Commissioning and Quality Assurance (QA) for MAGNETOM systems in radiation therapy

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Contents

Introduction to this QA Cookbook

This QA cookbook is intended to be a guide for medical physicists and technologists including suggestions on how you can perform quality assurance procedures for purposes of Radiation Therapy planning on your MAGNETOM MR scanner. This guide considers various methods for QA addressing the variants of the system which may influence geometric accuracy and other factors for MRI. This guide is not intended to replace or supersede the user manual or instructions for use for the MAGNETOM MR scanner but act simply as a suggested supplement to meet specific QA needs for radiotherapy.

MR Overview

1. MRI: General considerations for ensuring optimal performance

1.1 System components

The main system components

A typical MR system consists of three components or subsystems:

- a magnet with a main magnetic field,
- a gradient system, and
- the radiofrequency (RF) system

These are discussed briefly below. For more information, refer to the References section of this chapter.

Magnet

A strong magnet generates the homogeneous magnetic field characteristic in MR imaging. This magnetic field is generated by electric current flowing in large coils and exists in the center of the magnetic bore.

Magnets may be separated into permanent, resistive, and super conducting magnets. All types are used in MR-Imaging systems, but super-conducting magnets are the most stable (stable in terms of B_0 field) solution as the others are very sensitive to even smallest temperature changes.

Superconducting magnets

Superconductors are materials that have zero electrical resistance at a certain, usually very low transition temperature close to absolute zero (0 Kelvin ≈ – 273 °C). In a superconductor electrical current can flow without losing energy. A coil of superconducting wire forms a superconducting (electro) magnet which can generate a constant high magnetic field while on the inside the magnetic field is completely expelled (Meissner effect).

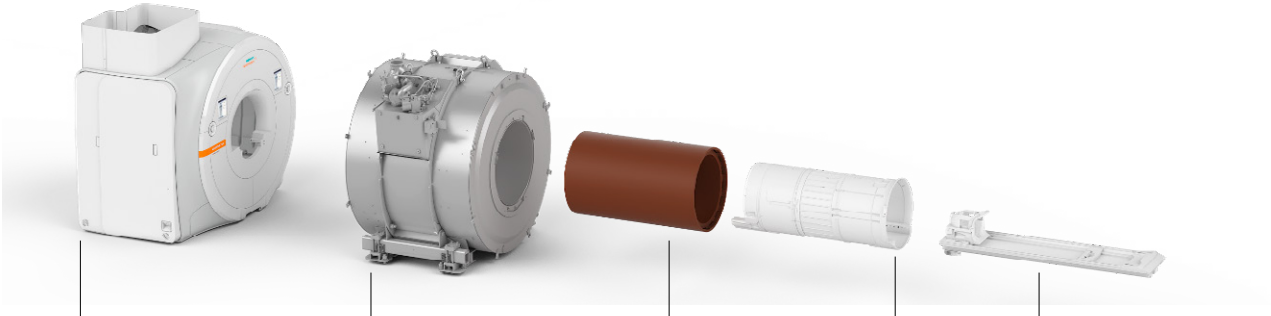
Superconductors are the basis for building the strong magnets currently used in most clinical MRI systems.

The superconductor needs to be kept below a critical temperature to exhibit superconducting properties. Liquid helium commonly used as a coolant in MRI systems.

All superconducting magnets exhibit a very slow decay of their nominal field strength over time, specified in the respective datasheets. This comes at no signal-to-noise penalty due to frequency adjustment, combined with the ability of their transmit-receive systems to operate over a large frequency bandwidth. As part of scheduled maintenance magnets are sometimes ramped up, in order to re-establish the original field strength from day of handover. This is not a quality problem, but instead a consequence of small ohmic losses at junctions in the superconducting magnet circuits.

Magnetic field drift

The magnetic field strength of MR systems is stabilized to assure that a frequency adjustment done at the start of scan remains valid over the whole patient examination. However, magnetic fields can drift around their nominal field strength, for a variety of reasons. The concept of the frequency adjustment assures optimum signal-to-noise during the full length of the MR exam.



The radiofrequency (RF) system

The RF system generates the RF fields and transmits them to the patient (transmit function). It also receives the MR signals emitted by the patient and provides them in digital format for image reconstruction (receive system).

The RF system of an MR installation consists of the following:

- RF coils
- RF transmit amplifier for sending RF pulses
- RF receive amplifier for amplifying the received MR signal

Figure 1: BioMatrix Head/Neck 20

RF coils

RF coils can be distinguished between the body transmit coil, local RF receive coils and local transmit/receive coils.

The body transmit coil, responsible for sending RF pulses, is integrated in the magnet bore. For many MR systems, the body transmit coil can also act as a basic receive coil.

Local RF receiver coils, responsible for receiving the MR signal, come in various shapes and forms, depending on the area of their application. Depending on the body region to be examined, they are positioned locally on the patient's body. Local coils can be categorized into:

- Volume coils
- Surface (array) coils

Flexible coils which adapt closely to the patient's anatomy result in improved Signal to Noise ratio over the image region of interest.

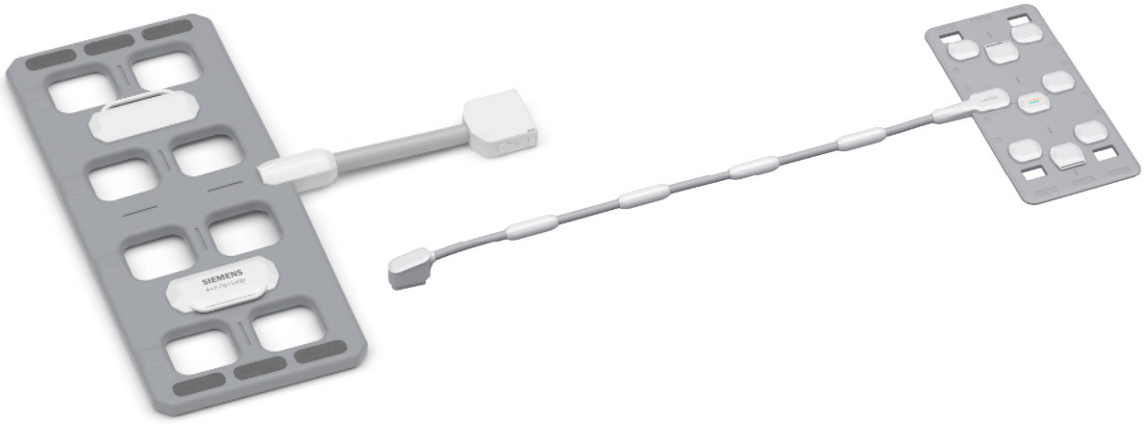


Figure 2: (left) Flex Large 4, (right) Ultra Flex Large 18

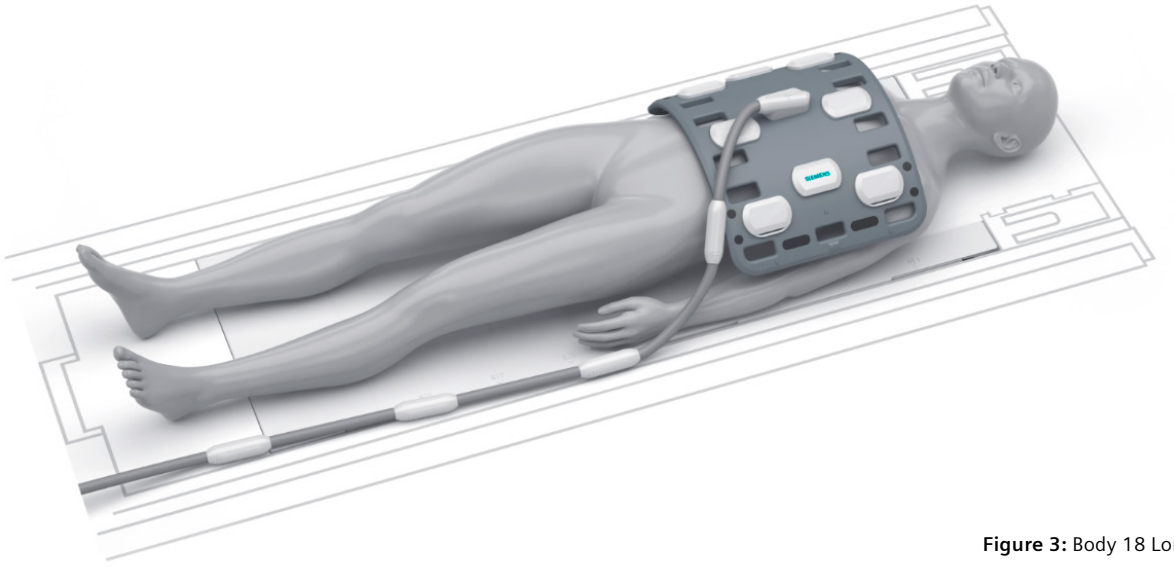


Figure 3: Body 18 Long

Gradient system

In addition to the basic magnetic field, the whole body gradient system generates linear dynamic magnetic field gradients in the three room orientations. The whole-body gradient system includes

- the gradient amplifier and
- the gradient coil.

Gradient coils

The MR system has three gradient coil arrangements for all three spatial directions (x, y, and z), situated around the magnet bore. The gradient coils do not generate a permanent magnetic field but are switched on briefly and multiple times during the examination. The gradient coils are operated via special power supplies, known as gradient amplifiers.

Gradients in MR allow positioning arbitrary slice planes. For example: the x-gradient (x = horizontal) encodes the frequency range for sagittal slice excitation, the y (= vertical) gradient for coronal slices and the z-Gradient encodes the range for transverse slices excitation. For oblique slice-excitation two or three gradients need to be combined.

References:
1. Magnets Spins and Resonances available **here.**
2. MAGNETOM Planning Guide System

1.2 Environmental factors that can influence system performance

Water flow supply

To ensure optimal performance of the MR system, the gradient coil and gradient amplifiers are cooled with a closed-loop water supply. This is to ensure its optimal operation as needed for fast and accurate MR imaging. Failure to provide optimal cooling may result in the risk of overheating gradients, which, once detected by the temperature monitoring systems, can lead to a premature stop of the image acquisition.

Power instability and quality

In order to realize a correct MR pulse sequence diagram for artifact-free MR images, a stabilized power supply is used to drive the gradient amplifiers. They are connected to the gradient coil using gradient cables.

The main power supply line must be split up to different sub line power distribution panels. The MAGNETOM system must be connected to a separate sub line power distribution panel. No other components must be connected to the MAGNETOM System sub power distribution panel. This is done to minimize interference on line voltage cables for the MAGNETOM.

The examination room installation must be completed according to local regulations and if necessary, connected to an emergency power supply.

Slow vibrations

Vibration of the site (caused by either external noise or internal noise sources) can affect the stability and homogeneity of the magnetic field and can lead to a degradation of the image quality. In the three spatial orientations the building must not exceed the following vibrational specifications.

- **Mass of floor plate:** should be about 600 kg/m^2 (corresponding to a thickness of about min. 20 cm or 8") to achieve a good vibration and structure-borne sound isolation.
- **Additional room shielding:** The fringe field of the MR system may make its location critical. Additional room shielding can be calculated and recommended where necessary.

Seismic events

The MR scanner and electronics cabinet are installed with additional seismic anchoring to provide stability in seismic zones. Seismic anchoring is related to local/national regulations, guidelines or codes.

Seismic anchoring is usually performed for the magnet, electronic cabinets and helium compressor.

- **Magnet:** seismic brackets are permanently mounted to the magnet box sections.
- **Electronic cabinet:** If seismic anchoring is needed for the site, a "Seismic Kit" for the cabinets must be ordered separately.
- **Helium compressor:** The seismic fixation of the helium compressor can be fitted to the housing.

Resources:
1. MAGNETOM Planning Guide System

	Nominal value	Tolerance
Voltage range	380, 400, 420, 440, 460, 480 V 3-phase and ground	+10%/–10%
Line to line unbalanced	–	max. 2%
Frequency	50/60 Hz	+/–1 Hz

Figure 4: On-site power specifications

1.3 Influence of the patient inside the bore

Physiological phenomena

Patient anatomy/physiology

The patient him-/herself influences the magnet homogeneity when introduced into the magnet bore. This influence can be measured and is also dependent on several factors including magnet strength and patient shape. For example, head and neck imaging homogeneity challenges can be more pronounced in comparison to other body regions due to different anatomical shapes over a small area of coverage.

Generally, this patient influence can be an order of magnitude greater than the empty-bore magnet homogeneity.

Susceptibility artifacts in the image

Susceptibility artifacts in MR images arise due to local field inhomogeneities because of different susceptibility of different tissue types and air. This can result in an altered or shifted signal as well as signal loss. Especially susceptible are transition areas between tissue and bones or between tissue and air.

Solution	What to do with it?	How does it help?
Spin-echo sequence	Use instead of gradient-echo	Eliminates possible signal loss by applying the rephasing 180° pulse
Voxel Size	Reduce	Reduces the susceptibility differences of neighboring voxels which is proportional to susceptibility artifact size
Echo Time (TE)	Reduce	Reduces the period of dephasing
Bandwidth	Increase	Sequences with higher bandwidths reduce distortions because bandwidth is inversely proportional to susceptibility artifact size
Gradient strength	Increase for given FOV	Variations in the field due to susceptibility differences have less effect on
B_0 field strength	Potentially go to lower field for severe cases	Susceptibility scales with B_0 field strength

Figure 5: Solutions for susceptibility artifacts

Problematic areas are, for example, the paranasal sinuses, the orbits, the lungs, heart, stomach and the intestinal loops.

- Static field inhomogeneities can be compensated for by the spin-echo technique.
- With gradient-echo techniques, local field inhomogeneity is not compensated for.
- With EPI imaging, the very low bandwidth of the sequences results in additional distortions in the phase encoding direction.

Breathing / heart rate

MR imaging procedures are sensitive to patient movement. Images may exhibit artifacts in the form of smears when motion times (for instance, during respiration or heartbeat) are short compared to measurement times. This can, in turn, hinder the accurate determination of treatment margins for target lesions, as needed for radiotherapy planning. This problem occurs particularly as a result of the patient's heartbeat during cardiac examinations or as a result of the patient's breathing during abdominal examinations.

Two different procedures are used to minimize motion artifacts in images:
- prospective triggering and
- retrospective gating.

Prospective triggering

During prospective triggering, a measurement is triggered by using a so-called trigger signal derived from the patient's physiological signal. This signal is usually defined based on the time-period during which organ movement is as low as possible. The trigger delay is, for example, set to the end of the systole for certain cardiac examinations so that the measurement is running during the akinetic diastole. For respiratory triggering during abdominal examinations, it is recommended to start the measurement at the end of the respiratory period.

To determine the start time for the measurement, an acquisition window is defined based on the signal form (e.g., R-wave in ECG, minimum of respiratory curve). For example, the size of the acquisition window is approx. 80% of the RR interval for ECG measurements. The acquisition window defines the range in which the measurement can be triggered. The trigger time is defined by the trigger delay.

Prospective triggering can be used for ECG, pulse, or respiratory signal curves as well as for external trigger signal curves.

Retrospective gating

Respiration-induced motion of lung tissue and abdominal organs can hinder the accurate determination of treatment margins for target lesions, as needed for radiotherapy planning. One way to overcome these problems is to use respiratory self-gating techniques, which derive respiratory information directly from the raw imaging data acquired.

For example, RT Respiratory self-gating for FL3D_VIBE allows to acquire a so-called "4D MRI" dataset during free breathing imaging examinations in the abdomen and thorax, and reconstruct 3D datasets for a selectable number of respiration phases, without the need for breath-hold commands.

It supports MR based radiotherapy planning of moving targets in the thorax and abdomen with deviceless retrospective gating.

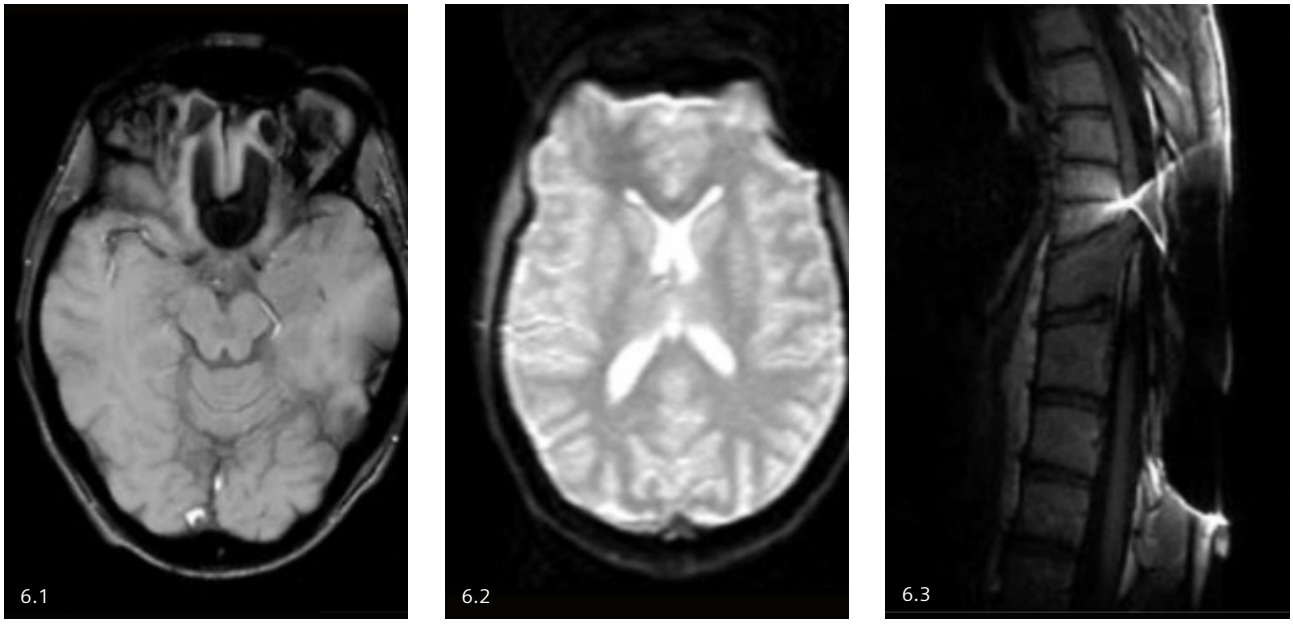


Figure 6: Different image artifacts
6.1: Artifacts with signal loss in the sinus region (gradient echo sequence)
6.2: Susceptibility artifacts in EPI imaging
6.3: Susceptibility artifacts caused by ferromagnetic objects on the patient's body

Retrospective gating fundamentally differs from prospective triggering. No actual triggering is taking place. The physiological signal and data acquisition times are recorded simultaneously. The measurement is performed completely independently of the patient's heartbeat or pulse.

A temporal assignment of images to the corresponding phase (e.g., heart stimulation) is performed after the measurement (retrospectively).

Retrospective gating can be used for ECG, pulse, or external trigger signal curves.

Metallic Implants[1]

Metallic implants can also cause susceptibility-related inhomogeneities. Note that although MRI safe implants exist, these can still induce artifacts which may distort the geometric integrity of the image. In addition to metallic implants, care should be exercised in the case of MRI-guided brachytherapy where, e.g., titanium applicators are sometimes employed.

Blood Flow

Spins that move along magnetic field gradients will exhibit spatially dependent phase shifts. This allows to depict blood with negative or positive signal and generate contrast from its flow speed and direction. Dynamic information of flowing blood can be derived via synchronization of MR imaging with cardiac motion. A variety of techniques employing contrast media bolus depiction, or phase-contrast techniques are described in the MAGNETOM instructions for use, together with application instructions to avoid flow related image artifacts.

Technical Adjustments

Resonance Frequency Adjustment

The resonance frequency is related to the main magnetic field (as given by the Larmor equation). As the patient is moved inside the bore, the main magnetic field is not homogeneous anymore, and additional shim adjustments are performed to ensure best possible main magnetic field homogeneity. The corresponding resonance frequency changes are accounted for and corrected in a process called the "frequency adjustment". This adjustment procedure is patient specific and is automatically done before a patient scan.

Transmitter Adjustment

Transmitter adjustment is the process whereby an appropriate voltage is found for the transmitter antenna of the RF body coil to generate a spin inversion (a 180-degree pulse flips the magnetization into the opposite direction of the z-axis.). This adjustment is patient specific and is done automatically before the beginning of a scan. Its result serves as the basis for patient-specific voltage selection for arbitrary RF pulses during the MR imaging examination.

RF Coil Selection

An element failure in an RF coil results in a poor SNR of the resulting signal but doesn't lead to any geometric distortions.

"Automatic coil select" and "prescan normalize" are automated procedures that run prior to a scan, but could be unintentionally omitted by operators, resulting in a scanning error. The former seeks to include or omit coil elements depending on whether they would bring an increase in SNR. Some elements only contribute towards noise and are therefore automatically omitted. The latter on the other hand, is used to assign specific weights to participating elements in a scan, depending on their distance to the area being imaged.

1 The MRI restrictions (if any) of the metal implant must be considered prior to patient undergoing MRI exam. MR imaging of patients with metallic implants brings specific risks. However, certain implants are approved by the governing regulatory bodies to be MR conditionally safe. For such implants, the previously mentioned warning may not be applicable. Please contact the implant manufacturer for the specific conditional information. The conditions for MR safety are the responsibility of the implant manufacturer, not of Siemens Healthineers.

References:
1. Operator Manual MR
2. Magnets, Flow and Artifacts available **here.**
3. Magnets, Spin and Resonances available **here.**

B_0 and B_1 shimming

In order to make the magnetic field more homogeneous, a technical process known as "shimming" is applied.

The homogeneity of the "empty" magnet will be strongly affected once a patient is positioned in the bore. This effect can result in several ppm of field inhomogeneity. This effect can easily be seen when forgetting to perform a patient-specific shim procedure.

The performance of the patient specific shim depends on two factors, namely the hardware and the software.

Hardware
Dedicated shim coils are commonly used for patient-specific shimming, for the shimming of linear terms and (if available) higher-order terms. These terms are listed in the table below.

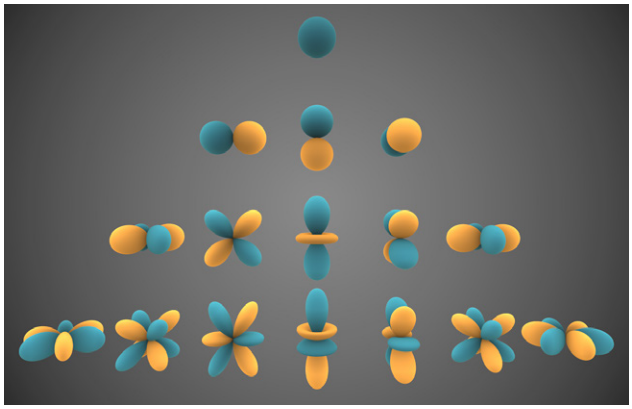
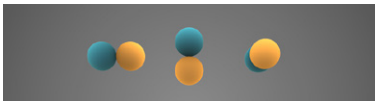
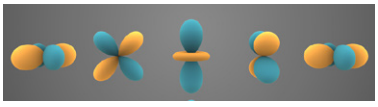
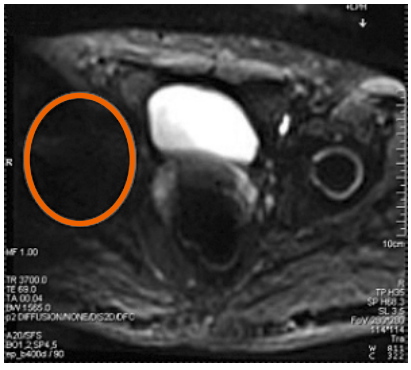


Figure 7: Visual representations of the real spherical harmonics up to 3rd order. Blue portions represent regions where the function is positive, and yellow portions represent where it is negative.

Source: Wikipedia, https://en.wikipedia.org/wiki/Spherical_harmonics

Spherical harmonics order	No. of terms	Description	Equipment for shimming	Visual representation
0th order	1	Static magnetic field B_0	–	
1st order	3	Linear deviations from the homogeneous B_0 field. 3 linear terms describe the linear deviations in x, y and z directions.	Standard gradient system	
2nd order	5	Quadratic deviations from the B_0 field. Terms: z^2, xz, yz, xy, x^2-y^2	Special 2nd-order shim coils. 5 additional power supplies and a software implementation are required. 2nd-order shim set standard with most 3T systems.	



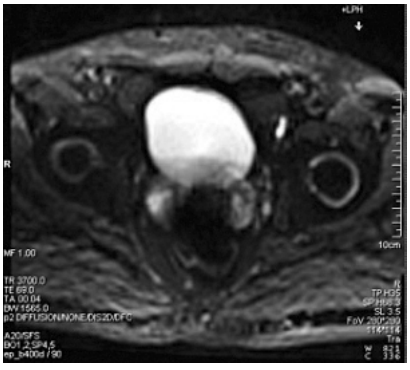


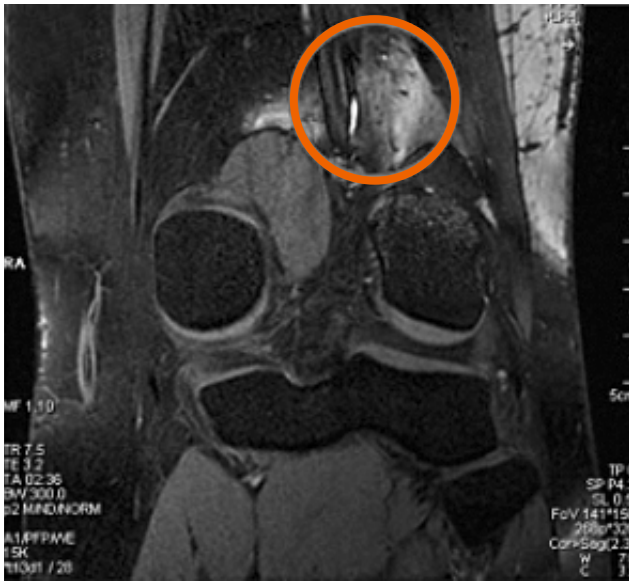
Figure 8: Pelvic imaging with diffusion-weighted single-shot EPI and spectral fat saturation, MAGNETOM Skyra 3T.

(left) With 1st-order shim only (2nd-order shim disabled).

(right) With 1st-order and 2nd-order shim. Note the strong spatial distortions (orange circle) in the presence of strong susceptibility changes without 2nd-order shimming.

Software
Shim algorithms are used for the measurement and correction of magnetic field inhomogeneities, making use of the available hardware. A common workflow of these algorithms is described in the figure on the right.

Magnetic field inhomogeneities	Measurement of shim volume	Shim current calculation
Calculated using phase sensitive scans	• Global measurement: whole imaging volume of the scanner measured. Relevant subvolume considered later. • Manual shim volume selection	Algorithm: calculates shim currents based on relevant imaging volumes using the available shim hardware for its calculations



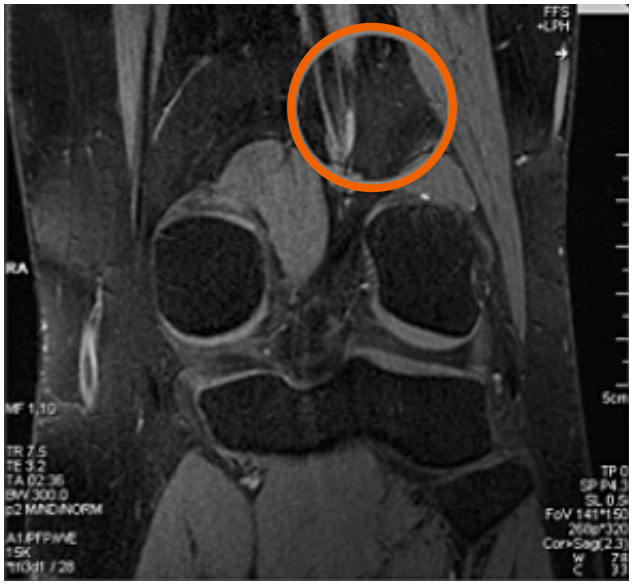


Figure 9: Knee imaging with spectral fat saturation in off-center position, MAGNETOM Skyra 3T.
(left) With 1st-order shim only (2nd-order shim disabled).
(right) With 1st-order and 2nd-order shim. Note the superior saturation when using 2nd-order shimming (orange circles).

References:
1. Magnets, Spins and Resonances, available **here.**
2. Blasche Mathias, Fischer D. Magnet Homogeneity and Shimming. MReadings: MR in RT (3) 2017,60-67. The issue is available **here.**

1.4 Image characteristics – SNR and CNR

Signal-to-noise ratio (SNR)

An important criterion for MR image quality is the relationship between the intensity of the wanted signal and the statistical noise, the signal-to-noise ratio (SNR):

$$SNR = \frac{Signal}{Noise}$$

A higher SNR means a less grainy image.

Noise in an image

The noise in the image appears as a grainy, random pattern representing statistical fluctuations in signal intensity that do not contribute to image information. There are basically two sources for this effect:

- Generated throughout the human body through Brownian motion of molecules
- Electronic noise of the receiver technology

We are faced with a problem when the signal from a slice is too weak. In this case, the signal may be "washed over" by noise.

Factors affecting SNR

1. Slice thickness: SNR is directly proportional to the voxel size. The thicker the slice, the stronger the signal and higher the SNR. Enlarging the voxel by measuring a thicker slice implies an increase in signal intensity, since more protons are contributing to signal strength. The portion of noise, however, remains the same since it is not just coming from the slice, but rather overall from the patient's entire body (or more precisely, from the sensitive volume of the receive coil).

Disadvantages: Increasing slice thickness reduces spatial resolution in slice direction. This may result in partial volume effects that distort image results (for example, bones protruding into soft tissue).

Please note: Doubling the matrix size to improve the in-plane resolution will decrease the voxel size by a factor of four. Consequently, SNR will be decreased by a factor of four as well.

2. Number of acquisitions: SNR is proportional to the root of the number of acquisitions. SNR can be improved by measuring one slice several times and adding the results in a single image. Disadvantage: The measurement time increases as the number of acquisitions increases.

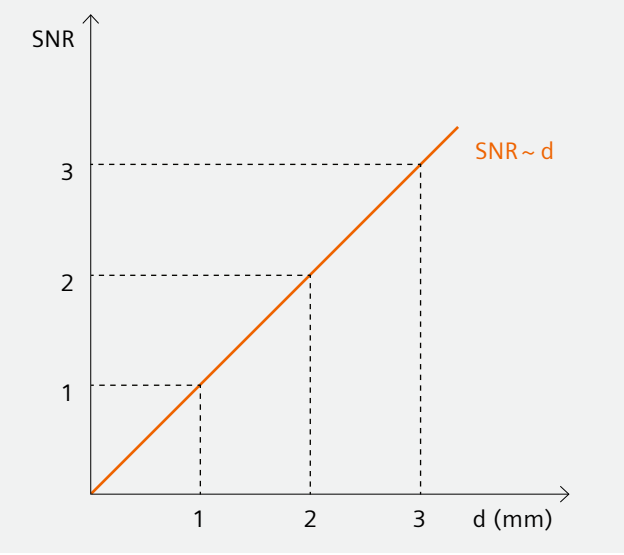


Figure 11: SNR relating to slice thickness

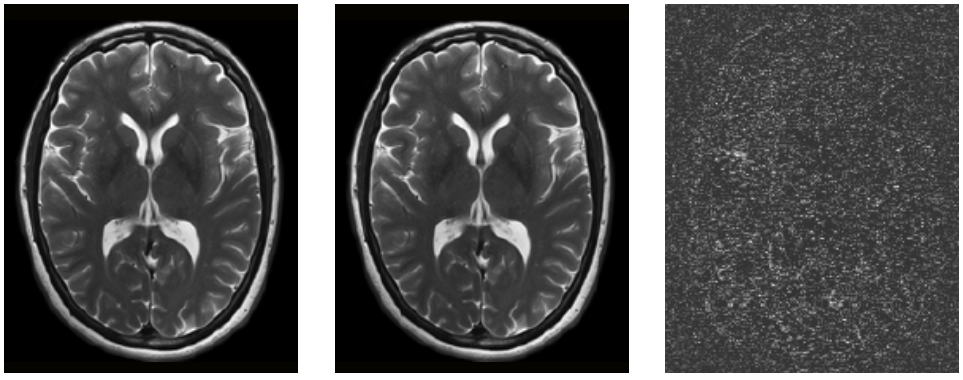


Figure 10: Image comparison – The two images on the left were acquired in the same way and subsequently subtracted from one another (= pixel-by-pixel difference in gray values). What remains is background noise (on the right).

