MRI Safety and QA

Can Wu, PhD
Assistant Attending
Chair of Rad Onc MRI Safety
Department of Medical Physics

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Memorial Sloan Kettering
Cancer Center

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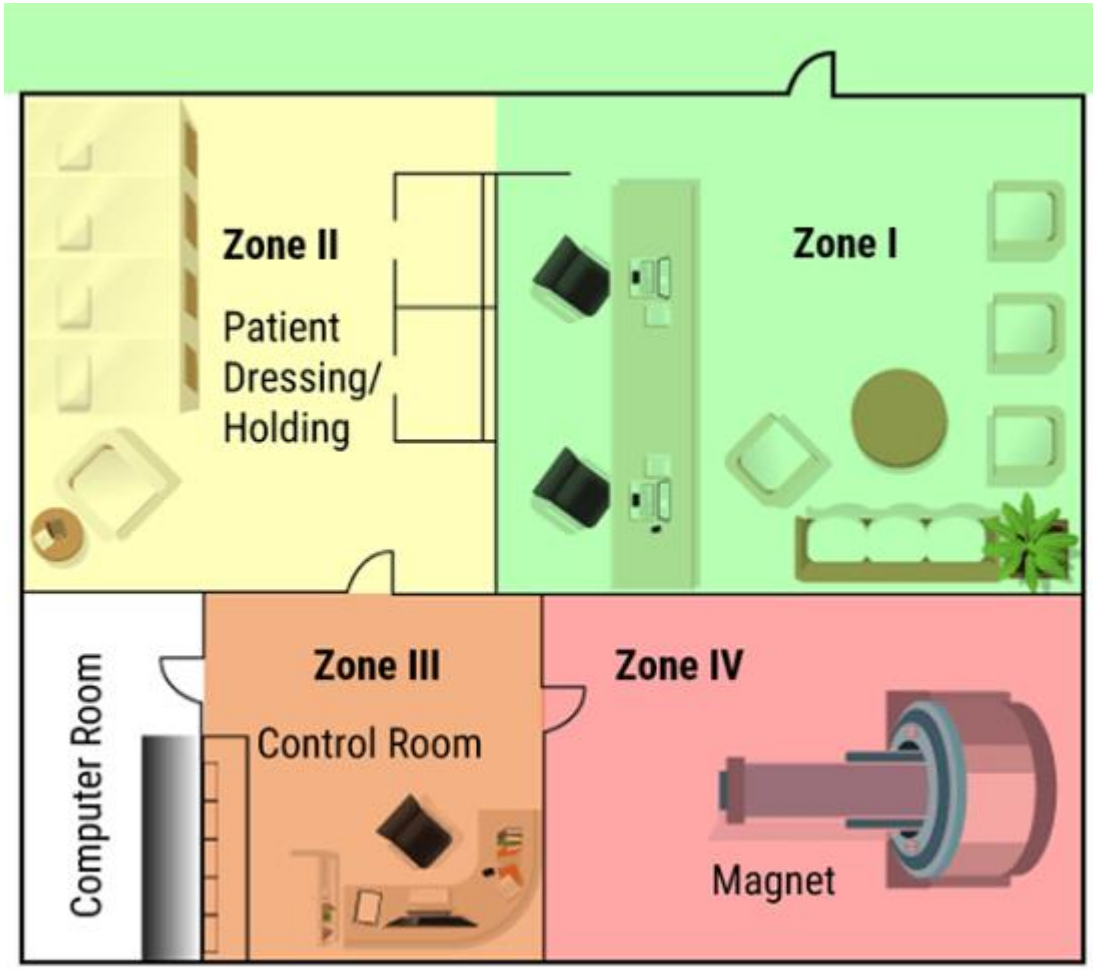
PART I: MRI Safety Outline

- **MRI Safety: Basics**
  - ACR MRI zones
  - MRI signages
    - MR safe/unsafe/conditional
  - Quench and emergency
  - MRI personnels
  - MRI safety roles
  - MRI safety screening

- **MRI Safety: Advanced**
  - Three magnetic fields
  - Projectile effect
  - RF heating
  - Peripheral nerve stimulation
  - Noise protection
  - Contrast agent (Gd^{3+})
  - Implants (passive and active)
  - Rad Onc MRI safety
  - MSK MRI safety resources

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ACR MRI Zones



MRI	
MRI ZONE I	MRI Access Area

NOTICE	
MRI ZONE II	MRI Patient Screening and Preparation

⚠ CAUTION	
MRI ZONE III	**Restricted Access** Screened MRI Patients and MRI Personnel Only

⚠ DANGER	
MRI ZONE IV	**Restricted Access** Screened MRI Patients Under Direct Supervision of Trained MRI Personnel Only

MSK MRI Zone Maps: https://mskcc.sharepoint.com/sites/pub-MRISafety/SitePages/MRI-Zone-Maps.aspx

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MRI Signages



Conditional



Unsafe



Safe











MRI Quench



https://www.youtube.com/watch?v=CXWqIz68eqw&ab_channel=MedicalOutfittersInc

Quench Buttons:

- Siemens
- GE
- Philips







Quench sometimes also refers to
“Emergency Run Down”

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Emergency

- **Emergency table stop:**



- Immediately stop MR scanning and **table motion**
- Usually found on or near the MRI console and on the MR bore front cover or the patient table
- Something is caught on the table and further table motion may result in damage or injury

- **Emergency power off:**





- Stop **electrical power** to the entire suite
- Should be used with caution and only in emergent situations only
- In the MR control room or on the wall inside Zone IV
- Used in case of fire, flooding, or voltage accidents

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MRI Personnels

- **Non-MR Personnel:** those that within the **previous 12 months have not** successfully completed the designated formal MRI safety education (training).
  - Patients, visitors, facility staff, healthcare providers

- **MR Personnel:**
  - **Level 1 MR Personnel:** those who have been educated and successfully mastered MR safety topics to ensure that they would not constitute a danger to themselves or others in the MR environment.
  - **Level 2 MR Personnel:** those who have been more extensively trained and educated in MR safety topics beyond level 1 MR training.
    - MR Technologists and MR Radiologists are required to be Level 2 MR personnel

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MRI Safety Roles

- **MR Medical Director (MRMD):**
  - A licensed physician or radiologist with appropriate training MR safety
  - Oversee overall MR facility operational safety
  - Develop, implement, and maintain specific MR safety policies and procedures

- **MR Safety Officer (MRSO):**
  - Often an MR technologist
  - Ensure accessibility at all times
  - Ensure that policies and procedures are implemented and enforced at all times

- **MR Safety Expert (MRSE):**
  - Often an MR physicist
  - Serve in an advisory role for the MRMD and MRSO for technical and physics-related MR safety issues

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MR Safety Screening

- **MRI Safety Screening Form**

CONFIDENTIAL INFORMATION – HANDLE ACCORDING TO HOSPITAL POLICY

Memorial Hospital For Cancer and Allied Diseases
Screening Questionnaire for MRI

Staff Visitor Name: Date: ID#:

WARNING: Certain implants, devices, or objects may be hazardous to you and/or may interfere with the MR procedure. Do not enter the MR system room or MR environment if you have any question or concern regarding an implant, device, or object. Consult the MRI Technologist or Radiologist or Nurse BEFORE entering the MR scanning. The MR system magnet is **ALWAYS ON!**

Please consult the MRI Technologist or Nurse if you have any questions or concerns BEFORE you enter the MRI room.

□Yes □No…..Have you had an injury to the eye involving a metallic object or fragment (e.g., metallic slivers, shavings, foreign body, etc.)? If yes, please describe: _____

□Yes □No…..Have you ever been injured by a metallic object or foreign body (e.g., BB, bullet, shrapnel, etc.)? If yes, please describe: _____

Please indicate if you have any of the following devices on or within your body:

□ Yes □No…….Cardiac pacemaker
□ Yes □No…….Implanted cardioverter defibrillator (ICD)
□ Yes □No…….Tissue expander (e.g., breast)
□ Yes □No…….Any metallic fragment or foreign body
□ Yes □No…….Magnets of any kind
□ Yes □No…….Eyelid spring or wire
□ Yes □No…….Magnetically-activated implant or device
□ Yes □No…….Spinal cord stimulator
□ Yes □No…….Bone growth/bone fusion stimulator
□ Yes □No…….Any type of prosthesis (eye, penile, etc.)
□ Yes □No…….Metallic stent, filter, or coil
□ Yes □No…….Shunt (spinal or intraventricular)
□ Yes □No…….Vascular access port and/or catheter
□ Yes □No…….Wire mesh implant
□ Yes □No…….Aneurysm clip(s)
□ Yes □No…….Tattoo or permanent makeup
□ Yes □No…….Acupuncture needle(s)
□ Yes □No…….IUD, diaphragm, or pessary
□ Yes □No…….Electronic implant or device
□ Yes □No…….Bone/joint pin, screw, nail, wire, plate, etc.
□ Yes □No…….Joint replacement (i.e., hip, knee, etc.)
□ Yes □No…….Neurostimulation system
□ Yes □No…….Internal electrodes or wires
□ Yes □No…….Cochlear, otologic, or other ear implant
□ Yes □No…….Heart valve prosthesis
□ Yes □No…….Surgical staples, clips, or metallic sutures
□ Yes □No…….Implanted drug infusion device
□ Yes □No…….Radiation seeds or implants
□ Yes □No…….Other implant _____
□ Yes □No…….Acupressure pellets or beads

The following items must be removed before entering the MRI room: Do you have any of the following?

□ Yes □No…….Hearing aid
□ Yes □No…….Insulin, pain medication or other infusion pump
□ Yes □No…….Dentures or partial plates
□ Yes □No…….Artificial or prosthetic limb
□ Yes □No…….Body piercing jewelry
□ Yes □No…….Medication Patch (except fentanyl)

IMPLANT Information: Manufacturer: _____ Type: _____ Model: _____

Signature of Person Completing Form: _____ Date ____/____/____
Signature

Form Completed By: □ Patient □ other _____
Print name and relationship to patient

Form Information Reviewed By Signature/ Title_____

Printed Name_____ Title_____ Date_____ Time_____

- **Ferromagnetic Metal Detectors**





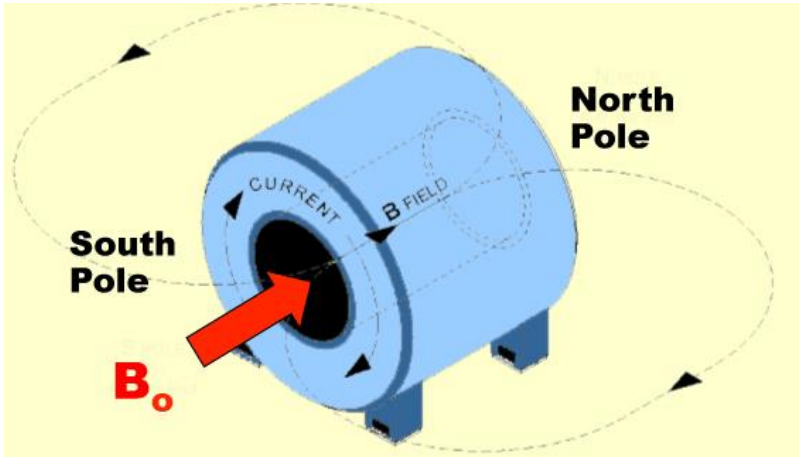




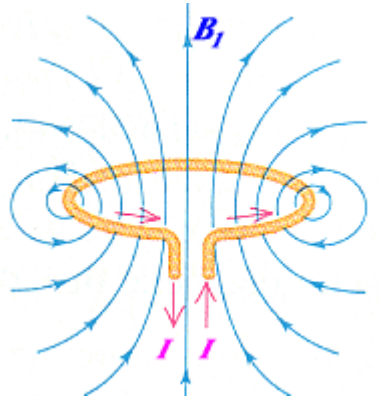
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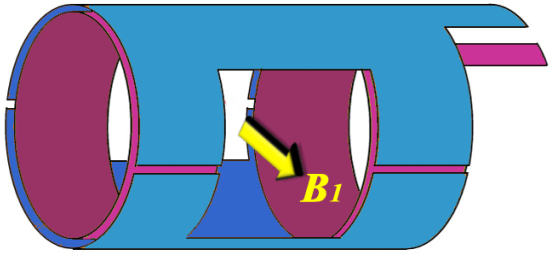
Three Magnetic Fields in MRI

- **Static magnetic field (B_0)**

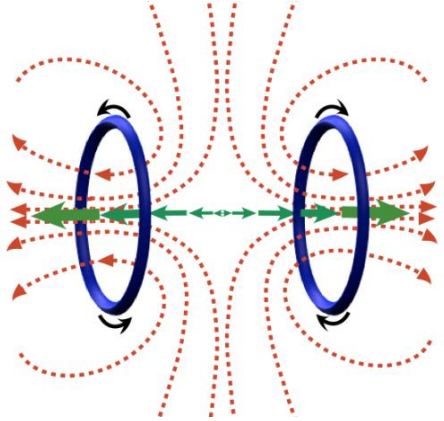


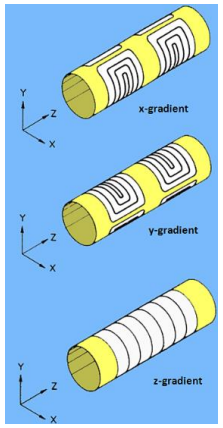
- **Time-varying RF magnetic field (B_1)**

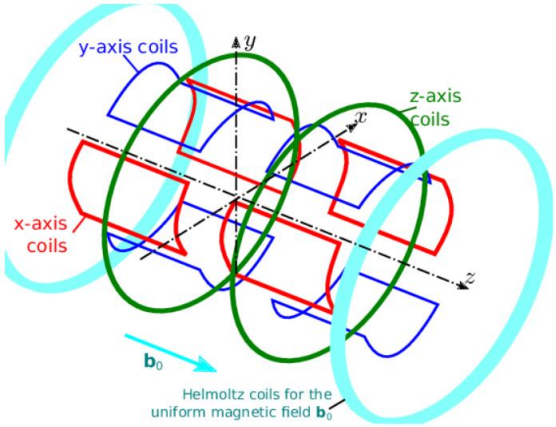


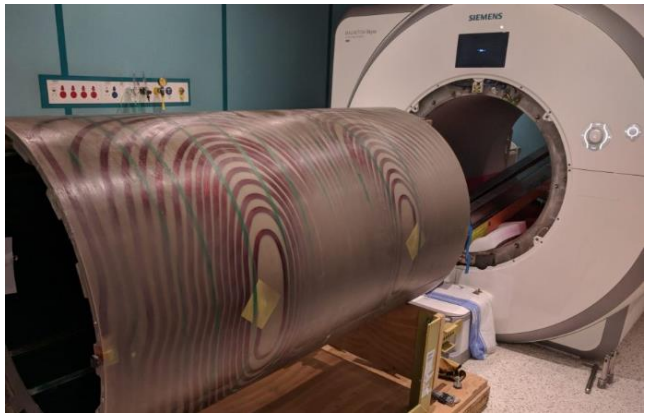


- **Time-varying gradient magnetic field (dB/dt)**





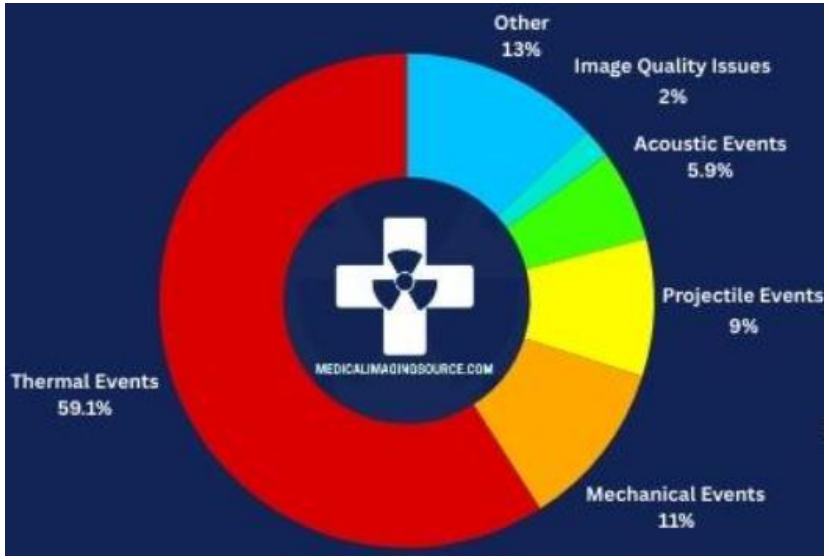




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MR Safety Concerns: Three Magnetic Fields

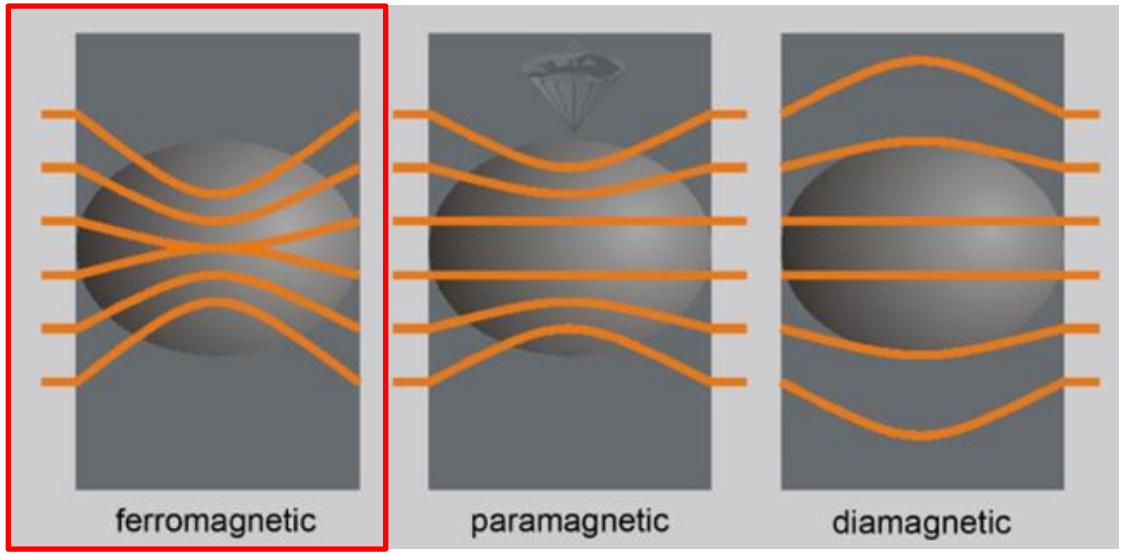
- **Static magnetic field (B_0, dB/dz)**
  - **Projectile effect (missile effect)**
  - Ferromagnetic implants and medical devices
  - Magnetophosphenes and sensory effects
- **Time-varying RF magnetic field (B_1)**
  - **Tissue heating (SAR)**
  - Burns from conductive materials
  - Heating of implants
  - Contact burns
  - Heating of tattoos and cosmetics
- **Time-varying gradient magnetic field (dB/dt)**
  - **Acoustic noise**
  - **Peripheral nerve stimulation (PNS)**
  - Induced currents in conductive loops
  - Heating of implanted devices



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MR Safety of B_0 Magnetic Field

- **Projectile effect (missile effect)**



- **Iron (Fe)**
- **Nickel (Ni)**
- **Cobalt (Co)**
- Alloys
- 400 stainless steel

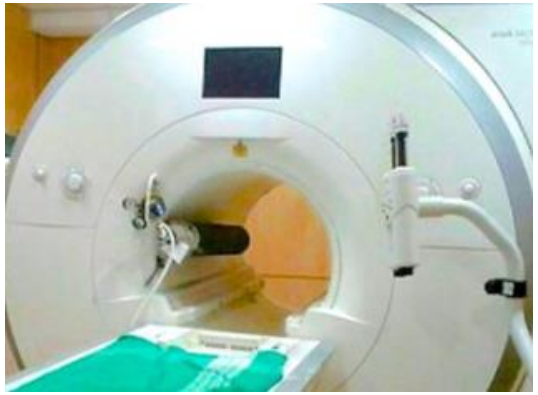
- **Oxygen (O_2)**
- Aluminum (Al)
- Titanium (Ti)
- Nitinol (Ni+Ti)

- **Water**
- **Fat**
- **Biological tissues**
- Gold
- Silver
- Copper

- **Ferromagnetic objects**







Demo of MRI Projectile (Missile) Effect

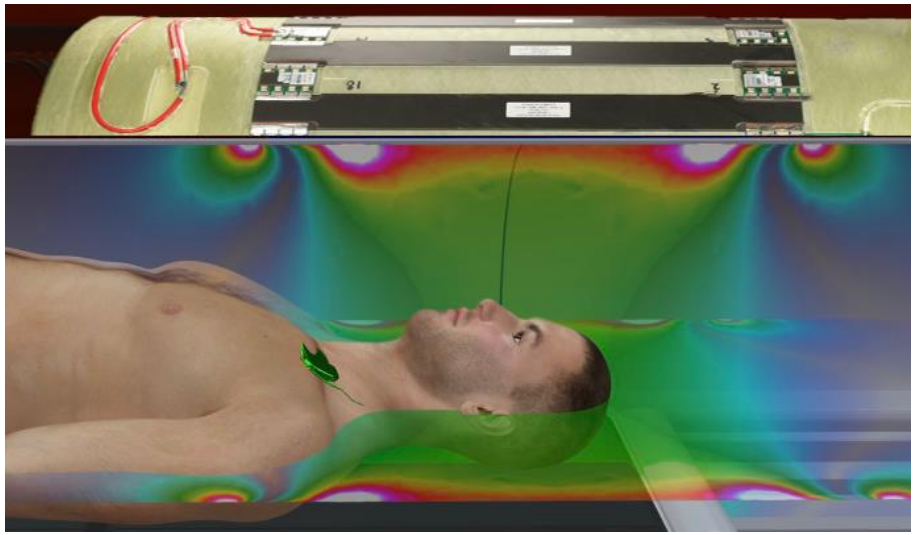
- https://www.youtube.com/watch?v=plvIEf7JsKo&ab_channel=ZaheerAbbas

