. Record the measured data in the annual system performance evaluation report.

3.12 Slice-Thickness Accuracy Test

Slice-Thickness Accuracy test is executed annually to assess the accuracy of a specified slice thickness. The measured slice thickness is compared with the prescribed slice thickness. Low slice thickness accuracy might not suggest that the slices are too thin or thick but also due to the image contrast and SNR value.

Slice thickness value is calculated using the following formula.

$$Slice_thickness = 0.2 \times \frac{top \times bottom}{top + bottom}$$

where "top" and "bottom" are the measured lengths of the top and bottom signal ramps.

3.13 Radio-frequency Coils Checks

Radio-frequency Coils checks ensures that the perfect radio-frequency is generated. Otherwise noise in the image will be high and SNR will be low. MRI vendor supplies the tools to check the radio-frequency coils.

3.13.1 SNR

There are two methods to measure the SNR,

1. Single-Image SNR Method
   Select an image of the phantom that is depicting its center along the central axis. Then create a mean signal region of interest that covers at least 0.75 of the cross sectional area of the phantom. Observe the mean signal - the average value of all the pixels in the defined region. Place a measurement ROI of as large as possible in a position in the background area outside the phantom volume in the frequency-encoding direction. And obtain the background noise and signal measurements.

   $$SNR = \frac{Mean\_Signal\_in\_Phantom}{\sigma}$$

   ;where σ = standard deviation in the air ROI

2. Two-Image SNR Method
   In this method first step is to acquire two identical images of a uniform homogeneous phantom at the same time. Then in the one of the image a mean

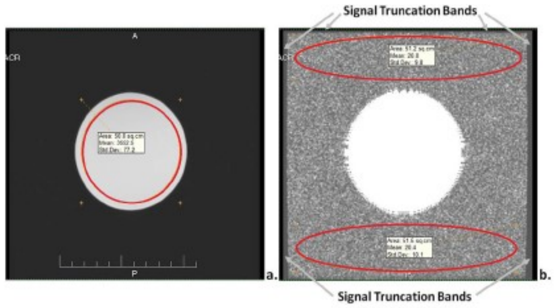

Figure 14: Single Image SNR Method

signal region of interest is defined(more than 75% of the whole image). Then record the mean signal which is the average of the all the pixels in the mean signal ROI. Then create the difference by subtracting each other. The difference image is used to create two more similar regions of interests and define the mean signal and determine the standard deviation.

$$SNR = \sqrt{2} \times \frac{Mean\_Signal}{\sigma}$$

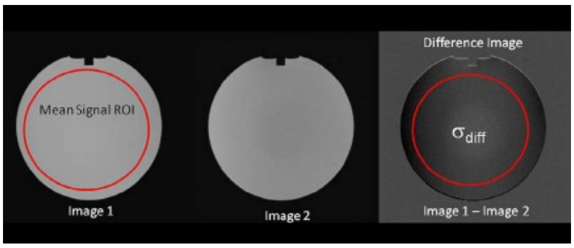

Figure 15: Two-Image SNR Method

3.13.2 Percent Image Uniformity (PUI)

This is test carried out annually to measure the uniformity of the image using a uniform cylindrical phantom. Here windowing is done in two ways. First time only the brightest points are seen. Second time only the darkest points are seen as shown in the following figure. From the both of the images define a region of interest which includes all the brightest and darkest spots. And measure mean signal values in each pixel. PIU is calculated from the following equation.

$$PIU = 100 \times (1 - \frac{Max\_ROI - Min\_ROI}{Max\_ROI - = +Min\_ROI})$$

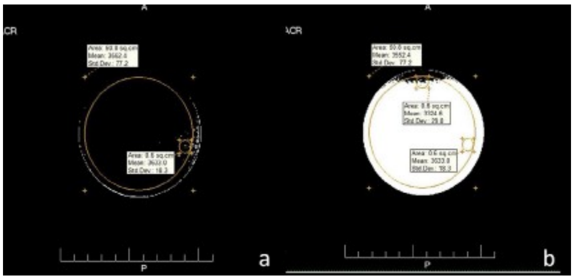

Figure 16: PIU Test

3.13.3 Percent Signal Ghosting (PSG)

Percent Signal Ghosting - PSG is a measurement of the phenomenon known as "Ghosting" which occurs due to movements of the subject. Even the blood flow causes the ghosting phenomenon. It is measured by following procedure.

First establish measurements ROIs in the four positions as shown in following figure. Then record each measured signal values. And calculate PSG value using following equation.

$$PSG = 100 \times \left|\frac{(Left + Right) - (Top + Bottom)}{2 \times MEan\_signal}\right|$$

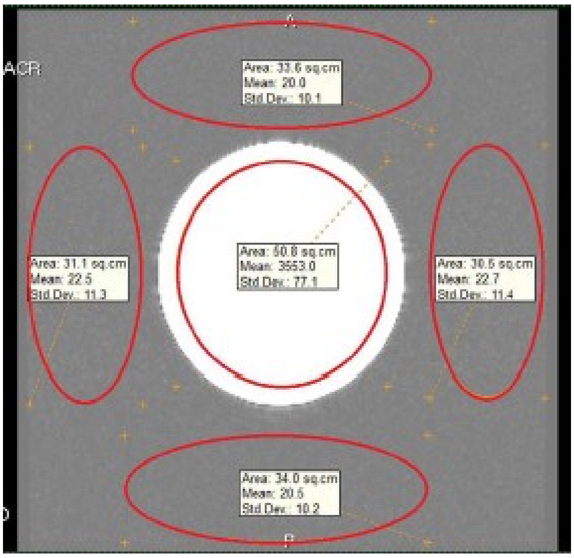

Figure 17: Placement of ROIs inside and outside the phantom to determine percent signal ghosting

4 Recent advancements in MRI Quality Assurance

MRI systems are highly technological devices. As the science and technology develops MRI systems get more chance to develop their performances. Early MRI systems were consisted of permanent magnets with low magnetic power. After then electromagnets were used. But after the discovery of superconductors it was a huge step for the MRI systems. Totally new technology was developed. From the beginning in 1970s, MRI systems were developed in big steps.So were the quality assurance technologies. As the technology develops, it needs more accurate quality assurance methods.

Phantoms are widely used in MRI quality assurance. Normally water based phantoms are used for MRI quality assurance. But due to inconvenience of using water phantoms, now scientists are researching for a substance that can replace water phantoms. BEAMSCAN is a such developed phantom and dosimeter system that is of higher accuracy even if it measures the parameter in less than half the conventional time. The phantom can be controlled and monitored through remotely connected computers using wireless communication.

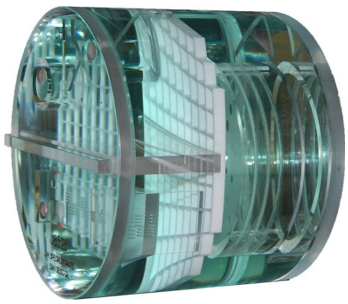

Figure 18: Phantom toolkit for MRI

Figure 19: BEAMSCAN

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