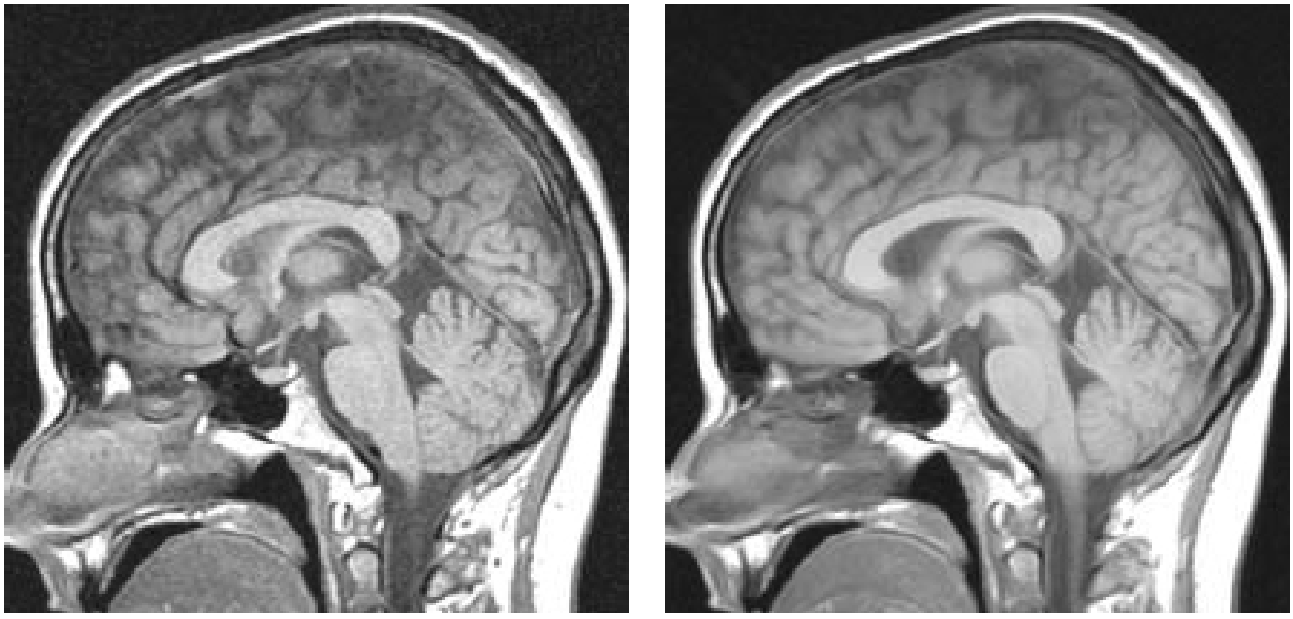


Figure 12: Image comparison – The figure on the right shows a slice that is three times as thick as the slice in the left image. As a result, the SNR is three times as high, however increasing partial volume effects.

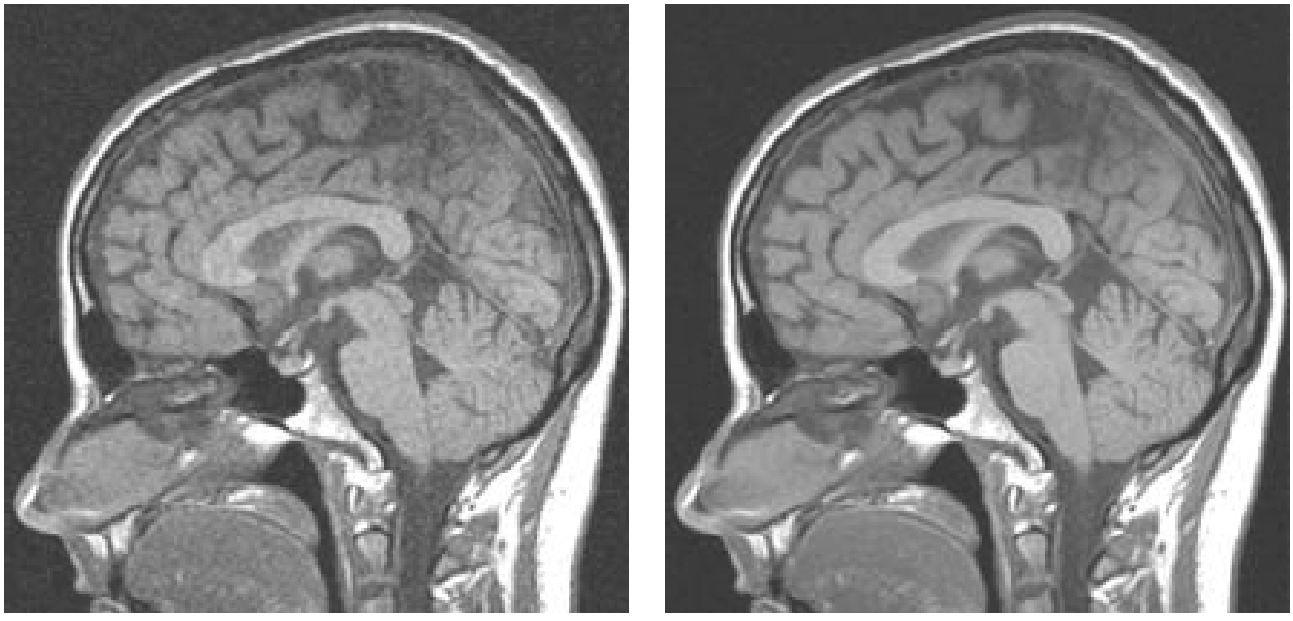


Figure 13: Image comparison – (left) 1 measurement, (right) 4 measurements. Results: The SNR on the right is double the SNR on the left.

Contrast-to-noise ratio (CNR)

The contrast-to-noise ratio (CNR) in an MR image is the difference between the signal-to-noise ratios between two tissue types, A and B:

$$CNR = SNR_A - SNR_B$$

The contrast we see and evaluate in the image is more than differences in signal intensity: This effective contrast is also related to the noise level.

A high signal-to-noise ratio (SNR) alone does not guarantee easy differentiation between two structures in an image. Since CNR equals effective contrast, it is a better quality criterion than SNR.

When contrast is too noisy

Assuming there is a noticeable difference in signal between two tissue types A and B, we could obtain good contrast. However, if we set this difference in signal in relation to high noise, the contrast drowns in noise.

To obtain good image quality, the difference in signal between two types of tissue must be significant despite the noise.

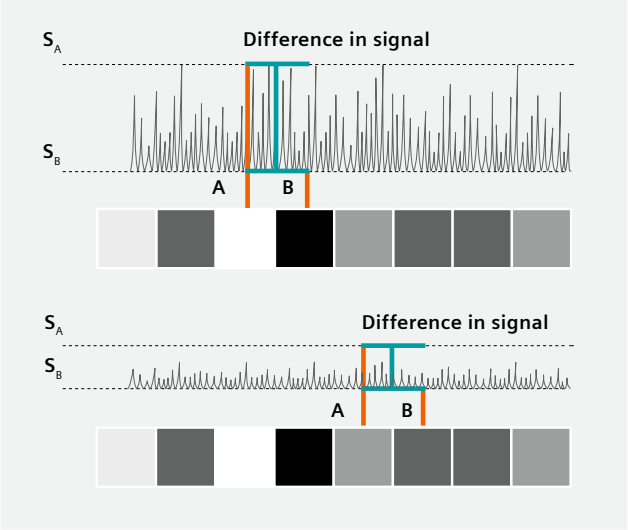
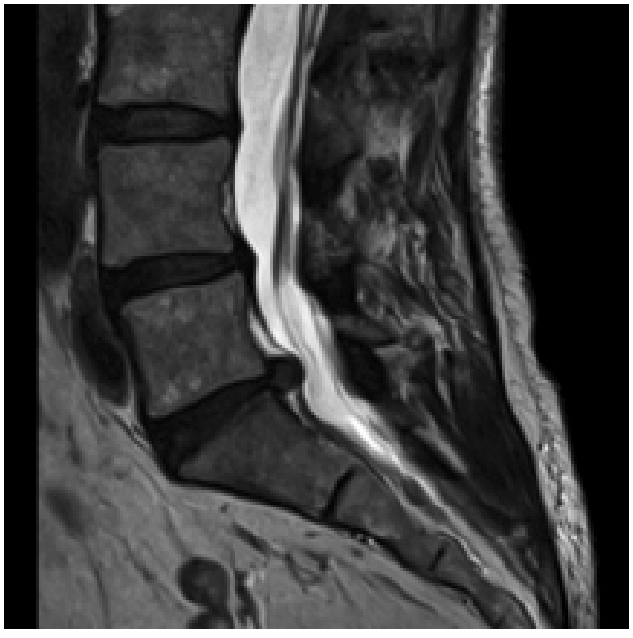


Figure 15: Although the difference in signal is higher in the first than in the second case, the CNR and consequently the effective contrast is lower.

Sources of image distortion

Image distortions are caused by inhomogeneity in the magnetic field, gradient non-linearity, or ferromagnetic materials in proximity to the examination.



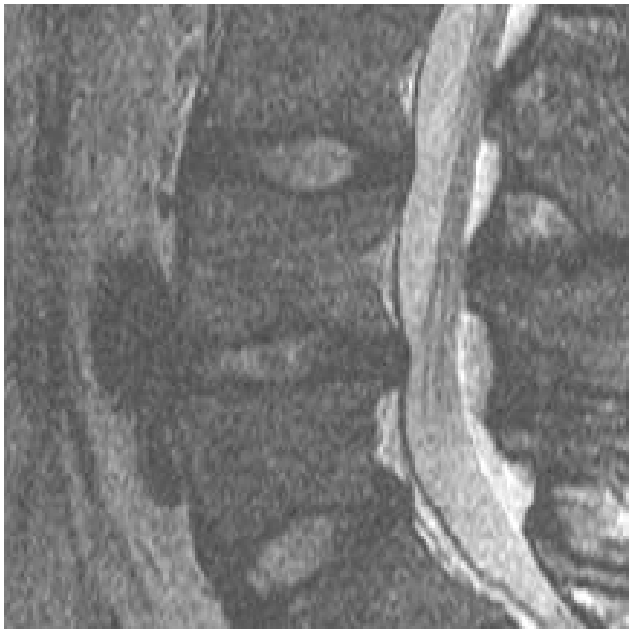


Figure 14: Image comparison – (left) good CNR, (right) poor CNR

Under ideal circumstances, magnetic field gradients rise linearly inside the imaging volume of the magnet. However, in reality, linearity decreases at the edge of the field of view. The size of the field of view that can be acquired by the gradient system, is for example, limited by the length of the gradient coil.

Figure 16 shows a 5% deviation at the edge of the measurement volume measuring 40 cm in diameter. This means that all spatial information along the edge is shifted by 5% (1 cm).

Correcting for distortions

It's possible that a discrepancy can exist between slice planning and the actual slice excitation. This occurs primarily outside the center region of the bore. It is important to note that with 3D distortion correction, all reconstructed slices show accurate geometric integrity/ accuracy of the image.

As part of the RT Dot Engine in the MAGNETOM RT Pro edition, distortion correction is considered with protocols that include automatic 2D and 3D distortion correction to ensure the images have optimal geometric accuracy.

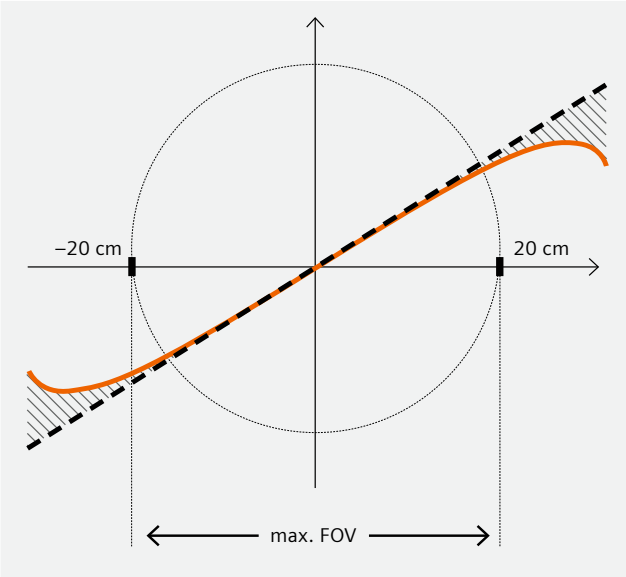


Figure 16: Image distortions at the edge of a large field of view

Resources:
1. Magnets, Spins and Resonances available **here.**
2. Magnets, Flows and Artifacts available **here.**

Summary

Challenge	Root cause	Risk	Solution	Usage principle
Gradients not perfectly linear	Physics (Maxwell)	Geometric distortion at FOV edges	2D/3D distortion correction	Part of image calculation
Magnetic field not perfectly homogeneous	Manufacturing tolerances	Signal loss and geometric distortion at FOV edges	Passive and active shim, field map measurement	Adjusted during installation, and for each patient
Resonance frequency	Susceptibility, chemical shift, field drift	Signal loss, image shift and distortions	Frequency adustment, segmented EPI	Adjusted for each patient
Transmitter power	Variability of patient weights	Signal and contrast losses, SAR, coil limitations	Transmitter adjustment, B_1 shim	Adjusted for each patient
RF coil breaks	Mechanical damage	SNR loss, signal inhomogeneity	Coil replacement	Hotline, preventive maintenance (AI)
Overall system safety	Component stress, violation of safety limits	Failure of operation, harm to patient	SW watchdogs, Safety related tests at regular intervals	Planned maintenance
Infrastructure problems	Power or cold water failure	Failure of operation	Recovery from infrastructure problems	Warning messages

2. Special considerations of MRI in radiotherapy

MRI Simulation requires the patient to be imaged in treatment position. This brings a set of requirements that are particular to radiotherapy and not in line with traditional radiology uses. In this chapter, you will find an overview of the radiotherapy needs, the way they can be accomplished and the tradeoffs that will be introduced. Here is an overview of the major differences between the two disciplines, partially adapted from a publication by **Dr. Eric Paulson, MCW, USA:**

	Diagnostic images	Planning images
Purpose	Detection, characterization, and staging of disease	Determination of 3D extent of tumor and critical structures
Field of view	Can acquire with reduced FOV	Full cross section required on at least one scan for body contour
Slice thickness	Typically 5 mm; many have interslice gaps	Contiguous and thinner slices, improving 3D delineation and DRR quality
Slice coverage	Prescribed over volume of interest	Increased coverage required for target and OAR delineation (DVHs), landmarks for registration and IGRT, etc.
Geometric distortion	Tolerated so long as diagnostic capability not affected	Required to be < 2 mm (or < 1mm, depending on application), in all planes over the volume of interest
Image uniformity	Tolerated so long as diagnostic capability not affected	Increased uniformity required for image registration, auto-segmentation, etc.
Slice orientation	Orientation often tilted for best diagnosis	True axial oriented slices are needed

Figure 17: Radiology versus radiotherapy needs on MRI *Courtesy of Dr. Eric Paulson, MCW, USA*

2.1 Imaging in treatment position

Patient immobilization devices

RT need:
During simulation, the patient has to be imaged in the position that will be used during treatment. This position needs to be comfortable enough to be achievable by the patient as well as reproducible throughout the duration of treatment. For linear accelerators that have flat tabletops, this needs to be replicated at the time of simulation. Furthermore, to avoid movement during treatment, it is common to use immobilization devices. These take different forms and shapes according to the body part being treated. A few examples are listed here:

- Stereotactic frames to keep the head fixed for highly precise treatments called stereotactic radiosurgery (SRS) and stereotactic radiotherapy (SRT)
- Head and neck masks which make sure that the patient's head and neck is in the same position during planning and treatment.
- Breast boards that are inclined to a comfortable position and have handles above the patient's head to keep the breast as static as possible
- Body vacuum bags that are molded to take the individual patient's shape and keep their torso immobile

How to achieve it:
The MAGNETOM RT Pro edition has been developed to address the specific needs of imaging patients in the RT treatment position. Custom-made flat couch tops from leading vendors (CIVCO, Orfit, QFix), in combination with Siemens Healthineers flex coils that wrap around immobilization devices and coil bridges can be offererd. Figure 18 shows an example of a patient in the treatment position for head and neck imaging utilizing the QFix INSIGHT flat couch top overlay, coil holders, and immobilization devices. Two Flex 4 Large coils and a Body 18 Long coil are used in conjunction with the Spine coil for the imaging.

What is the tradeoff:
The dedicated multi-channel coils which have been designed to encompass different body parts for diagnostic imaging can often not be used in combination with an immobilization device. Flex coils are used instead and these typically contain fewer elements, something that may have an impact on SNR. Measurements comparing a head acquisition employing two different types of flex coils (UltraFlex 18 versus Flex 4 large) revealed up to 21% more SNR, as shown in Figure 19.

Particularly for brain imaging, where anatomy is rigid, some users choose to forgo immobilization at MR and rely on a rigid registration with CT instead. Please see reference 1 for more details.

Figure 18: Example of immobilization setup when planning for H&N treatments using Siemens Healthineers Flex coils and QFix INSIGHT flat couch top and coil bridges[1]

Landmarks for registration

RT need:
MR images are often used in combination with CT for treatment-planning. Achieving an accurate registration between the two is often challenging as these types of images contain complimentary information and often have few commonalities. In order to overcome this, sometimes markers are implanted that can be detected by both types of images (e.g., gold markers in the prostate).

How to achieve it:
Additional sequences which can detect these markers need to be carried out. For example, T1w VIBE Dixon, used for generating synthetic CT images in the pelvis, shows signal void due to the presence of gold/platinum fiducial markers in the magnitude images because gold/platinum does not produce nuclear magnetic resonance signal. T2/T1w true FISP (steady-state coherent sequence with balanced gradients) can also be performed to visualize markers (void of signal) if preferred.

The extent of the signal void and fiducial marker artifact visibility varies with imaging parameters and their orientation with respect to the magnetic field. Care needs to be taken to avoid misclassification of bleeding or calcifications as fiducial markers which also appear as signal void in MR images. The usage of information from multiple sequences can improve the certainty of marker localisation.

What is the tradeoff:
Additional time spent on image acquisition.

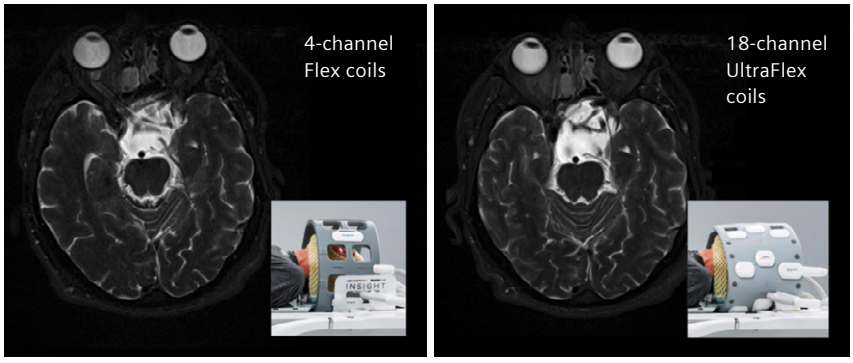


Figure 19: Superior SNR achieved with UltraFlex coils compared to Flex coils

Up to 21% more SNR

with UltraFlex 18 Large coils compared to Flex 4 Large coils[1]

[1] *The information shown herein refers to products of third-party manufacturer's and thus are in their regulatory responsibility. Please contact the third-party manufacturer for further information.*

Figure 20: External Laser Bridge, LAP[1]

Lasers

RT need:
Lasers are used in the treatment room in order to set up the patient reproducibly in treatment position. The projected laser lines are aligned on the patient's surface to reference the position of the treatment isocenter. This position is defined at the time of simulation and the patient is marked to provide a reference between internal and external anatomy. If a CT simulation scan has preceded the MR, then the lasers at the MR are only required to confirm the alignment of that position. If however, an MR-only simulation is carried out, then the lasers are needed to mark the patient for the first time.

How to achieve it:
An MR-compatible laser bridge is installed in the MRI suite. The two systems are setup in a way that transfer of patient coordinates from the RT Image Suite to the laser is enabled. It is recommended to enable "direct laser steering[2]", in order to provide direct transfer of marked positions on the images to the laser (available with compatible LAP-lasers). The laser is ideally installed when the room planning takes place, in order not to interfere with the Faraday cage. It must be affixed to the ground, according to the planning instructions of both devices, MR system and laser bridge. Its position relative to the MR scanner is measured with the help of a dedicated phantom, thereby allowing the exchange of coordinates of points of interest in space, that are valid in the DICOM patient coordinate system of the MR scanner, and the coordinate system of the laser bridge, defined according to IEC 61217.

What is the tradeoff:
The presence of the laser bridge needs to be carefully planned so that it doesn't restrict the movement of the technologist around the patient. Its position with respect to the MR scanner shall allow marking of the patient's head when positioned head first. It needs a power switch to be de-energized during MR scanning, in order to avoid any image artifacts.

[1] *The information shown herein refers to products of third-party manufacturer's and thus are in their regulatory responsibility. Please contact the third-party manufacturer for further information.*
[2] *Option within syngo.via RT Image Suite*

References:

1. *MR-integrated Workflows in Radiation Therapy for MAGNETOM Systems, available* **here.** *(Section Protocols)*

2.2 Principles for optimization of MRI in RT protocols

MRI is optimized to fulfill a different purpose in radiology compared to radiotherapy. In oncological radiology, the detection, characterization and staging of disease is the goal of the MR imaging procedure. This has already taken place in the case of imaging for radiotherapy, and the goal is instead to determine the extent of the target in all dimensions as well as to define the nearby organs at risk. Consequently, protocol optimization is done in a different manner. Major differences are described in this chapter.

Patient compliance and speed of acquisition

RT Need:
Patients frequently find it hard to comply with keeping still during an MR examination. Radiotherapy patients have to tolerate in addition a hard tabletop and an added immobilization device which make compliance more challenging.

How to achieve it:
A setup that is comfortable to the patient needs to be found. The speed of acquisition should take patient comfort into account and adjusted to the individual according to their tolerance of keeping still. Here are some techniques that speed up acquisition:

- **Adapt inplane resolution**
  Adapt the inplane resolution to your needs, for example a well accepted pixel resolution for region drawing is 1–1.2 mm. This may be too coarse when a partial volume effect will blur the contrast of a tiny structure, for example the prostate membrane, but in general global tumors or organs will be recognized with sufficient quality. Lowering the resolution coincides with speeding up the measure time together with a higher resulting SNR in the acquired image.

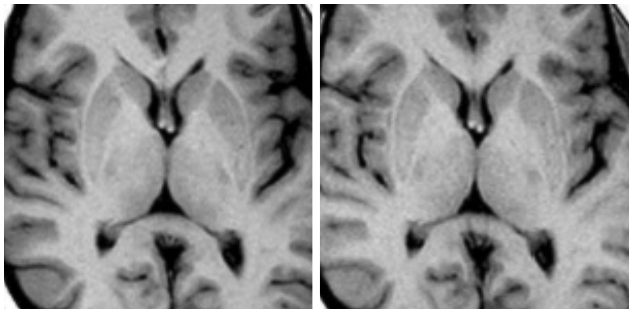


Figure 21: Measuring faster at the same resolution.
Image comparison: (left) FOV phase 100% and (right) 50%

  - **Example 1:** Change the scanned matrix from 256^2 to 128 x 256. This will lead to images with a nominal doubled pixel volume (= double SNR) at 50% scan time. The resulting images in this are still 256^2, but the phase-encoding direction is interpolated from 128 to 256.
  - **Example 2:** Change the matrix from 256^2 to 192^2. This will lead to images with an 1.8 times larger pixel volume, but the resolution in the images is lowered in both directions. The scan time is reduce by 25% and SNR is increased by 80% allowing further techniques for measurement time reduction such as parallel imaging.

- **Measuring faster at the same resolution**
  At half the FOV and half the number of phase-encoding steps, the voxel size remains unchanged and so does the resolution. SNR is decreased. So, a rectangular FOV is an acceptable choice for accelerating image acquisition.

What is the tradeoff:
SNR and/or resolution are affected.

Thin, contiguous slices

RT need:
Accuracy in target and OAR delineation in all dimensions during treatment-planning calls for contiguous slices.

How to achieve it:
- **In 2D:** Interleaving acquisition with an overlap of two slab-groups (“negative distance factor”). This comes standard with the RT Dot Engine (please see reference 1). In Brain stereotactic, Head & Neck and Pelvis RT Dot Engines, T2w protocols contain 2 interleaved slab groups resulting in e.g. 2 mm contiguous slices with high in-plane resolution. These images can therefore be used for contouring in sagittal or coronal views. 2D scanning can largely benefit from new acceleration techniques such as simultaneous multi-slice, mainly iterative denoising, namely Deep Resolve Gain. In the RT Dot library, protocols including such techniques are offered with even thinner contiguous slices and result in more effective reconstructions in all planes.
- **In 3D:** In Brain, Head & Neck, Pelvis RT Dot Engines, isotropic 3D T1w, T2w, T2w FLAIR TSE contrasts are offered with slice thickness in the order of a millimeter.

The sagittal 3D volume acquisitions can be then reformatted to the axial plane, according to the requirements of your TPS. Furthermore, the protocol T1w VIBE Dixon for synthetic CT generation generates 2 mm contiguous slices.
3D TSE volume acquisition combined with Compressed Sensing reconstruction techniques are available for Head& Neck and Pelvis RT Dot Engines for short acquisition times. Therefore, all reformatted images benefit from thin, high resolution isotropic slices.

What is the tradeoff:
When the interslice gap is reduced in 2D acquisitions, there is a potential introduction of crosstalk. New acceleration techniques, see above, such as simultaneous multi-slice, iterative denoising, namely Deep Resolve Gain, Compressing Sensing for 3D volumes and high channel coils, e.g., Ultraflex 18, support the acquisition of high resolution or isotropic protocols either quicker and/or with higher SNR for thin slice acquisition.

Coverage along the superior-inferior patient axis

RT need:
Treatment plan evaluation requires all anatomy of interest (targets as well as OAR) to be available for dose calculation to take place. Particularly in the case of parallel organs, where the dose received in a certain percentage of the total volume matters, it is important to acquire images over the whole organ anatomy. As a result, the protocol parameters that define the extent of the field of view (FOV) and resolution need to be carefully selected.

How to achieve it:
- Specify the FOV and acquisition matrix such that the whole anatomy of interest is included. For lengthy target volumes along the superior-inferior direction such as the spine, consider using multi-stage imaging.
- Enable 3D distortion correction to minimize geometric distortion at the outer edges of the FOV.

What is the tradeoff:
Acquisition time. Two stage scans may show smaller gaps at the section crossing, as a two stage measurement will lead to individual Frequency adjustments in the stage and potentially this could lead to spatial steps. If 2 transversal scans are in an already scanned coronal or sagittal scan, the same frequency can be copied into the 2 scans. You should make sure that combining multi-stage scans are performed with high bandwidth (general experience: > 350 Hz/pixel) to ensure that those pixels shifts are less than a third of an image pixel.

Inclusion of external patient contour

RT need:
For treatment planning to take place, it is required that all tissues that the radiation beams will traverse are included in the dose calculation and that they are accurately represented in terms of geometry. As a result, at least one of the acquired MR image sets should contain all anatomy up to the patient surface and including the immobilization device(s) used. The external surface should be subject to as little geometric distortion as possible. This is of particular importance in the case where no CT is used for treatment-planning ("MR-only treatment-planning").

How to achieve it:
- Select the FOV such that it covers the whole of the external surface for at least one acquisition.
- Enable 3D-distortion correction, to minimize geometric distortion at the outer edges of the FOV.
  (Note: if the RT-Planning Add-in is active, meaning attached to the protocol, this distortion correction is in the background without further notification. This is embedded in the RT Dot Engine.)
- Employ local surface coils to receive the MR signal and reconstruct the image.

What is the tradeoff:
Local surface coils are generally lightweight but can sometimes distort the external contour. You can employ coil holders that lift the body flex coils, however this increases the distance to the patient with a respective small loss in signal. Acquisition time is also increased to cover the whole patient volume.

Geometric Accuracy

RT Need:
Geometrically distorted images will affect the localization of the target volumes and the organs at risk with a knock-on effect on the quality of the resulting treatment plan. Furthermore, in the case of MR-only planning the resulting DRR, which will be used to set up the patient at the linear accelerator, may introduce systematic errors during treatment.

How to achieve it:

- Follow the MR scanner's user instructions.
- Carefully screen all patients for metallic masses, consider implants. Select carefully protocols/sequences which allow artifact reduction if large distortions were previously observed owing to patient specificities e.g. implants, air cavities, etc.
- Select MR imaging strategies according to patient conditions, to carefully balance the benefits of prolonged measurement times against artifacts from involuntary motion.
- Apply synchronization to physiological motion (breathing, heart) where necessary.
- Invest the time to shim the B_0 field homogeneity in challenging anatomic situations.
- Select readout bandwidth at double the fat-water shift where necessary.
- Enable distortion correction according to MR scanners user instructions.
- Position the treatment target in the magnet isocenter.
- Use caution when selecting single shot Echo Planar based imaging (DWI, fMRI) in anatomic regions with large susceptibility variations. Consider using the RESOLVE sequence where available, which has been shown to reduce susceptibility artifacts.

What is the tradeoff:
Training and experience in setting up MR imaging protocols for different anatomic areas must be established for all MR users.

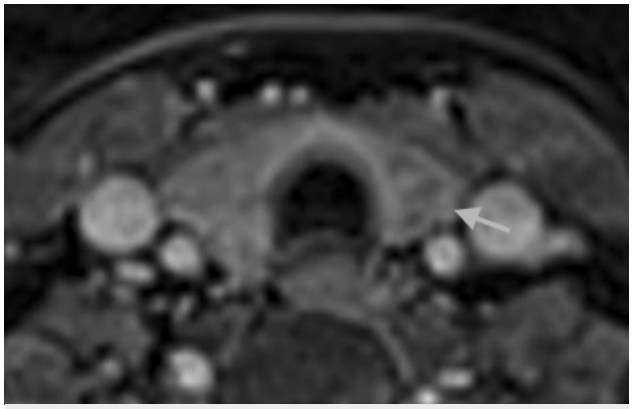
Respiratory motion management

RT need:
Depending on the clinical problem, there may be a need to either freeze the motion, or to fully analyze it in order to determine the optimal treatment strategy.

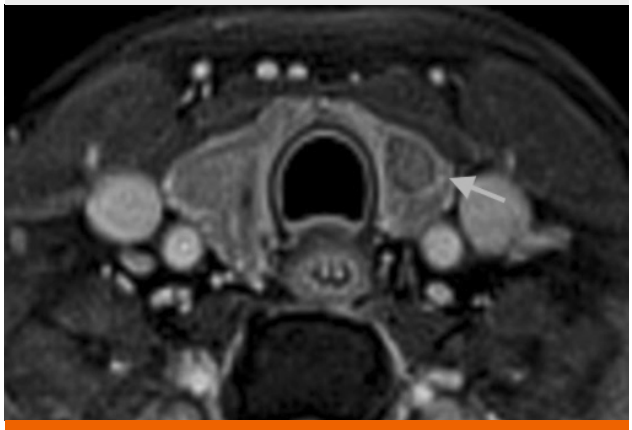
How to achieve it:

- Carefully position the patient according to application instructions.
- Follow the MR scanner's user instructions for physiological gating.
- Use breath hold techniques that take into account the patient's condition, consider training the patient on how to follow breathing instructions.
- Use fast MR imaging techniques like FREEZEit.
- Use "4D MRI" free-breathing acquisitions (RT respiratory self-gating) to analyze the movement of organs over the breathing cycle.

What is the tradeoff:
Respiratory gating can significantly prolong MR measurement times.



Conventional



FREEZEit – StarVIBE

Figure 22: Fast MR Imaging technique FREEZEit – Helps address involuntary motion throughout the body
Images courtesy of University of Arizona Medical Center, Tucson

[1] *The MRI restrictions (if any) of the metal implant must be considered prior to patient undergoing MRI exam. MR imaging of patients with metallic implants brings specific risks. However, certain implants are approved by the governing regulatory bodies to be MR conditionally safe. For such implants, the previously mentioned warning may not be applicable. Please contact the implant manufacturer for the specific conditional information. The conditions for MR safety are the responsibility of the implant manufacturer, not of Siemens Healthineers.*

References:

1. *Thörmer G, Requardt M. RT Dot Engine. MReadings: MR in RT (2)2016:18-20.*
2. *Liney GP et al., Br J Radiol. 2015 May; 88(1049): 20150034*

3. Safety

The following information summarizes the most important MR safety aspects, as documented in the related MAGNETOM user documentation including the system owner manual, which is to be followed by all users of MAGNETOM systems.

3.1 MRI safety

Main Magnetic Field

The strong magnetic field of the MR scanner affects the tissue as well as all other magnetic material in the vicinity of the magnet. The following biological effects have been studied.

Short-term effects:
These biological effects occur either in the magnetic field or shortly after leaving it, hence the name "short-term". These mostly occur at field strengths above 3T, and include the following:

- Dizziness
- Stomach upsets
- Metallic taste

Long-term effects:
To date, no biological long-term effects have been observed.

Magnetohydrodynamic effects:
The distribution of surface currents present during an ECG alters in the magnetic field. Cardiac functions are not affected by it, only the observed ECG signal is.

Time-varying Field

The gradient field could cause peripheral nerve stimulations.

RF Field

Following risks/effects have been studied in relation to RF field.

Tissue Warming:
RF electromagnetic waves generate currents in electrically conducting tissue and stimulate molecules in the tissue. The results of this behavior include:

- Resulting oscillations lead to tissue warming.
- Increase in temperature is usually less than 1 °C.

Specific absorption rate:
The specific absorption rate (SAR) is the RF output absorbed per time unit and kilogram. For safety reasons, the RF power emitted by the system into the body is monitored and the respective SAR values are limited accordingly.

The IEC limit values are

- 4 W/kg (whole body),
- 4–10 W/kg (partial body),
- 20 W/kg (local SAR head, trunk), and
- 40 W/kg (local SAR extremities).

Increase in RF field close to the coil:
This effect is observed if the receiving RF coil is in resonance with the transmitter. This increase in field strength is of particular concern when it occurs close to the eyes. To eliminate this effect, the system decouples the receiver coil during transmission.

Local Warming:
The RF field may induce AC currents in metal implants[1] or cables routed close to the patient (for example, ECG cables), resulting in local warming.

Cooling System

The magnet is filled with liquid helium as a coolant. Following installation, it is adjusted to the desired operating field strength. During normal operation, the magnet does not lose helium. Under special conditions – power failure, malfunctions of the cold head and maintenance activities – liquid helium must be refilled by Siemens Healthineers Customer Service or specially qualified personnel. Following risks have been observed with regards to the coolant:

- **Helium-related risks**
  Liquid helium presents the following properties that may result in hazardous conditions when not handled professionally:
  - Extremely cold – causes frostbites when it comes in touch with skin.
  - Oxygen in ambient air is displaced during boil-off – risk of asphyxiation.
- **Storage risks**
  Non-magnetic coolant containers must be used for the helium. Furthermore, it is prohibited to store flammable material in the vicinity of containers filled with coolants. Refer to your safety user guide for more information on the protocol of maintenance and repair.