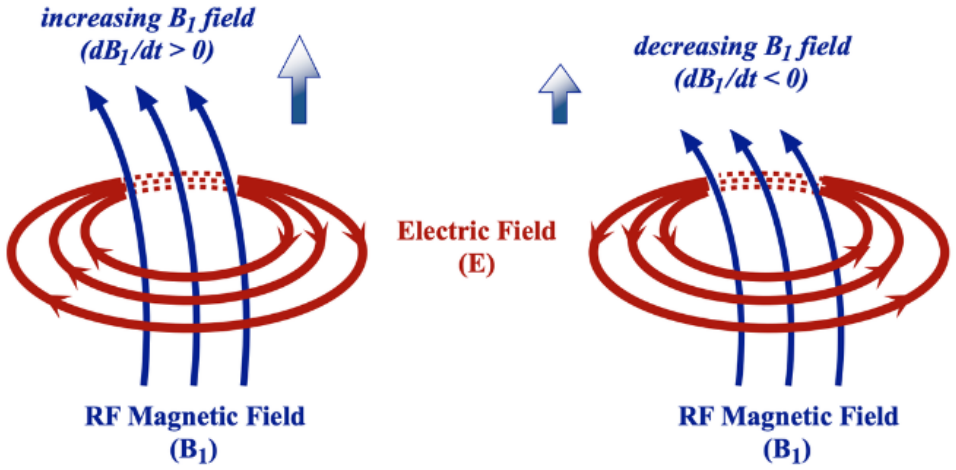


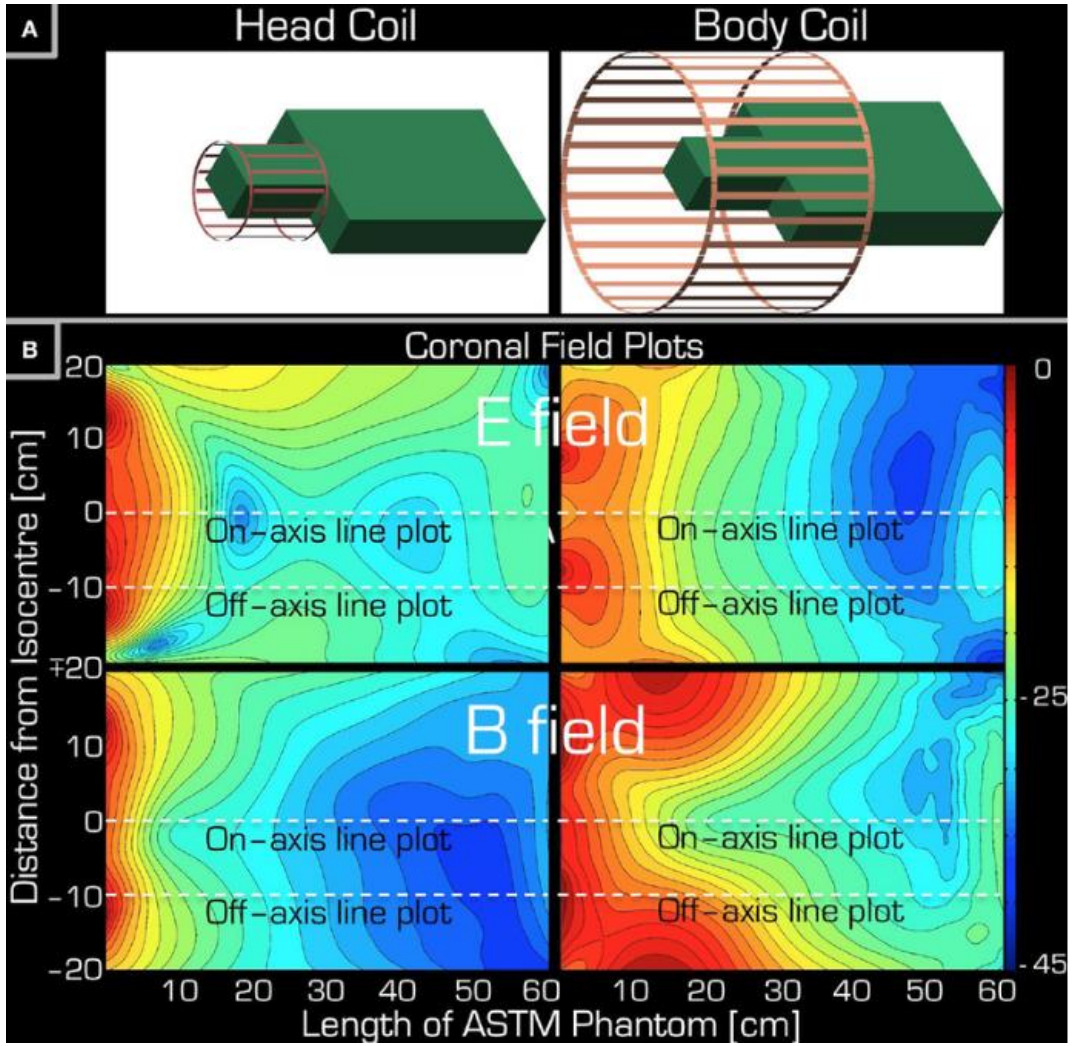
Source: Starck G and Ekholm S, 2004

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Time-Varying RF Magnetic Field (B1)





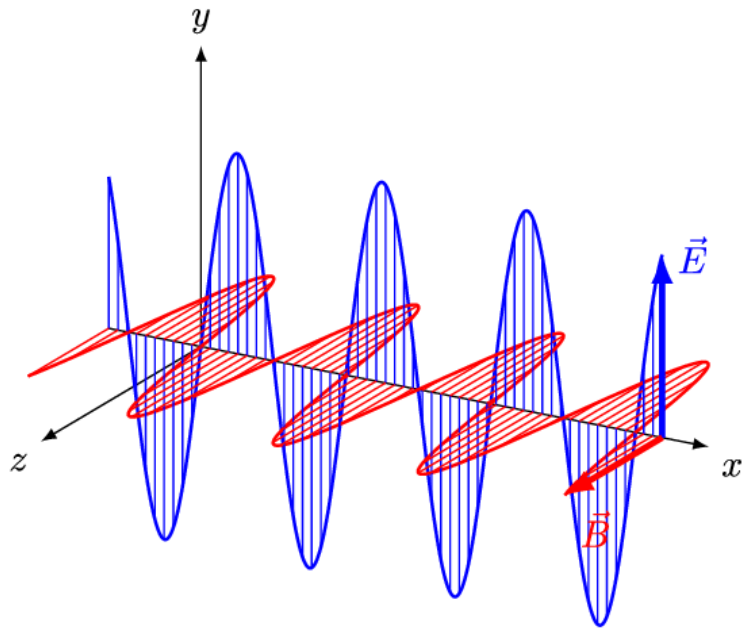


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RF Biological Effects

- **Non-thermal effects: controversial and unproven**
  - 1.5T: 64 MHz, 3.0T: 128 MHz
  - Generation of reactive oxygen species
  - Alteration of calcium flux across cell membranes

- **Thermal effects: major MR safety concern**
  - Coexistent electric field (**E**): responsible for nearly all thermal effects in MRI
  - Resistive heating: induced ionic currents
  - Dielectric heating: vibration of polar water molecules

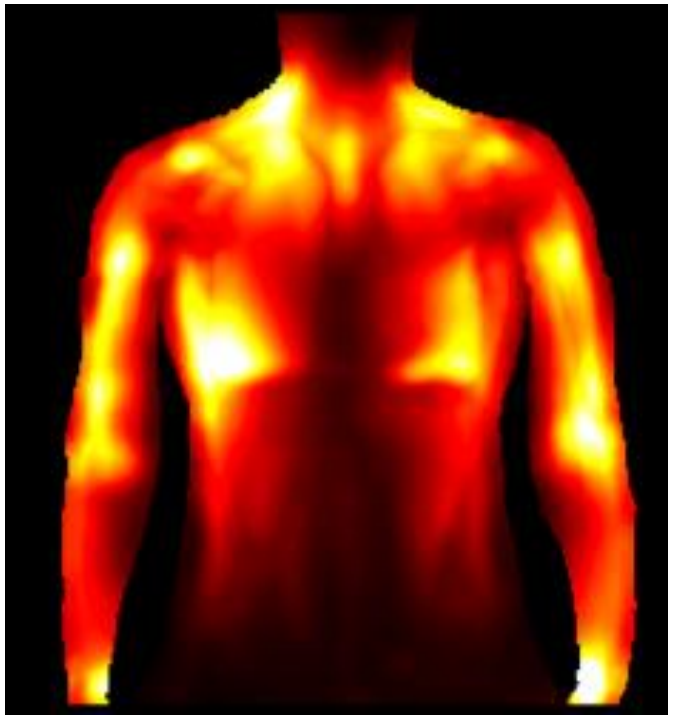


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Specific Absorption Rate (SAR)

- **SAR (Specific absorption rate):** a measure of the amount of power deposited by a RF field in a certain mass of tissue (e.g., 10 g).
- **Unit: watts per kilogram (W/kg)**
- **The International Electrotechnical Commission (IEC) SAR limits:**

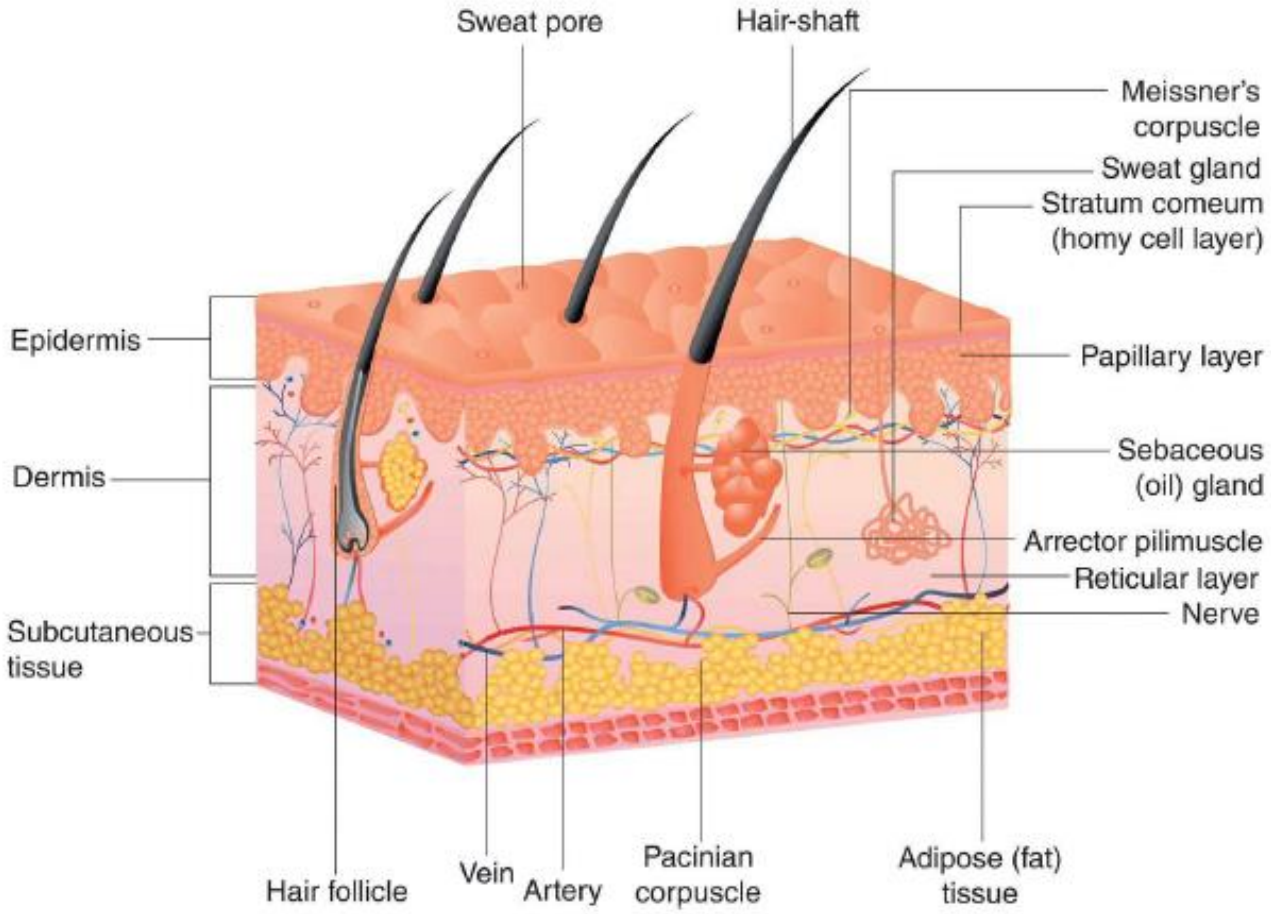
Operating Mode	Volume Transmit Coils			Local Transmit Coils		
	Whole body	Partial body	Head	Head	Trunk	Extremities
Normal	2	2-10[a]	3.2	10	10	20
1st Level	4	4-10[b]	3.2	20	20	40
2nd Level	<IRB limit	<IRB limit	<IRB limit	<IRB limit	<IRB limit	<IRB limit



Averaged SAR Map

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RF Burns



EKG electrodes



Cervical traction tong pins



Cables



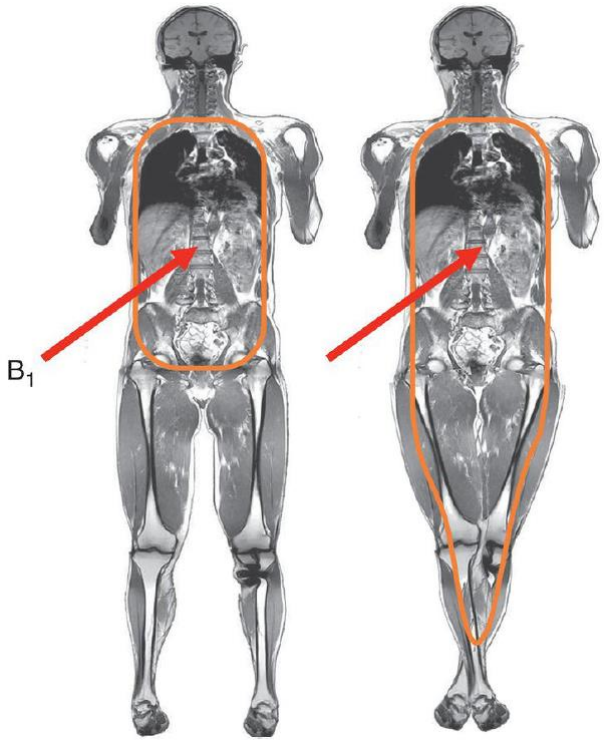
Tattoos

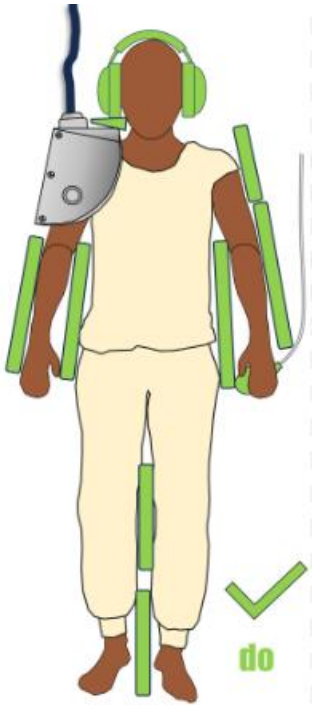


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Avoiding RF Burns

- **Avoid RF conduction paths**
- **Add padding**





- **Limit SAR (temperature)**

$$SAR = (\sigma A^2 \omega^2 B_1^2 D)/2\rho$$

- Lower static magnetic field B_0
- Reduce flip angle (B_1)
- Use gradient echo sequences
- Increase TR

Operating mode	Maximum temperature limits (°C)		Maximum core temperature rise (°C)
	Core	Local	
Normal	39	39	0.5
1st Level Controlled	40	40	1.0
2nd Level Controlled	>40	>40	>1.0

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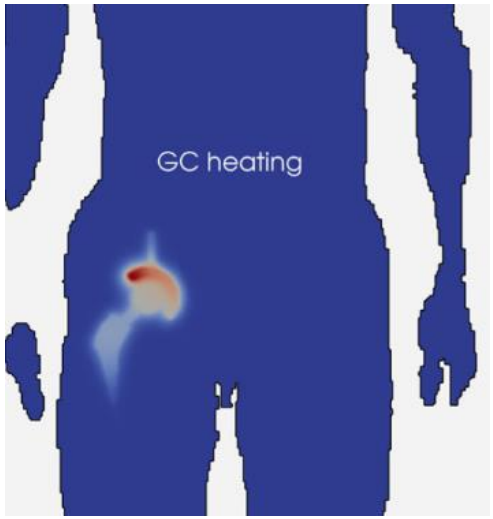
MRI Safety Concerns of Gradients

- **Acoustic noise**

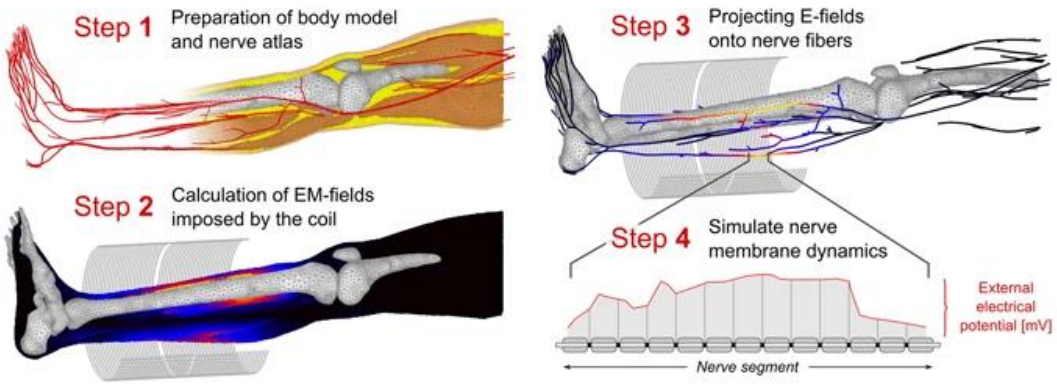




- Heating around implants



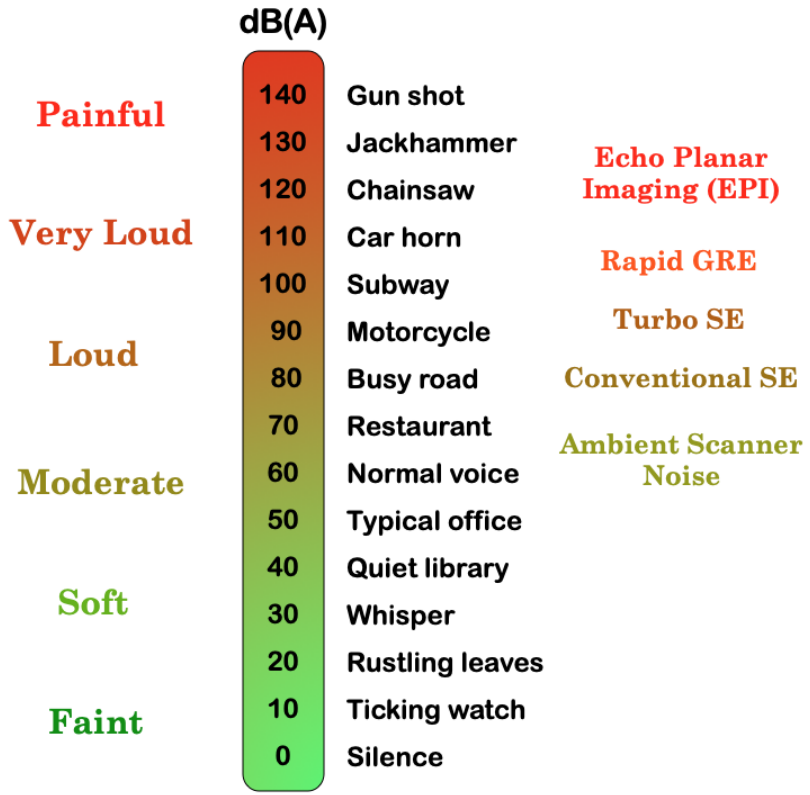
- **Peripheral nerve stimulation (PNS)**



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Acoustic Noise

- **Noise level is sequence dependent**



- **Acoustic noise demo**
  - Helium pump noise
  - Fast spin echo sequence
  - Diffusion tensor imaging
  - Echo planar imaging