[1] *The MRI restrictions (if any) of the metal implant must be considered prior to patient undergoing MRI exam. MR imaging of patients with metallic implants brings specific risks. However, certain implants are approved by the governing regulatory bodies to be MR conditionally safe. For such implants, the previously mentioned warning may not be applicable. Please contact the implant manufacturer for the specific conditional information. The conditions for MR safety are the responsibility of the implant manufacturer, not of Siemens Healthineers.*

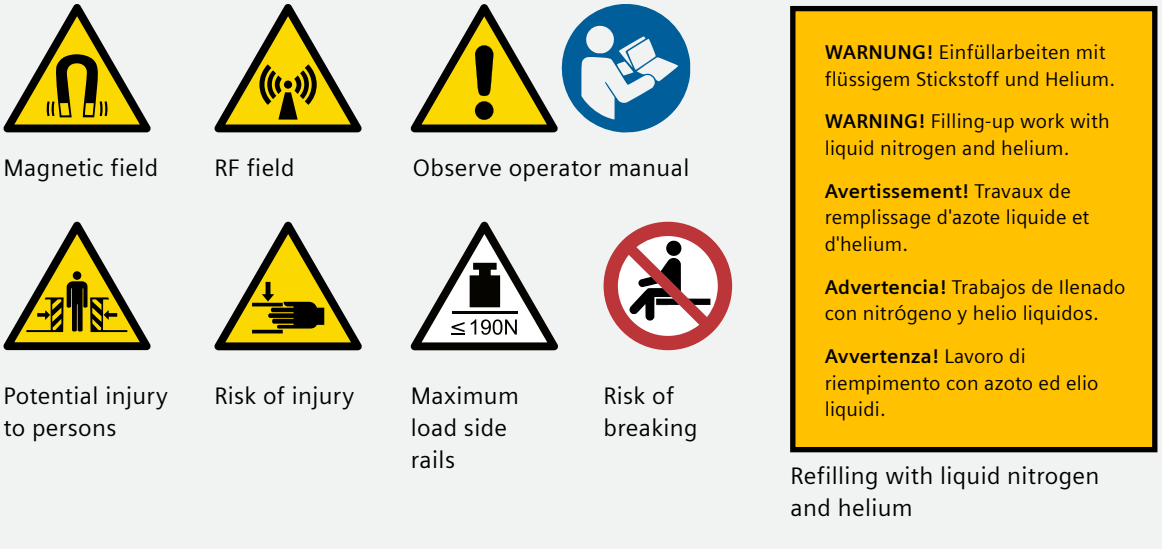


Figure 23: Warning signs

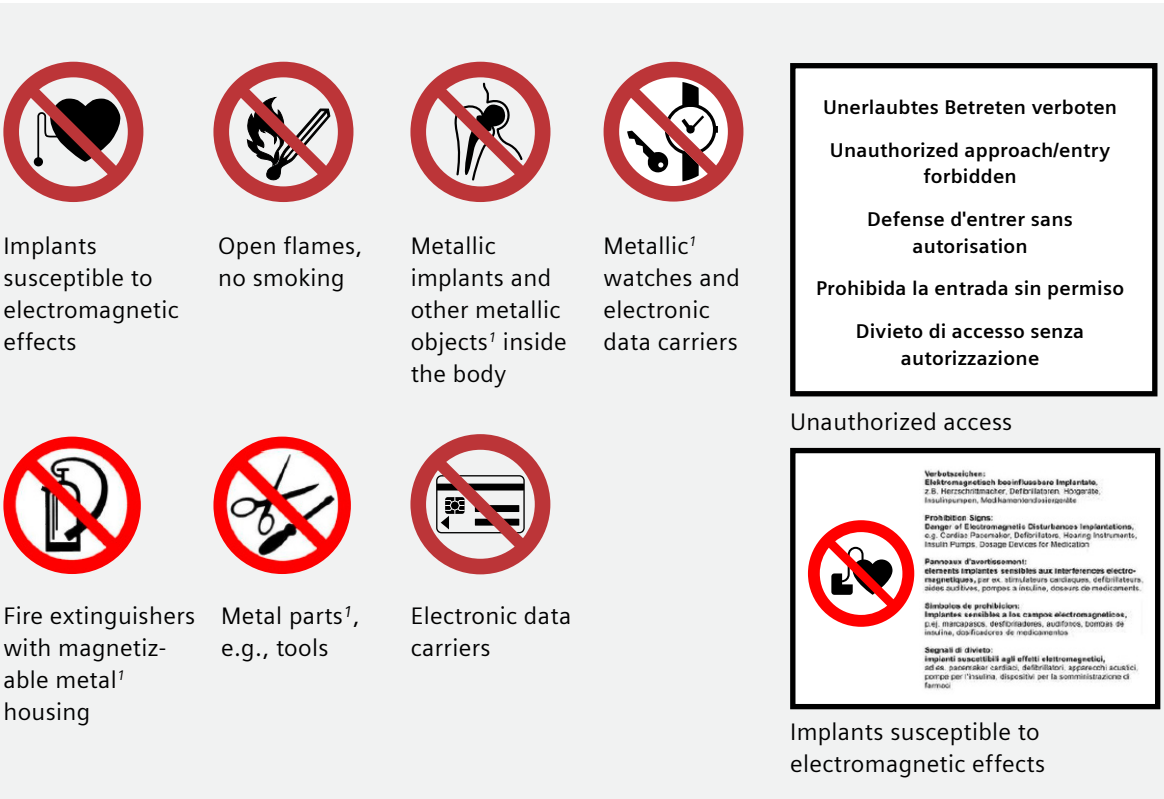


Figure 24: Prohibition signs

Figure 25: (left) Hearing protection mandatory, (right) Non-ionizing radiation

[1] *The MRI restrictions (if any) of the metal implant must be considered prior to patient undergoing MRI exam. MR imaging of patients with metallic implants brings specific risks. However, certain implants are approved by the governing regulatory bodies to be MR conditionally safe. For such implants, the previously mentioned warning may not be applicable. Please contact the implant manufacturer for the specific conditional information. The conditions for MR safety are the responsibility of the implant manufacturer, not of Siemens Healthineers.*

3.2 Staff safety

MR workers are individuals (e.g., operator, further personnel) who work within the controlled access area or MR environment. The system owner is responsible for ensuring that only trained and qualified MR workers and physicians are working on the MR system, so that they can perform all their tasks safely and efficiently, and in a way that minimizes their exposure to the electromagnetic field. In addition, the MR system may only be used as intended. The system includes a key switch to prevent unauthorized switch on.

MR personnel must read and understand the operator manual, paying special attention to the safety chapter, before working with the MR system. The safety hints regarding the magnetic fields must also apply to MR workers. An understanding of MR safety is especially important for those individuals who only work in the MR environment occasionally.

For further information, see: Operator manual of your MAGNETOM system.

3.3 Patient safety

Ferromagnetic materials are attracted by the MR magnet. This constitutes a potential source of hazard to the patient or the operating personnel.

Metal[1] parts in the patient are also a source for hazard. Metal splinters, clips, screws, or injection needles may be moved in the body by the magnetic forces.

Some electrical implants such as pacemakers or hearing aids are especially critical. The safety / exclusion zone for pacemakers has been established at a field strength of 0.5 mT outside the magnet.

Functionality of hearing aids may be compromised in strong magnetic fields.

Potentially hazardous materials	Examples	Effect of magnetic field
Metal parts in patient	Metal splinters, clips, screws, or injection needles	Materials may be moved in the body by the magnetic forces.
Electrical implants	Pacemakers	The safety / exclusion zone for pacemakers is at a field strength of 0.5 mT outside the magnet.
	Hearing aids	Functionality may be compromised.

Some patients may be unable to communicate potential overheating effects (for example, small children[2], seriously ill, paralyzed, unconscious, sedated, or handicapped patients) **→ Pay special attention when you examine patients at risk, for example, monitor vital parameters.**

To lower the effects of gradient fields or RF fields, ensure the patient is positioned with distance (5 mm) to magnet tunnel. Care must be taken that no loop forming happens, e.g. by avoiding crossing the hands. SAR can be further decreased by increasing TR, this however prolongs the overall acquisition time.

Ensure that the patient does not wear clothing that is wet or dampened by perspiration.

RF field may heat up or ignite synthetic blankets and covers containing metallic[1] threads during the measurement, causing patient burns **→ Use only covers made of paper, cotton or linen.**

Never use RF blankets or other conductive sheets within the magnet bore, as these could also lead to patient burns.

Prior to the examination, inform the patient about the possible occurrence of dizziness, nausea and light-headedness.

MR compatible and conditional devices in RT → practical examples of items in RT

The instructions for use of the respective manufacturers must be consulted when it comes to imaging patients with (immobilization) devices that are particular to radiation therapy. These may include but are not restricted to:

- Stereotactic frames
- Brachytherapy applicators
- Prostate brachytherapy seeds
- Thermoplastic masks
- External skin markers

[1] *The MRI restrictions (if any) of the metal implant must be considered prior to patient undergoing MRI exam. MR imaging of patients with metallic implants brings specific risks. However, certain implants are approved by the governing regulatory bodies to be MR conditionally safe. For such implants, the previously mentioned warning may not be applicable. Please contact the implant manufacturer for the specific conditional information. The conditions for MR safety are the responsibility of the implant manufacturer, not of Siemens Healthineers.*

[2] *MR scanning has not been established as safe for imaging fetuses and infants **less than** two years of age. The responsible physician must evaluate the benefits of the MR examination compared to those of other imaging procedures.*

References:

1. *Magnets, Spins and Resonances, available* **here.**
2. *MAGNETOM Family: System Owner Manual, available* **here.** *Please note that this page is not open access.*

MR Commissioning and tests following major upgrades

1. Magnetic Field Homogeneity

Siemens Healthineers' service performs a magnetic field homogeneity procedure as part of the installation process. It is done to decide how much and where to place a small amount of additional iron plates into so-called "shim pockets" (structures within the gradient coil) in order to achieve the desired homogeneity. This procedure is called passive shimming and accounts for external influences on the main magnetic field. Since those influences normally do not change during the system's lifetime, this procedure is to be repeated only in case, e.g., additional iron is put into the walls adjacent to an installed MAGNETOM system. In all other cases, a shimming report is produced at the end, which you may request for your records.

Alternatively, this service (shim plot, acquired with the "array shim device" by a Siemens Healthineers field service engineer) can be offered as an additional service post-installation.

All other influences on the main magnetic field homogeneity (e.g., coming from the patient) are addressed by a separate process, called electrical shimming. It is realized by running a controlled amount of electric current as an offset value through the 3 orthogonal coils of the gradient coil, and/or (if installed) through the optional additional 2nd order non-linear shim coil[1] (makes part of the gradient coil, too). This process is fully automatized and part of the patient-individual adjustments. It can also be run under operator control.

1.1 Shimming reports

The specification of the main magnetic field (B_0) homogeneity is taken from the MAGNETOM Skyra datasheet.

The values highlighted in the orange box within Figure 26 show the standard deviation V_{rms} (volume root-mean-square) measured with highly accurate 24 plane plot method (20 points per plane) on spherical phantoms[2] with diameters greater than 35 cm.

Magnet system

General	
Superconducting magnet	Short bore, patient-friendly design, high homogeneity 3 Tesla with 70 cm Open Bore design
	Easy siting due to AS (Active Shielding) and E.I.S. (External Interference Shielding) magnet technology
Magnet parameters	
Operating field strength	3 Tesla
Magnet type	Superconductor
Field stability over time	< 0.1 ppm/h
Weight (with cryogens)	5755 kg
Magnet length	1630 mm ± 2 mm
System length cover to cover	1730 mm

[1] *For details please refer to: MR Overview – 1.3 Influence of the patient inside the bore – B_0 and B_1 shimming (page 12).*
[2] *Please refer to Phantom Setup (Appendix 1) for more information on the phantom and setting it up.*
[3] *Incl. shim coils, gradient coil, RF body coil*

Homogeneity (based on highly accurate 24 plane plot)		
10 cm DSV	Guaranteed	0.01 ppm
	Typical	0.003 ppm
20 cm DSV	Guaranteed	0.05 ppm
	Typical	0.03 ppm
30 cm DSV	Guaranteed	0.3 ppm
	Typical	0.2 ppm
40 cm DSV	Guaranteed	1.4 ppm
	Typical	1.2 ppm
50 x 50 x 45 cm^3 DEV	Guaranteed	4.0 ppm
	Typical	3.6 ppm

Figure 26: Vrms values taken from MAGNETOM Skyra datasheet
In compliance with the German "Qualifikationsvereinbarung".

Standard deviation vrms (volume root-mean square) measured with highly accurate 24 plane plot method (20 points per plane).
Standard active shim with 3 linear channels (1st order) and 5 non linear channels (2nd order).

DSV = Diameter spherical volume;
DEV = Diameter elliptical volume (x, y, and z directions).

Sphere diameter: 0.1 m (x = 0; y = 0; z = 0)		
Type	**Spec (ppm)**	**Tolerance: 0.000 ... 0.010**
vrms	0.002	

Sphere diameter: 0.2 m (x = 0; y = 0; z = 0)		
Type	**Spec (ppm)**	**Tolerance: 0.000 ... 0.050**
vrms	0.018	

Sphere diameter: 0.3 m (x = 0; y = 0; z = 0)		
Type	**Spec (ppm)**	**Tolerance: 0.000 ... 0.300**
vrms	0.154	

Sphere diameter: 0.4 m (x = 0; y = 0; z = 0)		
Type	**Spec (ppm)**	**Tolerance: 0.000 ... 1.400**
vrms	1.155	

Figure 27: Vrms values for DSV = 40 cm, DSV = 45 cm and DSV = 50 cm as taken from a shim report on a MAGNETOM Skyra System. These can be compared against the specification of the main magnetic field (B_0) homogeneity from the MAGNETOM datasheet, such as the one specified above.

2. Gradient linearity

2.1 Rationale

A gradient coil deliberately deviates from perfect linearity towards the edges of the field of view. This is to make MR scanning faster (electrical inductance of the coil in case of perfect linearity is much higher, making the gradient switch much slower), and to avoid potentially painful examinations. A controlled amount of gradient non-linearity helps to reduce dB/dt rate induced nerve stimulations and keeps the inductance low for fast switching.

The gradient coil allows for small but predictable changes in the main magnetic field. This allows the resonance frequency of protons to vary as a function of position, thus allowing the spatial encoding of the MR signal. As a result, gradient nonlinearities, which are introduced for the reasons specified above, must be accounted for through some distortion correction scheme, for correct spatial encoding of the MR signal. The motivation behind the test is to examine the quality of distortion correction algorithms that address gradient nonlinearity and make part of the MR image reconstruction.

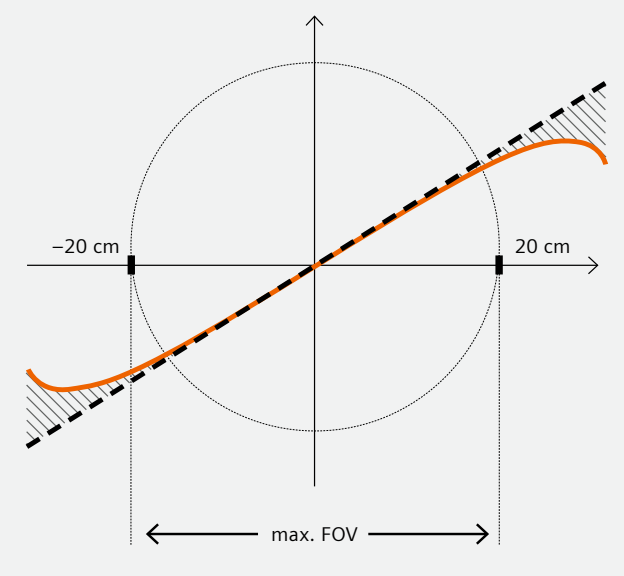


Figure 28: Gradient nonlinearity

2.2 Workflow

A phantom with a diameter that extends into the expected nonlinear area of the gradient system is suitable to perform the test. The workflow shown here is with a 2D MR distortion phantom. However, many more are commercially available and can be used for commissioning a MRI.

The recommended approach for evaluating the performance of the distortion correction algorithm is by using the reverse gradient technique.

Rationale behind reverse gradient technique

MR imaging of 2D (slices) or 3D (volume) regions usually employs pulse sequence schemes where spatial directions are encoded by either frequency or phase of the acquired MR resonance signal. MR raw data dimensions react differently on system imperfections and patient induced signal variation. In order to test the influence of readout or phase encoding direction on the depiction of, e.g., small details it is sometimes proposed to acquire MR images of identical resolution phantoms under variation of the direction of frequency and phase encoding gradient. Please refer to Reference #1 of this section. A reversal of the polarity of the readout gradient will result in distortions related to inhomogeneities of the main magnetic field B_0 be reversed along this axis, while distortions from gradient nonlinearity remain untouched.

User Interaction

The current phase-encoding direction (direction of the phase encoding gradient) is indicated in the main orientations of the whole-body patient coordinate system. With the “Phase Encoding Dir.” parameter, the phase encoding and readout direction can be swapped. Using this method allows the user to prevent aliasing artifacts in the phase-encoding direction or change the direction of flow and motion artifacts.

The “Phase Encoding Dir.” selection list provides only possibilities that would be useful during current orientation.

The reverse gradient technique is easily accomplished by inverting the phase-encoding direction A >>> P in the **Routine** tab card of many MAGNETOM pulse sequences, which results in a reversed polarity of the readout gradient, too.

Figure 29: Reverse Gradient Technique

Phantom Setup

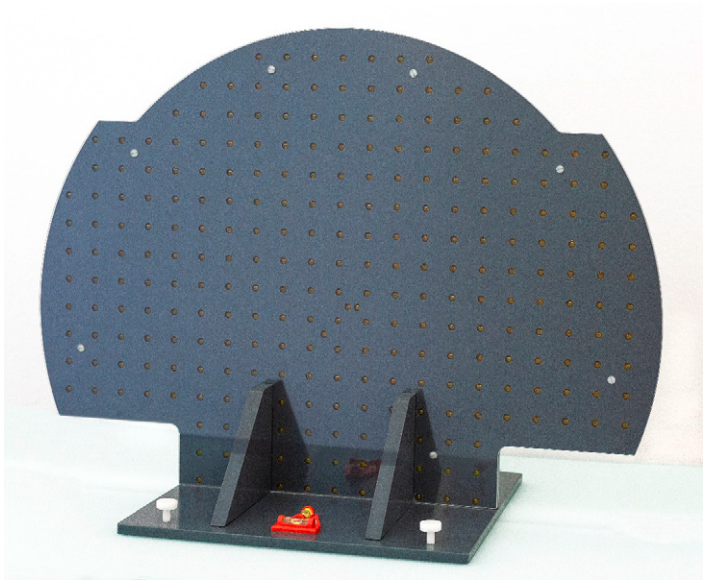


Figure 30: 2D MR distortion phantom[1]

Figure 31: Phantom setup

[1] *The product/feature (mentioned herein) is not commercially available. Due to regulatory reasons its future availability cannot be guaranteed.*

Performing the scan

1. Acquire sample MR images with your chosen distortion phantom, both with and without distortion correction. See Operator Manual – Measurement Parameters, see resolution/filter parameter card. Images as shown in Figure 32 should be obtained.

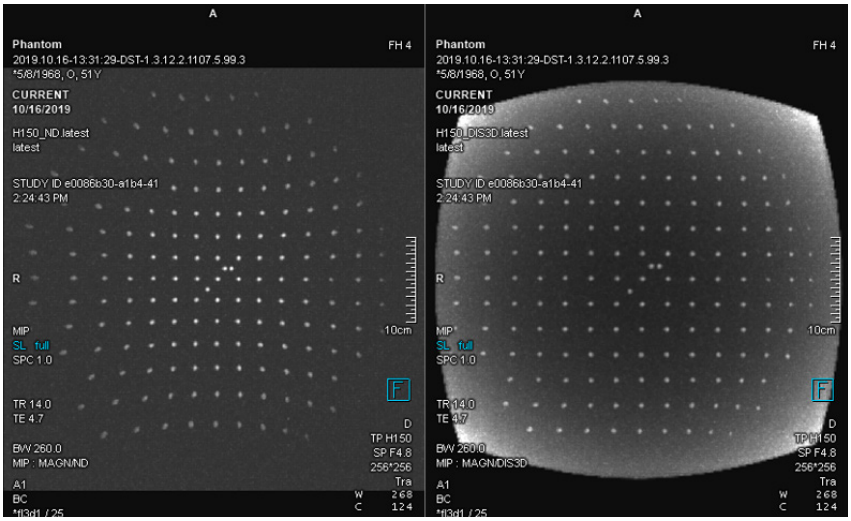


Figure 32: Sample MR images, acquired with a 2D MR distortion phantom[1], without (left), and with (right) distortion correction

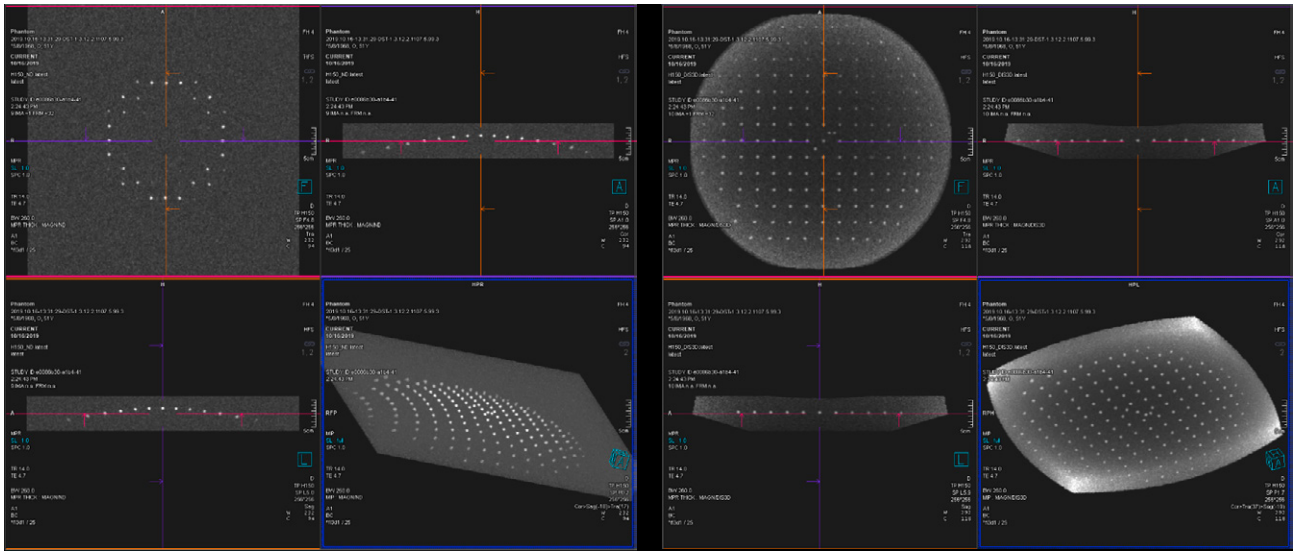


Figure 33: Sample MR images in all 3 cardinal plane orientations acquired with 2D MR distortion phantom[1] without distortion correction switched on

[1] *The product/feature (mentioned herein) is not commercially available. Due to regulatory reasons its future availability cannot be guaranteed.*

2. A comparison of how well the distortion correction algorithm performs can be done in any image registration application. Here we have carried out the registration of CT and MR images within *syngo*.via RT Image Suite.

   a. Ground truth information can be obtained using CT.

   b. Shown in Figure 35 is a comparison of residual deviations between CT and MR, both without and with distortion correction switched on.

   c. Rigid registration was performed between the CT and MR images to visually compare the performance of the distortion correction algorithm, as shown in Figure 36.

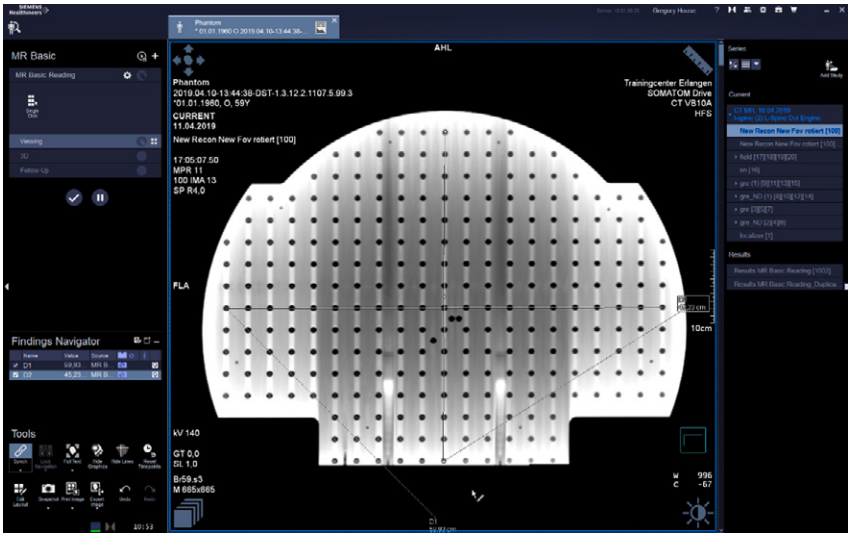


Figure 34: Ground truth information via CT scan of 2D MR distortion phantom[1]

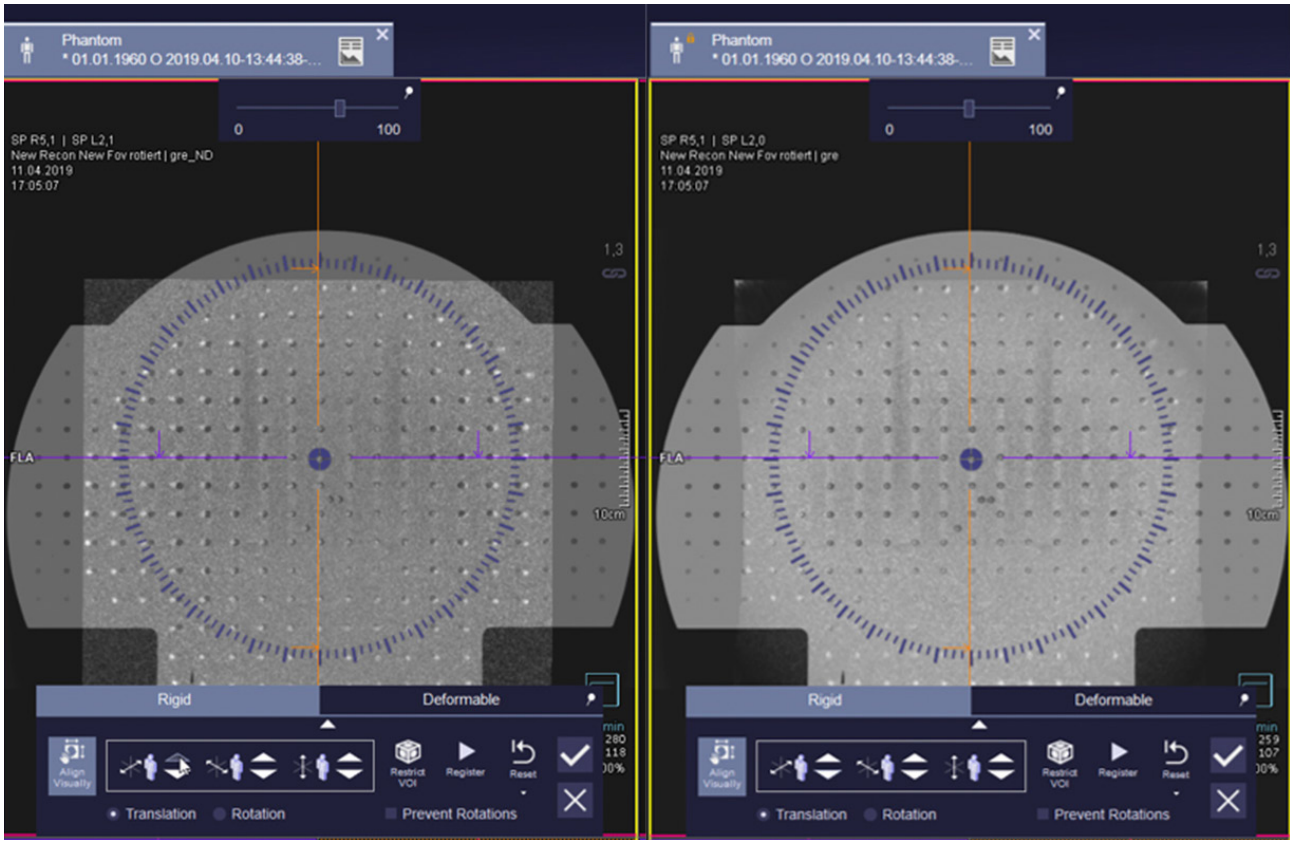


Figure 35: Visual comparison of residual distortion, visualized on rigidly fused CT and MR, without (left) and with (right) distortion correction switched on, in *syngo*.via RT Image Suite

[1] *The product/feature (mentioned herein) is not commercially available. Due to regulatory reasons its future availability cannot be guaranteed.*

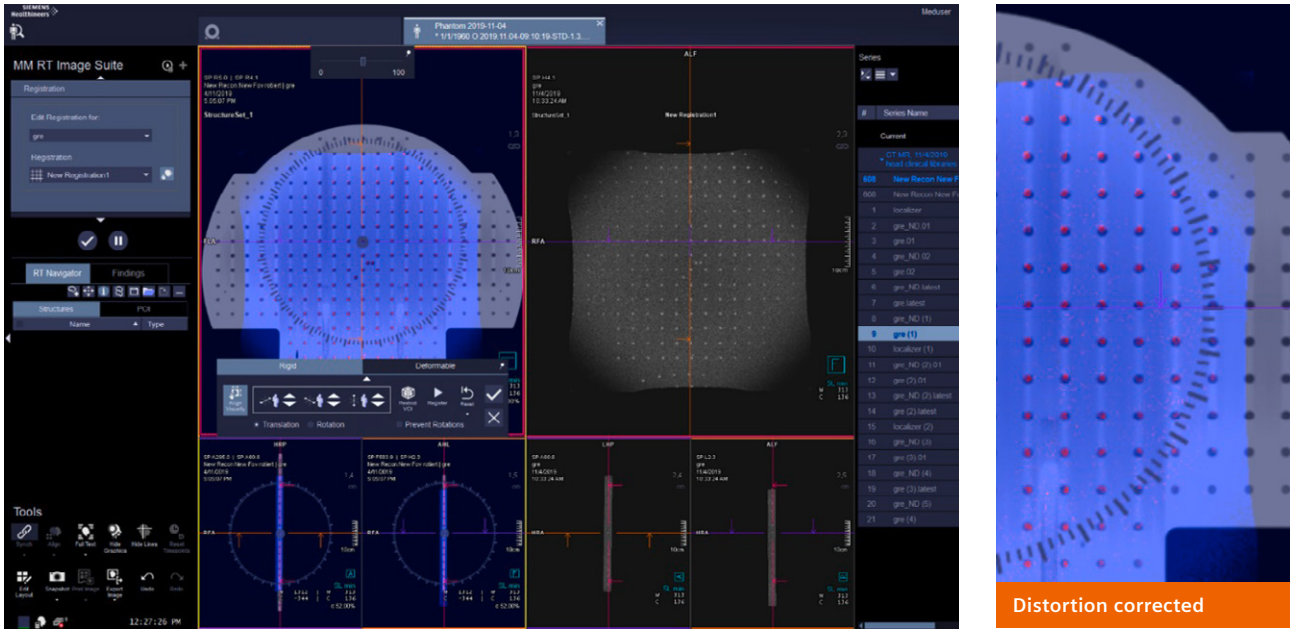


Figure 36: Rigid registration within *syngo*.via RT Image Suite, of MR and CT images, for visual comparison

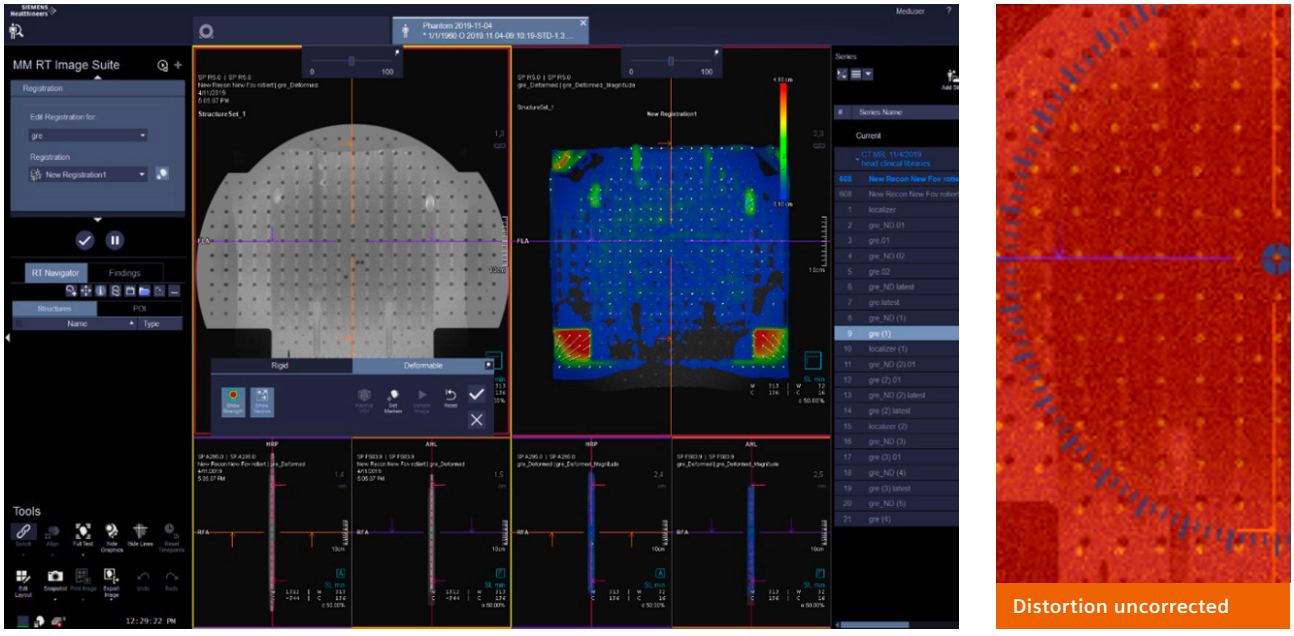


Figure 37: Deformable registration within *syngo*.via RT Image Suite, of MR and CT images, for visual comparison

3. RF Coil Evaluation

To evaluate the performance of an RF coil during commissioning, its signal-to-noise ratio (SNR) can be measured. Several SNR measurements can be recorded, and these should serve as baseline measurements for calculating standard deviation. This standard deviation can subsequently be employed as a benchmark during the regular System QA to ensure that the coil is performing optimally.

3.1 Rationale

Lesion conspicuity in MR imaging is greatly dependent on signal-to-noise and contrast-to-noise of the underlying MR measurement. Pulse sequence parameters and MR echo formation technique determine tissue contrast, whereas signal strength is mainly influenced by the field strength of the main magnetic field and the quality and proper application of receiving RF coils.

Please refer to section 1.4 Image characteristics of the MR Overview section for details.

3.2 Workflow

Phantom Setup

The following phantom setup is employed to perform the customer coil QA. The choice of phantom will vary depending on the coil undergoing quality assurance.

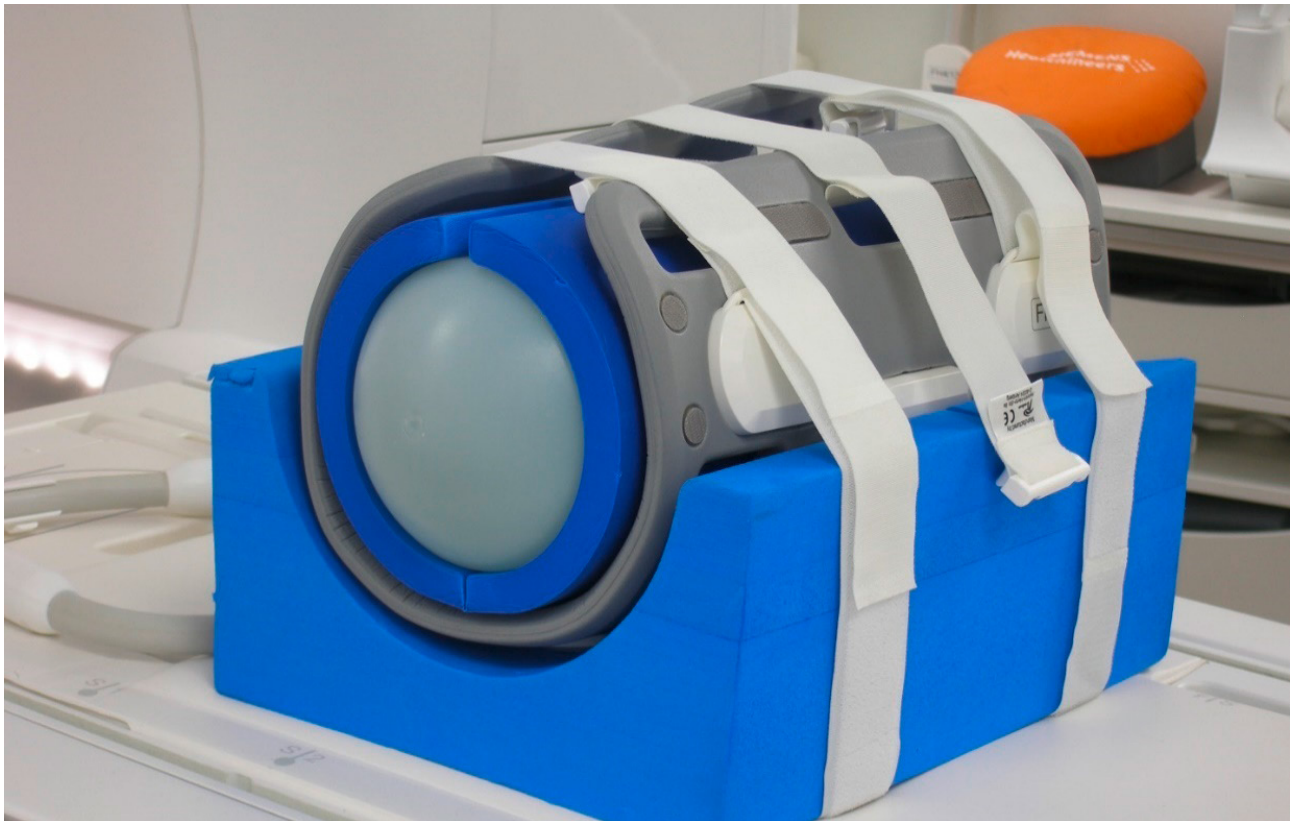


Figure 38: SNR measurement setup for flex coils

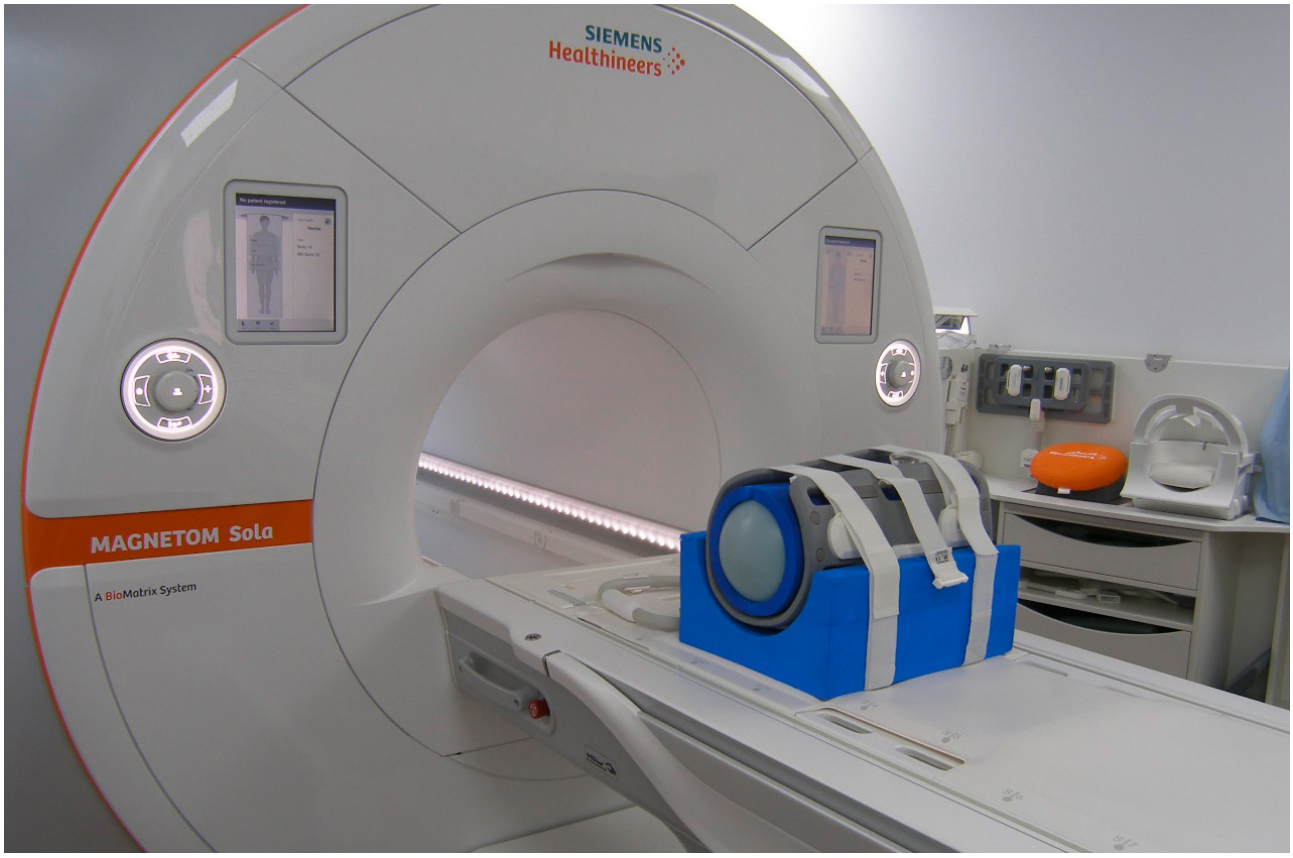


Figure 39: SNR measurement setup for flex coils

Performing the scan

Signal-to-noise measurements can be performed as follows: select a simple pulse sequence, acquire a set of MR images and use the ROI selection tools during image display to quantify the mean signal within the object, relative to the standard deviation of the object-free background. This method is standardized in the NEMA Standards Publication MS 6-2008.

1. Select a simple pulse sequence. For example, the sn sequence from the service sequence folder was used here for demonstration purposes. However, other pulse sequences available in the customer sequences can be used.

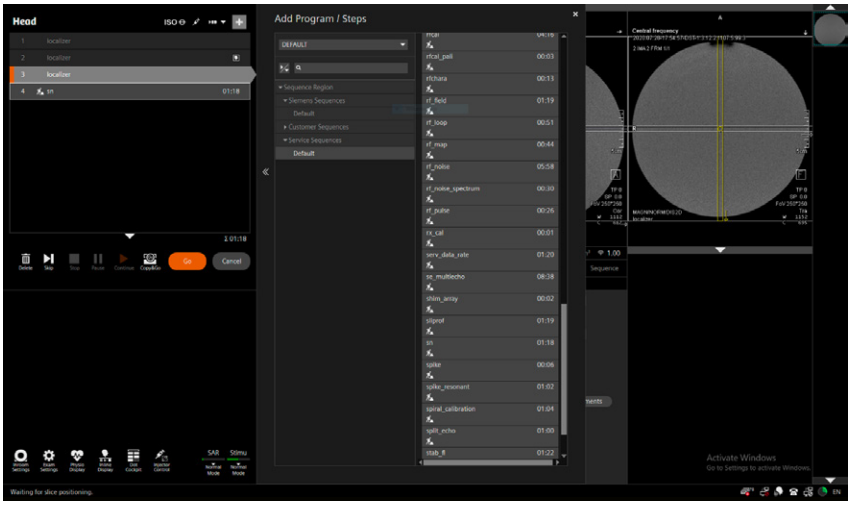


Figure 40: Selection of a sequence

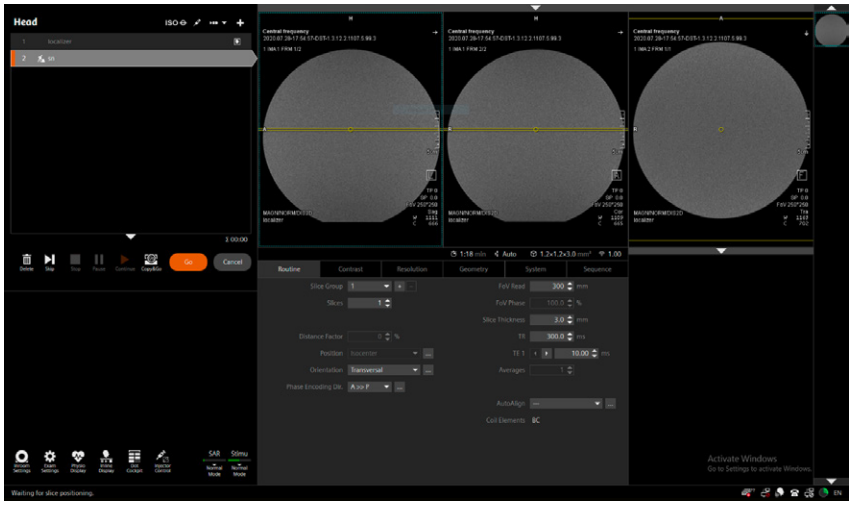


Figure 41: Selection of desired parameters

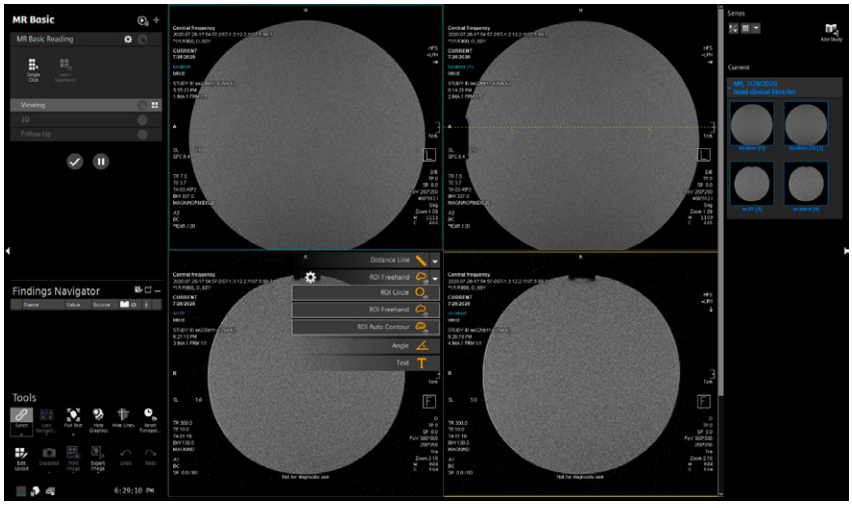


Figure 42: ROI selection tools

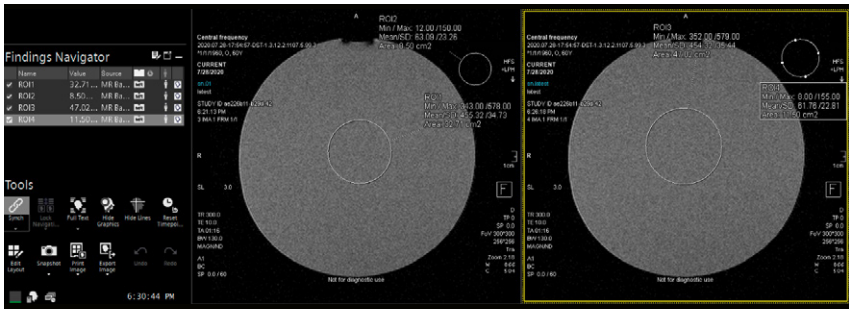


Figure 43: SNR evaluation

2. Select desired parameters and press Go to run the sequence to acquire images of the phantom.
3. Use the ROI selection tools during image display to quantify the mean signal within the object, relative to the standard deviation of the object-free background.
4. Draw ROI circle in the object region as well as in the background. Divide these to get an estimate of the signal-to-noise ratio SNR.

- For example, for the phantom image on the left in Figure 43, ROI1 can be seen as having the following values for mean and SD:
  Mean/SD: 455.32/34.73

  Similarly, for ROI2, which is chosen in the object-free background:
  Mean/SD: 63.09/23.26
  SNR = 455.32 / 63.09 = 7.22

- For the phantom image on the right in Figure 43, ROI3 has the following values:
  Mean/SD: 454.32/35.44

  Similarly, for ROI4 which is chosen in the object-free background:
  Mean/SD: 61.76/22.81
  SNR = 454.32 / 61.76 = 7.35

5. Repeat several of the above measurements to calculate a standard deviation on the SNR measurements using the RF coil.

$$\sigma = \sqrt{\frac{\Sigma(\chi_i - \mu)^2}{N}}$$

σ: Standard deviation
χ_i: Several SNR measurements
μ: Mean of all SNR measurements
N: Total number of measurements

4. External laser to isocenter distance

External laser bridges are operated within the Faraday cage of an MR installation. Siemens MR has certified certain external laser bridges for use with 1.5T and 3T. This is to assure that no negative interference occurs in the combined use of both medical devices. If RF interference would be present, this would appear in the form of image artifacts.

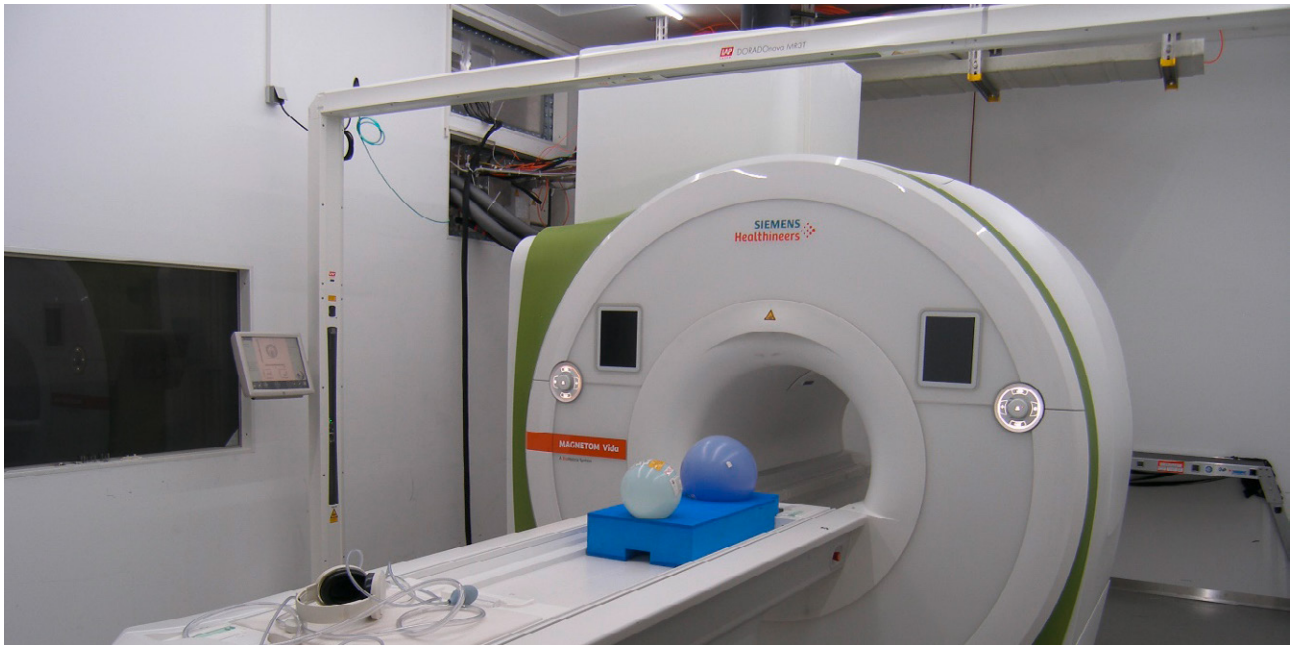


Figure 44: The LAP laser bridge[1] can be visualized here

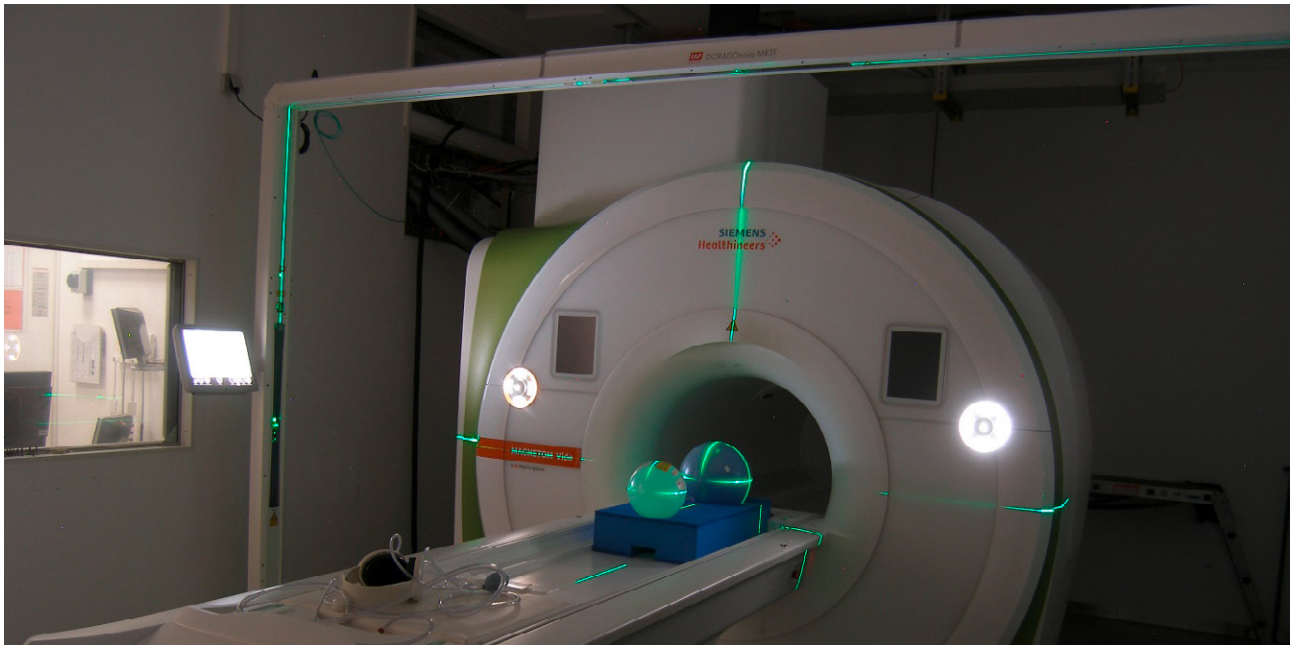


Figure 45: Phantom alignment with external laser bridge[1]

[1] *The information shown herein refers to products of third party manufacturer's and thus are in their regulatory responsibility. Please contact the third party manufacturer for further information.*

4.1 Rationale

If your MAGNETOM system is planned to be used as an MRI simulator, the distance between the external laser marks and the MR isocenter, as defined by its gradient coil needs to be defined for accurate patient positioning.

This involves a length measurement that quantifies the distance between the MR isocenter, and the vertical illumination plan realized by the laser bridge. *syngo*.via RT Image Suite requires this distance to be entered as a configuration parameter.

Note, that there will usually be a distance of typically 9 cm or more, between the internal MAGNETOM system laser and the laser illumination plane of the external laser, dependent on the actual position of the laser bridge relative to the MAGNETOM system.

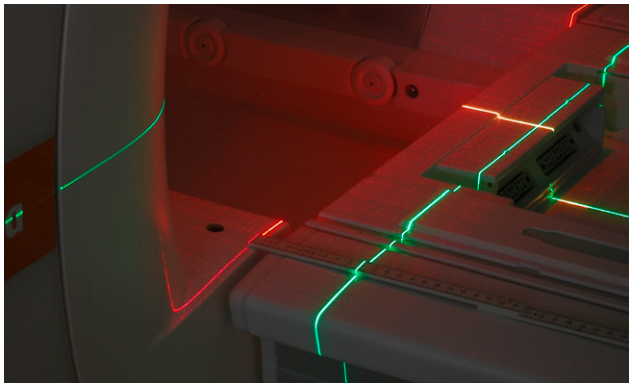


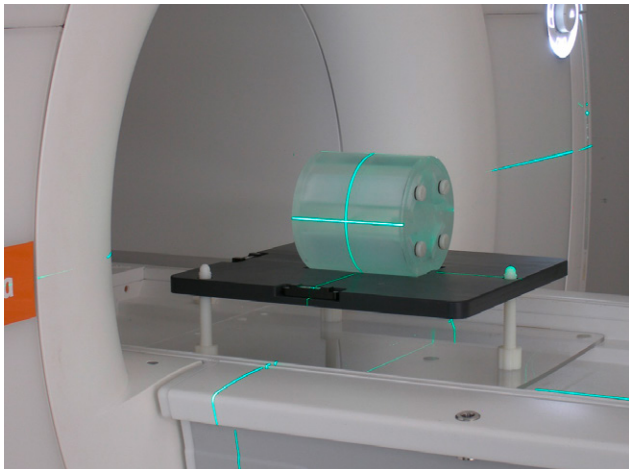
Figure 46: Distance between the MAGNETOM system laser and illumination plane of external laser is visualized to be around 9 cm, as measured by a ruler

4.2 Workflow

Phantom setup

Conventionally, this is performed by the laser manufacturer during installation. However, in case you want to perform or repeat the test, the following text can serve as a guideline.

The distance measurement involves MR images taken with a dedicated phantom (provided by the manufacturer of the laser bridge) that contains internal structures with corresponding marks on its surface. The example shown here was carried out with the Aquarius phantom of LAP. The phantom must be aligned so that the laser planes pass exactly through the grooves on the phantom. The measurement strategy is to position the phantom on the MR patient table such that its internal structure coincides with the isocenter defined by the gradient coil of the MR scanner.[1]



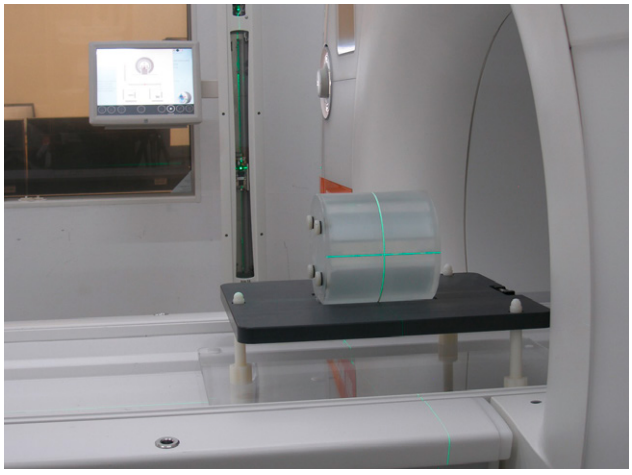


Figure 47: Alignment of LAP Aquarius phantom[1]

[1] *The information shown herein refers to products of third party manufacturer's and thus are in their regulatory responsibility. Please contact the third party manufacturer for further information.*

Performing the scan

1. For details on the relevant protocols, please refer to the installation guide provided by your laser manufacturer.
2. Acquire MR images with the phantom provided by the manufacturer of the laser bridge.
3. For each of the three coordinate axes, select the image where the cross structure is completely visible. Ideally, this should be the slice at position zero (for each of the three axes). In case of any misalignment re-check the initial phantom positioning.
4. The phantom[1] cross must be aligned correctly in the center of each image axis. This is shown in the following set of images for transversal, coronal and sagittal views.
5. When moving the phantom out of the MR scanner into the illuminated plane of the laser bridge, the required travel distance of the patient table is the required calibration distance.

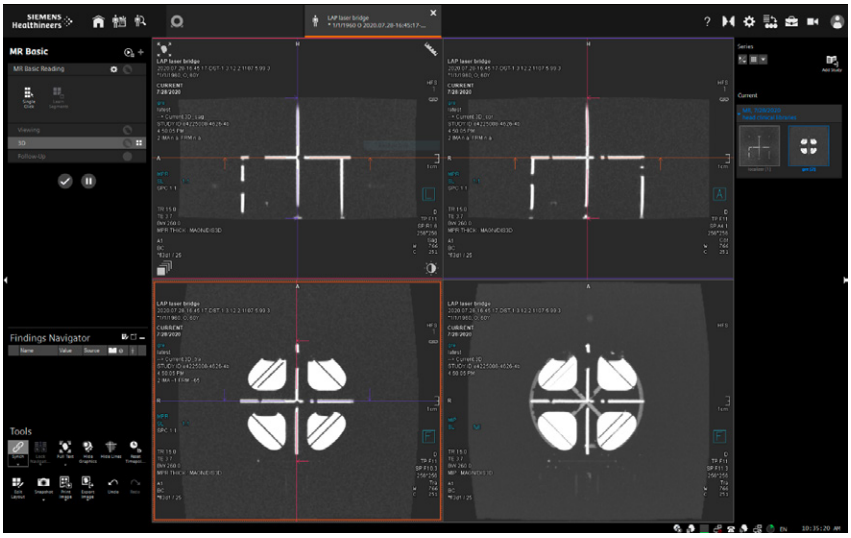


Figure 48: Images with the LAP Aquarius Phantom in each of three coordinate axes

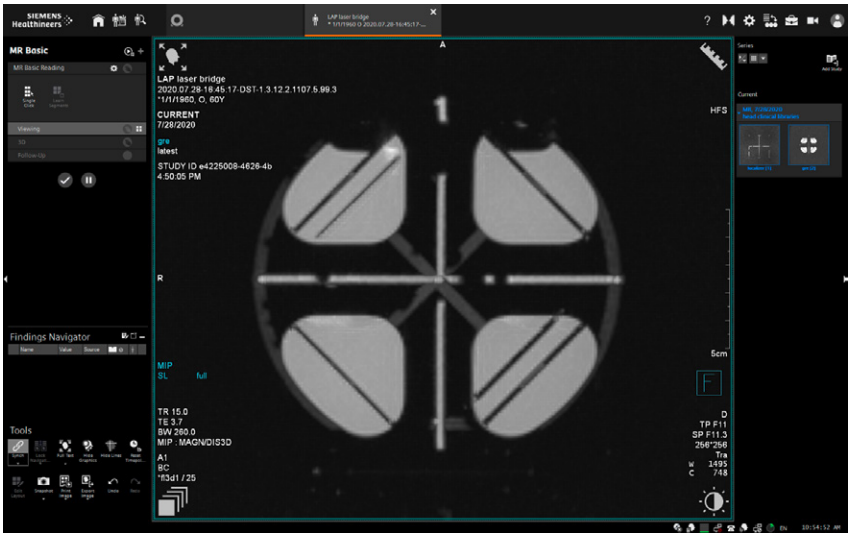


Figure 49: Phantom[1] center point visualization in transversal plane

[1] *The information shown herein refers to products of third party manufacturer's and thus are in their regulatory responsibility. Please contact the third party manufacturer for further information.*

Figure 50: Phantom[1] center point visualization in coronal plane

Figure 51: Phantom[1] center point visualization in sagittal plane

syngo.via RT Image Suite allows to directly use this calibrated distance when connected to the LAP built DORADOnova MR3T[1] laser bridge via the Direct Laser Steering option. This then supports an automatic patient marking workflow (see the instructions for use for details).

The manufacturer of the laser bridge might suggest further quality checks, e.g., the alignment of the external marks of the internal phantom structure with a zero position within the plane that is defined by the movable lasers, visible on the outside of this phantom.

[1] *The information shown herein refers to products of third party manufacturer's and thus are in their regulatory responsibility. Please contact the third party manufacturer for further information.*

5. Patient monitoring and emergency testing

5.1 Verifying initial operation

During the commissioning, ensure that all patient monitoring and emergency systems, such as the squeeze ball, pneumatic headphones, patient monitor etc., are operational.

Verify that pressing the squeeze ball creates an alert and causes an alarm to go off.

Initial operation of all other patient monitoring and emergency systems can be similarly verified.

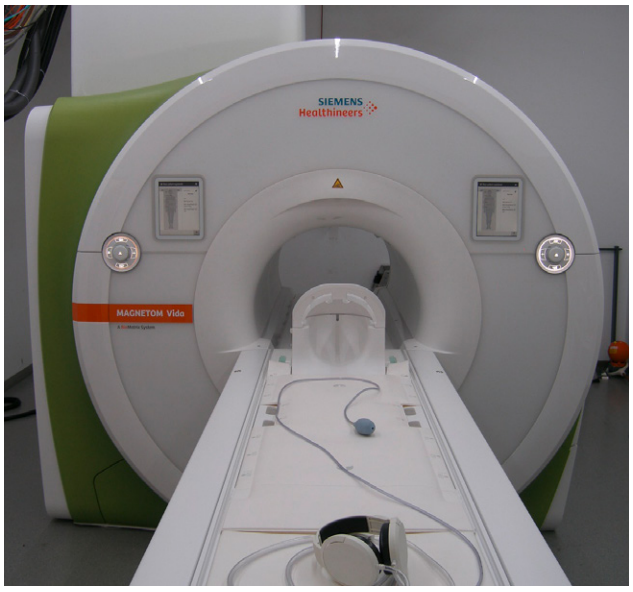


Figure 52: Squeeze ball, to be used by the patient in case of an emergency

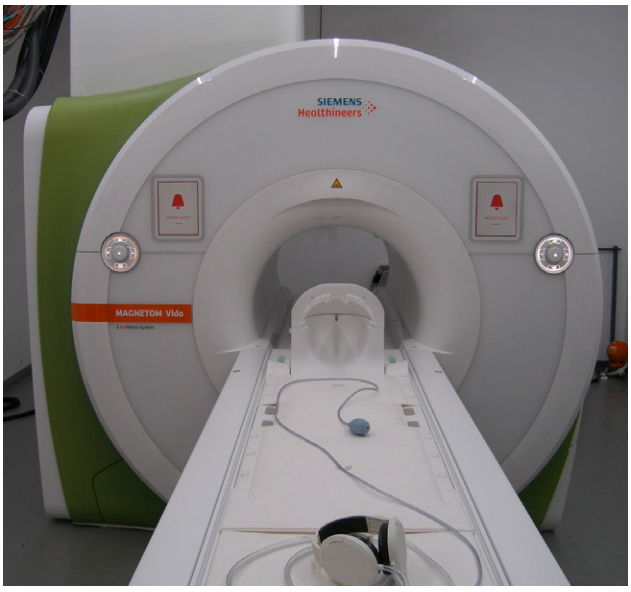


Figure 53: Patient alert warning visualized on screen after pressing the squeeze ball

5.2 Verifying the ability to quench the magnet in an emergency situation

Rationale

In the hypothetical case that a ferromagnetic object was involuntarily attracted by the MR magnet while a patient is undergoing scanning, it might be necessary to initiate a controlled quench by pressing the magnet stop switch. Under certain circumstances this might be the only chance to free the patient from the MR scanner.