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Acoustic Noise Protection

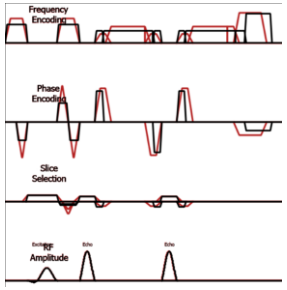
- **Use MR safe earplugs**



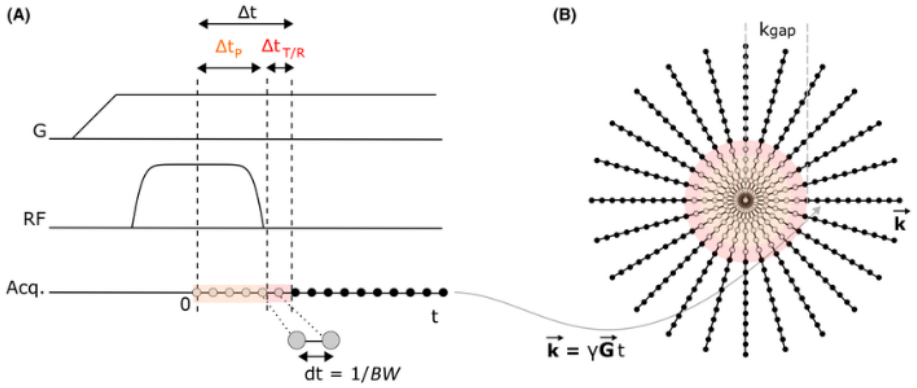
- **Use MR safe headsets**



- **Noise-reduction MRI Sequences**
  - ComforTone (Philips)
  - Silent Scan (GE Healthcare)
  - Quiet Suite (Siemens)



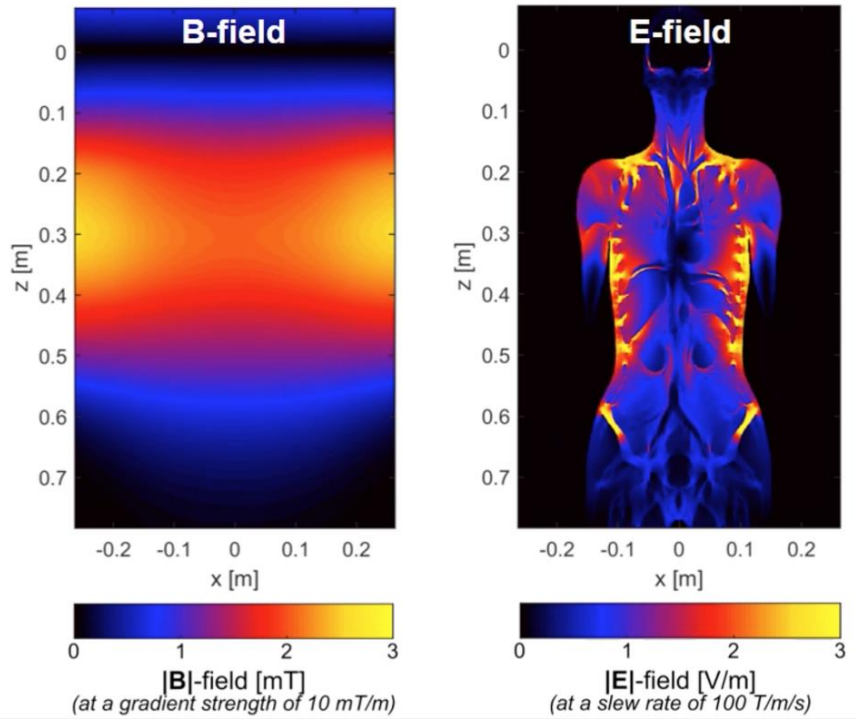
- **Zero-echo time (ZTE) sequences**
  - No fast gradient switching



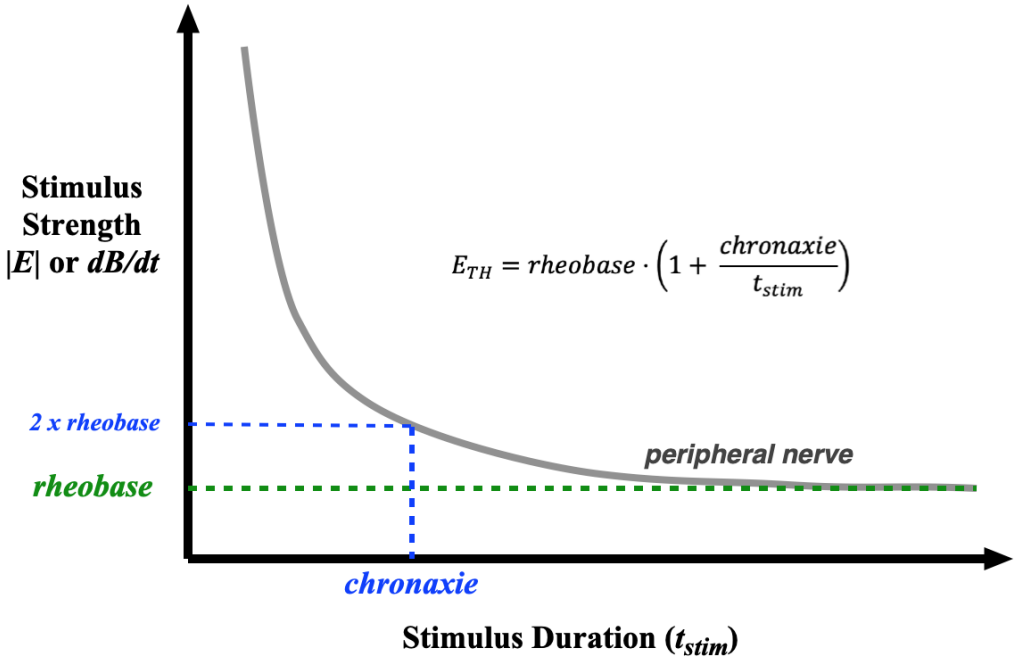
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Peripheral Nerve Stimulation

- **Peripheral nerve stimulation (PNS):** direct depolarization of nerves by rapid gradient switching
- Most common with **echo planar imaging (EPI)**



Strength-duration (SD) curve

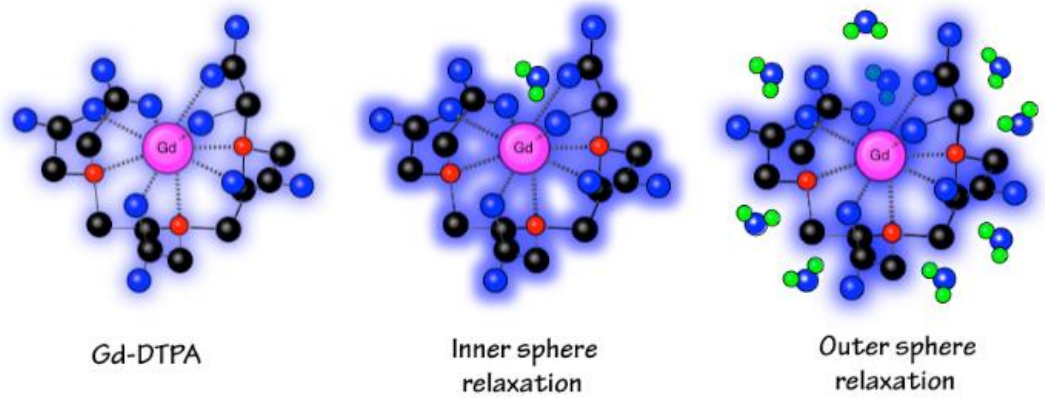


$[dB/dt]_{TH}$ = rheobase x (1 + 0.36/t)

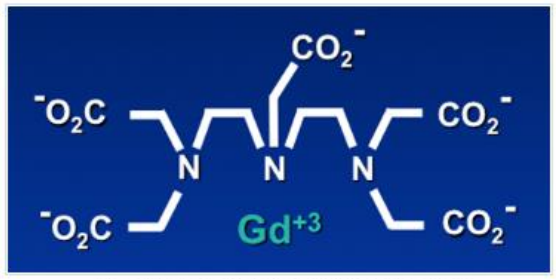
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Gadolinium-Based Contrast Agent (GBCA)

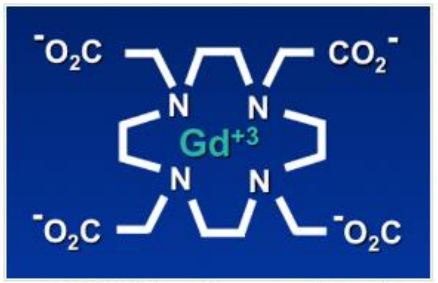
- **Increased relaxation → reduced T1 value**



- **Linear vs. cyclic structures**



Gd-DTPA (Magnevist®) - a linear contrast agent



Gd-DOTA (Dotarem®) - a macrocyclic agent

- **Classified into three groups**

ACR Classification of Gadolinium-Based Contrast Agents According to Risk of NSF

Group I: Associated with greatest number of NSF cases
- Gadodiamide (Omniscan®)
- Gadopentetate (Magnevist®)
- Gadoversetamide (OptiMark®)

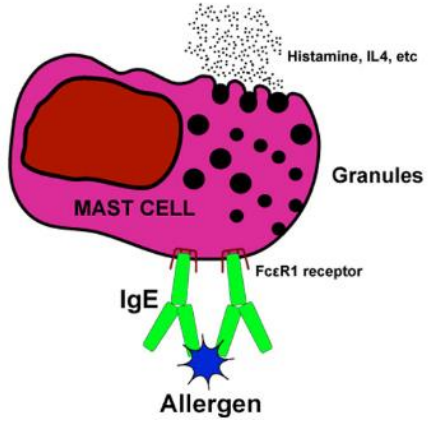
Group II: Associated with few, if any, unconfounded cases
- Gadobenate (MultiHance®)
- Gadobutrol (Gadovist®)
- Gadoterate (Dotarem®/Clariscan®)
- Gadoteridol (ProHance®)

Group III: Limited data, but no reported cases of NSF
- Gadoxetate (Eovist®)
- Gadopiclenol (Vueway®)

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GBCA Safety Risk

- **Acute safety:** very low incidence of acute reactions (< 2.5%)



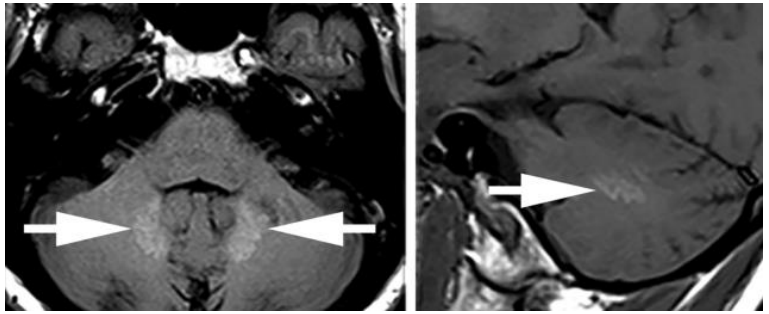


  - **Allergic reactions** (hives, swelling, respiratory distress, etc.)
  - **Incidence:** 1/1000 within 1 hour of contrast administration

- **Chronic safety:**
  - Nephrogenic systemic fibrosis (NSF)
    - Skin thickening
    - Fibrosis of multiple organs



  - Gadolinium accumulation in tissue



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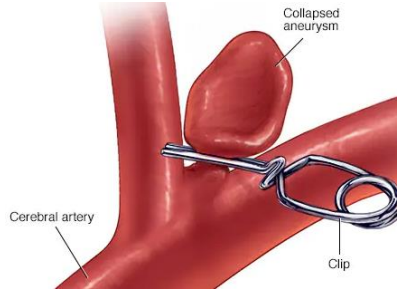
Passive Implants

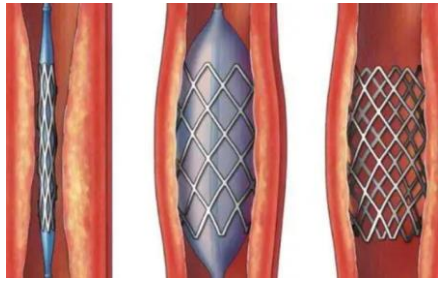
- **Passive implants**
  - No active electronic components or power sources
  - **Types of passive implants**
    - Orthopedic implants
    - Dental implants
    - Aneurysm clips
    - Vascular stents
    - Intraocular lenses
    - Heart valve prostheses
    - External fixation devices
    - Electric leads
    - … …

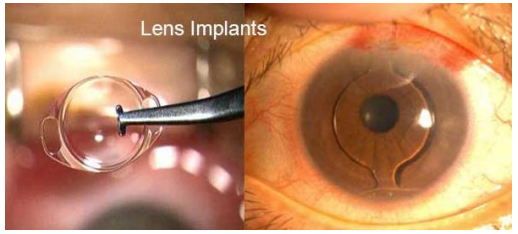


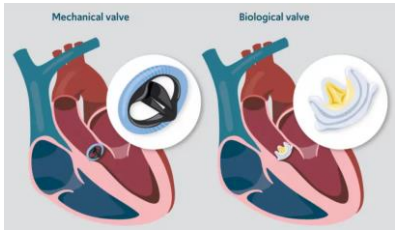










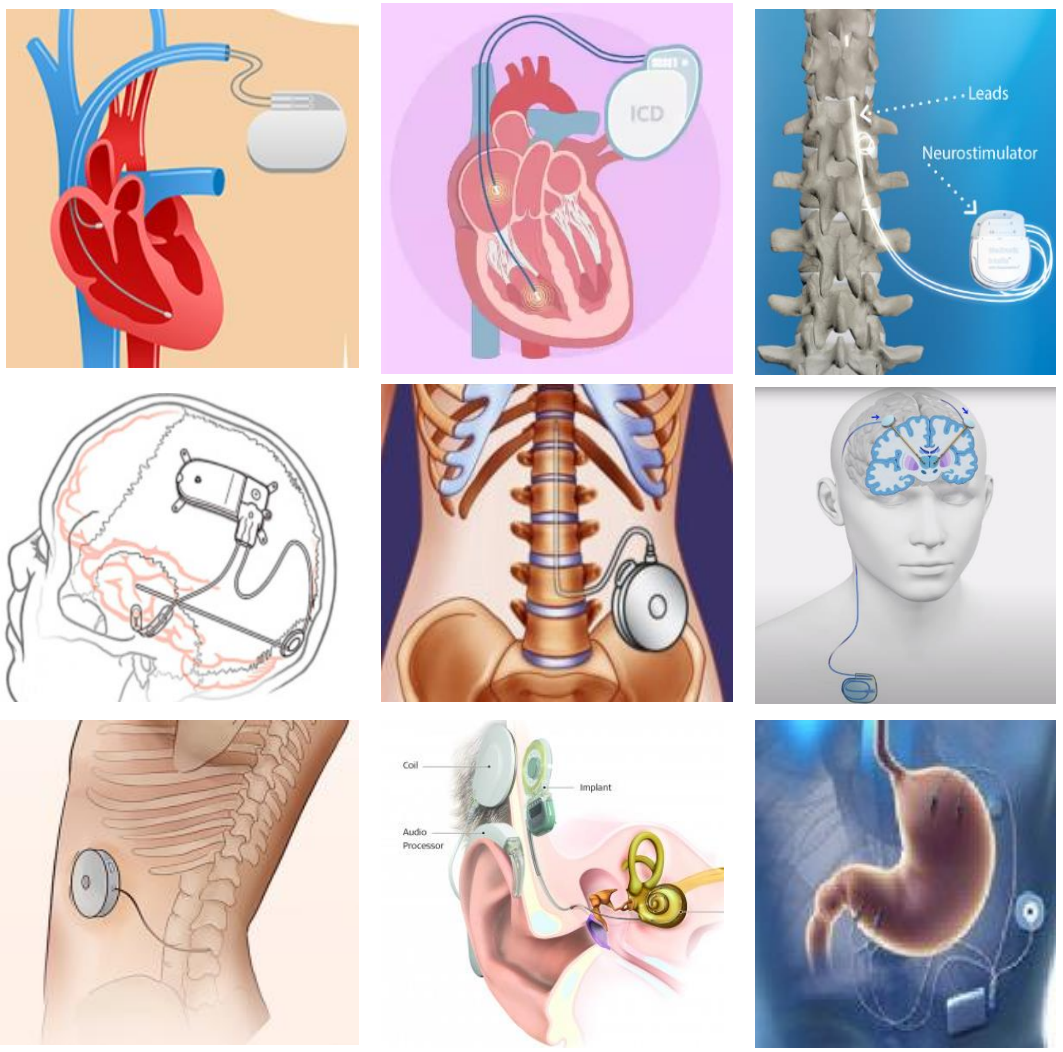


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Active Implants

- **Active implants**
  - Also called active implantable medical devices (AIMDs)
  - Require external power to operate

  - **Types of active implants**
    - Cardiac pacemakers
    - Internal defibrillators
    - Neurostimulators
    - Implanted infusion pumps
    - Drug pumps
    - Cochlear implants
    - Deep brain stimulators
    - Spinal cord stimulators
    - Gastric electrical stimulators
    - … …



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MRI Safety Risk of Implants

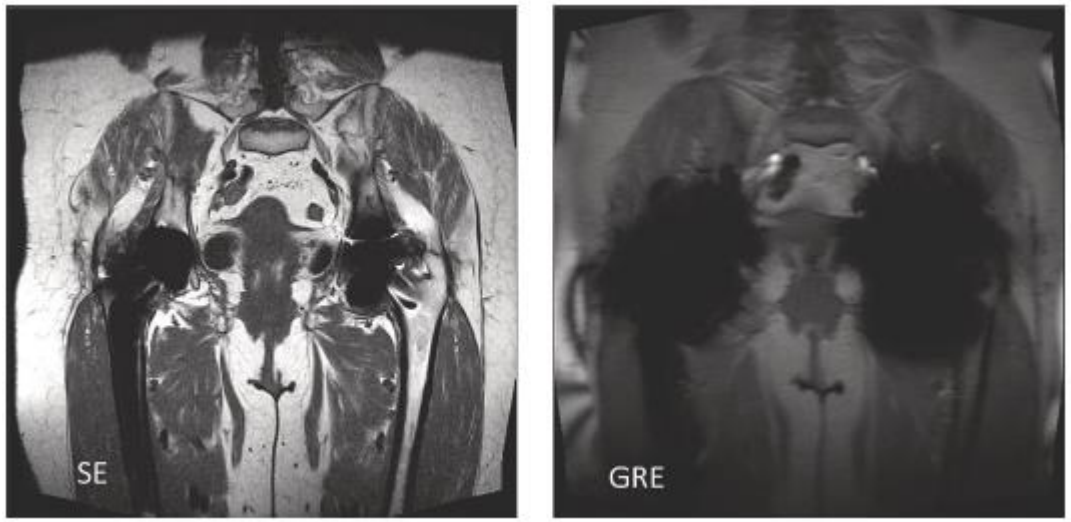
- **Passive implants**
  - **Displacement:** translational force (Fz) due to spatial gradient product (B*dB/dz)
  - **Twisting:** torque (T) due to static magnetic field (B_0)
  - **Vibration:** fast alternating torque due to gradient switching
  - **Heating:** eddy currents induced by RF and gradients
  - **Magnetization:** due to static magnetic field (B_0)

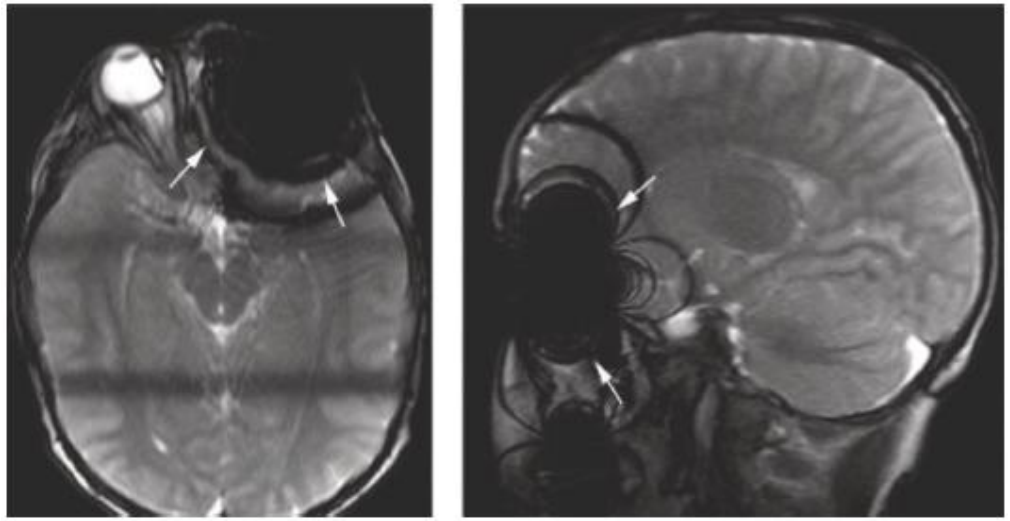


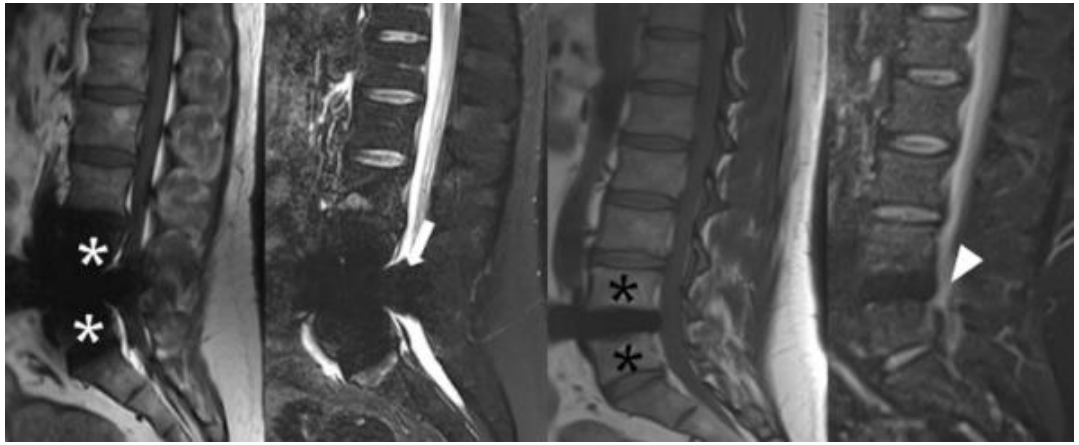
- **Active implants**
  - All risks with passive implants (displacement, twisting, vibration, heating, magnetization)
  - **Device reset or damage:** B_0, B_1, and gradients
  - **Spurious input or output:** induced currents in leads