During a quench, the super-conductivity of the magnet is lost. The energy of the magnetic field is converted into heat and the magnet field strength falls off. The liquid helium (coolant) boils off rapidly during this process and is released to the outside via the exhaust vent line. The escape of gaseous helium via the exhaust line is very noisy.

The MR operator is responsible for maintenance of the MR system. In the case of MAGNETOM MR scanners these are detailed out in the System Owner Manual, under Operator Responsibilities for Maintenance. Proof of these activities is required by authorities in certain countries.

Verification of magnet stop switch

Checks of the correction function of the magnet stop switch is part of the safety-related tests. Please go through the chapter “Info on safety-related tests” for further details.

There are two different versions of the **Magnet Stop** switch on the MR system: as an individual switch or as an integral part of the alarm box. The switches may also be installed in other places of the MR system.

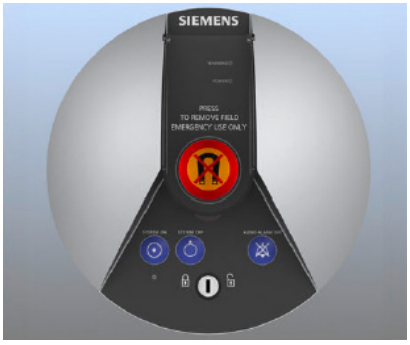


Figure 54: (left) **Magnet Stop,** example individual switch
(centre / right) **Magnet Stop on the alarm box** ("Press to remove field. Emergency use only.")

5.3 Display of signs

International safety standards and local regulations require to display user icons, button labeling, warning labels and warning signs at appropriate places and locations of an MR system installation.

The original placement is performed during the installation of the MAGNETOM system and checked and documented as part of the initial safety-related tests. Please go through 6. Info on safety-related tests of Commissioning section for further details.

Figure 55: Warning signs

6. Info on safety-related tests

6.1 Rationale for check

MR vendors require that the operator of their products take responsibility for maintenance. In the case of MAGNETOM MR scanners these are detailed out in the System Owner Manual, under Operator Responsibilities for Maintenance. Proof of these activities is required by authorities in certain countries.

Routine checks include: Daily, weekly, and monthly inspections as well as legally required checks as described in the "Safety Checks" chapter of the operating instructions. Normally, the system operator entrusts the clinical operating personnel with the task of performing these routine checks.

Periodic maintenance includes:
- Safety check (including safety-related tests)
- Preventive maintenance
- Quality and function tests

This work must be performed by qualified and authorized service engineers only. In this context, qualified means that the engineers have been trained accordingly or have acquired practical experience through routine service activities. Authorized means that the engineers have been granted authorized permission by the operator of the system to perform maintenance work.

Upon first start-up of the system, a staff member should be designated responsible for ensuring that routine checks, preventive inspection, and maintenance work are performed. This staff member is responsible for archiving all certificates in the "System Owner Manual" binder.

In addition to repair service, Siemens Healthineers also offers a complete range of services for the preventive inspection and maintenance of the MAGNETOM system. These services can be called on as required or agreed upon in a flexibly drafted maintenance contract.

If these services are of interest, a Siemens Healthineers representative can be contacted to get a quotation from the Siemens UPTIME Services organization.

Please consult the "System Owner Manual – 7: Operator Responsibilities for Maintenance" document that comes with your MAGNETOM for a maintenance plan, and a list of safety checks (including safety-related tests), information about preventive maintenance and quality and function tests.

6.2 Workflow

In the System Check, go to the tab Maintenance. From here, go to Safety related Tests – Quality Assurance. This displays the list of checks.

Figure 56: Maintenance – Safety Related Tests – Quality Assurance

References:

1. *Chang H, Fitzpatrick, J.M. A Technique for Accurate Magnetic Resonance Imaging in the Presence of Field Homogeneities. IEEE Trans Med Imag, 11(3), pp 319-329, Sept 1992*
2. *System Owner Manual*
3. *APOLLO MR3T (Laser System for Patient Alignment in RT)*

System Quality Assurance (QA)

1. Patient safety interlock testing

The MR system contains several features that can ensure that the patient stays safe and comfortable during the examination. Details for these are provided below.

System Quality Assurance (QA)
This section contains an overview of all proposed quality assurance checks that may be needed to be carried out in an MR for RT installation. For instructions on the frequency of these tests, please refer to your local guidelines.

1.1 Rationale and recommended tests

Squeeze bulb

The MR system features a squeeze bulb, which is meant to be held by the patient during an examination, in order to allow the patient to request communication with the operator of the MR system.

- You can test its functionality by squeezing it and checking whether an alarm is triggered by this action. This will also appear in the built-in system monitors as shown in Figure 57.

Pneumatic headphones

The MR system features an intercom system using pneumatic headphones. These are meant to be worn by the patient during an examination, in order to allow the operator of the MR system to talk to the patient (Figure 58).

Patients might feel more comfortable receiving information during a scan session.

- Two people are needed for testing this functionality: one wearing earplugs and well as the headphones while laying on the table, and the other one speaking through the control console to ensure adequate communication.

It may be both uncomfortable and inconvenient to have a patient wear the headphones while positioned in a thermoplastic mask, with the flex coils for brain imaging. The headphones are primarily for patient comfort but are not essential, especially with use of earplugs, and can be avoided when the patient is in a thermoplastic mask.

Patient supervision

The MR system features an additional patient supervision camera with monitor (Figure 59). This is meant to be used by the operator of the MR system during scanning, as another means to supervise the patient.

- Test that the camera view is not obstructed and a person inside the bore can be clearly seen.

Further information for all three above-mentioned interlocks can be found at the operator manual of your MAGNETOM system.

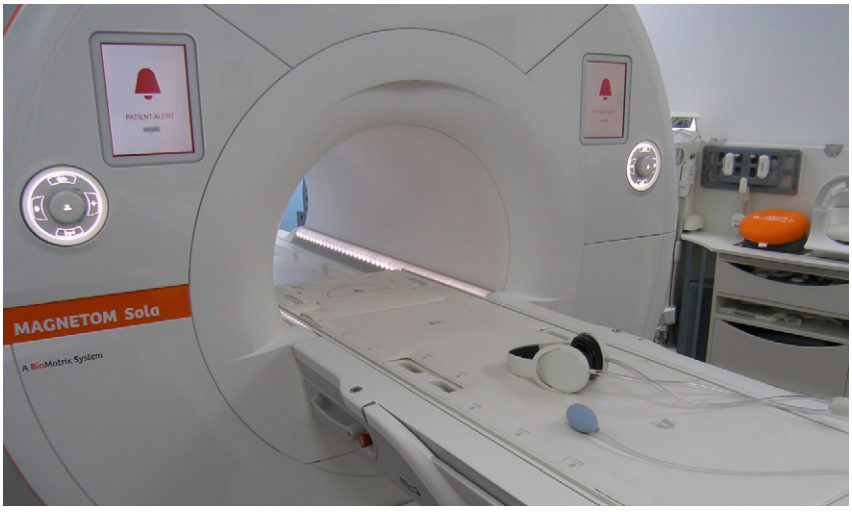


Figure 57: Alarm goes off as the ball is squeezed and a patient alert is shown at the system monitors

Figure 58: Pneumatic headphones

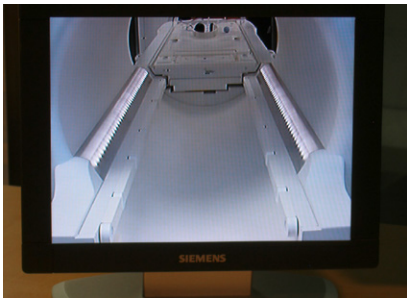


Figure 59: Patient supervision monitor at the system control console

2. System automated checks

2.1 Rationale for the test

The MR system needs certain environmental and infrastructure requirements to be fulfilled as prerequisite for safe and efficient operation. These are explained in the MAGNETOM planning guide, with is the basis for site planning and infrastructure realization.

2.2 Workflow

Clicking the **System Check** icon provides a simple and fast overview over the status of the whole MR system. The System Check icon indicates the status of the MR system:

Figure 60: The MR system is ready.

Figure 61: Actions required before operating the MR system.

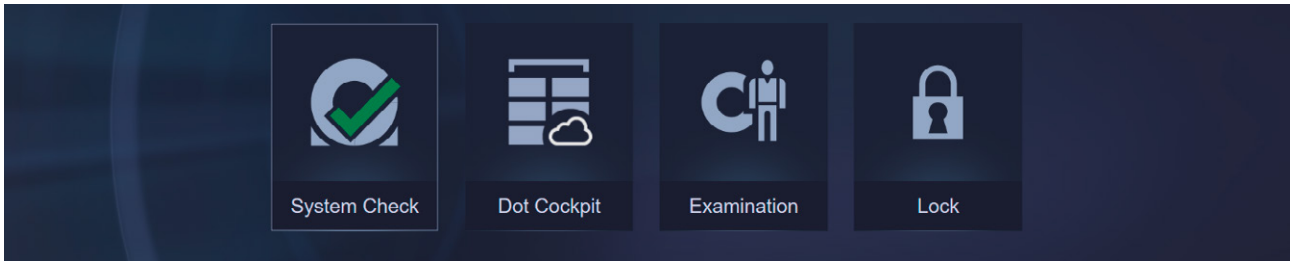


Figure 62: System Check Overview

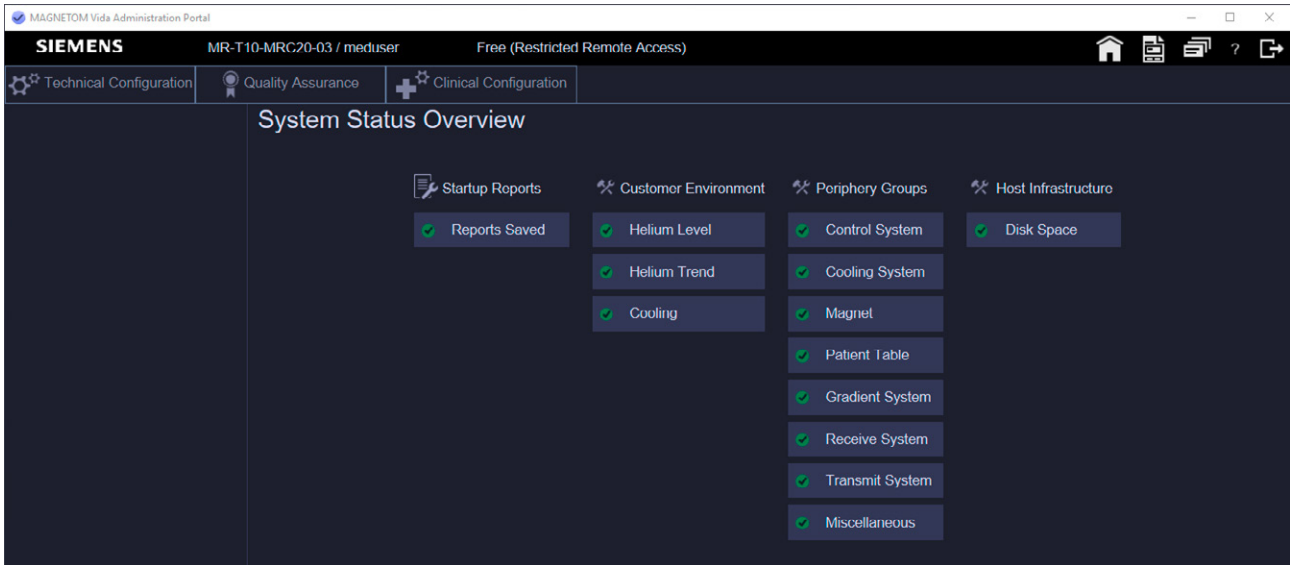


Figure 63: System Status Overview tab

The Home Screen contains a quick access to the System Status Overview tab of the Administration Portal.

Information such as the Customer Environment, Startup Reports (especially the safety related test report), Periphery Groups and Host Infrastructure is displayed (Figure 63). The status of each component is represented by one of the icons suggested in Figure 64.

Helium level and trend, as well as cooling water status are indicated in the Customer Environment tab.

Icon	Status	Comment
	Operational	The component is running without errors.
	Warning	The component indicates a warning.
	Error	An error occurred. However, the component is still able to run.

Figure 64: Status of components

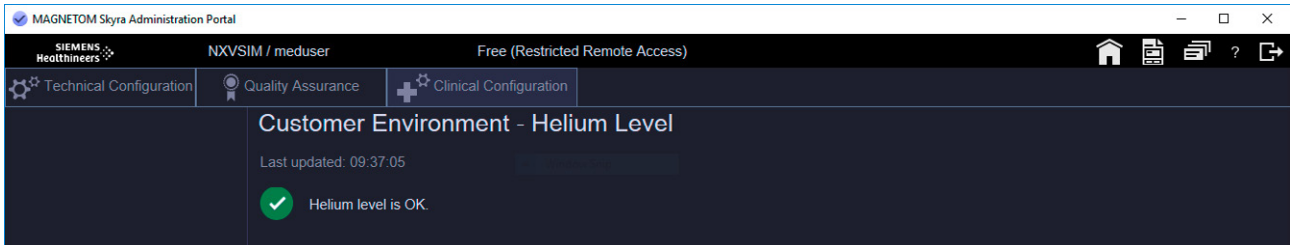


Figure 65: Customer Environment – Helium Level

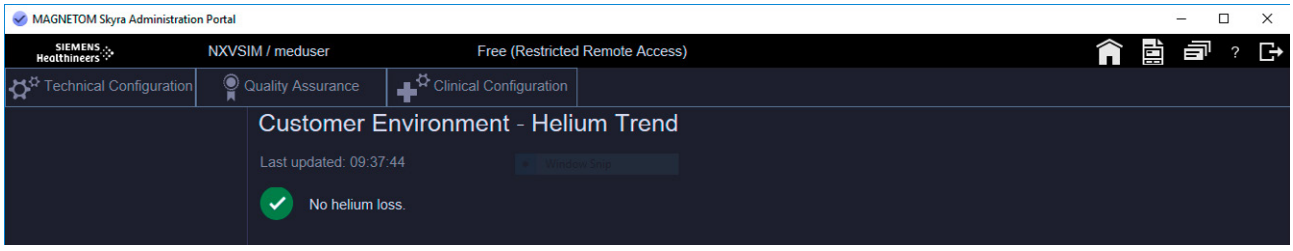


Figure 66: Customer Environment – Helium Trend

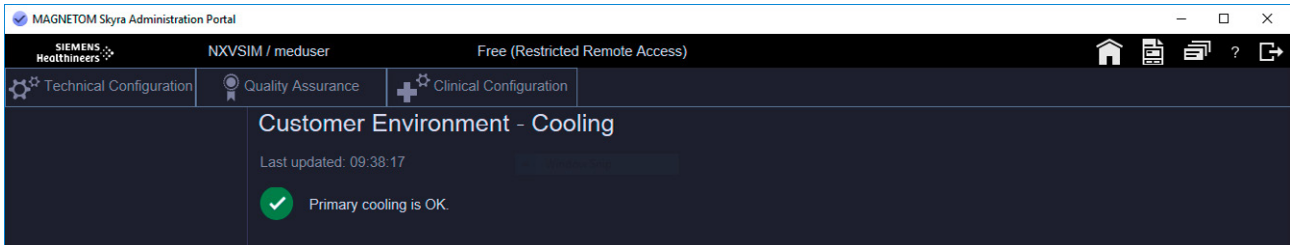


Figure 67: Customer Environment – Cooling

3. External laser position accuracy

The external laser accuracy depends on infrastructure deployed at the customer's specific setting. It is recommended to review the laser manufacturer's guidelines.

Check that the distance values conform to benchmark (measured during commissioning) and are within limits (as suggested by guidelines). To obtain or measure these distance values, please refer to the Commissioning section.

4. Table accuracy and reproducibility

4.1 Rationale for the test

The MR system features a patient table that can be moved horizontally, in order to allow to move the patient in and out of the magnet. System control units that are positioned on the front cover can be used to move the table, in steps of 1 mm. The actual position of the patient table is depicted on the system control. When MR is used for treatment-simulation, the accuracy and reproducibility of the table need to be verified.

4.2 Workflow

The actual extent of an expected movement of the patient table can be checked by using, e.g., a non-magnetic folding yardstick and post-it markers, comparing moving and steady parts of the patient table. The home position is the one and only position of the patient table, where it can be moved vertically. This typically corresponds to a value of around 900 mm for MAGNETOM Vida and 760 mm for MAGNETOM Sola, which is the distance that the patient table has to travel into the system such that an object on the table that was aligned with the system laser reaches the isocenter of the gradient coil.

A schematic of the workflow for this test is shown in Figure 68.

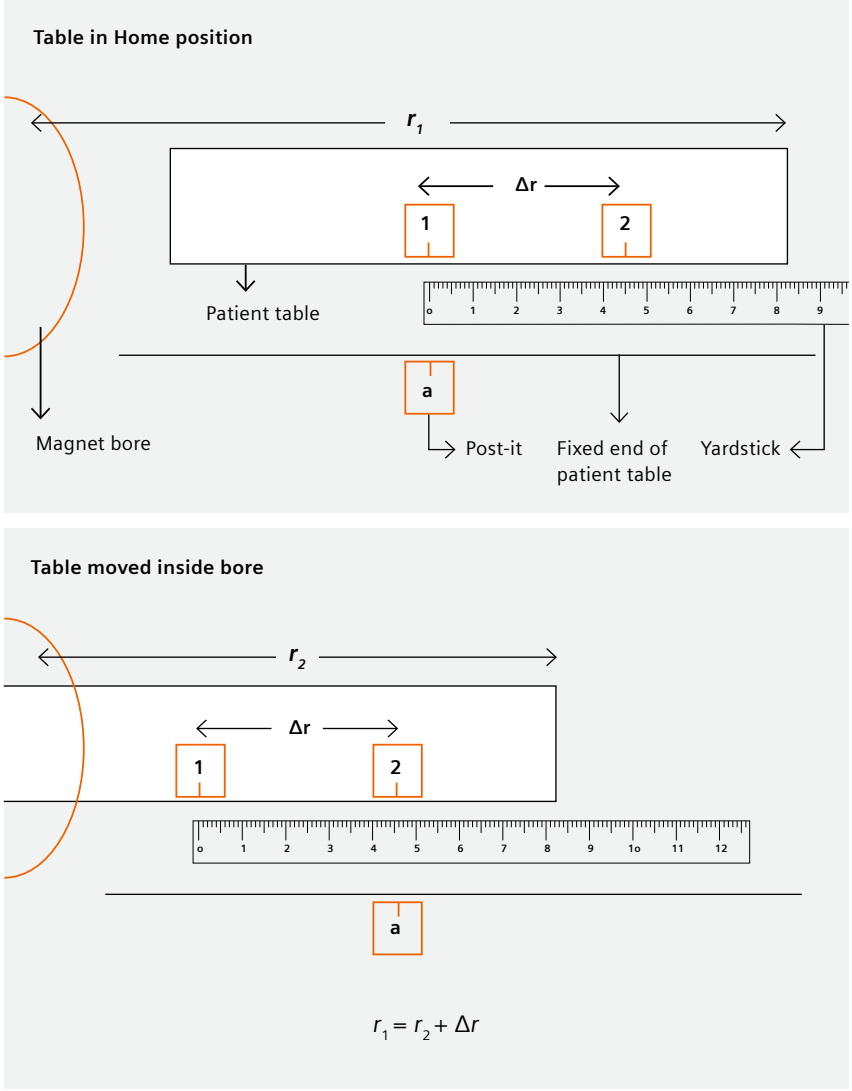


Figure 68: Table positioning schematic

1. The setup in Figure 70 is arranged while the patient table is in the Home position. This position value is denoted by r_1 for the rest of this experiment and differs depending on the system. Please refer to the Workflow section of this test for details on the Home position.

2. Place a non-magnetic yardstick/ ruler on the fixed end of the patient table as shown in the Figure 69. Post-it markers **1** and **2** are placed such that they are an arbitrary distance Δr apart. The distance between **1** and **2** should be a significant distance which is measurable by yardstick. Place a post-it on the fixed end of the patient table aligned with the Post-it 1. In Figure 69, this is shown to be marked as **a**.

   For demonstration purposes and to aid in understanding, the test stated below is provided with numeric values. Please understand that these values would be different, depending on your system and how far apart **1** and **2** are kept. For the experiment detailed here, this distance is 564 mm.

3. Use the system control units to move the table inside the magnet bore such that post-it notes **2** and **a** are aligned, as shown in Figure 71.

Figure 69: Table position setup

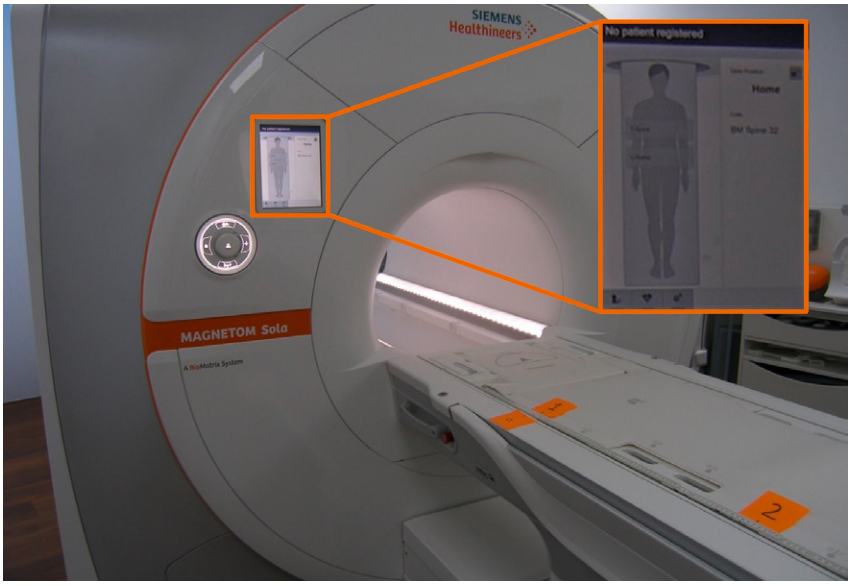


Figure 70: Setup employed in Home position

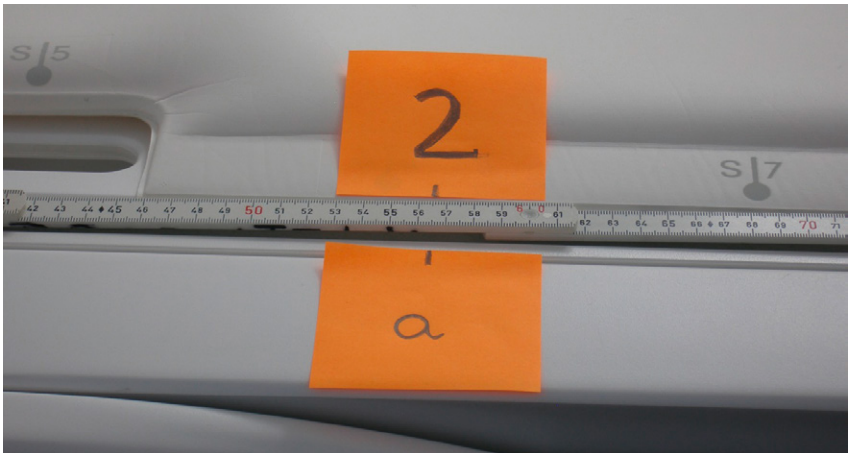


Figure 71: Table moved inside the magnet bore to align **2** and **a**

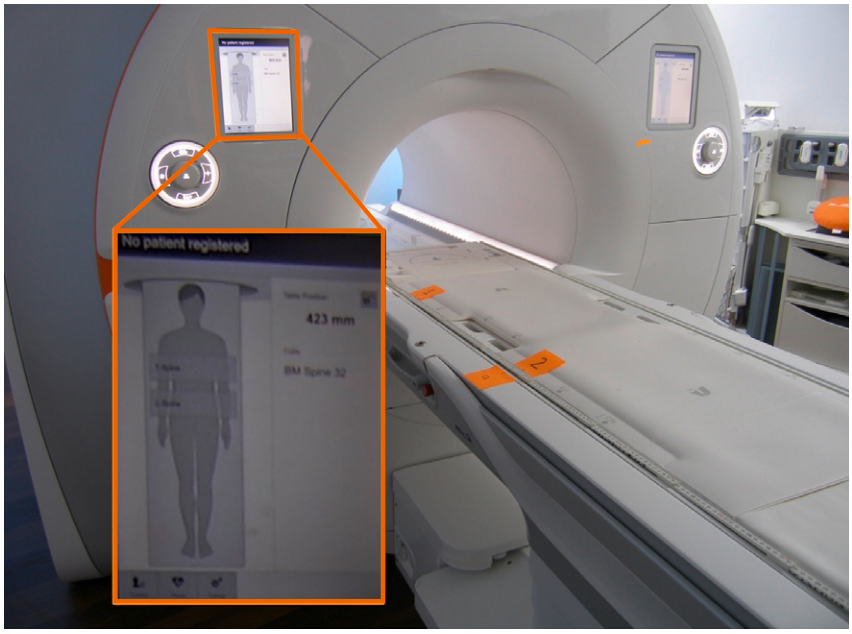


Figure 72: Table position as it is moved inside the bore to align **2** and **a**

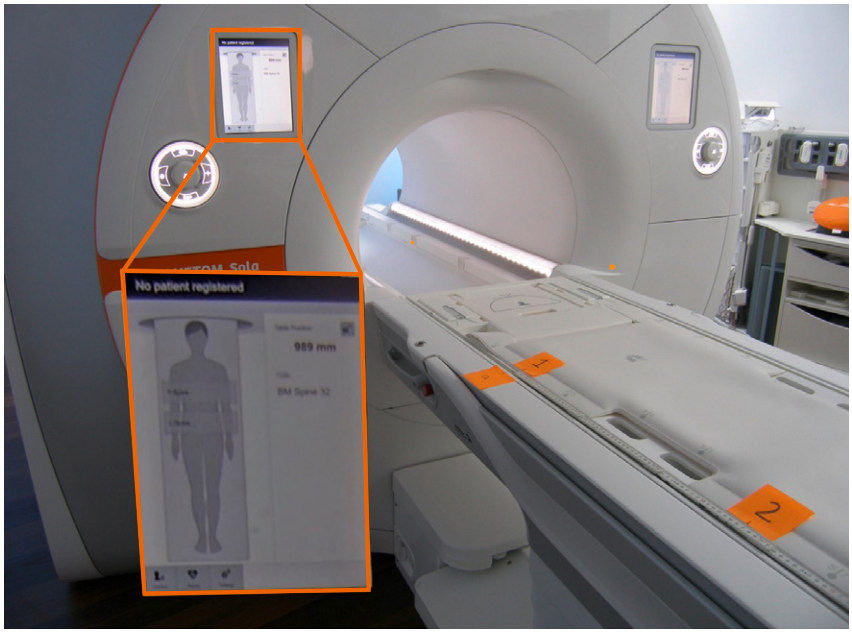


Figure 73: Table position back at Home, corresponding to approximately 990 mm.

4. Note the position on the system control when post-its **2** and **a** are aligned. This value is r_2. For the setup employed in this experiment, this value came out to be 423 mm.
5. If r_2 and Δr are added together, this value must correspond to the position value in the Home position.

$$r_1 = r_2 + \Delta r$$

For the setup employed, this came out to be the following:

$$r_1 = 423\ mm + 566\ mm = 989\ mm$$

6. As the system control is used to bring the table back to the Home position, the position can be visualized on the screen. This must be equal to r_1. The post-its **1** and **a** are aligned once again, as in the Home position setup of Figure 69.

5. Flex coils

5.1 Rationale for the test

RF-coils are undergoing daily mechanical stress when used for patient examination. This may eventually lead to coil malfunctioning and consequently degraded MR image quality. A quality measurement is performed for each RF coil to verify satisfactory operation. This workflow is supported in the Customer QA section of the MR Service Menu and uses a phantom setup that is available with every MAGNETOM.

5.2 Workflow

Phantom Setup

The following phantom setup is employed to perform the coil QA (Figure 74). The choice of phantom will vary depending on the coil undergoing quality assurance.

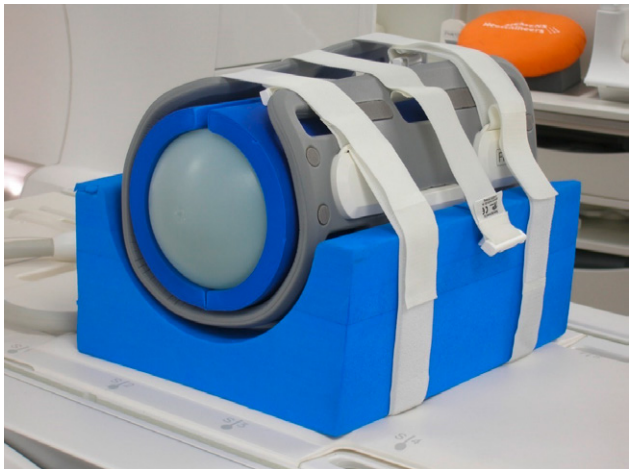


Figure 74: Coil QA setup for flex coils

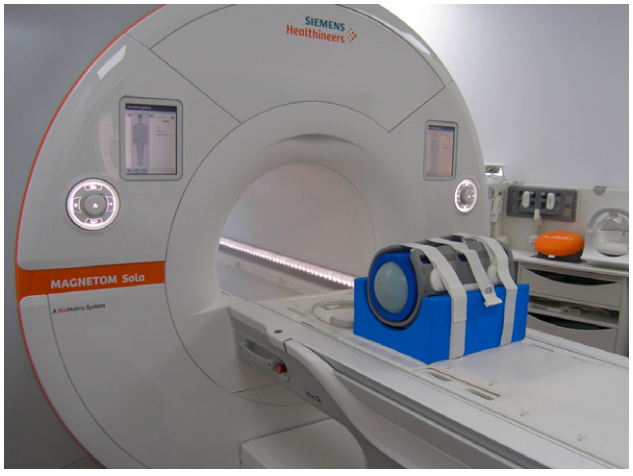


Figure 75: Coil QA setup for flex coils (room view)

Performing Quality Assurance (software)

Selecting the coil

1. In the Administration Portal, select **Quality Assurance.** The dialog box Quality Assurance – Coil Configuration opens.

Figure 76: Coil Configuration

2. Go to the selection list and select the coils for quality assurance.

Registering the coil

It may be that some coils are not available in the list. Coils of these coil types must be registered before starting the quality assurance.

1. Coil is connected to the patient table.
2. In the **Quality Assurance – Coil Configuration** dialog box, click the **Add Plugged Coils** button to add the type of the connected coil to the list.
3. Wait at least one minute until the update process is complete.

The list is updated automatically.

Configuring the coil measurement

During the quality measurement, the signal-to-noise ratio and the signal uniformity of the individual coils are checked.

1. The coil is selected.
2. In the **Quality Assurance – Coil Configuration** dialog box, configure the list of coils to check and save it.
3. In the **Customer Quality Assurance** dialog box, select the check box of the coils to be checked.

Starting the quality measurement

1. The quality measurement is configured.
2. Follow the instructions for positioning the coil, the phantom, as well as the phantom holder.
3. Connect the coil to be measured.
4. In the **Customer Quality Assurance** dialog box, click the button **Go.**
5. Once the quality assurance check is complete, the status changes to **Ok.**

During the measurement, messages regarding the measurement status are displayed.

In case of failure of the test, carefully test the positioning of coil and phantom and rerun the test. In case of repeated failures, contact Siemens Healthineers Service.

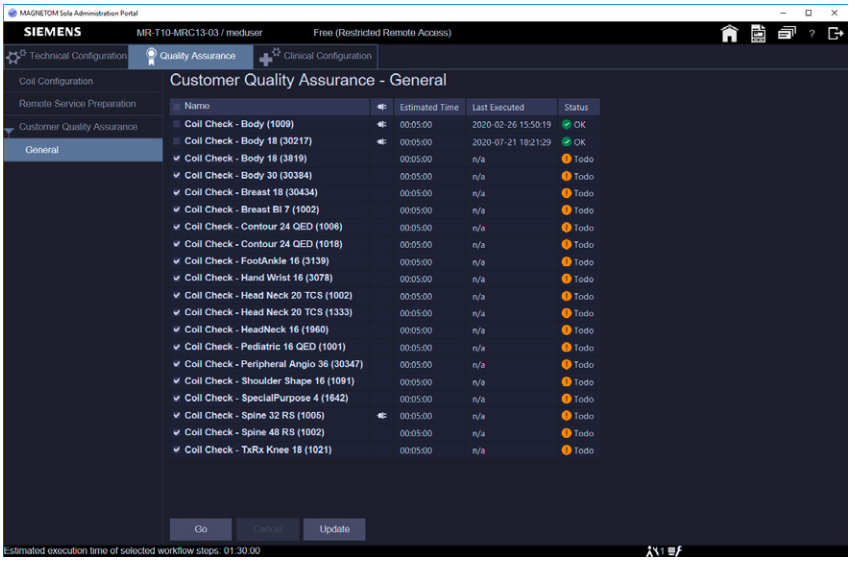


Figure 77: Checking relevant tests

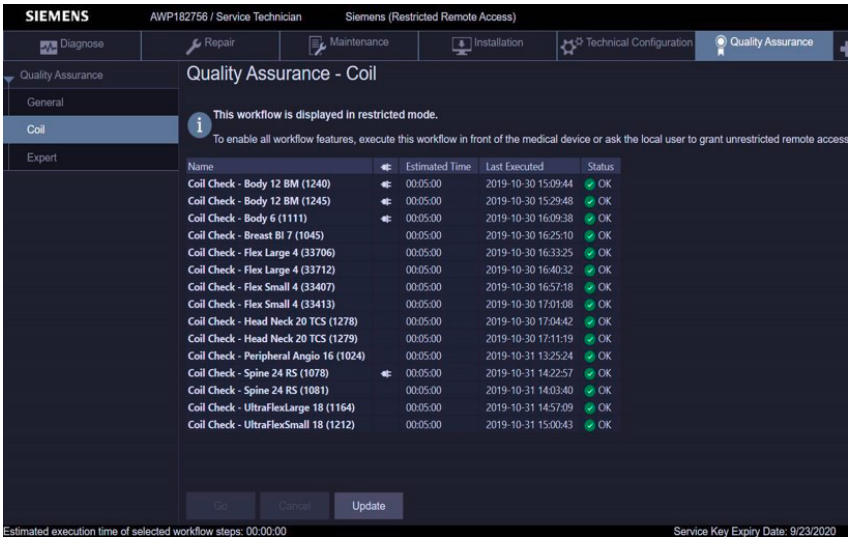


Figure 78: Completed Customer Coil Quality Assurance

Status	Status of quality measurement
ToDo	Measurement still waiting to be performed
Running	Running
Done	Completed. Parameters correspond to specifications.
NotOk	Completed. Parameters are out of specification.
Error	Measurement cannot be performed.

Figure 79: Status of Quality Assurance

6. Image quality tests

6.1 Low contrast detectability

This test forms part of the QA tests used for analyzing image quality. Please refer to ACR Phantom Testing Positioning and Workflow (Appendix 3) for details on carrying out this text.

6.2 High contrast spatial resolution

This test forms part of the QA tests used for analyzing image quality. Please refer to ACR Phantom Testing Positioning and Workflow (Appendix 3) for details on carrying out this text.

6.3 Slice thickness and position accuracy

This test forms part of the QA tests used for analyzing image quality. Please refer to ACR Phantom Testing Positioning and Workflow (Appendix 3) for details on carrying out this text.

7. Center frequency adjustment

7.1 Rationale

MR systems employ the effect of nuclear magnetic resonance to generate images of the human body. This resonance effect requires a special adjustment that is not known from other imaging modalities like computerized tomography (CT) or ultrasound (US), namely the adjustment of the MR frequency.

The MR frequency needed by the nuclei to resonate is proportional to the main magnetic field and the magnetic properties of the isotope involved, but also features a dependence on the chemical environment of the participating nuclei.

Since the human body mainly consists of water, its protons deliver a strong MR signal at the water resonance. However, fat bound protons resonate at slightly lower frequency. This gives rise to a spectrum of a high water and a usually much lower fat peak, which can be visualized as a result of the MR frequency adjustment.

The magnetic field strength of MR systems is stabilized to assure that a frequency adjustment done at the start of scan remains valid over the whole patient examination. However, magnetic fields can drift around their nominal field strength, for a variety of reasons. The concept of the frequency adjustment assures optimum signal-to-noise during the full length of the MR exam.

All superconducting magnets exhibit a very slow decay of their nominal field strength over time, specified in their respective datasheets. This comes at no signal-to-noise penalty due to the frequency adjustment process, combined with the ability of their transmit-receive systems to operate over a large frequency bandwidth. As part of scheduled maintenance, magnets are sometimes ramped up, in order to re-establish the original field strength from day of handover. This is not a quality problem, but instead a consequence of small ohmic losses at junctions in the superconducting magnet circuits.

7.2 Workflow

Phantom Setup

Please refer to the Phantom Setup (Appendix 1) for details on phantom setup.

User Interaction

The MR frequency adjustment procedure can be tested with the service phantoms that come with each MAGNETOM.

1. Select an arbitrary pulse sequence and open its protocol in the measurement queue.
2. Select the **System** tabcard and invoke **Manual Adjustments.** This allows to trigger a frequency adjustment.

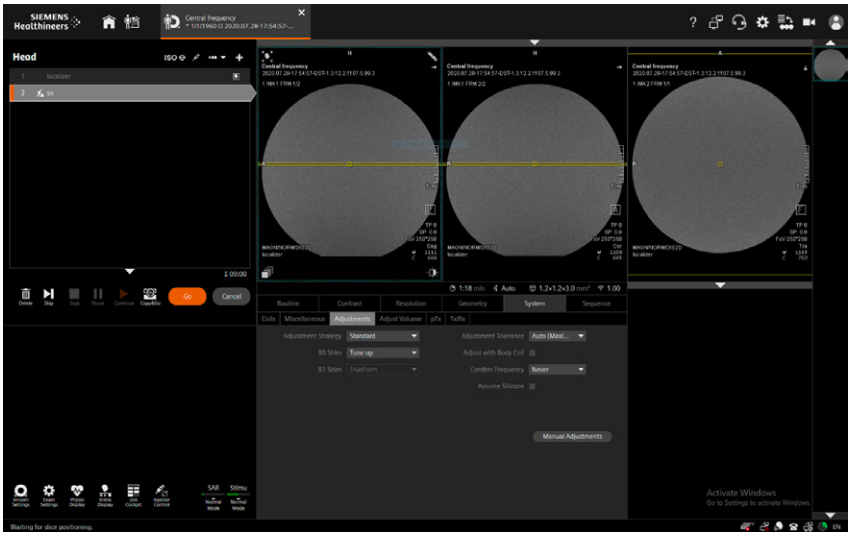


Figure 80: Frequency Adjustment Menu

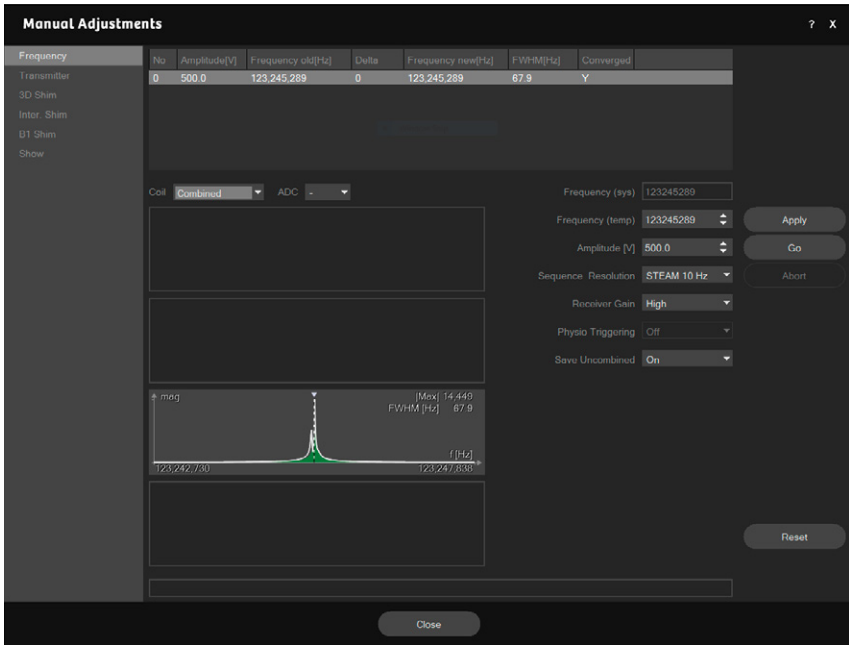


Figure 81: Frequency Peaks characteristic of water and fat

3. In Figure 81 the results obtained from the test can be observed. The two peaks of the frequency distribution indicate the resonance frequencies of protons in the phantom fluid. Being able to resolve the two frequency peaks of the oil phantom is also indicative of a good homogeneity of the main magnetic field B_0.
4. The same experiment performed with the smaller 170 mm phantom shows just one frequency peak which is due to its pure water filling.

8. Spatial integrity tests

8.1 Phantom Shim Check

Overview

The Phantom Shim Check is one of the three checks forming the automated test procedure for spatial integrity available in all MAGNETOMs. This test measures the quality of the magnetic field homogeneity within the phantom volume.

Rationale for check

The terms of the mathematical decomposition of the magnetic field can be accurately determined based on the frequency distribution in the volume elements making up the phantom image. Two measurements are performed with the parameters from the corresponding Tune-up procedure to determine the remaining field terms and the overall homogeneity within the phantom volume. This setting is sufficient for standard imaging protocols without special requirements. For systems with the advanced shim option, the procedure is performed with shim currents applied.

The actual shim status of the system is measured with a 3D-DESS-sequence (Double Echo Steady State with a FISP [Fast Imaging with Steady-State Free Precession] and PSIF [reverse FISP] echo). The Software analyzes the resulting voxels (cubes).

The field homogeneity is evaluated based on the frequency of the voxels. For the check of the B_0 field, it is sufficient to compare the field differences between neighboring voxels. The field difference is obtained by comparing the phases of the magnetization vectors. The complete data set is evaluated by a differential shim equation. This equation minimizes the difference between the field generated by the 3 Gradient Coils (and the optional 5 shim coils) and the measured magnetic field inhomogeneities.

The following results are present in the report:
- Field terms
- MR Frequency
- Gradient Offsets
- Shim Currents (optional)

Field Term

Field Term	Value [ppm]	Tolerance
Bpp	**1.102**	0.000 ... 3.000
Brms	**0.106**	0.000 ... 0.400

Gradient Offset

Axis	Gradient Offset [mT/m]	PPM absolute [ppm]
$Grad_X$	**0.506**	**–50.426**
$Grad_Y$	**–0.389**	**38.746**
$Grad_Z$	**–0.101**	**8.748**

Shim Currents

Shim Channel	Shim Current [mA]	PPM absolute [ppm]

Figure 82: Field Terms, Gradient Offset terms and Shim Currents in Phantom Shim Check report

Workflow

Phantom Setup

Please refer to Phantom Setup (Appendix 1) for details on phantom setup.

User Interaction

Please refer to User Interaction Workflow (Appendix 2) for details on performing the check.

Once the check has been performed, the service report can be called up as a PDF document. It shows the outcome, as well as the underlying measurement values for the parameters listed above. In case the test fails, you may want to proceed with detecting foreign metal[1] in bore.

Detecting foreign metal in bore (optional)

Rationale for check

Metallic or ferromagnetic objects in the magnet bore could lead to distortion artifacts. Distortion artifacts occur due to local field inhomogeneities and cause altered or shifted signal intensities. In order to ensure that the images are free of such artifacts, the presence of foreign metal should be checked.

Workflow

For a more detailed overview and localization of the metallic object, the workflow detailed below can be employed.

Phantom Setup

Please refer to Phantom Setup (Appendix 1) for details on phantom setup.

User Interaction

1. Run the field sequence from the service sequence folder. In the absence of any external metallic[1] object in the bore, Figure 83 is obtained for the spherical phantom.

[1] *The MRI restrictions (if any) of the metal implant must be considered prior to patient undergoing MRI exam. MR imaging of patients with metallic implants brings specific risks. However, certain implants are approved by the governing regulatory bodies to be MR conditionally safe. For such implants, the previously mentioned warning may not be applicable. Please contact the implant manufacturer for the specific conditional information. The conditions for MR safety are the responsibility of the implant manufacturer, not of Siemens Healthineers.*

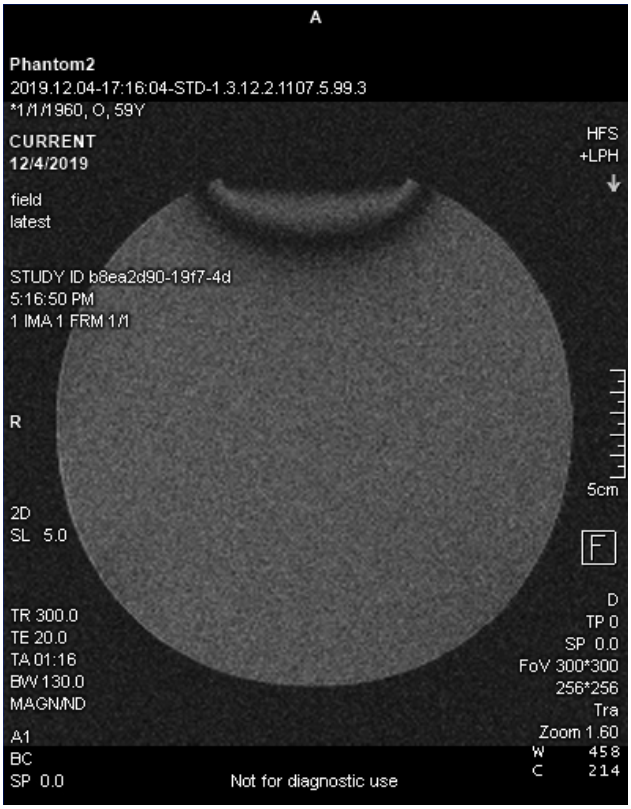


Figure 83: Field Sequence with Echo Time (TE) = 20 ms with no external object inside bore

Figure 84: Tennis Ball filled with small metallic pieces

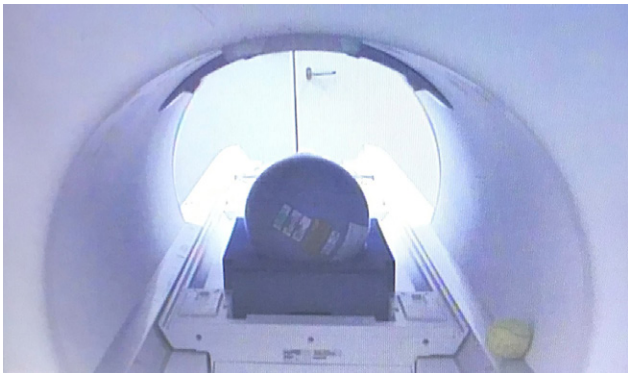


Figure 85: Ball placed inside the bore

2. For the purpose of demonstrating the effect of metal[1] inside the bore, a tennis ball filled with a small ferro -magnetic coin was placed inside the bore and the effect measured at different echo times (see Figure 84 and Figure 85).
3. Figure 87 and Figure 88 demonstrate this effect. The direction where the stripes are pointing at, shows the location of the metal. The distance between them, changes according to the applied echo time TE. B_0 inhomogeneities can be measured as in Figure 86.

Echo time TE is used to adjust B_0 sensitivity:

$$Echo\ Time = \frac{1}{(sensitivity \cdot B_0 \cdot \frac{\gamma}{2\pi})}$$

Sensitivity [ppm]	B_0 [T]	TE [ms]
2	1.5 / 3	7.9 / 4.1
1	1.5 / 3	15.8 / 8.1
0.5	1.5 / 3	31.5 / 16.3

Figure 86: Visualizing B_0 inhomogeneities with a phantom using the service sequence field

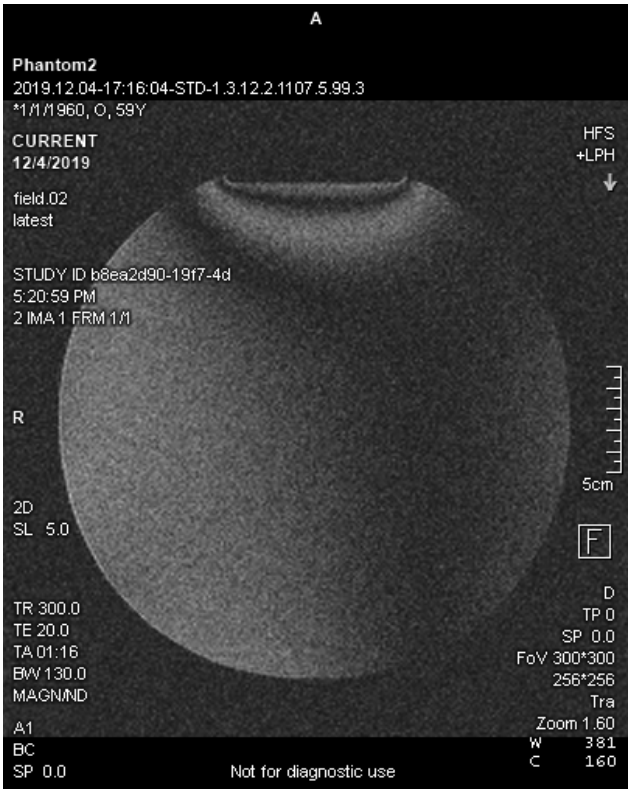


Figure 87: Resulting image with Echo Time (TE) = 20 ms

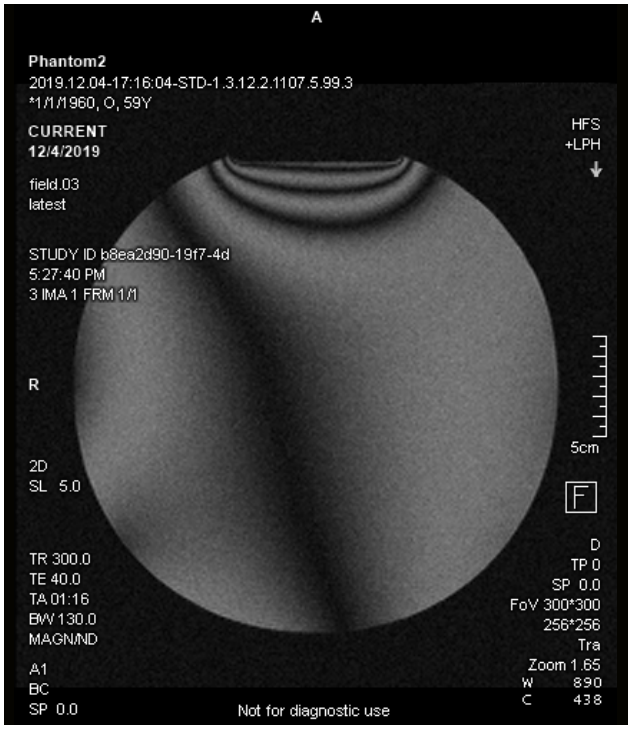


Figure 88: Resulting image with Echo Time (TE) = 40 ms

[1] *The MRI restrictions (if any) of the metal implant must be considered prior to patient undergoing MRI exam. MR imaging of patients with metallic implants brings specific risks. However, certain implants are approved by the governing regulatory bodies to be MR conditionally safe. For such implants, the previously mentioned warning may not be applicable. Please contact the implant manufacturer for the specific conditional information. The conditions for MR safety are the responsibility of the implant manufacturer, not of Siemens Healthineers.*

4. When the metal[1] is placed closer to the phantom as shown in Figure 89, the disturbance to the magnetic field homogeneity can be much more closely observed from the field sequences. Figure 90, Figure 91 and Figure 92 show the corresponding images when measured with an echo time of 10 ms, 20 ms and 40 ms respectively. As the echo times increase, the lines become more frequent and closer to each other.

[1] *The MRI restrictions (if any) of the metal implant must be considered prior to patient undergoing MRI exam. MR imaging of patients with metallic implants brings specific risks. However, certain implants are approved by the governing regulatory bodies to be MR conditionally safe. For such implants, the previously mentioned warning may not be applicable. Please contact the implant manufacturer for the specific conditional information. The conditions for MR safety are the responsibility of the implant manufacturer, not of Siemens Healthineers.*

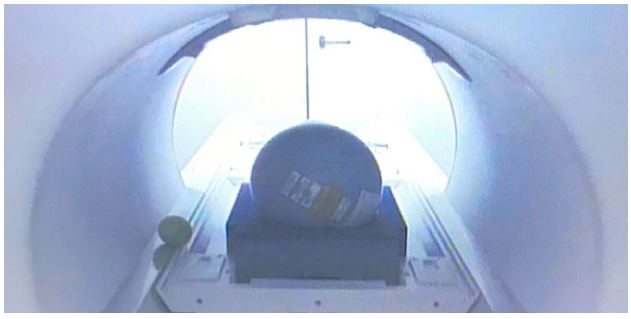


Figure 89: Ball placed closer to center of magnet

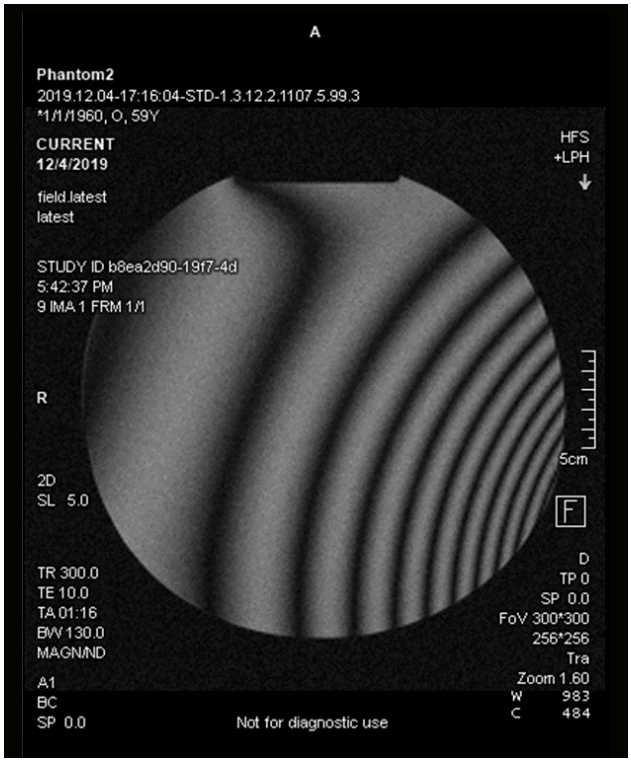


Figure 90: Resulting image with Echo Time (TE) = 10 ms and metal closer to center of magnet bore

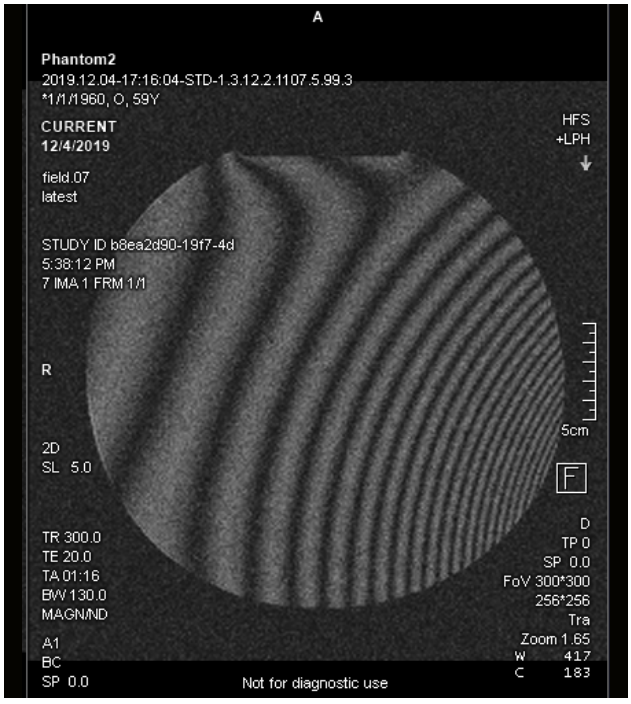


Figure 91: Resulting image with Echo Time (TE) = 20 ms and metal closer to center of magnet bore

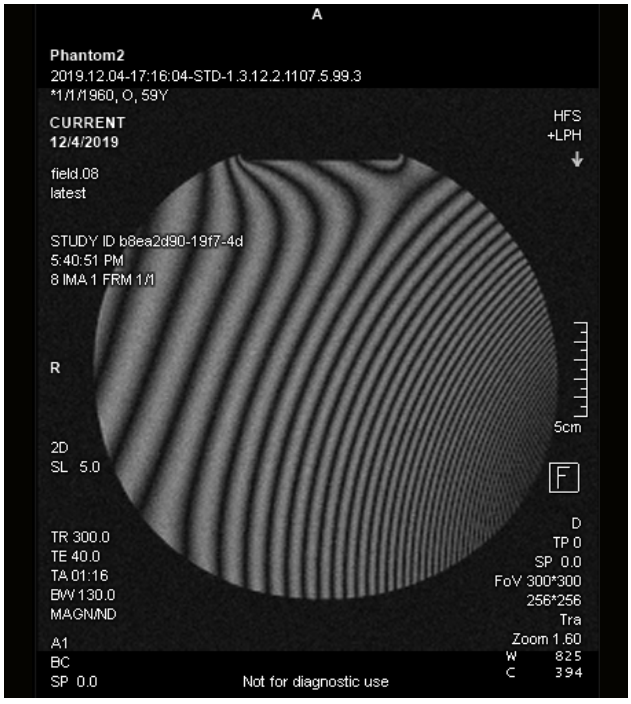


Figure 92: Resulting image with Echo Time (TE) = 40 ms and metal closer to center of magnet bore

8.2 Gradient Sensitivity Check

Overview

The Gradient Sensitivity Check forms another one of the three checks for spatial integrity. This procedure checks the Gradient Sensitivity values previously adjusted in TuneUp to ensure that the system uses correct gradient strengths and measures the correct phantom image size in all orientations. For the measurement, the distortion correction filter is enabled to compensate for gradient field non-linearities.

Rationale for check

A standard 2D imaging sequence is repeated three times: one measurement for each orientation. The three images are then analyzed to determine the exact location of the center of the phantom and the phantom diameters. The standard readout and phase encoding direction for each orientation is swapped to determine the center and diameter of the phantom. The average of these two results determines the final diameter value. The measured values are evaluated and compared with the well-known diameters of the phantom for verification of the correctly adjusted gradient sensitivities.

Report results:
- Measured phantom diameter in all three dimensions
- Measured phantom centers in all three dimensions
- Gradient sensitivities

Workflow

Phantom Setup

Please refer to Phantom Setup (Appendix 1) for details on phantom setup.

User Interaction

Please refer to User Interaction Workflow (Appendix 2) for details on performing the check.

Phantom diameter		
	Average [mm] Tolerance: 238.0 ... 242.0	Deviation Read / Phase [mm] Tolerance: 0.0 ... 5.0
Diameter X	**240.1**	**0.0**
Diameter Y	**240.0**	**0.6**
Diameter Z	**240.0**	**0.2**

Phantom position			
	Average [mm]	Tolerance	Deviation Read / Phase [mm] Tolerance: 0.0 ... 2.0
Position X	**– 0.7**	**– 20.0 ... 20.0**	**0.2**
Position Y	**– 0.4**	**– 20.0 ... 20.0**	**0.3**
Position Z	**– 1.2**	**– 2.0 ... 2.0**	**0.2**

Gradient sensitivities	
	TuneUp values [mT/m]
Sensitivity X	**0.00012231**
Sensitivity Y	**0.00012314**
Sensitivity Z	**0.00012115**

Figure 93: Phantom diameter terms, phantom position terms and gradient sensitivity terms in Gradient Sensitivity Check report

8.3 Synthesizer Check

Overview

The Synthesizer Check forms the last of the three checks for spatial integrity. Validation of the frequency and phase quality of the synthesizer is important for the accuracy of the slice position and thickness.

Rationale for check

Verification of the frequency and phase operation of the RF reference signal is performed by using the MR signal itself. After demodulation of the received MR signal, the reference signal is compared to the MR signal in terms of frequency and phase. In one test, the reference signal is varied in frequency over the whole range of the MR system. A second test modifies the phase in fixed intervals.

With this test, the entire operating range of the oscillator can be tested. The test is performed for one RX-NCO (Receive system Numerically Controlled Oscillator) from group 1 and one RX-NCO from group 2. The two RX-NCOs are validated and can be used for testing the other NCOs.

Loop-measurements between the tested RX-NCOs and the TX-NCOs (Transmit system Numerically Controlled Oscillator) approve the correct function of the TX-NCOs. In additional steps, all other RX-NCOs are tested against the approved TX-NCOs by testing group 1 RX-NCOs and group 2 RX-NCOs separately.

Results in Report:
Frequency- and phase-deviations for all used NCOs

Workflow

Phantom Setup

Please refer to Phantom Setup (Appendix 1) for details on phantom setup.

User Interaction

Please refer to User Interaction Workflow (Appendix 2) for details on performing the check.

Frequency and phase deviations		
NCO	**Frequency Deviation [Hz]** **Tolerance: 0.00 ... 10.00**	**Phase Deviation [deg]** **Tolerance: 0.00 ... 10.00**
1	0.91	0.33
2	0.79	0.27
3	0.47	0.29
4	0.34	0.34

Figure 94: Frequency and Phase deviation terms in Synthesizer Check report

Appendix 1

Phantom Setup

The following is a guideline on the positioning and setup of the spherical phantom needed to perform the Phantom Shim Check, Synthesizer Check and Gradient Sensitivity Check. Any sequences run with the spherical phantom can also employ this to setup the phantom.

1. The larger spherical phantom is used for the tests. Its diameter is 240 mm. The smaller phantom can be left inside the phantom holder during the measurement.
2. With a phantom holder, the head coil and cushion as well as the tabletop and spine coil must be taken out. This can be visualized in Figure 96 and Figure 97.

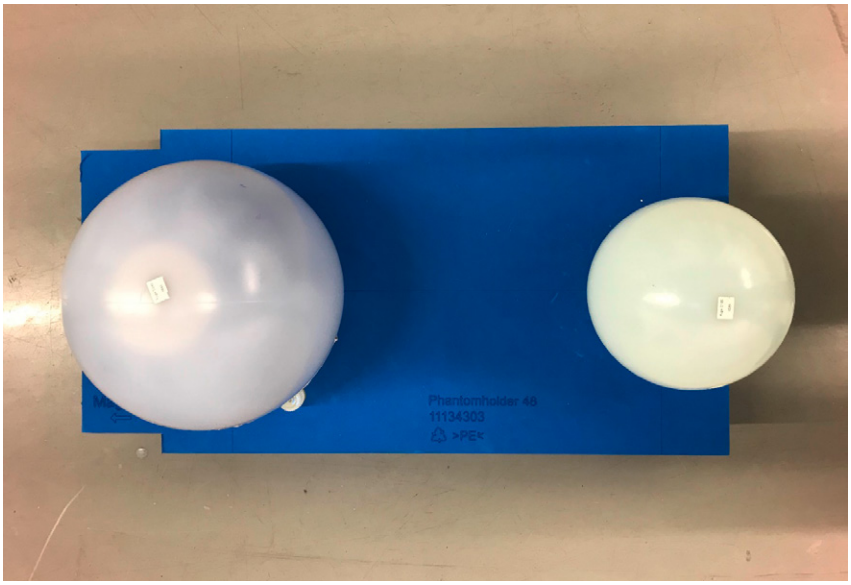


Figure 95: Spherical phantom with a diameter of 240 mm (bluish in color, left), placed inside a phantom holder

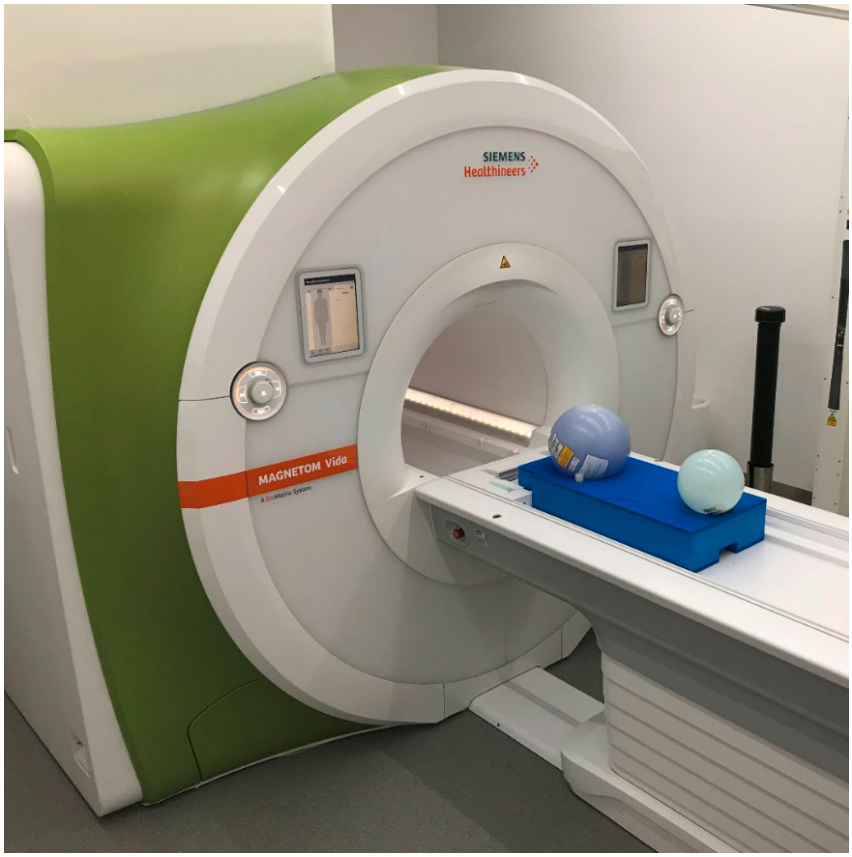


Figure 96: Spherical Phantom Setup, side view

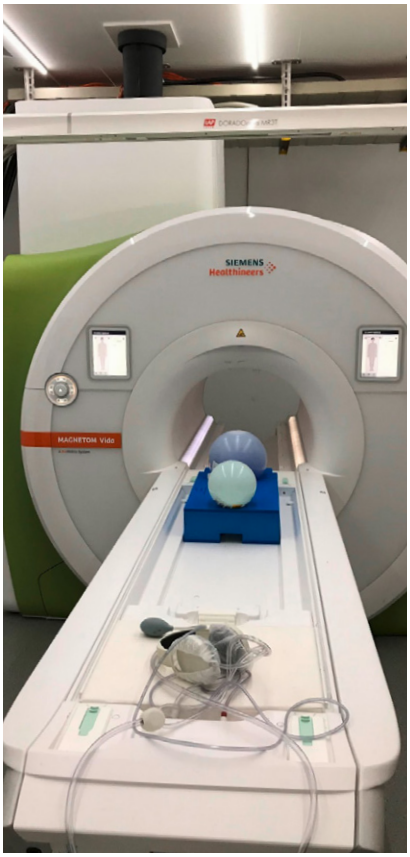


Figure 97: Spherical Phantom Setup, front view

3. The phantom is positioned such that it can be moved into the isocenter of the magnetic field. This is done by aligning it with the center of the system laser as in Figure 98.