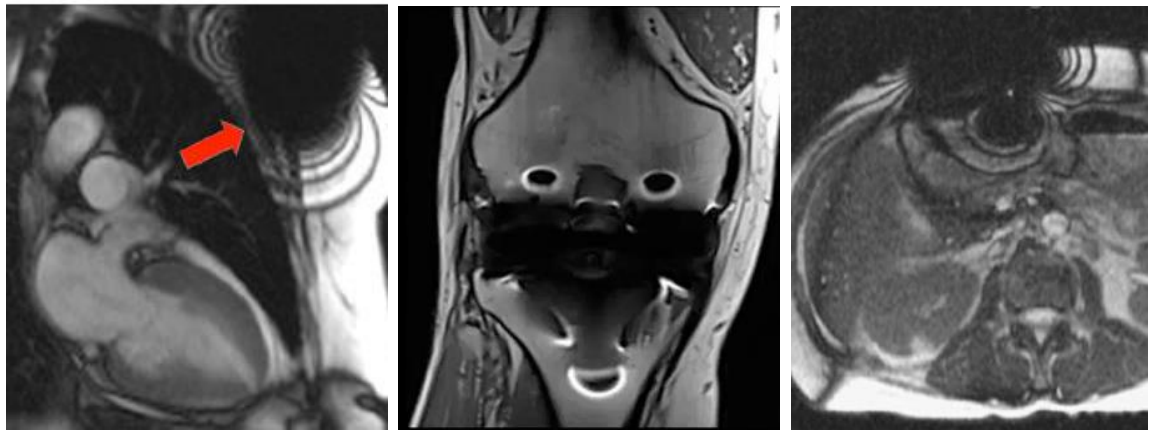
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MRI Image Artifacts with Implants







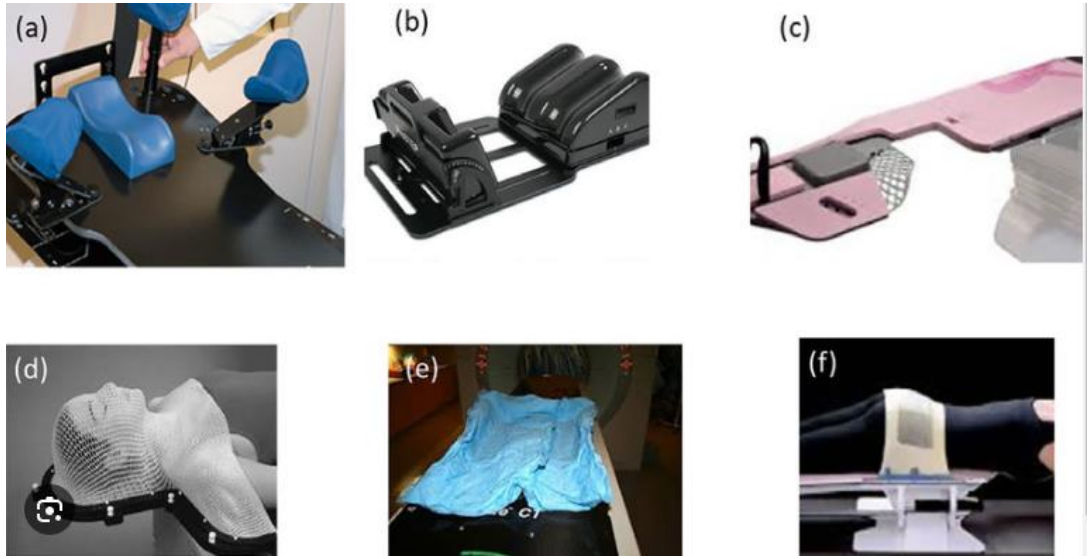


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Radiation Oncology MRI Safety

- **Immobilization devices**



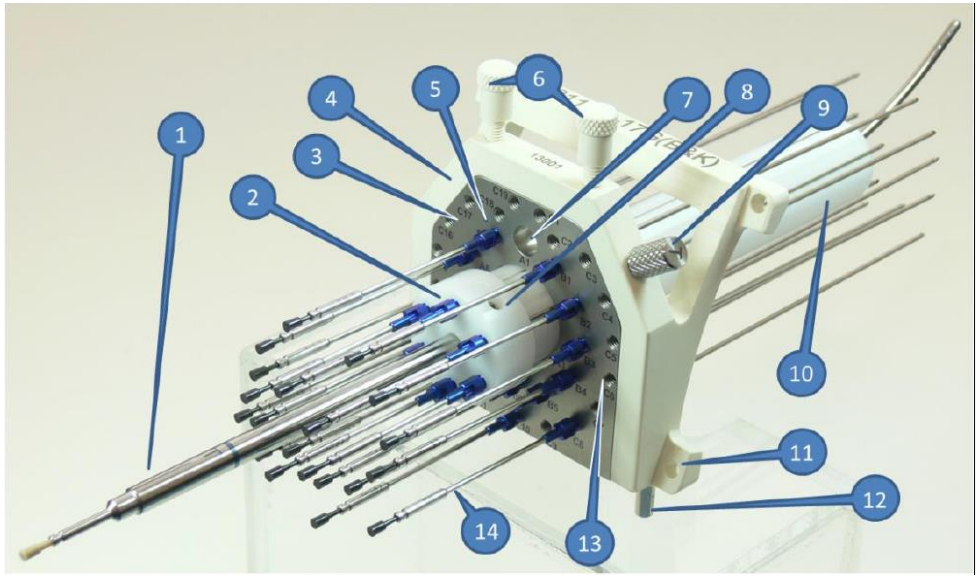


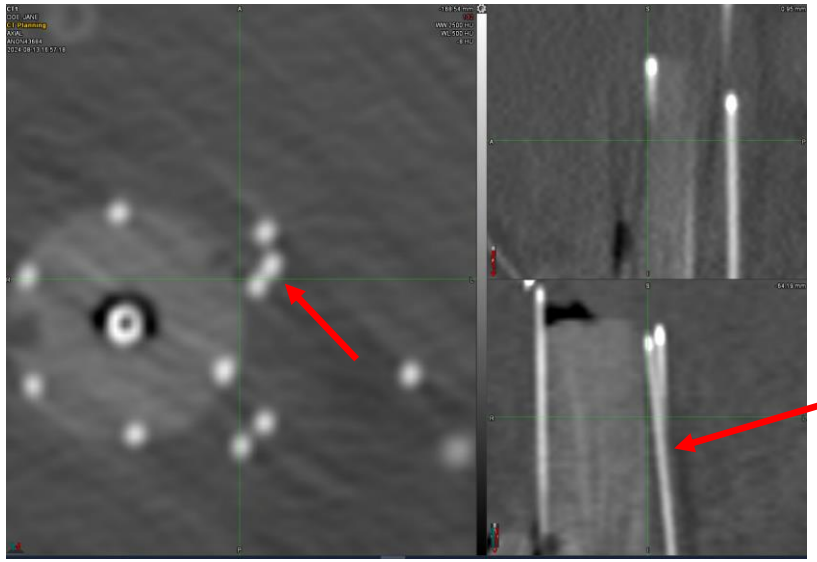
- Make sure the immobilization devices are **MR safe**
- Immobilization may cause image artifacts

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Radiation Oncology MRI Safety

- **Brachytherapy needles**





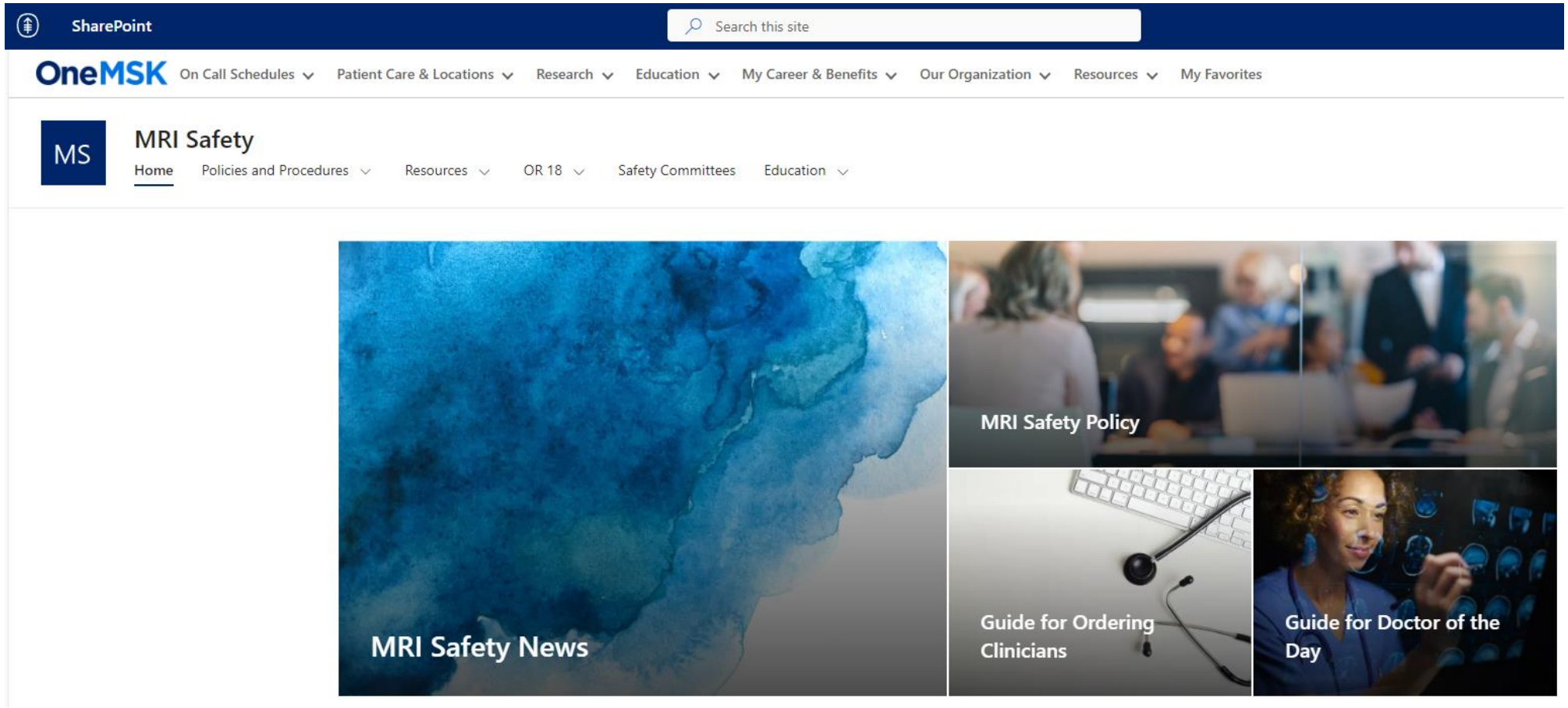
Needles crossing

- Material: Titanium
- **RF heating** is the major concern
- Need to consider crossing of the needles during the MRI scan

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MSK MRI Safety Resources

- MSK MRI Safety SharePoint:
https://mskcc.sharepoint.com/sites/pub-MRISafety



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MSK MRI safety SharePoint



Policies and Procedures

- MRI Safety Policy and Procedures
- Guide to Implants, Devices, Tattoos and Foreign Bodies: Is it Safe?
- MRI Medication Patch and Infusers Safety Policy
- Pregnancy, Breastfeeding and Contrast Enhanced MRI
- Chest X-ray for Pacemaker Patients
- Appendix of Equipment in MRI
- MRI Thermal Injury Policy
- MRI Emergency Shutdown and Contacts
- MRI Contrast Policy
- MRI Contrast Documents
- Requirement for Second Person During MRI Testing
- Access to MRI Suites



About RISQ

Reporting to Improve Safety and Quality (RISQ) is a system that allows staff to report actual events and near misses that have the potential to cause harm but are caught and corrected before they reach the patient. Any employee can enter an event or near miss into RISQ.

All RISQ reports are reviewed by the Division of Quality and Safety in collaboration with Nursing Quality, and Departmental QA Chairs. An employee can view the status of their submitted events through RISQ tracker.

Various groups review the events to identify common themes and opportunities for improvement. A performance improvement team may be formed to address the problem and develop solutions to prevent similar occurrences.

0	Near Miss	An unplanned event that did not reach the patient but may have resulted in injury or illness if it had.
1	No Harm	An event that reached the patient but resulted in no harm to the patient.
2	Temporary/Minor Harm	An event that results in any observable bruise, contusion, abrasion, etc.; an event that requires treatment as a result, such as a dressing, ice, suturing, administration of platelets or blood; an event that requires return to the hospital for procedures such as additional radiation oncology treatments, repeat scans, endoscopy procedures.
3	Permanent/Significant Harm	An event that results in an injury that requires a higher level of care, hospital admission, and/or surgery; injury that requires insertion of a device such as an endotracheal tube or chest tube; severe injury expected to impact activities of daily living such as fracture or intracranial bleed.
4	Death	The patient dies as a result of injuries related to the event



MRI Safety Steering Committee

OR 18 MRI Safety Committee

Radiation Oncology MRI Safety Committee

Radiology MRI Safety Committee

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References

- https://mriquestions.com/index.html
- Donald W. McRobbie, Essentials of MRI Safety
- ACR manual on MR safety 2024
- https://mskcc.sharepoint.com/sites/pub-MRISafety

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PART II: MRI QA Outline

- **PART I: MR-Sim QA**
  - PIQT: periodic image quality test (daily, weekly)
  - ELPS: external laser positioning system (Monthly)
  - Geometric QA: evaluate geometric distortion (Monthly)
  - ACR phantom (Monthly)
- **PART II: MR-Linac QA**
  - Daily and weekly QA
    - PIQT
    - SNR test
    - Scaling test
  - 3D Geometric QA
  - Longitudinal QA

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Part I: MR-Sim QA

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Curved vs. Flat Tabletop

Curved Tabletop



Flat Tabletop







- **Curved tabletop:** diagnostic imaging
- **Flat tabletop:** radiotherapy simulation and treatment

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PIQT

- **PIQT: Periodic Image Quality Test:** measure baseline system values to assess the performance of the MR imaging system

- **Tabletop:** reports are only generated using the curved tabletop or the new CouchTop XD



- **Scan time:** ~ 15 minutes

- **Frequency:** daily

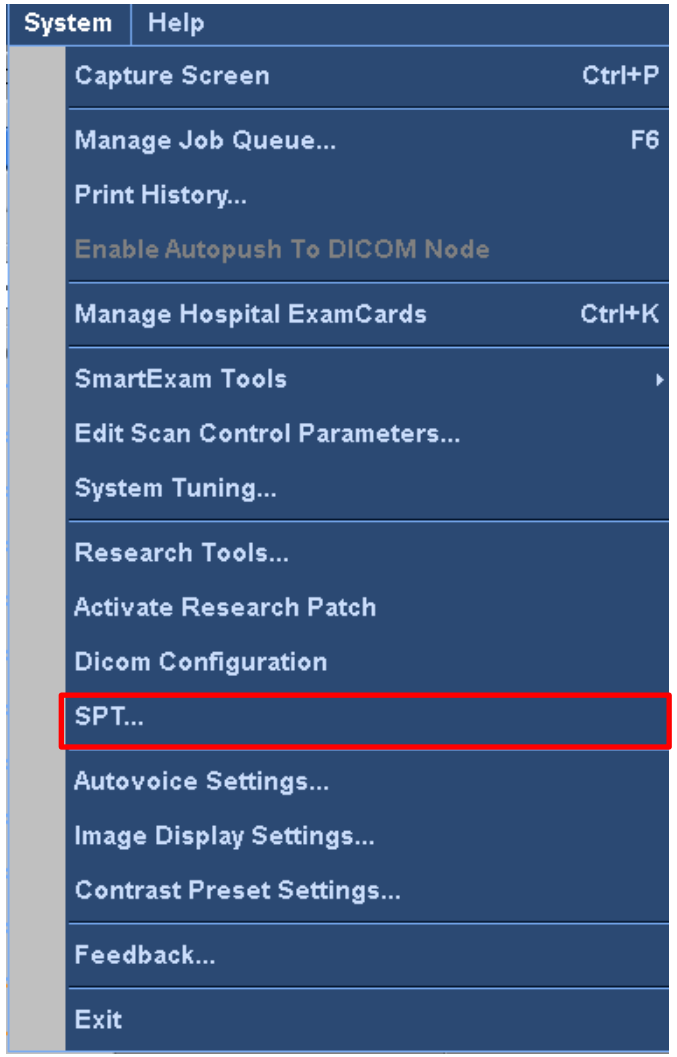
- **Operator:** MR technologist, therapist

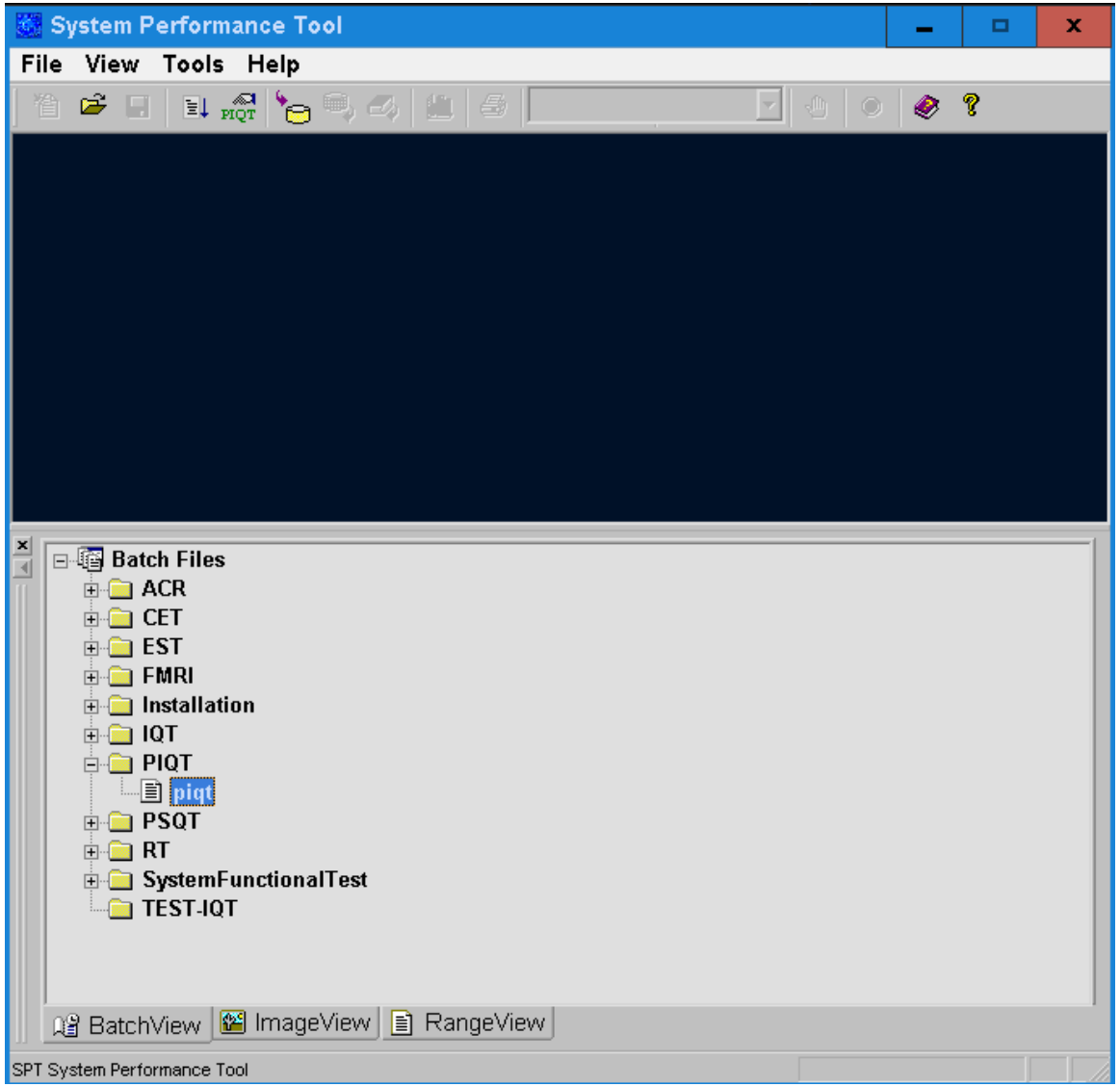
- **Analysis:** a report is automatically generated to show whether the PIQT test has been passed or failed

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PIQT Procedures

- SPT: system performance tool





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PIQT Phantom Positioning



Base of head coil



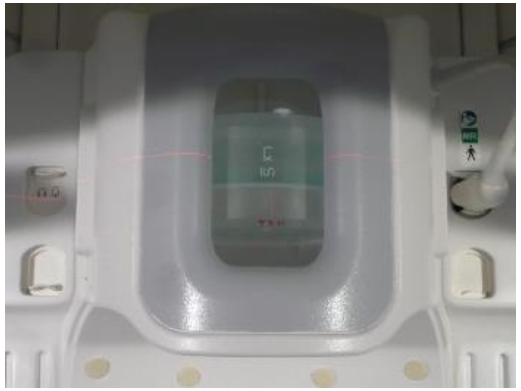
Phantom holder



“T” marker (facing front at 12 o’clock)