4. The patient table can be controlled via the movement buttons and the jog-wheel on the control unit. For details, please refer to the system operator manual.

   A) Table Up / Inward button
   B) Jogwheel, Center Position button
   C) Home Position button
   D) Table Down / Outward button

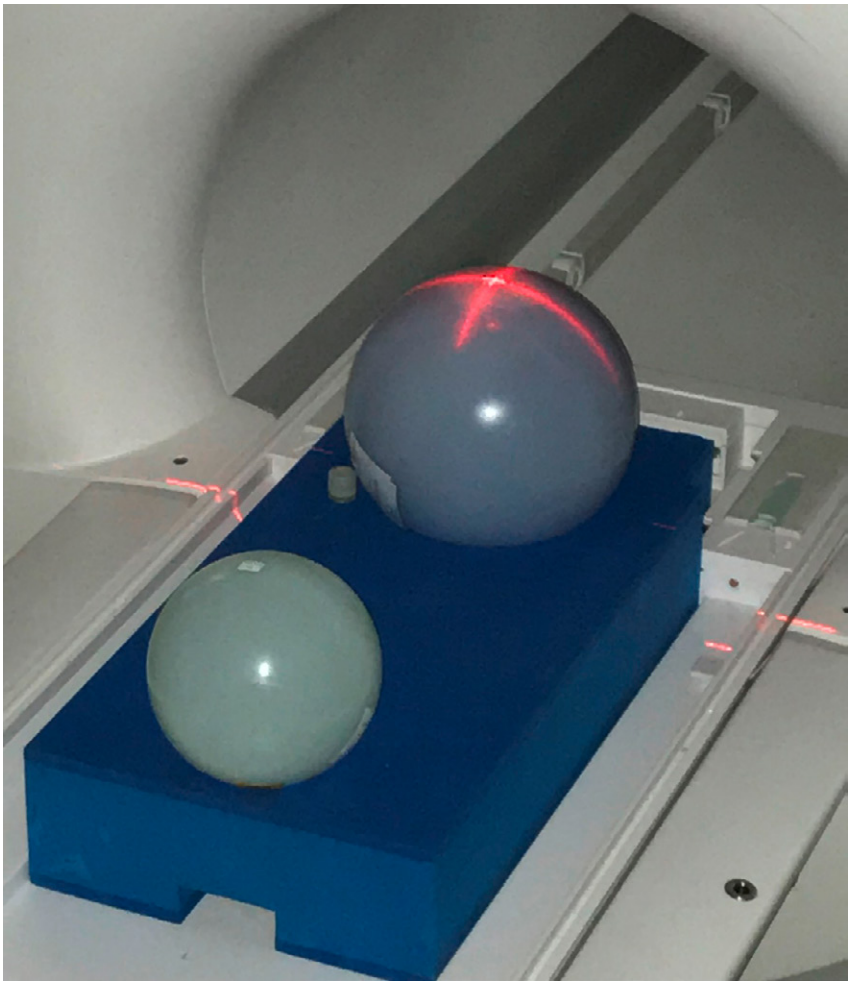


Figure 98: Phantom alignment with system laser

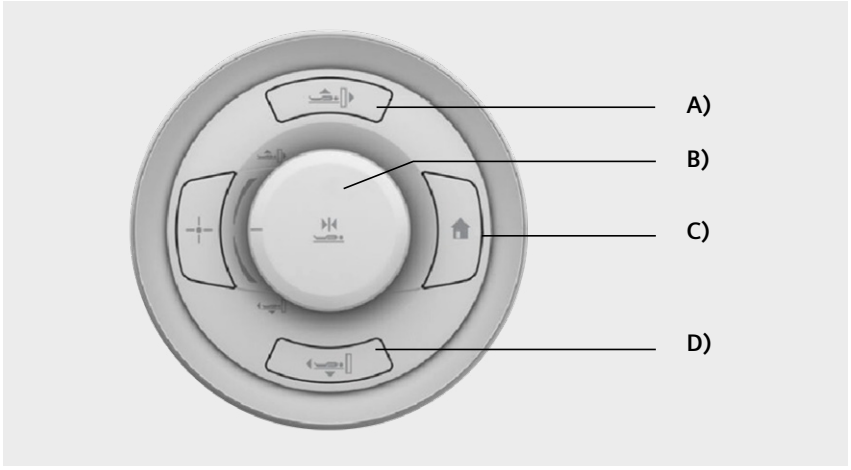


Figure 99: Jog-wheel and corresponding controls

Appendix 2

User Interaction Workflow

The following is a guideline for performing the three QA checks related to spatial integrity, namely Gradient Sensitivity, Phantom Shim, and the Synthesizer check.

1. To enter the system, click the tab **System Check**. Every user can enter System Check within "Kiosk mode".
2. Call **Quality Assurance** within **System Check.**
3. Perform the three fully automatized QA checks, as shown by the red boxes in Figure 102. Check the three QA tests[1]. Uncheck any other tests. Click **Go**.

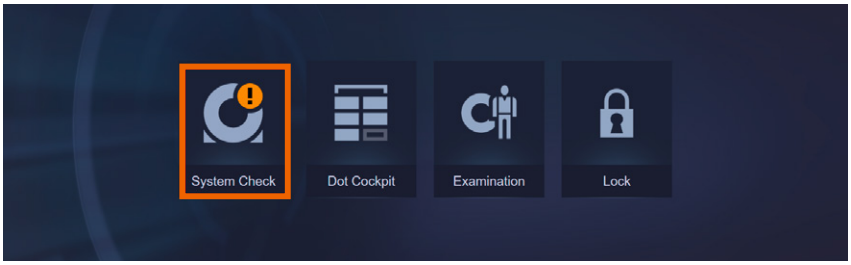


Figure 100: Entering the system to perform QA tests

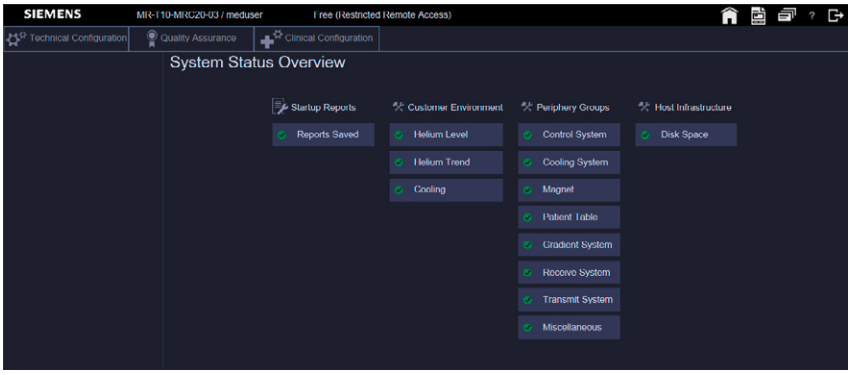


Figure 101: System Status Overview

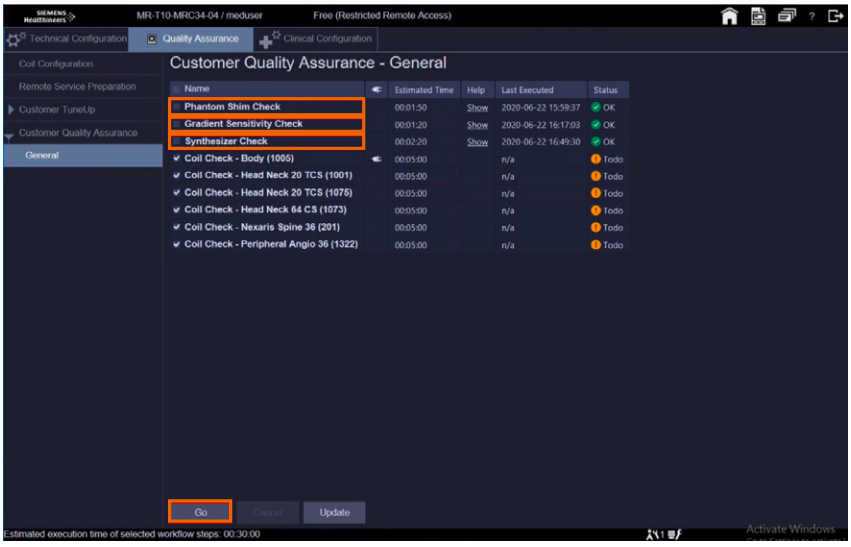


Figure 102: Every user can perform the three QA checks

[1] *These tests will be accessible in the Customer QA area for RT Dot Engine users starting from software version MR XA31. Software MR XA31 is currently under development and not commercially available for sale. Its future availability cannot be guaranteed.*

Note:
A user that owns a service key can enter **System Check** with more privileges as can be seen in Figure 103. The relevant tests can be selected or deselected by clicking on the small box in front of the test as shown in Figure 104.

The estimated executed time for the selected experiments can be found at the bottom of the screen (Figure 105). After selecting the relevant tests, click “Go”.

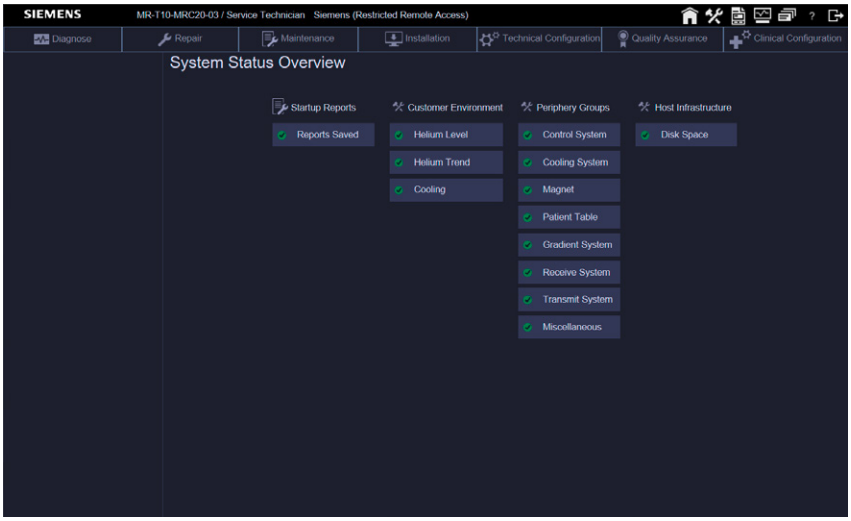


Figure 103: System Check with service key access

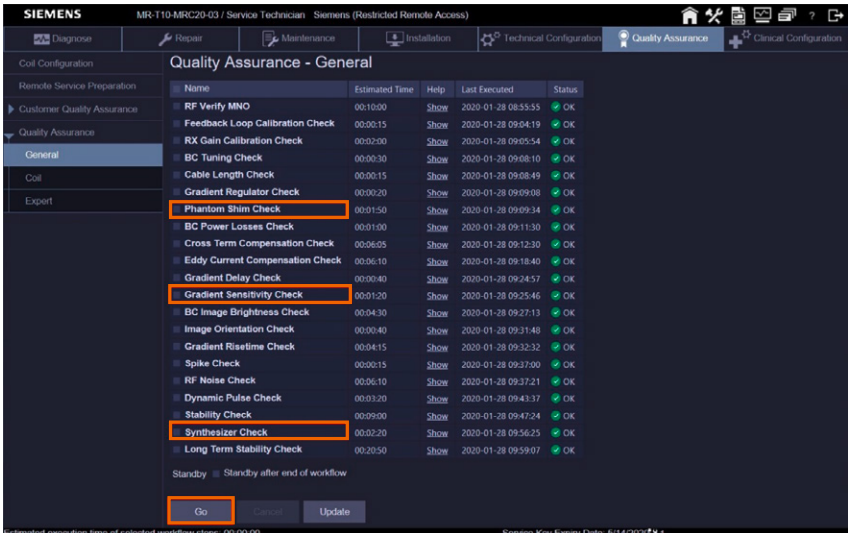


Figure 104: QA checks with service key

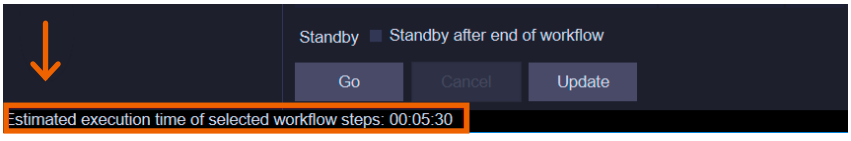


Figure 105: Estimated execution time for all selected tests

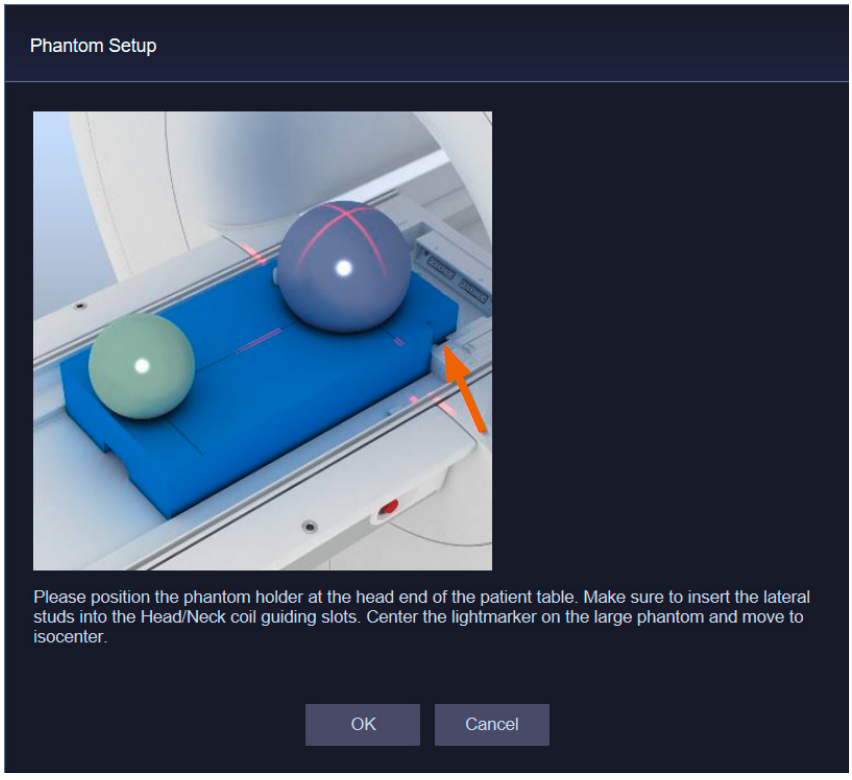


Figure 106: Instructions about phantom setup

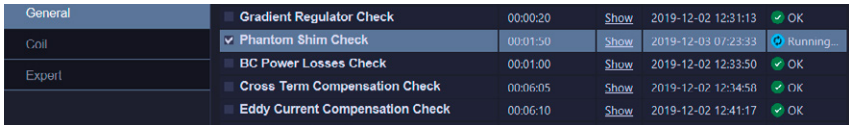


Figure 107: Status "Running"

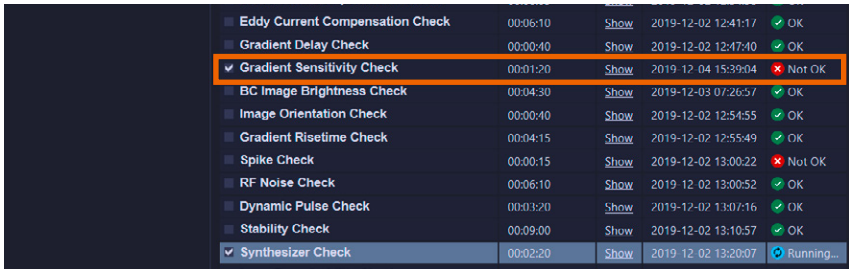


Figure 108: Test failure: Status goes from Running to Not OK

4. Once the tests are initiated, a dialogue box appears giving instructions about the correct phantom setup (Figure 106). If the phantom positioning is correct, press OK.
5. Once a test starts, its status changes to **Running** Figure 107). Necessary preconditions are checked, followed by steps needed to perform the test. This is shown in the bottom left corner as the evaluation goes on.
6. In case a test fails, the status changes from **Running** to **Not OK** (Figure 108).

7. A message appears once the tests are over, indicating the status (Figure 109).
8. To check the service reports once the tests are over, click on the icon at the top right of the screen, as indicated in Figure 110:
9. The service report for a test can be accessed by clicking on a test name. The tests performed most recently will appear at the top of the list.

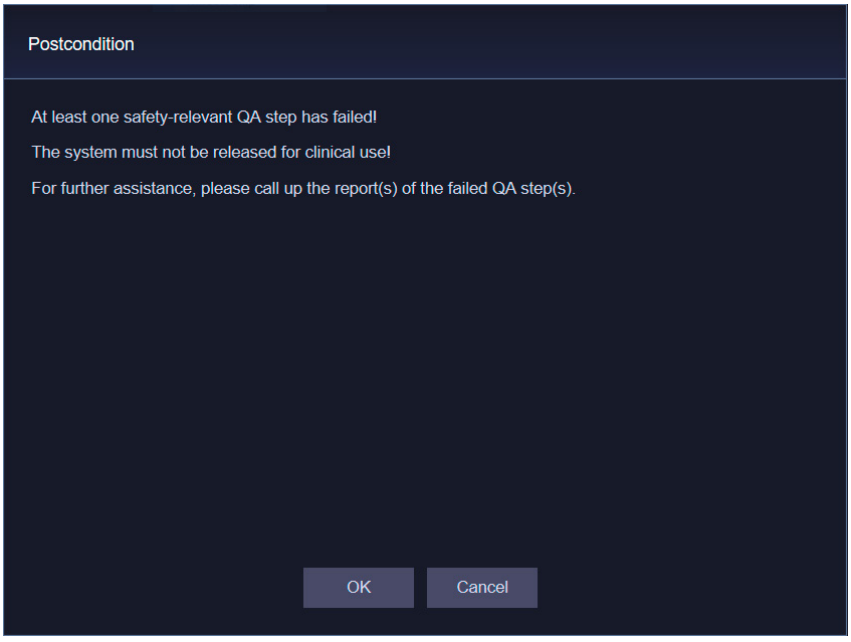


Figure 109: End test message

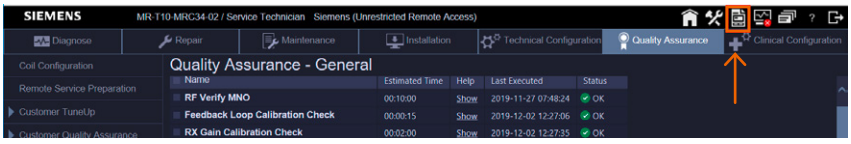


Figure 110: Accessing service reports

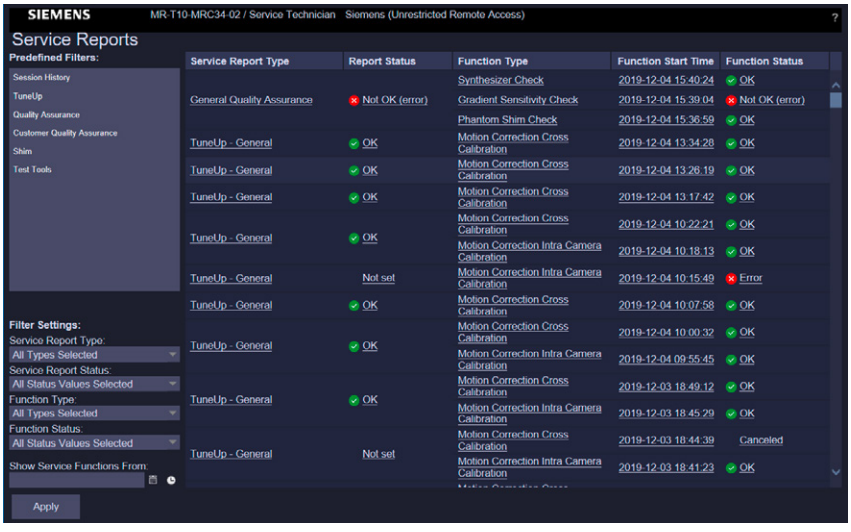


Figure 111: Accessing service reports

Figure 112: Summary of test

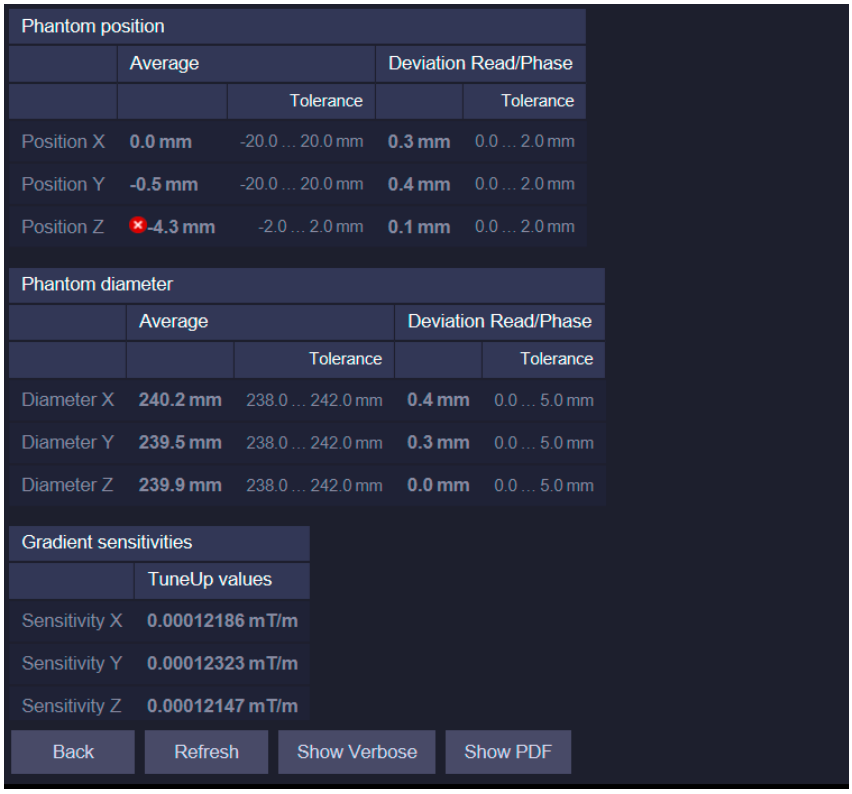


Figure 113: Detailed specification of test results

10. The results of a test can be seen in the **Summary** of the Service Report for that test.
11. The measurements from a check and detailed specifications can also be accessed. For example, as indicated inFigure 113, the gradient sensitivity check failed because the Z position was not within the range, due to an incorrectly positioned phantom.

Note:
In such cases, a repetition of the test is recommended. Following the example of the wrongly positioned phantom, the **Position Z** can be now be seen to be within tolerance after repositioning. Consequently, the status changes to **OK**. (Figure 114)

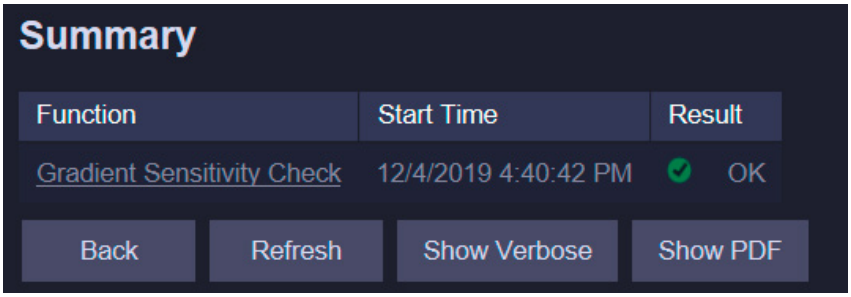


Figure 114: Status changes to OK after repositioning the phantom

Figure 115: Position Z now within range

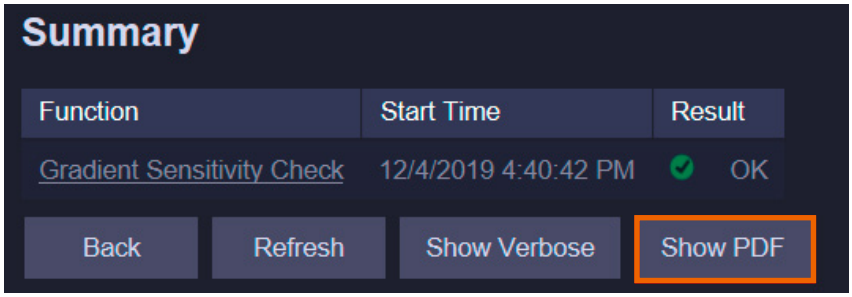


Figure 116: Show results as PDF

12. The service report for a test can be saved as a pdf document. Click **Show PDF** at the bottom of the screen. This leads to a dialogue box titled **PDF Settings** to appear. Click on **Show** after selecting the appropriate settings. (Figure 116 and Figure 117)

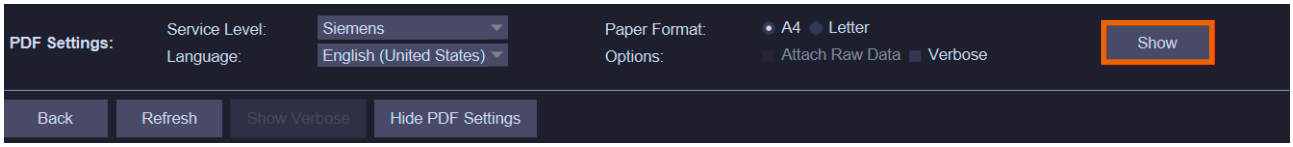


Figure 117: Settings for the PDF document

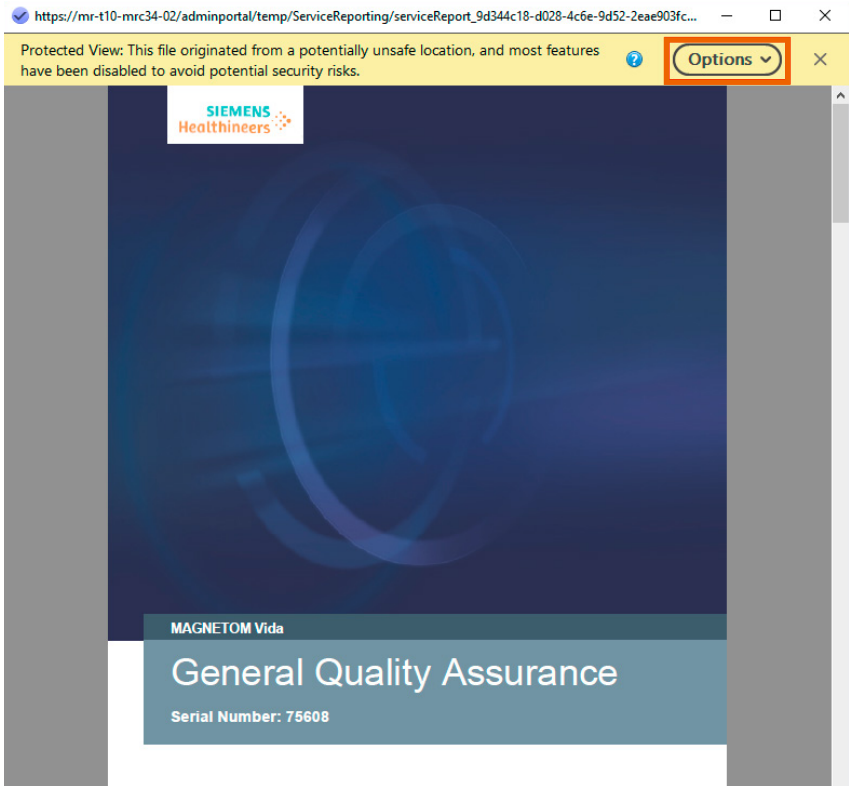


Figure 118: Saving the PDF report

13. Once the PDF document with settings shows, it can be saved from within the document interface by selecting **Options**.

Appendix 3

ACR Phantom Testing Positioning and Workflow

The tests for analysis of image quality that have been directed to this appendix all require the same setup and set of sequences as prerequisites for analysis. A detailed description of how to carry these out in your MAGNETOM system has been detailed **here.**

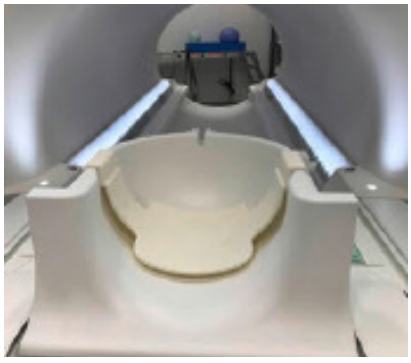
Once all necessary images have been acquired, these can be analyzed as described in the ACR document named "Phantom Test Guidance for Use of the Large MRI Phantom for the ACR", which can be downloaded from the ACR website **here.**

For demonstration purposes we chose the head coil in this description, however these tests can be run with any flex coil of your preference.

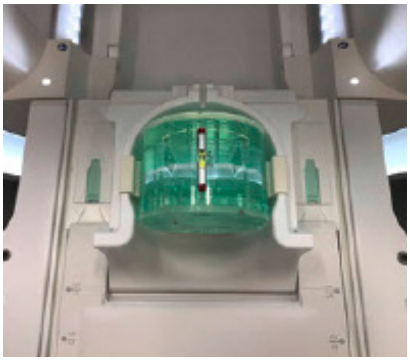
The ACR phantom includes labels to assist with proper positioning. The phantom is placed in the Head Coil as if the patient were positioned, Head/First, Supine.

- **"NOSE"** label facing up
- **"CHIN"** label facing towards the feet

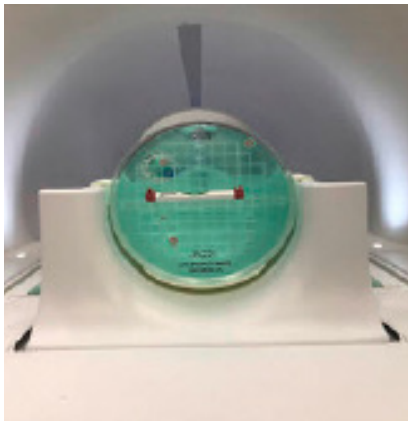
Phantom and setup



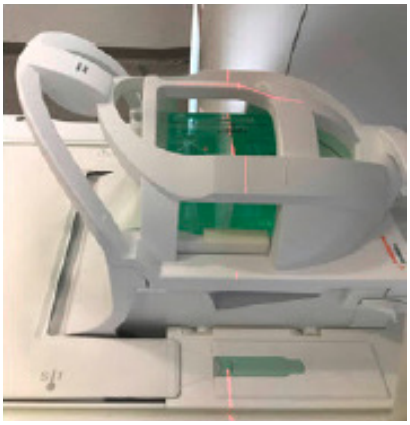
Head of Coil with Phantom Holder



Phantom with Bubble Level on Top



Phantom with Bubble Level in Front



Head ACR Phantom – Laser Light / Nose

Figure 119: ACR phantom setup

Positioning and setup

1. Connect the base of the **head coil** to the patient table.
2. Insert the ACR phantom **holder** into the base of the head coil.
3. Place the ACR phantom into the holder.
   - **"Nose"** label – facing up
   - **"Chin"** label – faces the feet

4. Stabilize the phantom using positioning aids. Place positioning aids on both sides of the phantom in the head coil.
5. Level the ACR phantom.
   - Level Head to Foot – insert gauze or paper to assist with leveling the ACR phantom.
   - Place the ACR bubble level on the shelf of the phantom.
   - Level Right to Left – rotate phantom until bubble is centered in the level.
6. Connect the anterior portion of the head coil to the base.
7. Turn on Laser Light.
8. Re-check ACR phantom alignment – ensure phantom "NOSE" mark is aligned with the laser light.
9. Turn off Laser Light.
10. Advance head coil to isocenter.