Top of coil in position

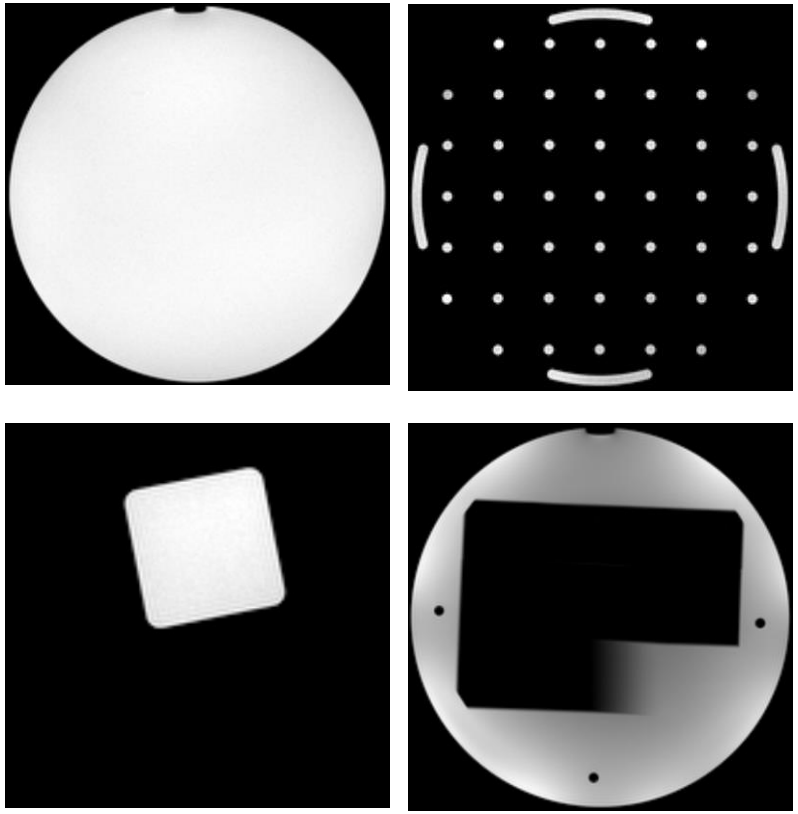


Light beams cross the center

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PIQT Tests

- **PIQT tests include the following:**
  - Signal-to-noise ratio (SNR)
  - Flood field uniformity (FFU)
  - Spatial linearity (SPL)
  - Spatial resolution (SPR)
  - Slice profile and thickness (SLP)



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PIQT Report

Flood Field Uniformity

Date Tue, 6 Aug 2024 10:31:05
List Type MRL with SPEC
Applied Verification File(s)
C: wa30r5v7l1_gr8_rf3_l06_irf.cust
Field Strength WA30
Gradient Chain WA Quasar Dual
Gradient Coil WideAperture1
RF Chain Dual iRF
Magnet WA_30T
Tested by -
Gradient Amplifier 787
Gradient Switchbox Gradient Switchbox
RF Amplifier 8134_128
Order -

Patient	PIQT				PIQT	
Scan_Name	QA1H:MS,SE				QA2H:MS,FE	
Scan_Date	06-08-2024				06-08-2024	
Scan_Time	10:19				10:24	
Bw/Pixel	364.38				361.69	
Trans_Q	216				216	
Drive	0.66				0.65	
RF_Factor	0.84				0.82	
Rec_Q	217				217	
Req_Att	20				20	
Central_freq	127753422				127753427	
Coil_type	irf irf				irf irf	
Actual_12nc	459800171172 459800171182				459800171172 459800171182	
Original_serial_nr	98960302353600118 98960302353600118				98960302353600118 98960302353600118	
Scan_Seq	SE		SE		FFE	
Off_cen_dist	-2.45		-2.45		-2.45	
Image_Type	M		M		M	
Slice_No	3		3		2	
Echo_No	1		2		1	
Dyn_Scan_No	1		1		1	
Dist_sel	-2.45		-2.45		-2.45	
Echo_Time	30		100		15	
SNR_Factor	2.94		2.27		2.02	
Nema S/N (B)	117.07	C > 90	84.18	C > 68	75.95	C > 63
Nema_Int_Unif	10.53	C < 21	10.42	C < 21	10.57	C < 21
Nema_Art_Level	1.48	C < 3	1.75	C < 3	0.32	C < 3
Meas_Ok	OK		OK		OK	
Verify_Ok	OK		OK		OK	



Flood Field Uniformity

Date Tue, 6 Aug 2024 10:31:05
List Type MRL with SPEC
Applied Verification File(s)
C: wa30r5v7l1_gr8_rf3_l06_irf.cust
Field Strength WA30
Gradient Chain WA Quasar Dual
Gradient Coil WideAperture1
RF Chain Dual iRF
Magnet WA_30T
Tested by -
Gradient Amplifier 787
Gradient Switchbox Gradient Switchbox
RF Amplifier 8134_128
Order -

Patient	PIQT		
Scan_Name	QA3B:2D,SE		
Scan_Date	06-08-2024		
Scan_Time	10:26		
Bw/Pixel	364.38		
Trans_Q	215		
Drive	0.65		
RF_Factor	0.82		
Rec_Q	215		
Req_Att	20		
Central_freq	127753435		
Coil_type	irf		
Actual_12nc	-		
Original_serial_nr	-		
Scan_Seq	SE	SE	SE
Off_cen_dist	-2.45	-2.45	-2.45
Image_Type	M	M	M
Slice_No	1	1	1
Echo_No	1	2	3
Dyn_Scan_No	1	1	1
Dist_sel	-2.45	-2.45	-2.45
Echo_Time	50	100	150
SNR_Factor	20.5	17.97	15.76
Nema S/N (B)	166.61	142.45	112.96
Nema_Int_Unif	6.86	7.76	8.28
Nema_Art_Level	2.89	1.84	1.05
Meas_Ok	OK	OK	OK
Verify_Ok	-	-	-



Spatial Linearity

Date Tue, 6 Aug 2024 10:31:05
List Type MRL with SPEC
Applied Verification File(s)
C: wa30r5v7l1_gr8_rf3_l06_irf.cust
Field Strength WA30
Gradient Chain WA Quasar Dual
Gradient Coil WideAperture1
RF Chain Dual iRF
Magnet WA_30T
Tested by -
Gradient Amplifier 787
Gradient Switchbox Gradient Switchbox
RF Amplifier 8134_128
Order -

Patient	PIQT	
Scan_Name	QA1H:MS,SE	
Scan_Date	06-08-2024	
Scan_Time	10:19	
Bw/Pixel	364.38	
Trans_Q	216	
Drive	0.66	
RF_Factor	0.84	
Rec_Q	217	
Req_Att	20	
Central_freq	127753422	
Coil_type	irf irf	
Actual_12nc	459800171172 459800171182	
Original_serial_nr	98960302353600118 98960302353600118	
Scan_Seq	SE	
Off_cen_dist	-24.95	
Image_Type	M	
Slice_No	2	
Echo_No	1	
Dyn_Scan_No	1	
Dist_sel	-24.95	
Echo_Time	30	
SNR_Factor	2.94	
Meas_Ok	OK	
Verify_Ok	OK	
diff_lin_(2-44)	-0.03	
diff_lin_(3-43)	-0.04	
diff_lin_(4-42)	0.02	
diff_lin_(7-39)	-0.12	
diff_lin_(11-35)	0.05	
diff_lin_(13-33)	-0.08	
diff_lin_(19-27)	-0.07	
diff_lin_(20-26)	-0.04	
nema_perc_dif.	0.12	C < 0.5



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PIQT Report

Slice Profile

Date Tue, 6 Aug 2024 10:31:05
List Type MRL with SPEC
Applied Verification File(s)
C: wa30r5v7l1_gr8_rf3_l06_irf.cust
Field Strength WA30
Gradient Chain WA Quasar Dual
Gradient Coil WideAperture1
RF Chain Dual iRF
Magnet WA_30T
Tested by -
Gradient Amplifier 787
Gradient Switchbox Gradient Switchbox
RF Amplifier 8134_128
Order -

Patient	PIQT		PIQT	
Scan_Name	QA1H:MS,SE		QA2H:MS,FE	
Scan_Date	06-08-2024		06-08-2024	
Scan_Time	10:19		10:24	
Bw/Pixel	364.38		361.69	
Trans_Q	216		216	
Drive	0.66		0.65	
RF_Factor	0.84		0.82	
Rec_Q	217		217	
Req_Att	20		20	
Central_freq	127753422		127753427	
Coil_type	irf irf		irf irf	
Actual_12nc	459800171172 459800171182		459800171172 459800171182	
Original_serial_nr	98960302353600118 98960302353600118		98960302353600118 98960302353600118	
Scan_Seq	SE	SE	FFE	
Off_cen_dist	20.05	20.05	20.05	
Image_Type	M	M	M	
Slice_No	4	4	3	
Echo_No	1	2	1	
Dyn_Scan_No	1	1	1	
Dist_sel	20.05	20.05	20.05	
Echo_Time	30	100	15	
SNR_Factor	2.94	2.27	2.02	
Meas_Ok	OK	OK	OK	
Verify_Ok	OK	-	OK	
Nema_Phantom	WEDGE	WEDGE	WEDGE	
Nema_Prof_Type	MODULUS	MODULUS	MODULUS	
Nema_Phant_Rot.	0	0	0	
Nema_Angle	11.28	11.25	11.24	
Nema_Pos_shift	0.13	0.14	0.03	
Nema_FWHM	1.97 C1.8 - 2.2	1.85	1.98 C1.8 - 2.2	
Nema_FWTM	2.99	2.86	3.11	
Nema_Slice_int.	1.98	1.86	2	

Spatial Resolution

Date Tue, 6 Aug 2024 10:31:05
List Type MRL with SPEC
Applied Verification File(s)
C: wa30r5v7l1_gr8_rf3_l06_irf.cust
Field Strength WA30
Gradient Chain WA Quasar Dual
Gradient Coil WideAperture1
RF Chain Dual iRF
Magnet WA_30T
Tested by -
Gradient Amplifier 787
Gradient Switchbox Gradient Switchbox
RF Amplifier 8134_128
Order -

Patient	PIQT	
Scan_Name	QA1H:MS,SE	
Scan_Date	06-08-2024	
Scan_Time	10:19	
Bw/Pixel	364.38	
Trans_Q	216	
Drive	0.66	
RF_Factor	0.84	
Rec_Q	217	
Req_Att	20	
Central_freq	127753422	
Coil_type	irf irf	
Actual_12nc	459800171172 459800171182	
Original_serial_nr	98960302353600118 98960302353600118	
Scan_Seq	SE	SE
Off_cen_dist	42.55	42.55
Image_Type	M	M
Slice_No	5	5
Echo_No	1	2
Dyn_Scan_No	1	1
Dist_sel	42.55	42.55
Echo_Time	30	100
SNR_Factor	2.94	2.27
Meas_Ok	OK	OK
Verify_Ok	OK	-
Nema_Hor_pxl_size	1.02 C < 1.2	0.99
Nema_Ver_pxl_size	1.09 C < 1.25	1.18

Flood Field Uniformity

Date Fri, 26 Apr 2024 15:08:00
List Type MRL with SPEC
Applied Verification File(s)
C: wa30r5v7l1_gr8_rf3_l06_irf.cust
Field Strength WA30
Gradient Chain WA Quasar Dual
Gradient Coil WideAperture1
RF Chain Dual iRF
Magnet WA_30T
Tested by -
Gradient Amplifier 787
Gradient Switchbox Gradient Switchbox
RF Amplifier 8134_128
Order -

Patient	PIQT		PIQT	
Scan_Name	QA1H:MS,SE		QA2H:MS,FE	
Scan_Date	26-04-2024		26-04-2024	
Scan_Time	12:33		12:37	
Bw/Pixel	364.38		361.69	
Trans_Q	216		216	
Drive	0.66		0.65	
RF_Factor	0.83		0.83	
Rec_Q	216		216	
Req_Att	20		20	
Central_freq	127764747		127764752	
Coil_type	irf irf		irf irf	
Actual_12nc	459800171172 459800171182		459800171172 459800171182	
Original_serial_nr	98960302353600118 98960302353600118		98960302353600118 98960302353600118	
Scan_Seq	SE	SE	FFE	
Off_cen_dist	-7.13	-7.13	-7.13	
Image_Type	M	M	M	
Slice_No	3	3	2	
Echo_No	1	2	1	
Dyn_Scan_No	1	1	1	
Dist_sel	-7.13	-7.13	-7.13	
Echo_Time	30	100	15	
SNR_Factor	2.94	2.27	2.02	
Nema S/N (B)	115.99 C > 90	86.63 C > 68	80.51 C > 63	
Nema_Int_Unif	11.86 C < 21	12.97 C < 21	10.58 C < 21	
Nema_Art_Level	0.81 C < 3	3.6* C < 3	0.66 C < 3	
Meas_Ok	OK	OK	OK	
Verify_Ok	OK	NOT OK*	OK	

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Possible Causes of PIQT Failure

- **Phantom position is not accurate**
  - Position the phantom as instructed
  - Correct orientation and no tilting
- **Failure or connection issue of the coil**
  - Use the correct head coil
  - Check coil connection
  - Ask service engineer to check for other coil issues
- **RF noise**
  - RF interferences (light bulbs, RF door sealing, etc.)
- **Other causes**
  - Mis-calibrated gradients, high B_0 inhomogeneity
  - RF amplifier nonlinearity, motion of the phantom

Flood Field Uniformity

Date	Fri, 26 Apr 2024 15:08:00		
List Type	MRL with SPEC		
Applied Verification File(s)			
C: wa30r5v7l1_gr8_rf3_l06_irf.cust			
Field Strength	WA30		
Gradient Chain	WA Quasar Dual	**Gradient Amplifier**	787
Gradient Coil	WideAperture1	**Gradient Switchbox**	Gradient Switchbox
RF Chain	Dual iRF	**RF Amplifier**	8134_128
Magnet	WA_30T		
Tested by	-	**Order**	-

Patient	PIQT				PIQT	
Scan_Name	QA1H:MS,SE				QA2H:MS,FE	
Scan_Date	26-04-2024				26-04-2024	
Scan_Time	12:33				12:37	
Bw/Pixel	364.38				361.69	
Trans_Q	216				216	
Drive	0.66				0.65	
RF_Factor	0.83				0.83	
Rec_Q	216				216	
Req_Att	20				20	
Central_freq	127764747				127764752	
Coil_type	irf irf				irf irf	
Actual_12nc	459800171172 459800171182				459800171172 459800171182	
Original_serial_nr	98960302353600118 98960302353600118				98960302353600118 98960302353600118	
Scan_Seq	SE		SE		FFE	
Off_cen_dist	-7.13		-7.13		-7.13	
Image_Type	M		M		M	
Slice_No	3		3		2	
Echo_No	1		2		1	
Dyn_Scan_No	1		1		1	
Dist_sel	-7.13		-7.13		-7.13	
Echo_Time	30		100		15	
SNR_Factor	2.94		2.27		2.02	
Nema S/N (B)	115.99	C > 90	86.63	C > 68	80.51	C > 63
Nema_Int_Unif	11.86	C < 21	12.97	C < 21	10.58	C < 21
Nema_Art_Level	0.81	C < 3	3.6*	C < 3	0.66	C < 3
Meas_Ok	OK		OK		OK	
Verify_Ok	OK		NOT OK*		OK	

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ELPS QA

- **ELPS:** External Laser Positioning System

Laser bridge



Laser control pad

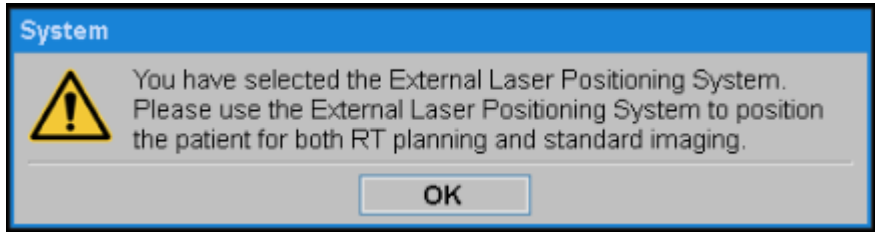


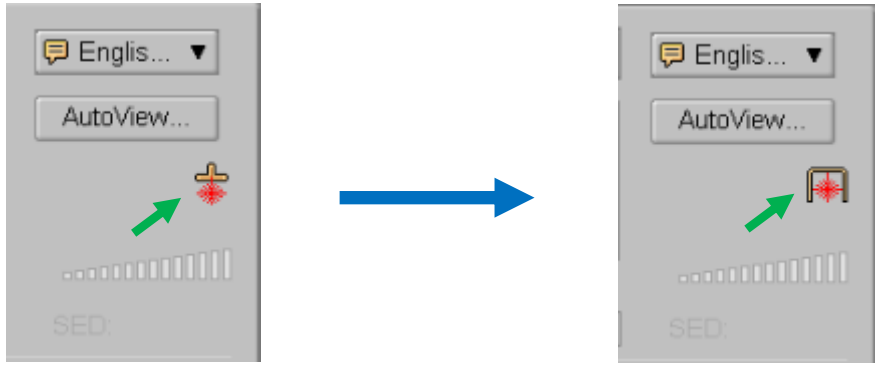


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ELPS QA Setup

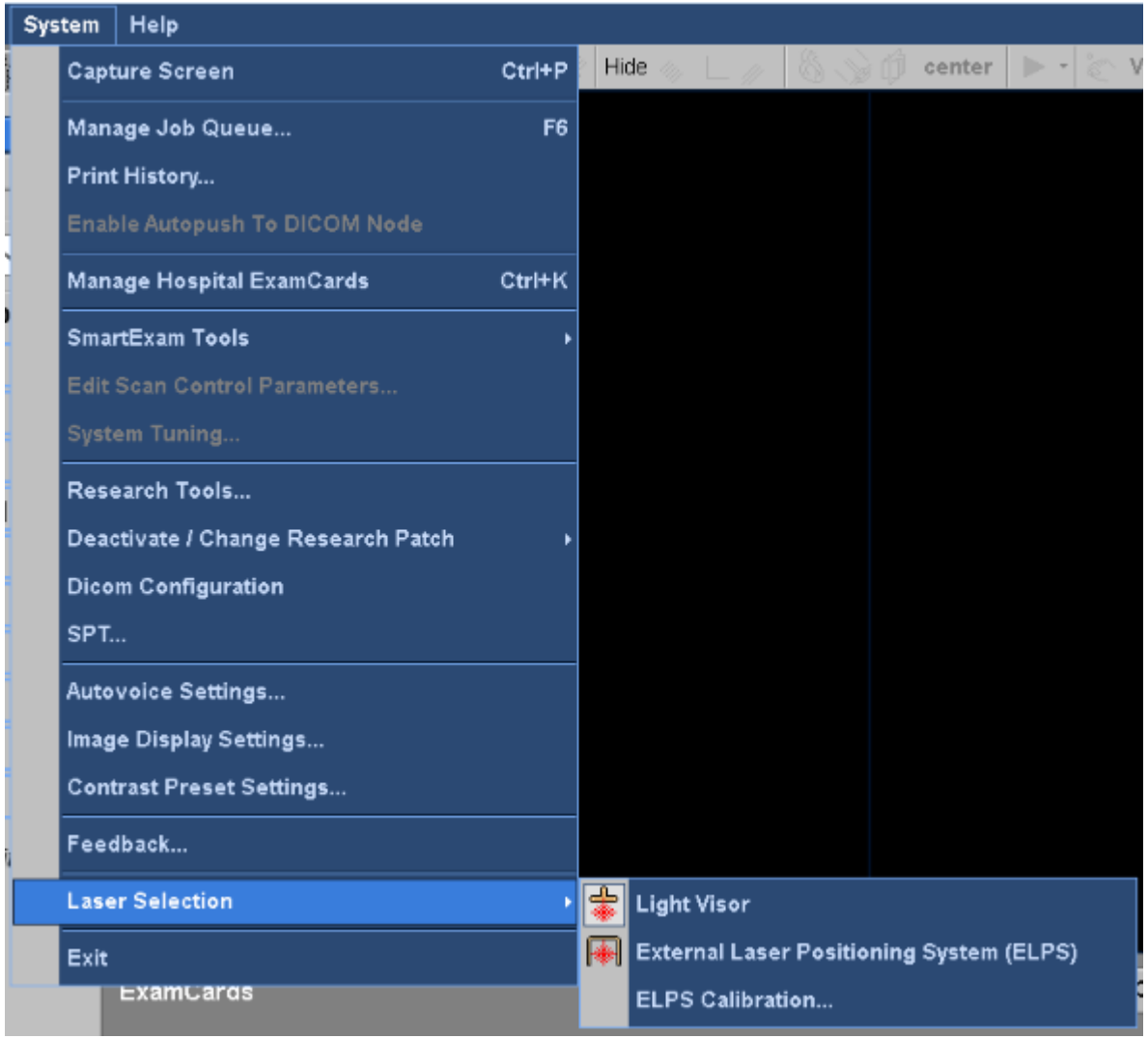
- The ELPS QA is performed to test the laser system's integration to the MR system





Before change

After change

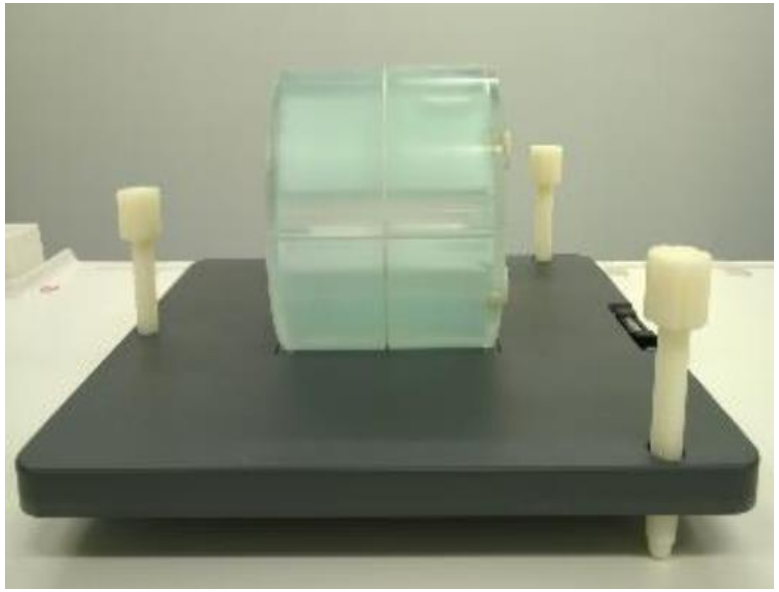


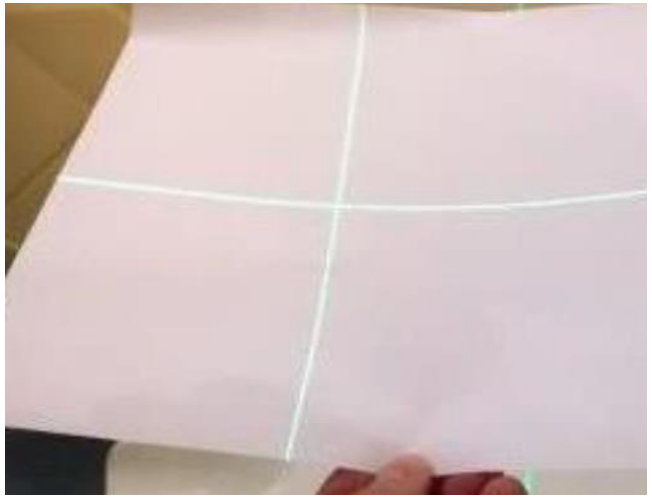
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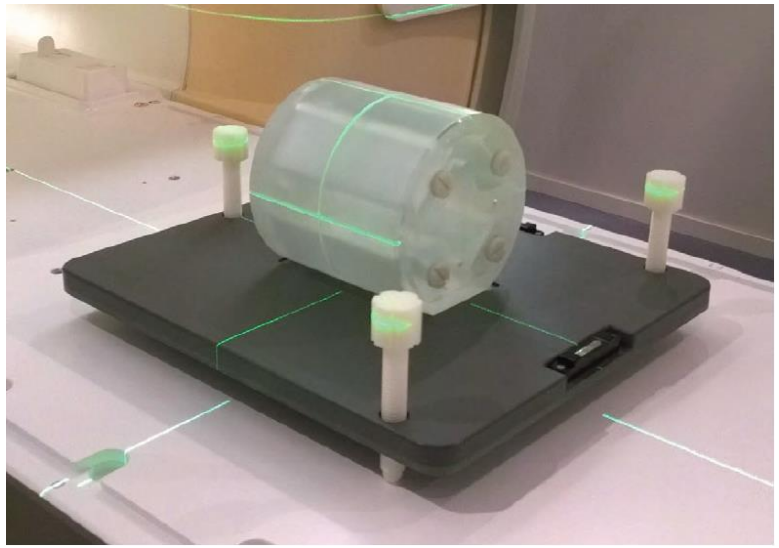
ELPS QA Phantom

- **ELPS QA phantom components:**
  - Laser alignment phantom
  - Leveling platform

- **Check laser line alignment**
  - White paper (splits, focus, etc.)
  - Wall markers (position change)









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ELPS QA Procedures

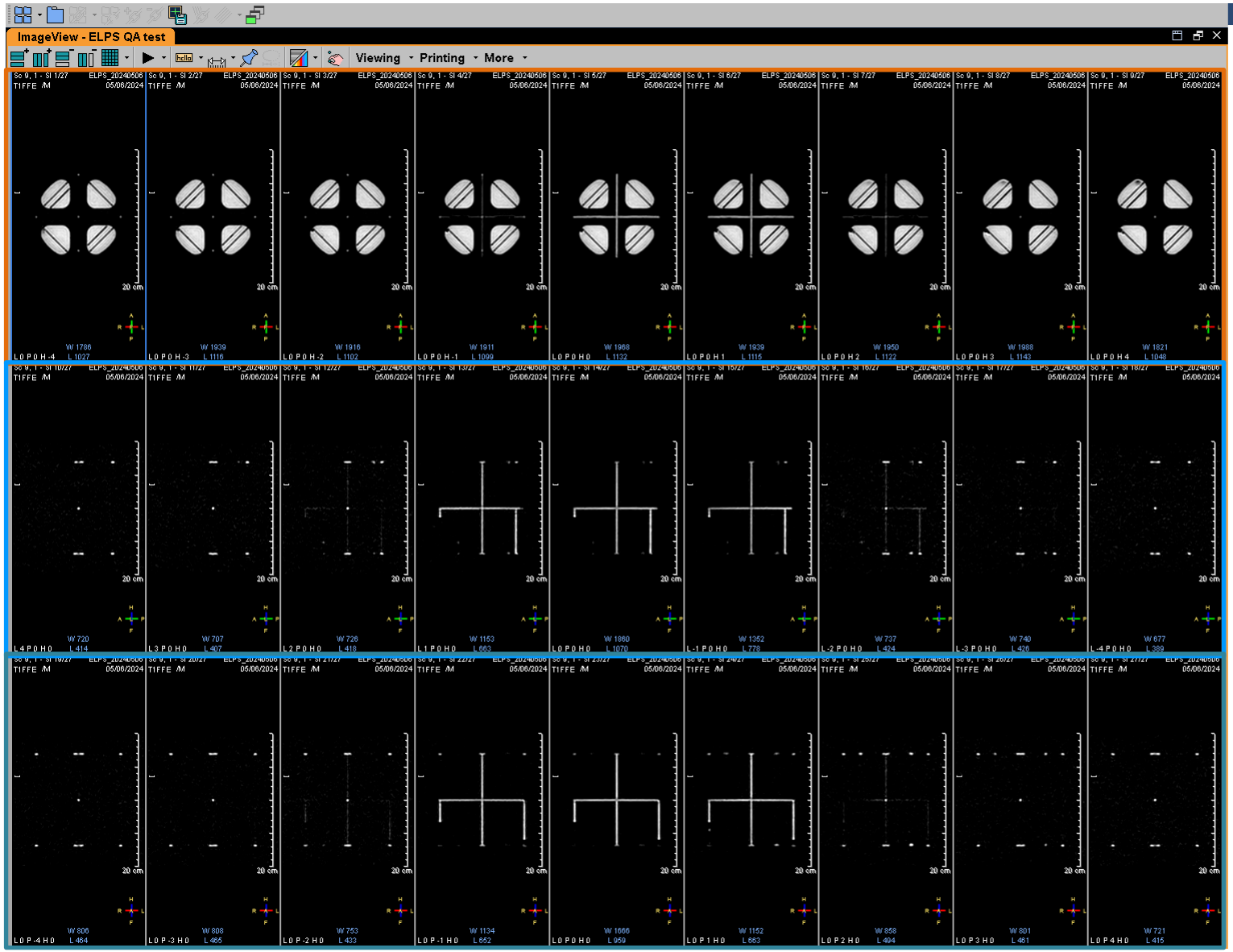
- Switch the laser to ELPS (External Laser Positioning System)
- Switch on the LAP laser (in the MRI control room)
- Load the ELPS phantom scan exam card
- Position the ELPS phantom using the LAP laser
- **Switch off the laser (in the MRI control room)**
- Run the ELPS phantom scan and assess the laser offsets
- **Switch the laser back to the default “Light Visor” (!!!!!)**





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ELPS QA Image Analysis



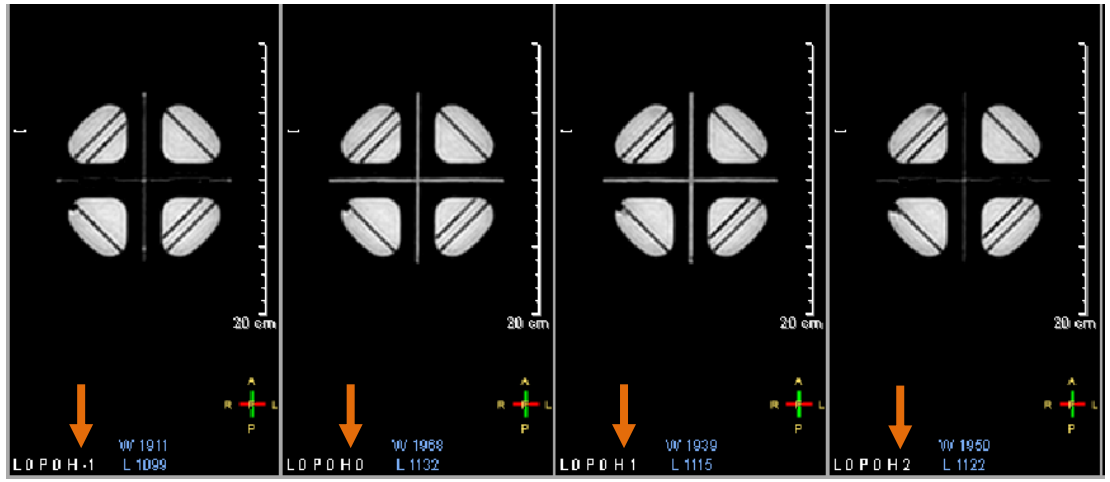
Transverse Plane
(images 1-9)

Sagittal Plane
(images 10-18)

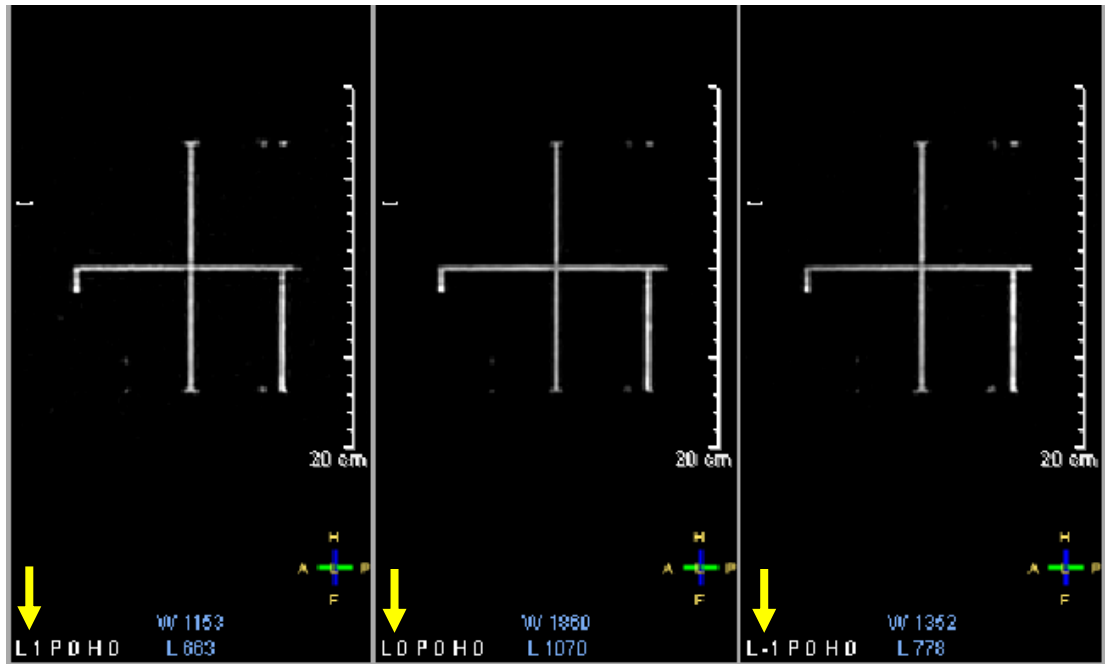
Coronal Plane
(images 19-27)

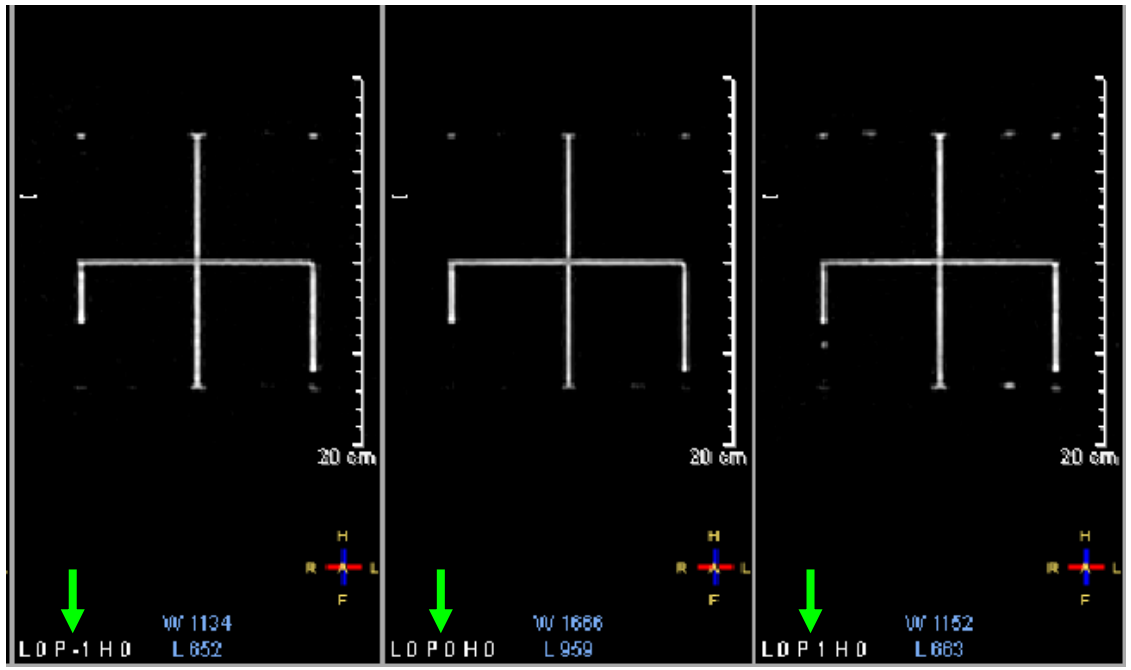
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ELPS QA Image Analysis



- Check the offsets for each orientation:
  - Transverse: (H -1, 0, 1, 2)→ H 0.5
  - Sagittal: (L 1, 0, -1) → L 0.0
  - Coronal: (P -1, 0, 1) → P 0.0
- Offsets tolerance: **±2.0 mm**





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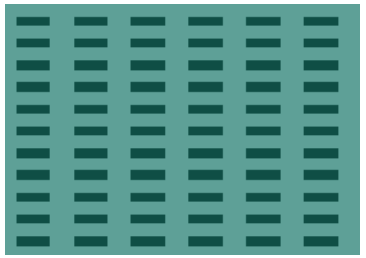
Geometric Accuracy in Radiotherapy

- In radiotherapy, **geometric accuracy** and precision is very important
  - Minimize the variability of the treatment planning
  - Reduce geometrical and delineation variations

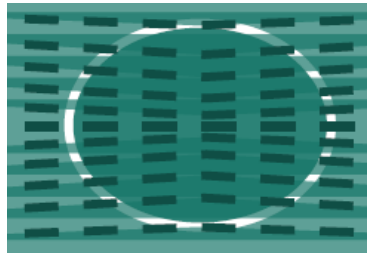
- **MRI in radiotherapy**
  - Excellent soft-tissue contrast
  - Susceptible to geometric errors and uncertainties due to system imperfections and patient-related distortion

- **Image distortion in MRI**
  - Machine-related: inhomogeneous magnetic field B_0, non-linear gradient field
  - Patient-related: susceptibility causes local field inhomogeneities (air-tissue, bone-tissue, etc.)
  - Implants causes local field disturbance





Uniform B_0

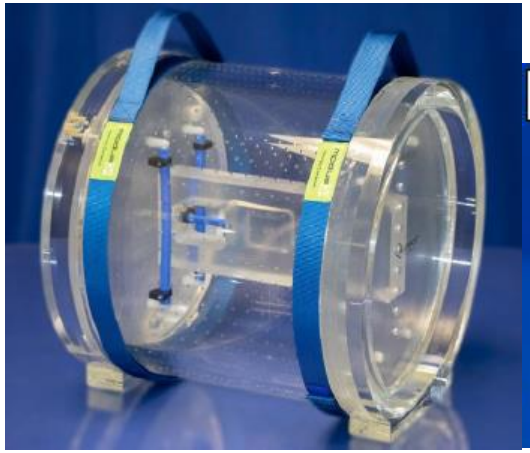


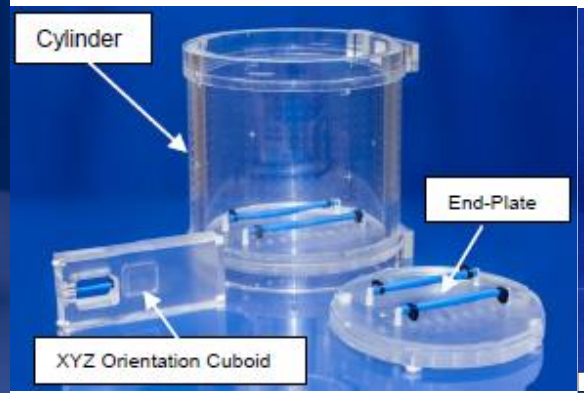
Distorted B_0

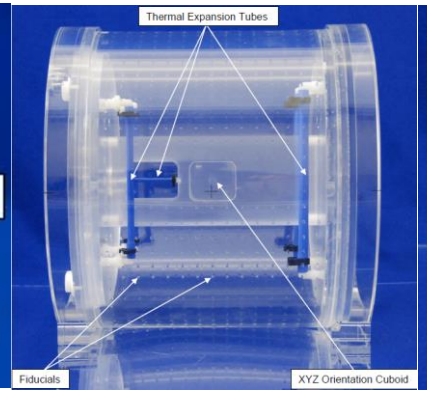
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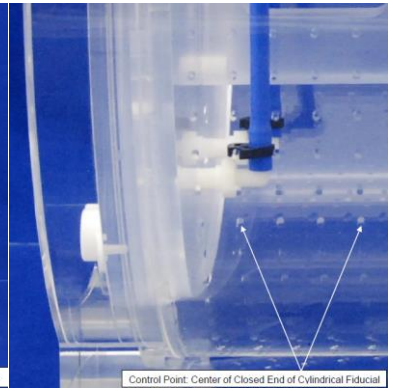
Geometric QA Phantom