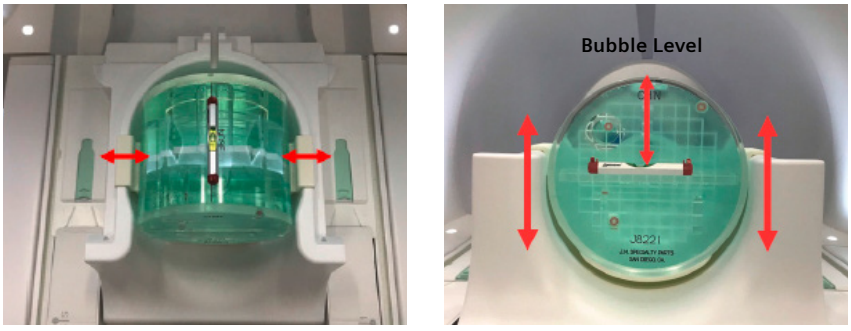


Figure 120: Stabilization of ACR phantom

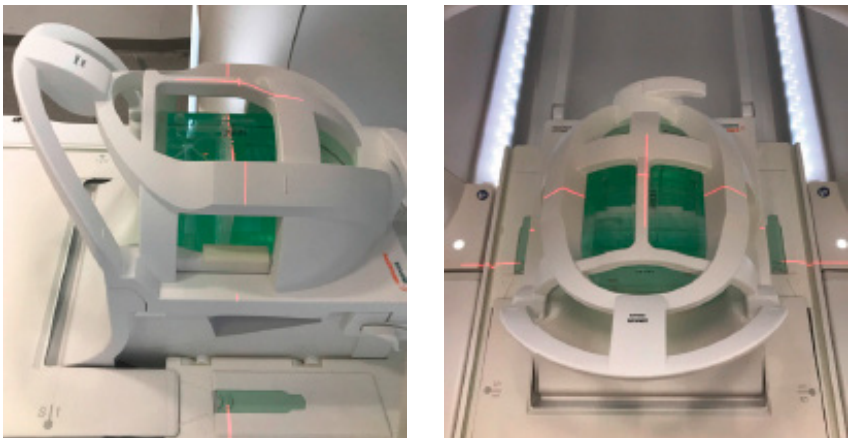


Figure 121: Positioning with laser

Import ACR phantom .exar1 file

These protocols can be downloaded **here.** (at section Protocols incl. QA)

1. Open **Dot Cockpit.**
2. Select **User Tree.**
3. Click on **Explorer** then the **Import** tab.

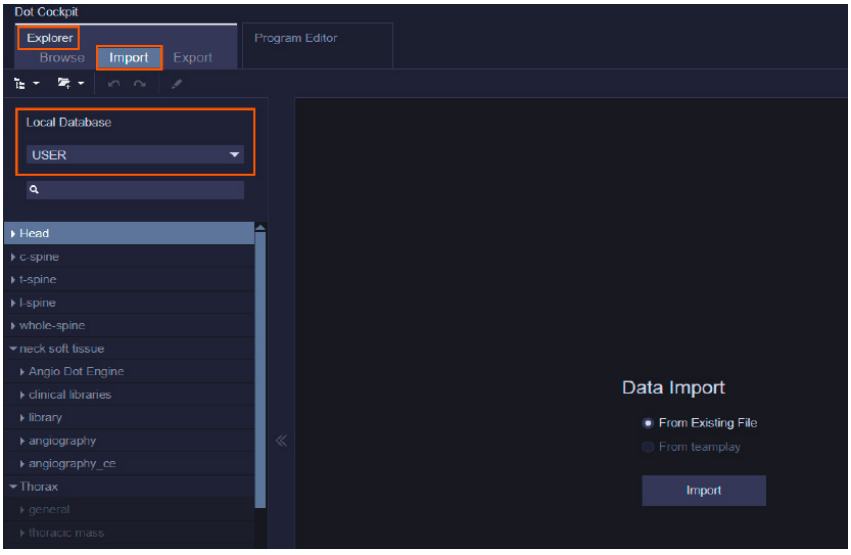


Figure 122: Dock Cockpit

4. Click on **Data Import.**
5. Click on the **From Existing File** tab and then select **Import.**
6. When Windows Explorer opens, select **External Drive** (e.g., USB).
7. Select the **ACR Phantom .exar1** file.
8. Click the **Open** button.
9. Click on the **Dot Cockpit.** The Explorer opens.
10. Select **ACR.**
11. Select double arrows **(<<).** The protocol loads in the User Tree.

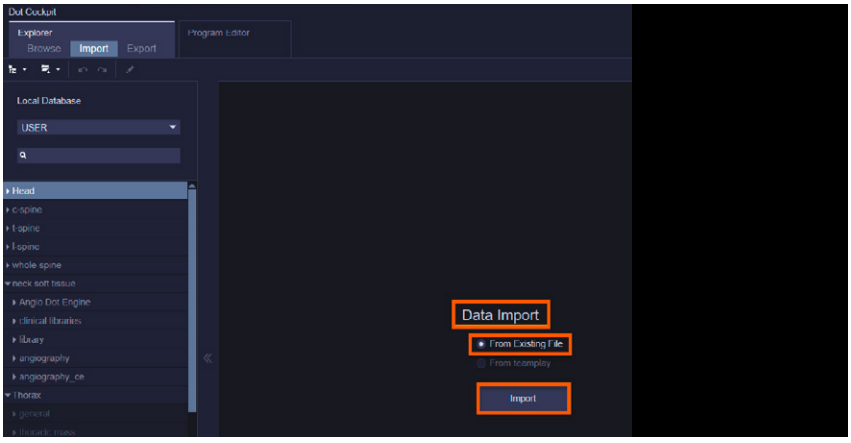


Figure 123: Import file Setup

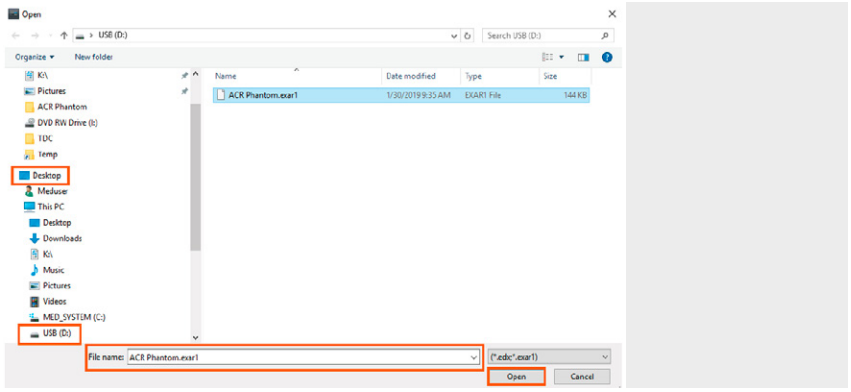


Figure 124: Import file

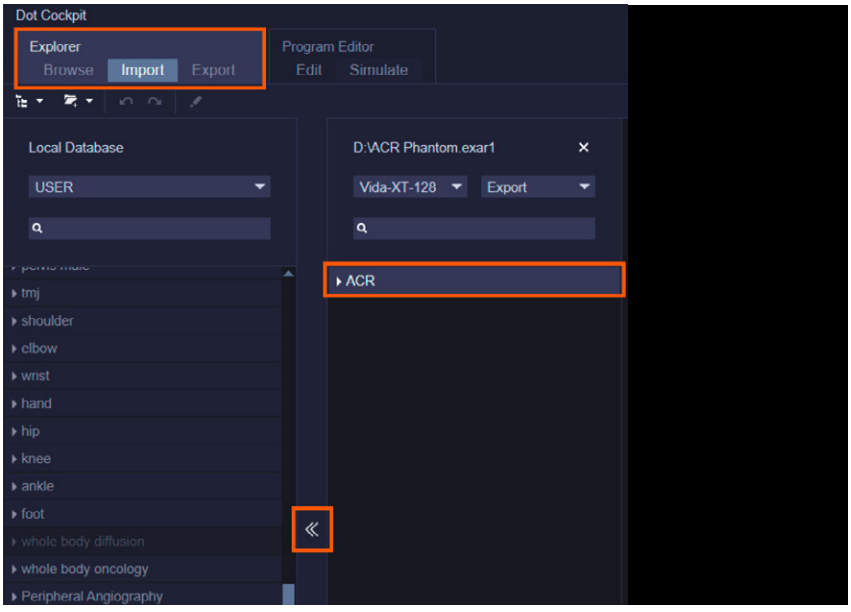


Figure 125: Loading the protocol in User Tree

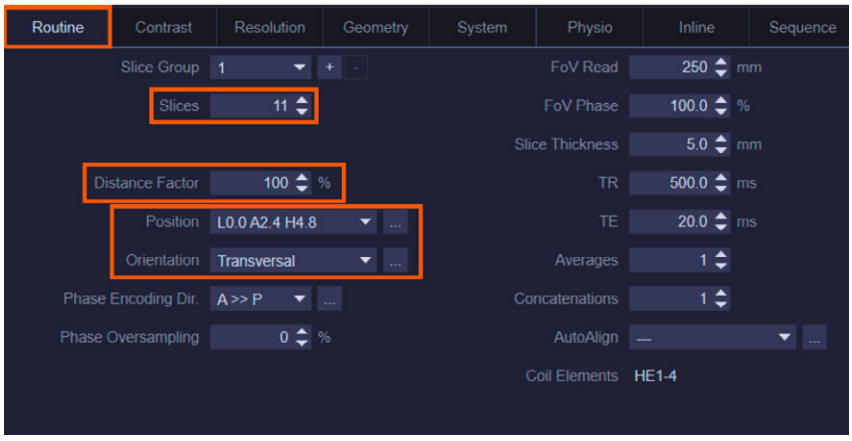


Figure 126: Selection of optimal protocols

Figure 127: Selection of optimal protocols

ACR Phantom Site Protocols

Perform the following steps to optimize the parameters for the ACR phantom protocols; Site T1 and Site T2.

Sequences Site T1 and Site T2

1. Open the **Dot Cockpit** and select **User/Customer ACR Protocol.**
2. Select the **Program Editor** and click on the Edit button.
3. Click on the **Customer Tree** and select **Brain >T1 & T2 Axial sequences.**
4. Press the right mouse button and select **Copy.**
5. Select **ACR > ACR Phantom > ACR Phantom.**
6. Select **Paste.**
7. Open **Site T1** and modify the parameters as follows:

- Routine Parameter Card
  i. Slices = **11**
  ii. Distance factor = **100**
  iii. Orientation = **Transversal**
  iv. Position = **L-P-H**

8. Open Site T2 and modify the parameters as follows:

- Routine Parameter Card
  i. Slices = 11
  ii. Distance factor = 100
  iii. Orientation = Transversal
  iv. Position = L-P-H

Patient Registration

Now that you have built your protocol and properly positioned the ACR phantom on the table, you are ready to perform the data acquisition.

The Patient Registration process includes the following steps:

1. Open the Patient Registration window.
2. Complete the required Patient Registration fields marked with an asterisk (*) with the following information:

- Last Name = **ACR Phantom**
- Patient ID = **1234**
- Date of Birth = **##/##/####**
- Age = **## Year(s)**
- Sex = **Other**
- Height = **#Ft #in**
- Weight = **## lbs**
- Body Part and Laterality = **Brain**
- Patient Orientation = **Head First Supine**

3. On the **Program Selection** tab, select the following:

- Under the **All Programs** section, click to expand and display levels.
- Select **ACR > ACR Phantom > ACR Phantom.**
- **Program Selection** updates to show the protocol selected under **All Protocols** section.
- Click the **Exam** button to compete the registration.
- ACR phantom sequences are automatically loaded into the Exam UI.

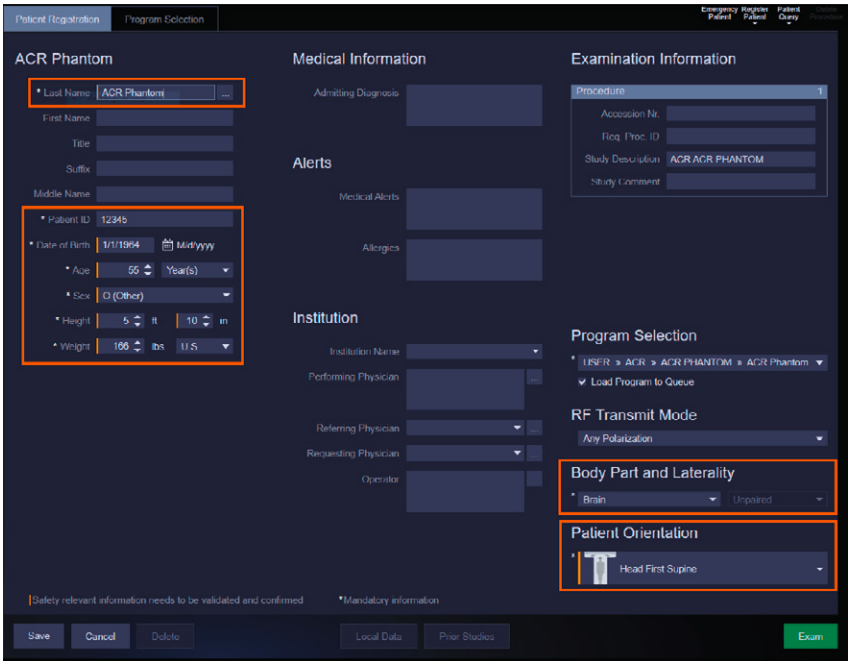


Figure 128: Patient Registration

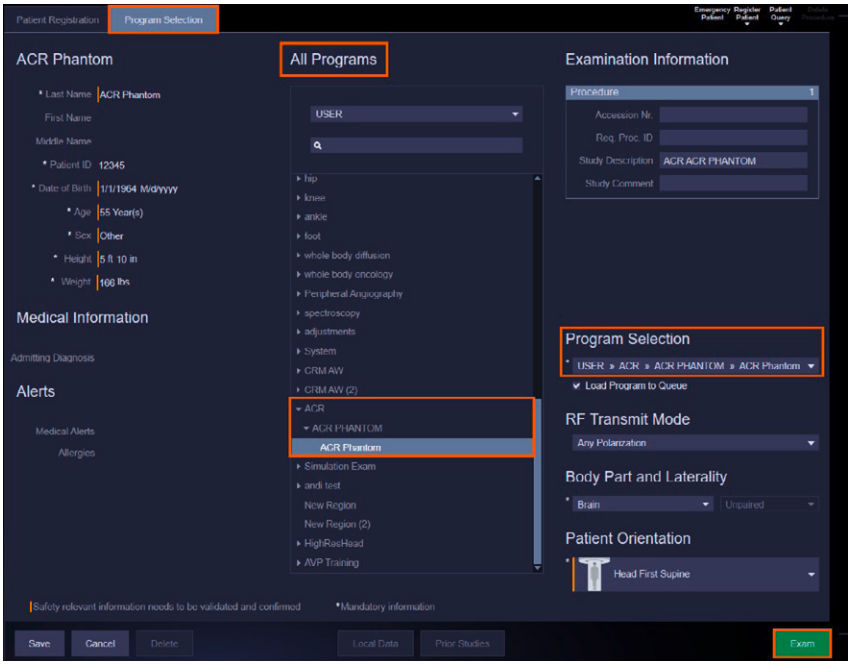


Figure 129: Program Selection

Figure 130: Protocols

4. Protocols include:

- 3 Plane Localizer
- ACR Sag Loc
- ACR T1 Axial
- ACR T2 Axial
- Site T1 Axial
- Site T2 Axial

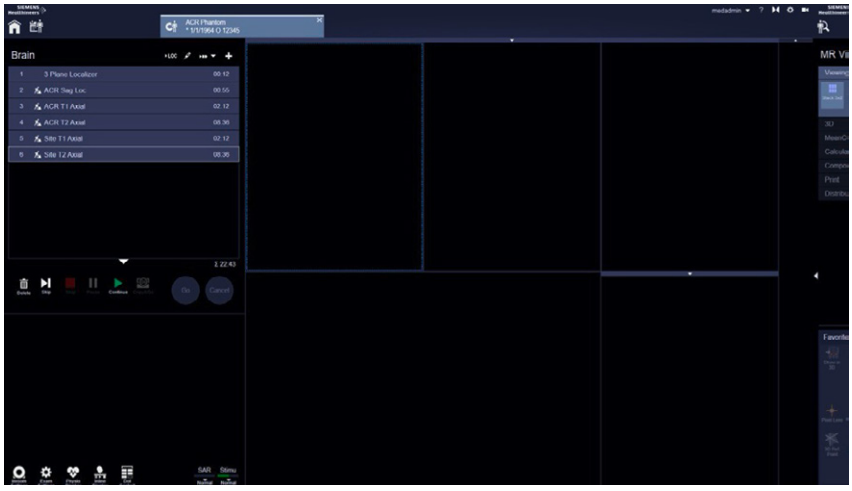


Figure 131: Validating phantom position and sequences

ACR Phantom Data Acquisition

The following steps describe the process for validating the position of the ACR phantom and the required sequences.

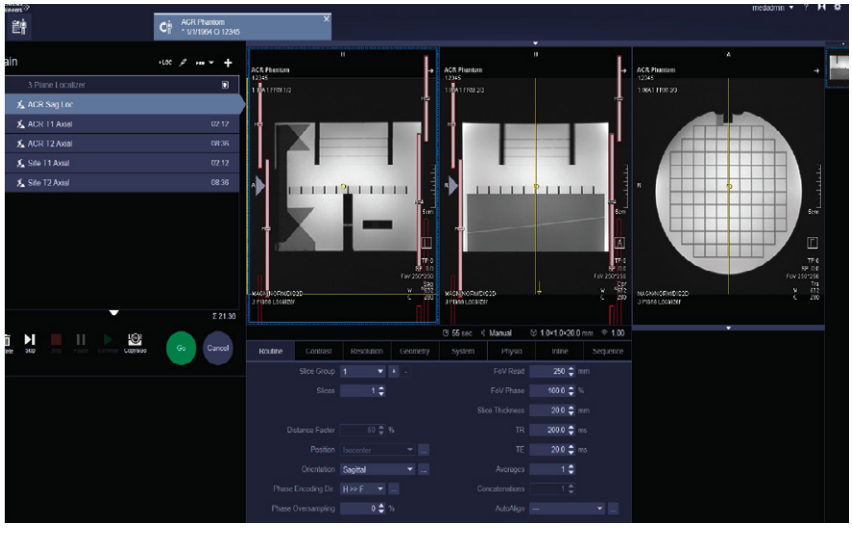


Figure 132: Three Plane Localizer

Three Plane Localizer to verify Phantom Positioning

1. Select the Three Plane Localizer and click on the Go button to run the scan.

- Verify the position of the phantom; check the Sagittal and Axial images to ensure the phantom is level and not rotated.

2. If the phantom is not properly positioned:

- Reposition the phantom.
- Re-run the Three Plane Localizer.
- Repeat steps until the phantom is properly positioned.

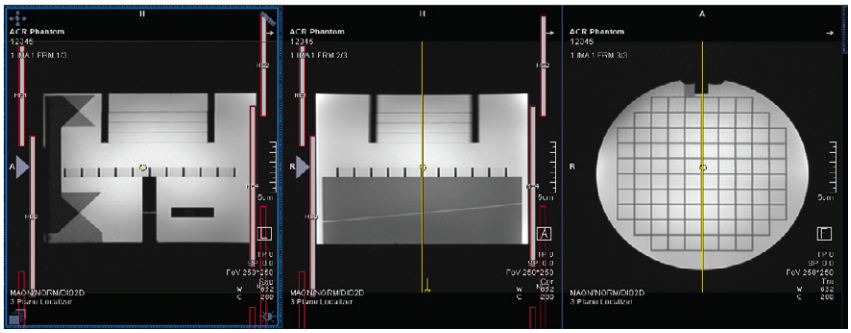


Figure 133: Three Plane Localizer

Sagittal Localizer

1. Check the Sagittal slice position.
2. Click the Go button to run the Sagittal Localizer sequence.

ACR T1 and T2 protocols

The following steps describe the process to acquire and position the slices on the phantom for the ACR T1 and T2 protocols.

Figure 134: Line Mode

Acquisition of ACR T1 Protocols

1. ACR T1 sequence is open and ready for slice positioning.
2. Select the GSP (Graphical Slice Positioning) Flyout Toolbar (see Operator Manual – Scanning).
3. Turn on Line Mode.
6. Once slices are positioned check and reset the **A>P** and **L>R** offsets. Enter offset values in the Position Window.

- L/R = 0.0, P/A = 0.0, H/F = **offset value is based on where slices were positioned.**

7. Click the **Go** button to run the sequence.

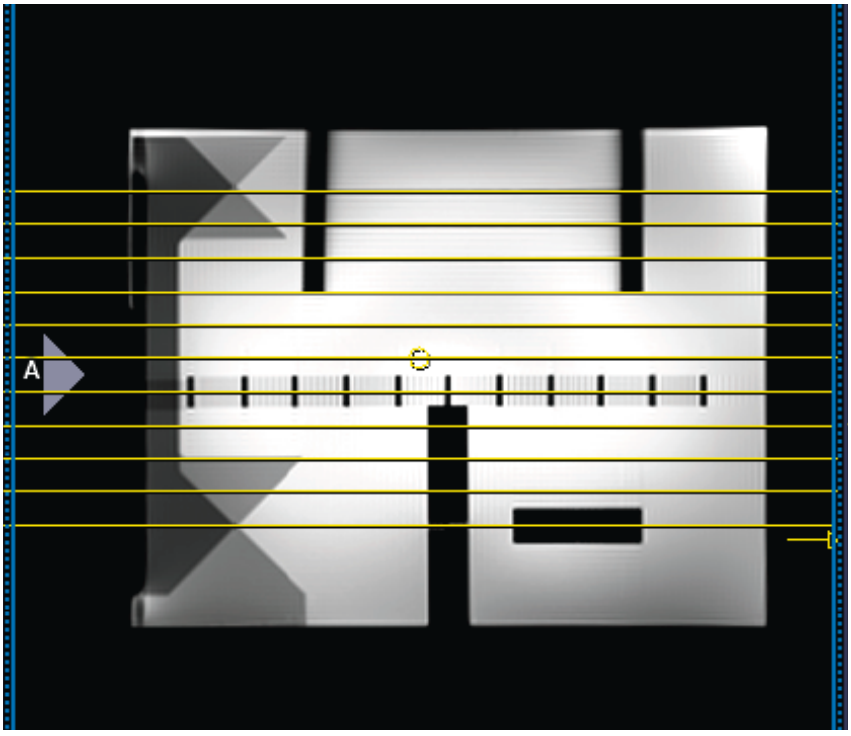


Figure 135: Positioning ACR T1 slice group

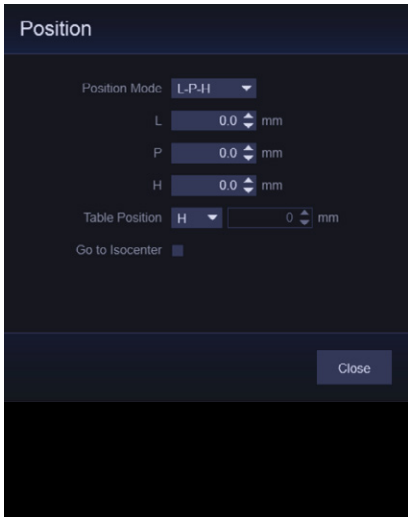


Figure 136: Setting positioning parameters

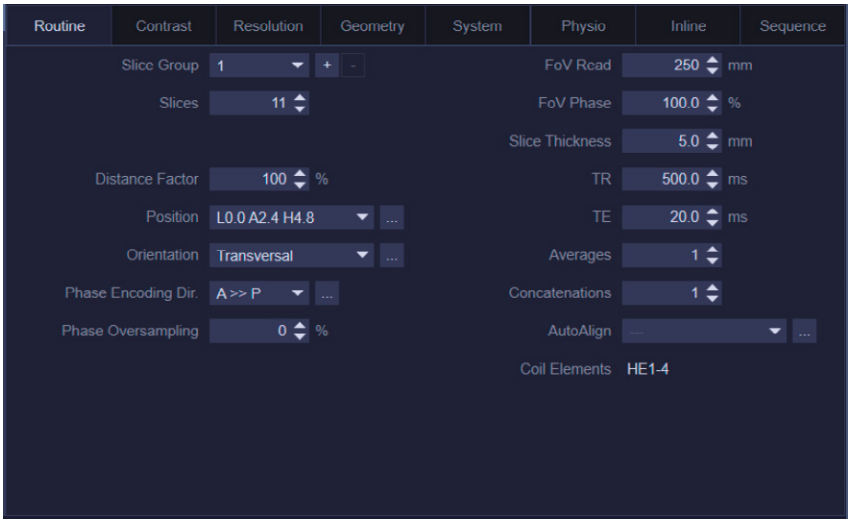


Figure 137: Parameters Overview

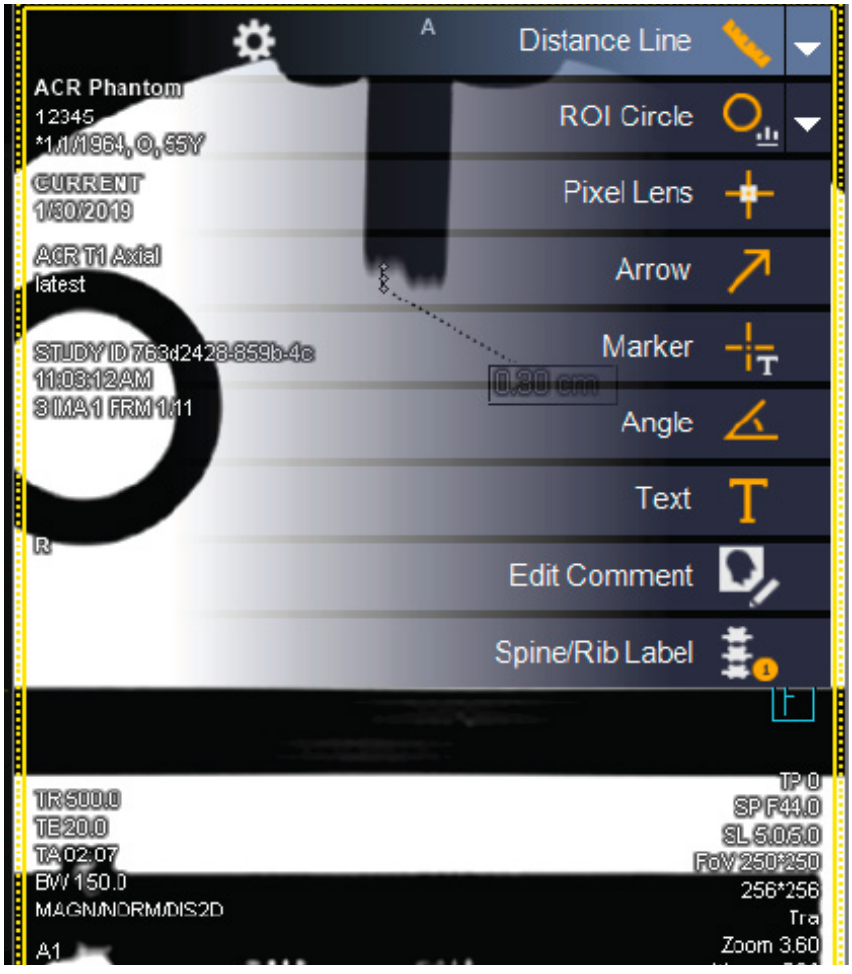


Figure 138: Selection of Distance Line

Verify accuracy of Slice Positioning

1. Select **View&GO > ACR Phantom** folder.
2. Select **ACR T1 Axial** image segment.
3. Select **Slice 1.**
4. Select **Distance Line** (Upper Right Corner).
5. Draw a Distance Line on the **ACR T1 Axial > Slice 1**. Measure the difference between two bars displayed at the 12:00 position.

- Maximum Distance between 2 bars should be less than 0.4 cm.
- Reposition the slice group for distances greater than 0.4 cm.

Acquisition of ACR T2 Protocols

1. **ACR T2** sequence is open and ready for slice positioning.
2. Right click on **ACR T1** sequence then select **Copy Parameters.**
3. Select **Slices** then click on **OK**.
4. Click the **Go** button to run the sequence.

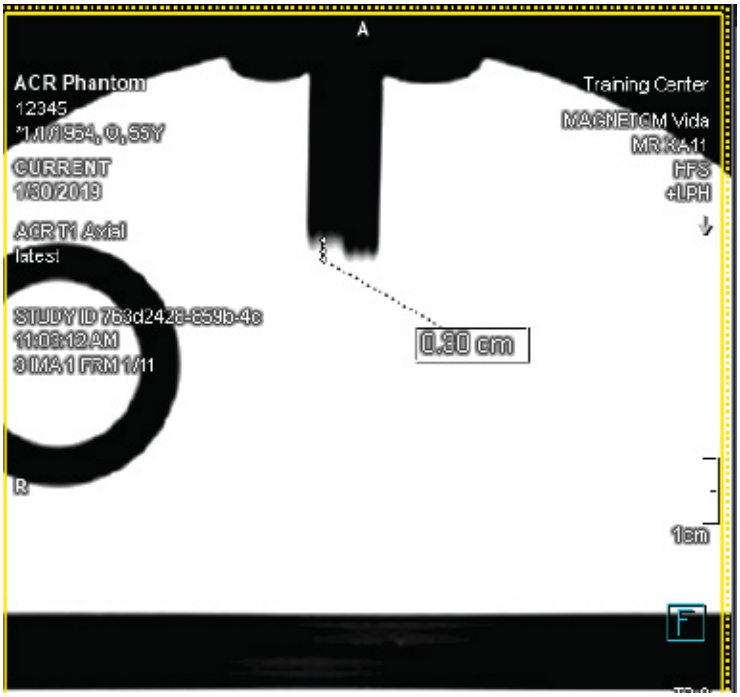


Figure 139: Maximum distance between 2 bars

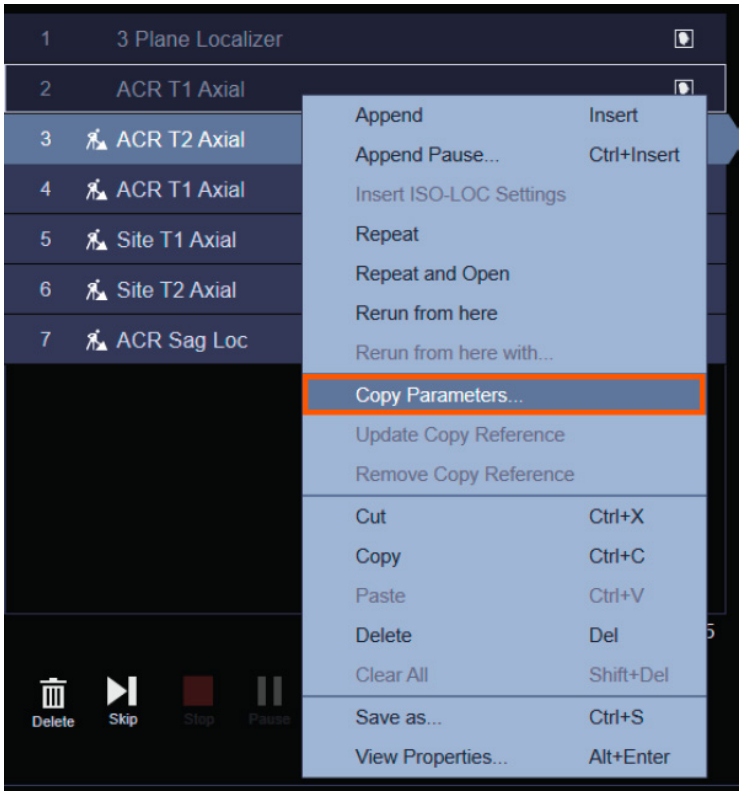


Figure 140: Setting up parameters for ACR T2 sequence

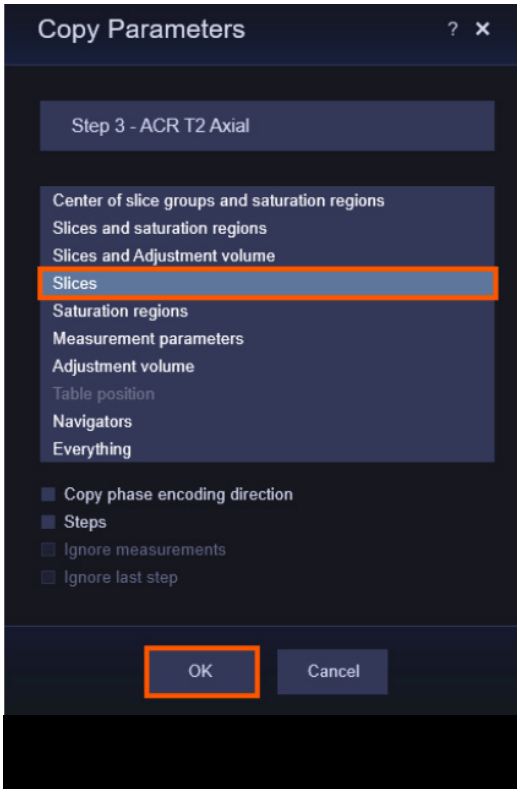


Figure 141: Setting parameters for ACR T2 sequence

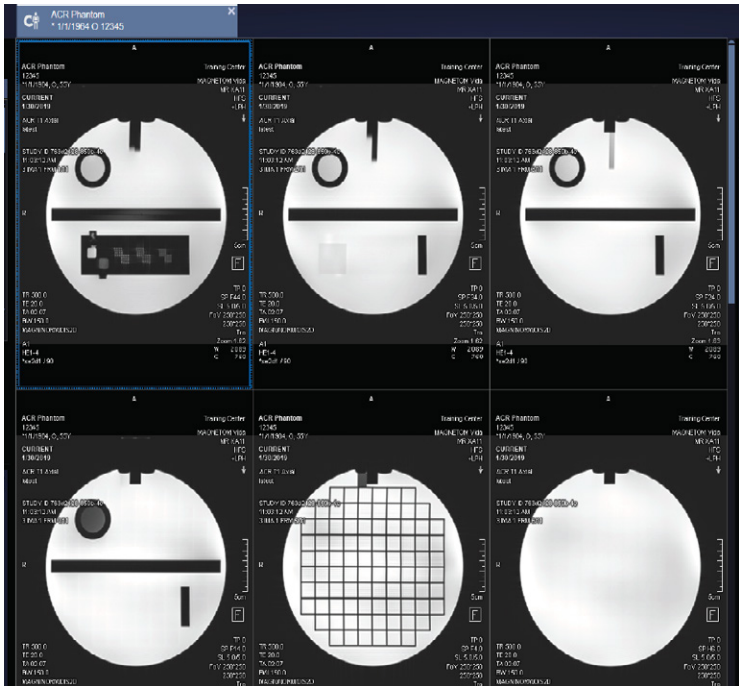


Figure 142: Reviewing acquired images

T1 and T2 Site Protocols

To acquire the T1 and T2 Site Protocols, complete the following steps.

Site T1 Sequence

1. Site T1 sequence is open and ready for slice positioning.
2. Right click on the **ACR T1** sequence and then select **Copy Parameters.**
3. Select Slices and then click on OK.
4. Click on the Go button to run the sequence.

Site T2 Sequence

1. Site T2 sequence is open and ready for slice positioning.
2. Right click on the **ACR T2** sequence and then select **Copy Parameters.**
3. Select Slices and then click on **OK.**
4. Click on the **Go** button to run the sequence.

View&Go – Image Review

1. Select View&Go.
2. Select the **ACR Phantom folder**.

- Review all the MR ACR phantom images acquired for artifacts using normal **Window** and **Level** settings.

References:

1. Workbook | Siemens MRI ACR Phantom Testing – Numaris X

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