- QUASAR™ MRID3D Geometric Distortion Analysis System



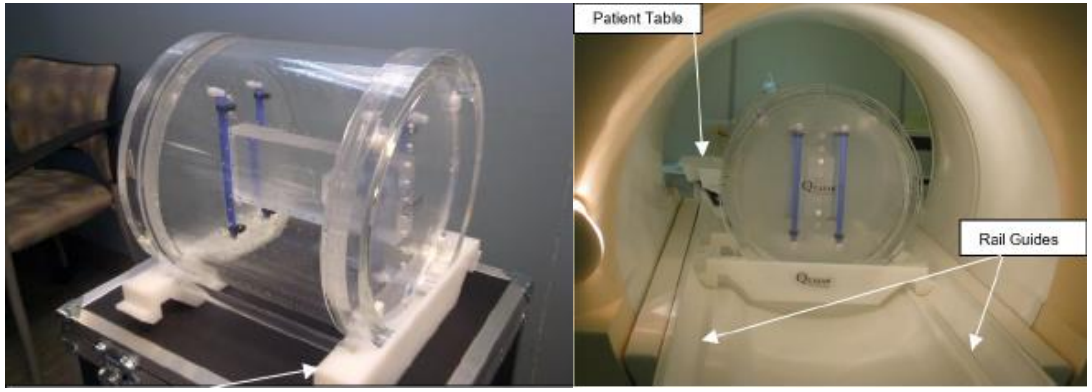




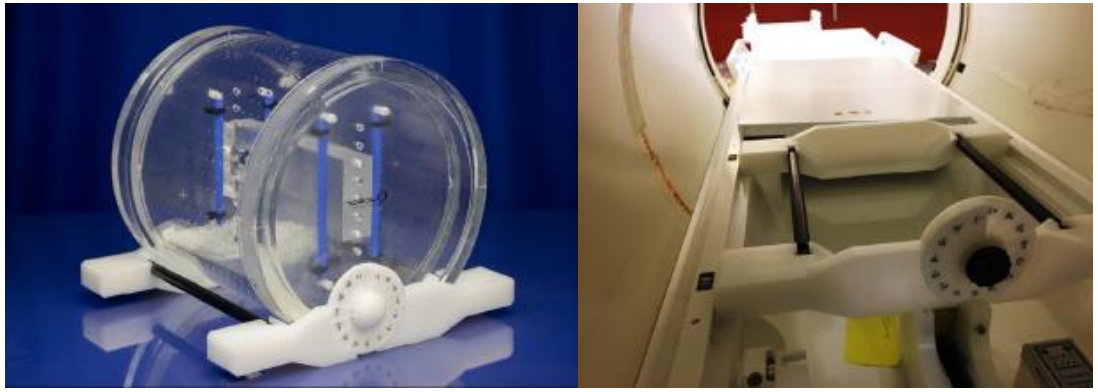


- Cradle Assembly

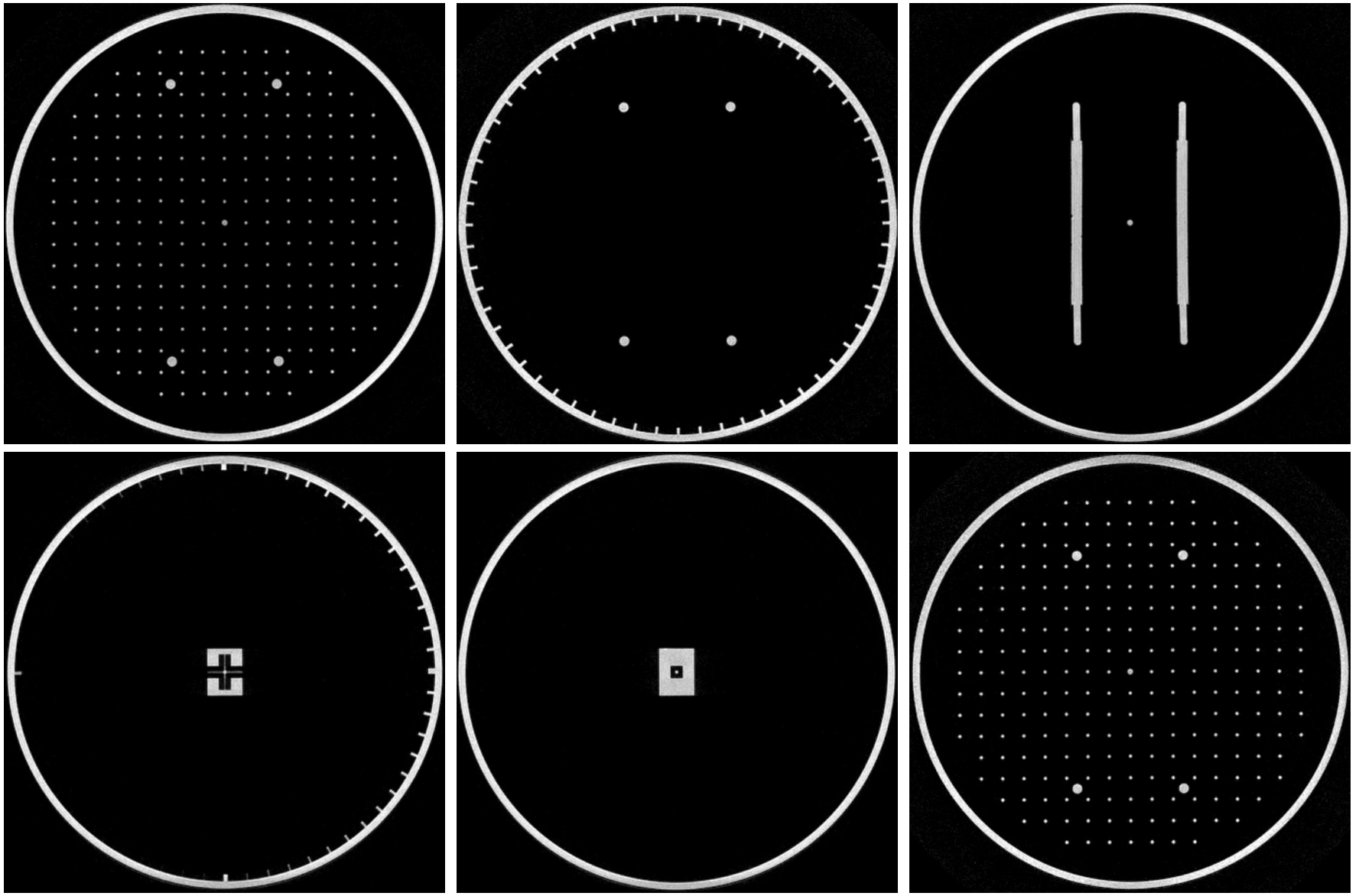
Philips Ingenia MR-Sim System



Elekta Unity MR-Linac System

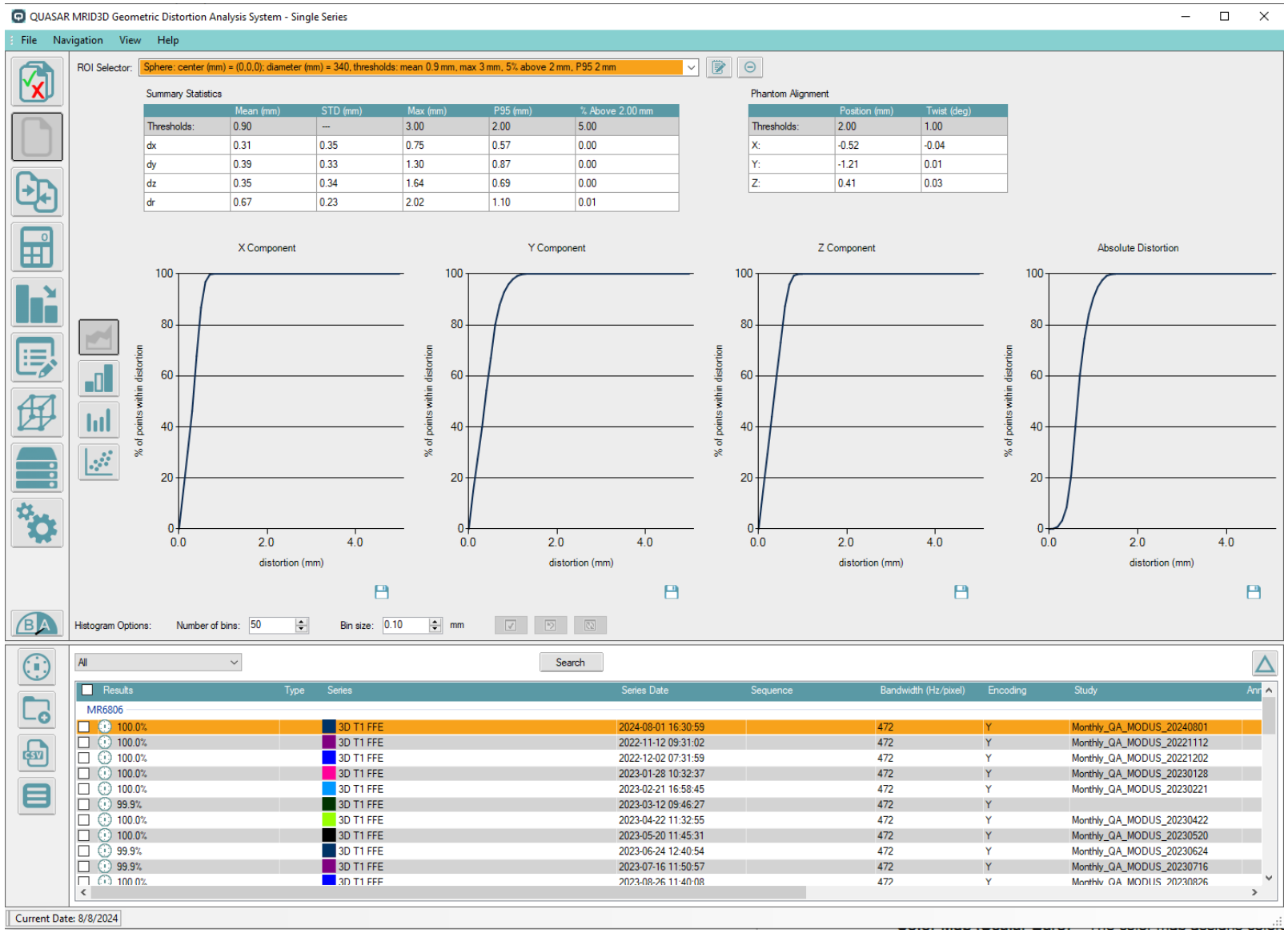


Phantom Structure and Images



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Geometric QA Analysis

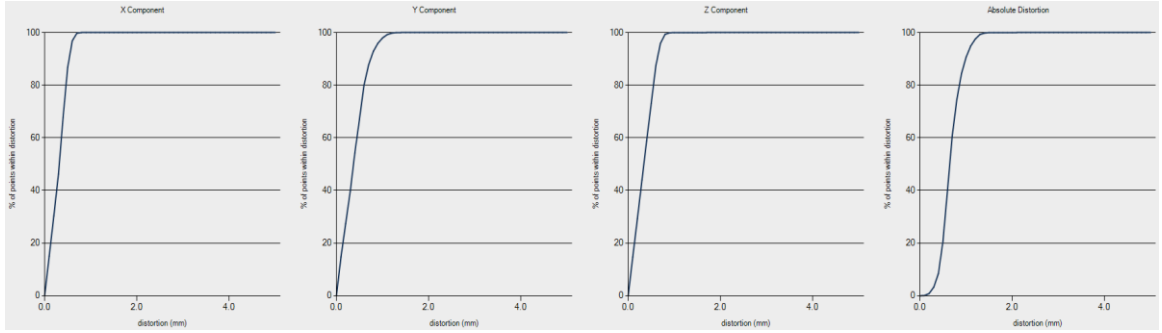


- Automatic analysis tool
- **Two diameters:**
  - 200 mm
  - 340 mm
- Offsets in dx, dy, dz, and dr directions
- % above 2.00 mm: < 5%
- Offsets in X, Y, Z directions < 2.00 mm
- Twist < 1.00 degree

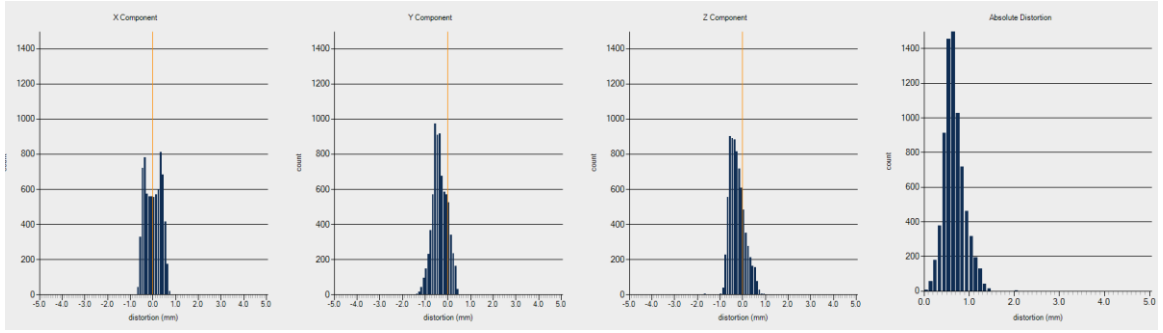
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Distortion Charts

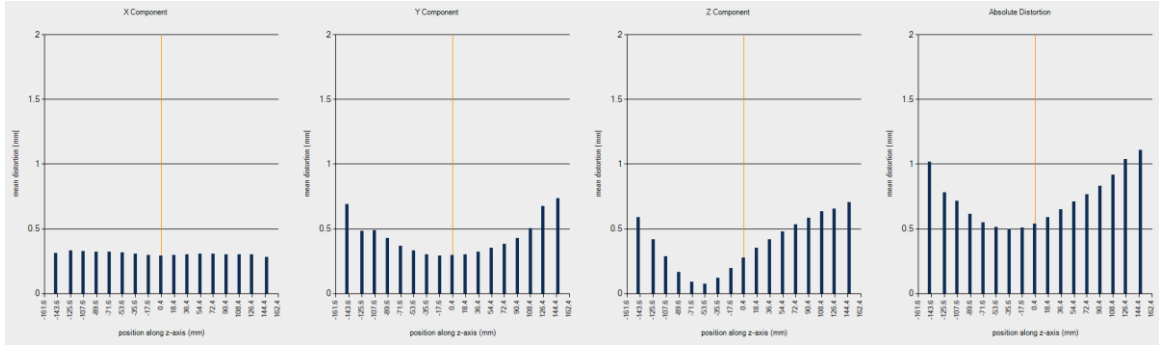
1. Cumulative percent below a given distortion



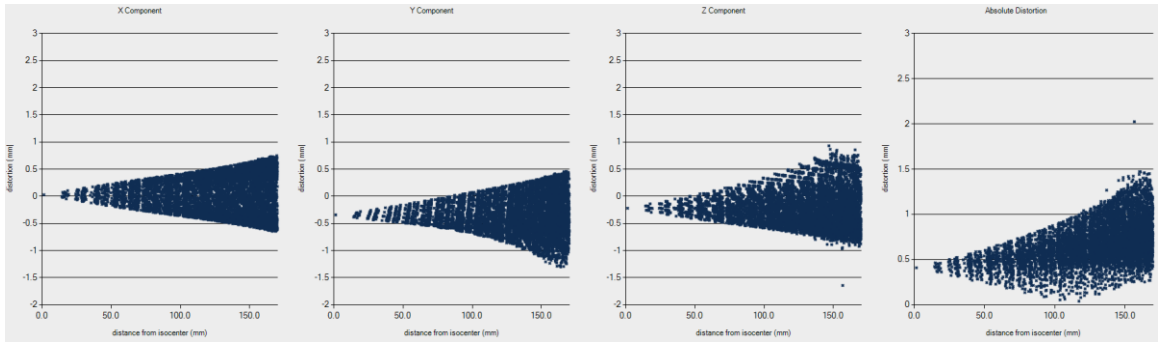
2. Histogram of the amount of distortion



3. Distortion by position along z axis



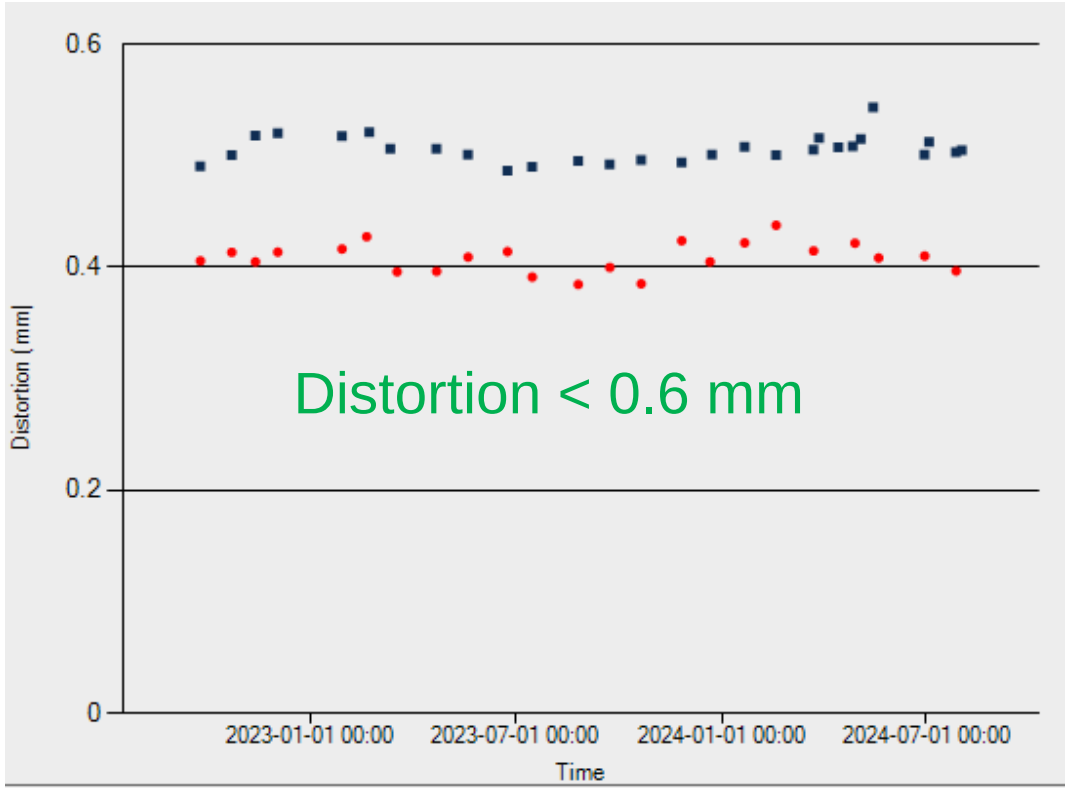
4. Distortion scatter plot



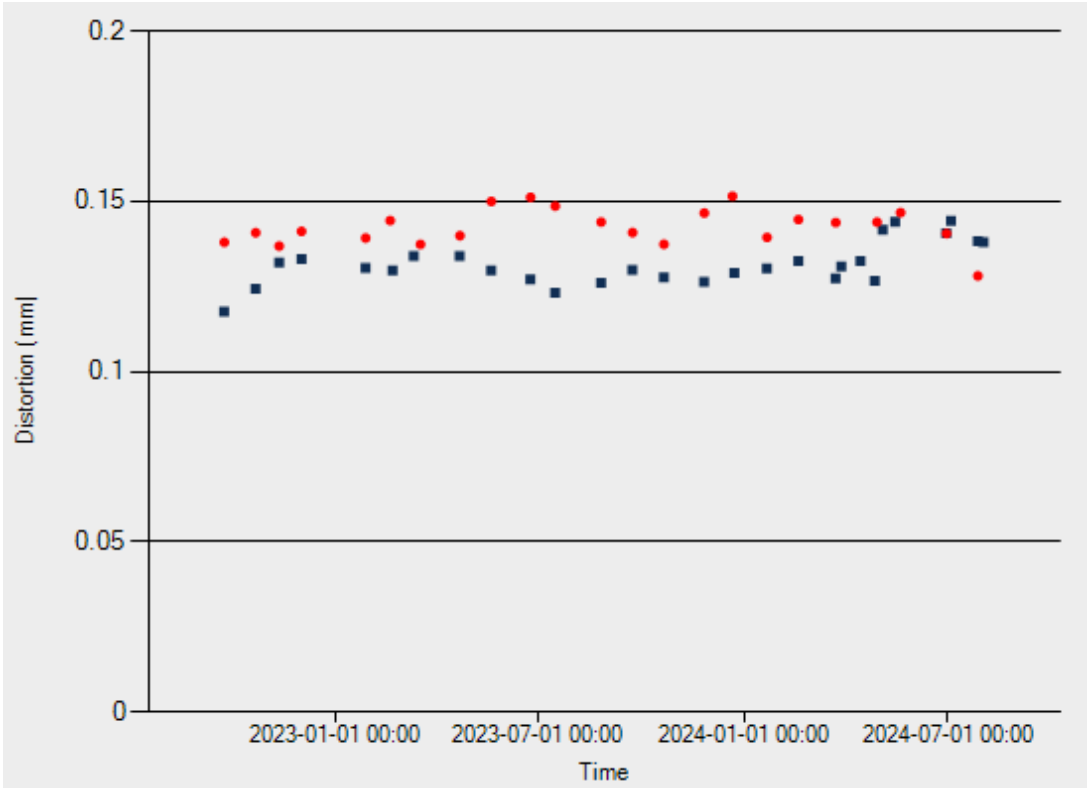
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Trend of Total Distortion Over Time

Trend in **Mean** over time



Trend in **Standard Deviation** over time



- Philips Elition 3T (Koch)
- Philips Ingenia 3T (Main Campus)

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Part II: MR-Linac QA

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MR-Linac PIQT Setup

- PIQT tests are the same as MR-Sim
- Phantom setup is different

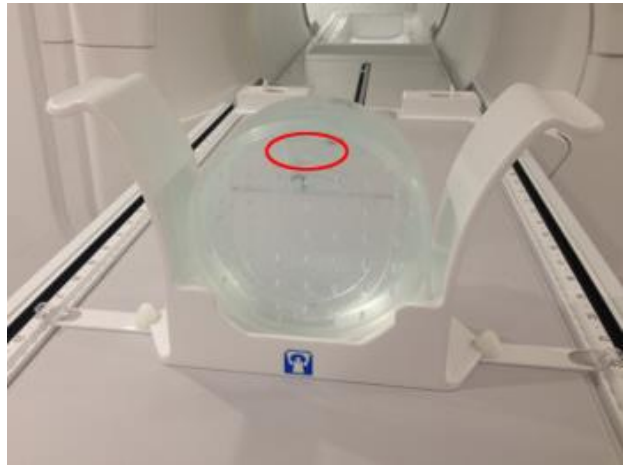
Index 22



Phantom holder

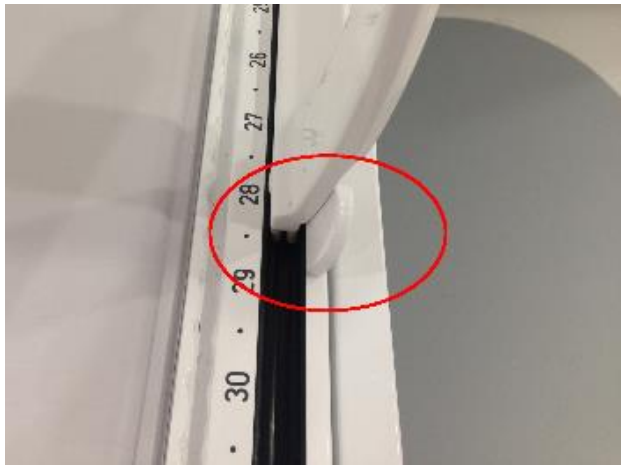


PIQT phantom

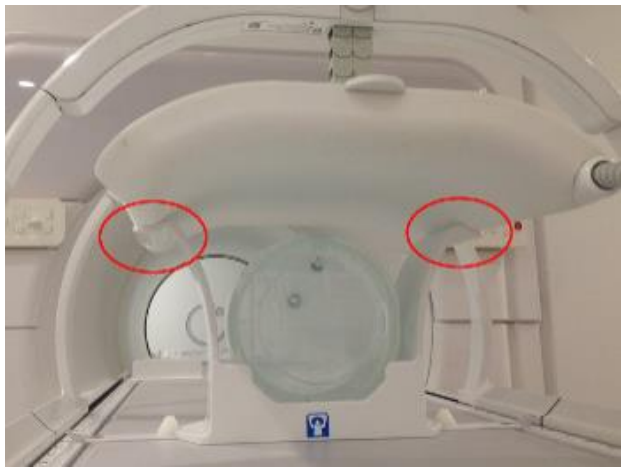




Coil frame



Lock coil frame



Lower the coil



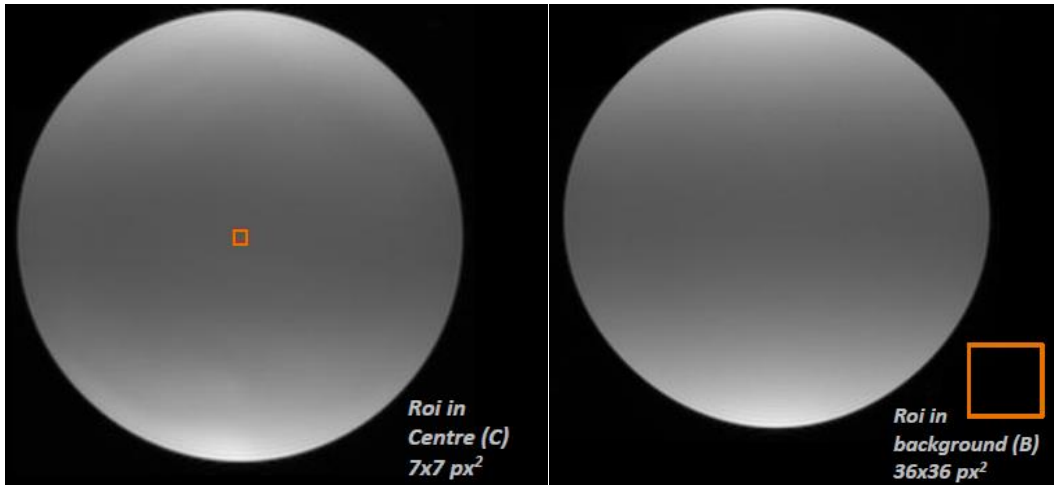
Lock the chains

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Coil Signal-to-Noise Ratio (SNR)

- **Purpose:** to assess the overall performance of the Marlin system, especially the function of the RF receive coils
- The coil SNR test is performed **daily** to verify that:
  1) the system can provide sufficient image quality (SNR of the whole image)
  2) all coil elements are working (SNR of each coil element)
- The phantom and setup is the same as PIQT (200 mm head phantom)

- **Full image SNR calculation:**



$$SNR = \frac{S}{N} = \frac{mean\,(C)}{std\,(B)/0.655}$$

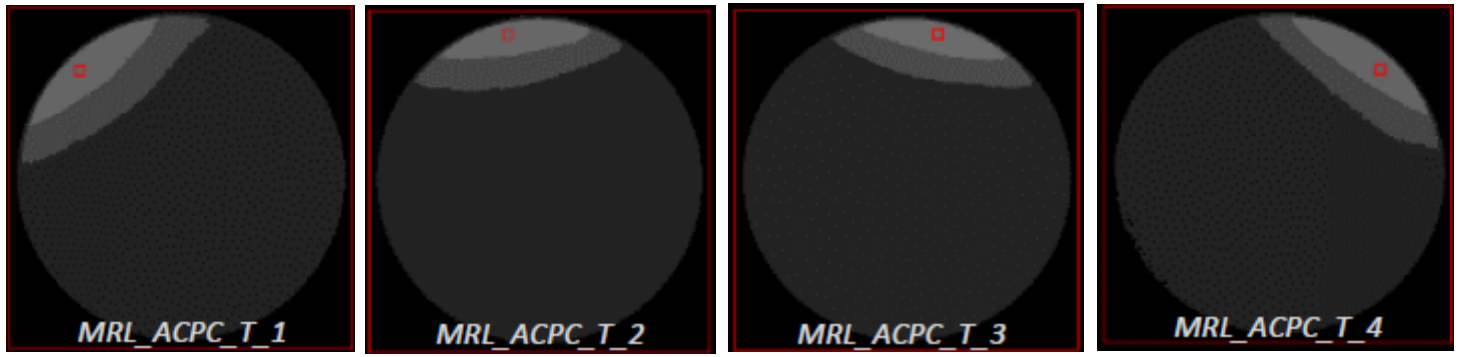
- Rician distribution of the background noise in a magnitude image
- The factor of 0.655 because noise variations can be negative and positive.

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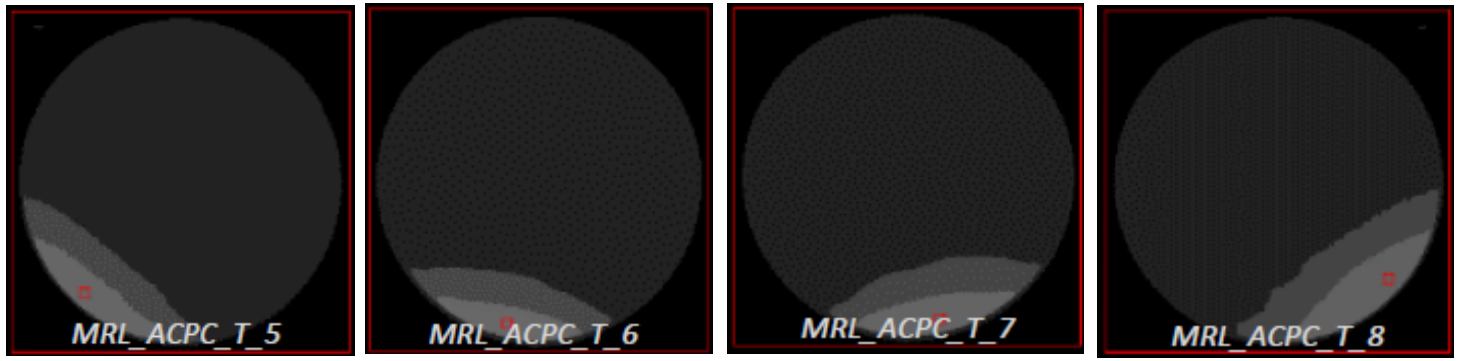
Coil SNR Test

- **Element-by-element coil SNR calculation:**

Anterior coil
(4 channels)



Posterior coil
(4 channels)



- Signal ROI in each coil channel

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Results Report and Causes of Failure

Patient	MRL_QA_SNR		MRL_QA_SNR		MRL_QA_SNR		MRL_QA_SNR		MRL_QA_SNR		MRL_QA_SNR		MRL_QA_SNR		A_SNR	
Scan_Name	MRL_ACPC_T		MRL_ACPC_T_1		MRL_ACPC_T_2		MRL_ACPC_T_3		MRL_ACPC_T_4		MRL_ACPC_T_5		MRL_ACPC_T_6		MRL_ACPC_T_7	CPC_T_8
Meas_Ok	OK		OK		OK		OK		OK		OK		OK		OK	
Verify_Ok	OK		OK		OK		OK		OK		OK		OK		OK	
Nema S/N (B)	124.07	C > 87	117.42	C > 79	158.73	C > 113	175.66	C > 113	111	C > 79	121.54	C > 85	267.48	C > 170	230.61	C > 170	125.05	C > 85
Nema_Int_Unif	99.22		99.95		99.95		99.95		99.95		99.95		99.95		99.95		99.95	

Result of the SNR for the whole image

Elementwise SNR results
Anterior coil elements 1-4 , Posterior coil elements 5-8

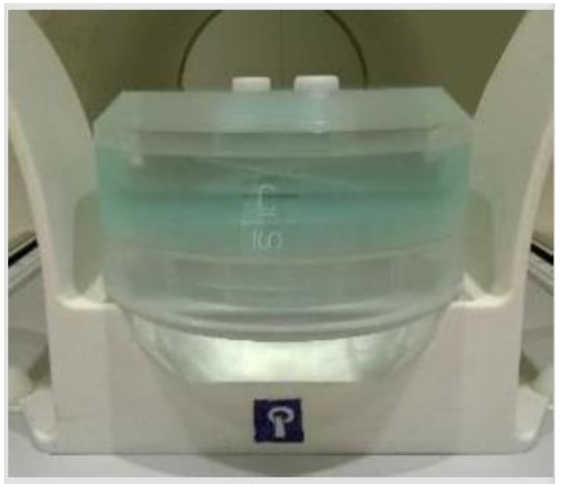
- **Possible causes of failure:**
  - Incorrect coil and phantom placement
  - Defective or broken coil elements
  - Failure of coil components (such as decoupling)
  - RF interference from Linac system and patient positioning system

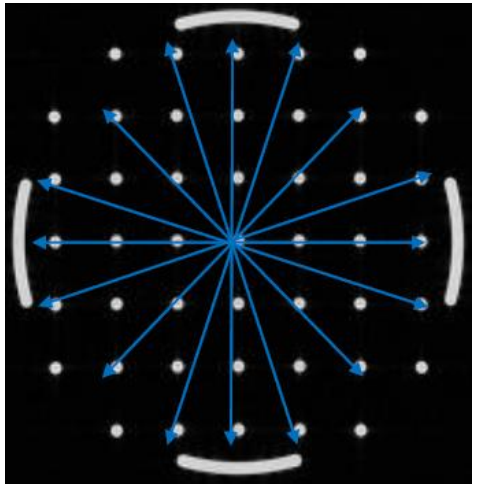
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Scaling Test

- **Purpose:** to evaluate image scaling in the transverse and coronal planes







- The scaling test is performed **daily** to verify that:
  1) The scaling of images are within specifications inside the phantom dimensions
  2) Changes outside of this field of view are unknow

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Test Results and Causes of Failure

Meas_Ok	OK		OK	
Verify_Ok	OK		OK	
diff_lin_(2-44)	-0.23		-0.01	
diff_lin_(3-43)	-0.15		0.01	
diff_lin_(4-42)	-0.32		0.01	
diff_lin_(7-39)	-0.18		-0.09	
diff_lin_(11-35)	-0.11		0	
diff_lin_(13-33)	-0.16		-0.03	
diff_lin_(19-27)	-0.08		-0.03	
diff_lin_(20-26)	-0.06		-0.06	
nema_perc_dif.	0.32	C < 0.5	0.09	C < 0.5

- nema_perc_dif.

$$\text{nema_perc_dif.} = \max_{i-j}(\text{abs}(\text{diff_lin}(i-j)))$$

- diff_lin_(xx-xx)

$$\text{diff_lin}(i-j) = \frac{d^{i,j}_{\text{measured}} - d^{i,j}_{\text{actual}}}{d^{i,j}_{\text{actual}}} \cdot 100\%$$

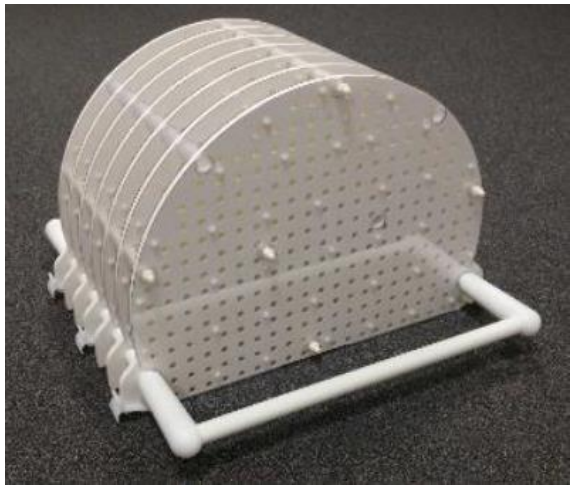
where, i, j are discs and d is distance

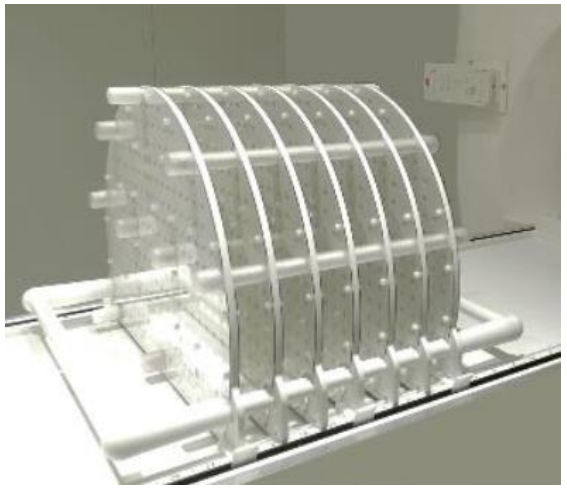
- **Possible causes of failure:**
  - Mis-calibrated gradients: the gradient amplifiers need time to warm up and stabilize after they are turn on
  - High B_0 inhomogeneity: ferromagnetic objects (such as hair clip) in the magnet bore or modification of the Linac hardware

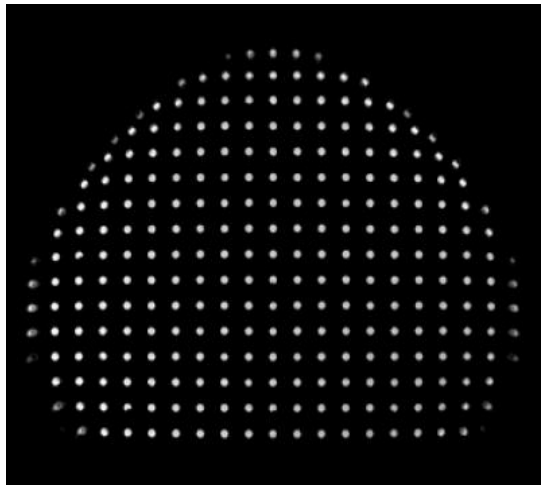
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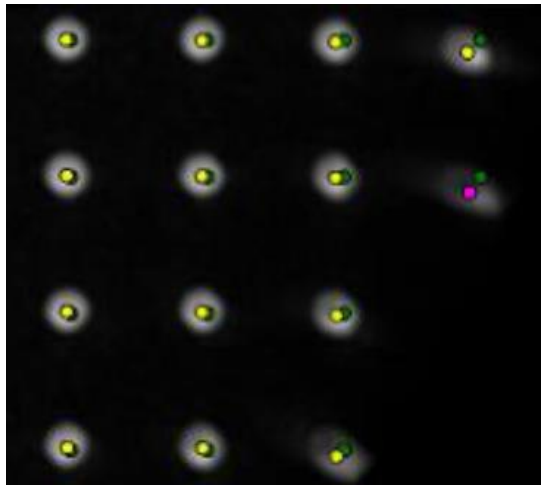
3D Geometric QA

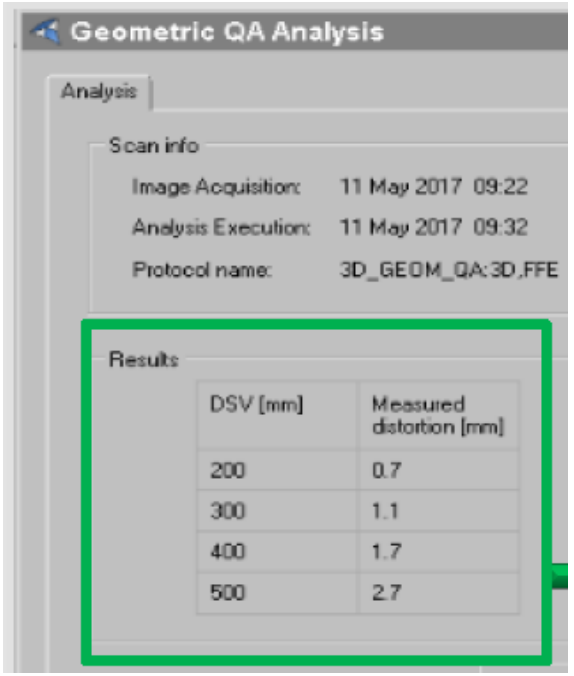
- **Purpose:** to evaluate the geometric accuracy of MR images with the Marlin system

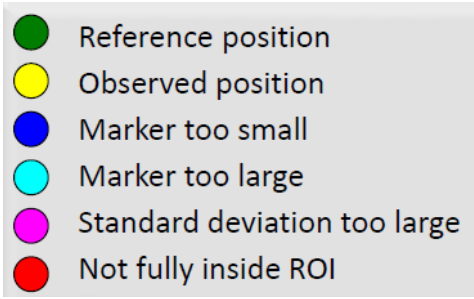








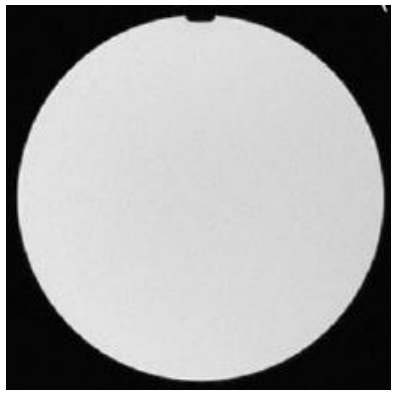


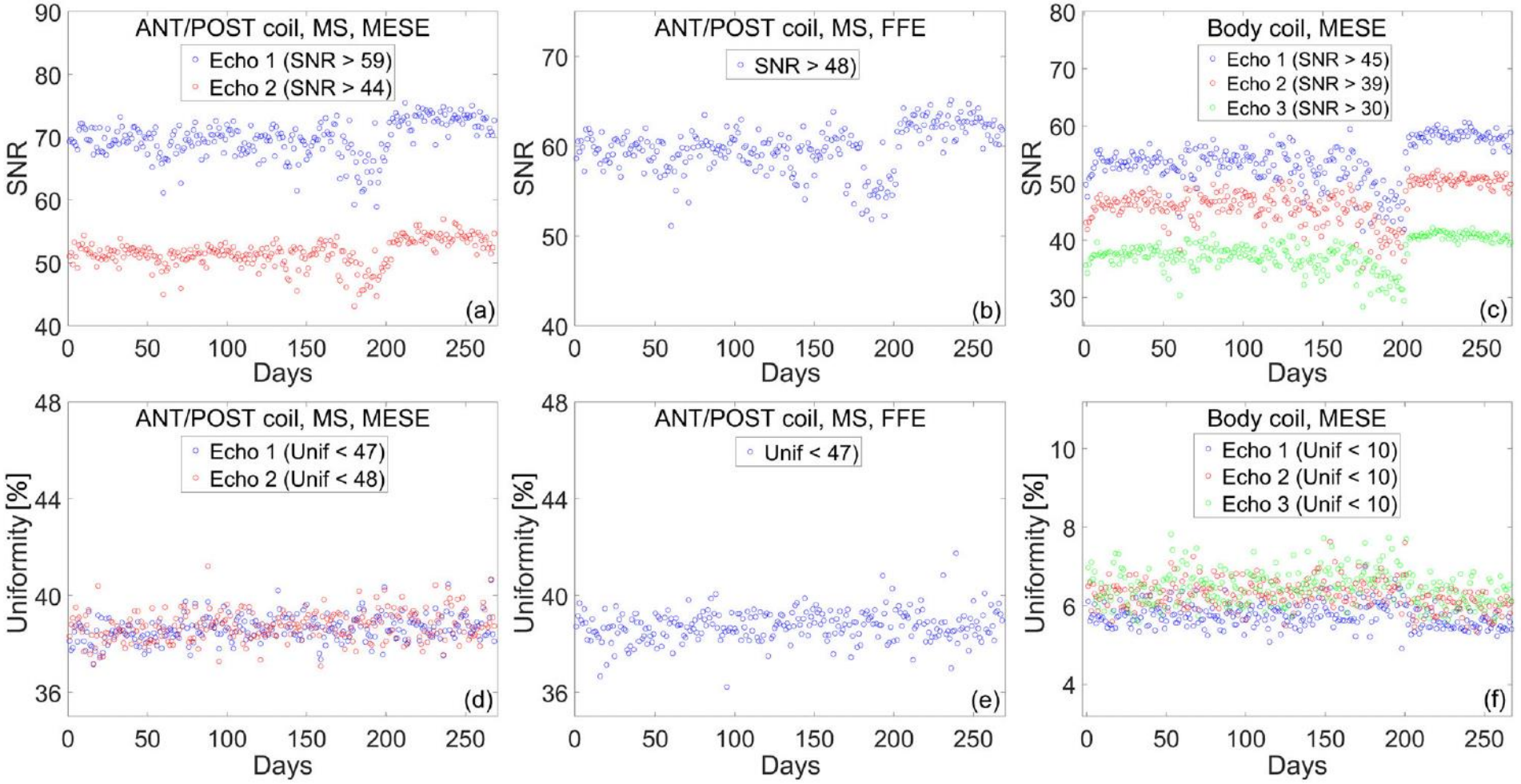


- **Scan time:** ~ 10 minutes
- **Coil:** system body coil (QBC)
- T1-weighted 3D FFE scan
- Relatively large distortion at the edges of the isocenter plane (Marlin gradient coil gap)

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Longitudinal SNR and Uniformity

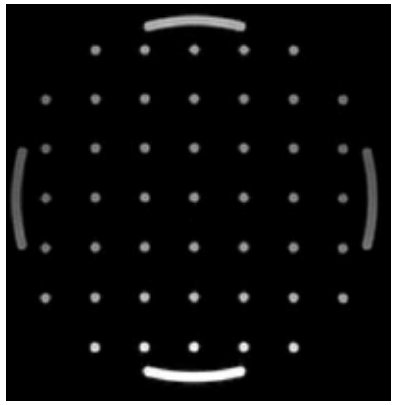


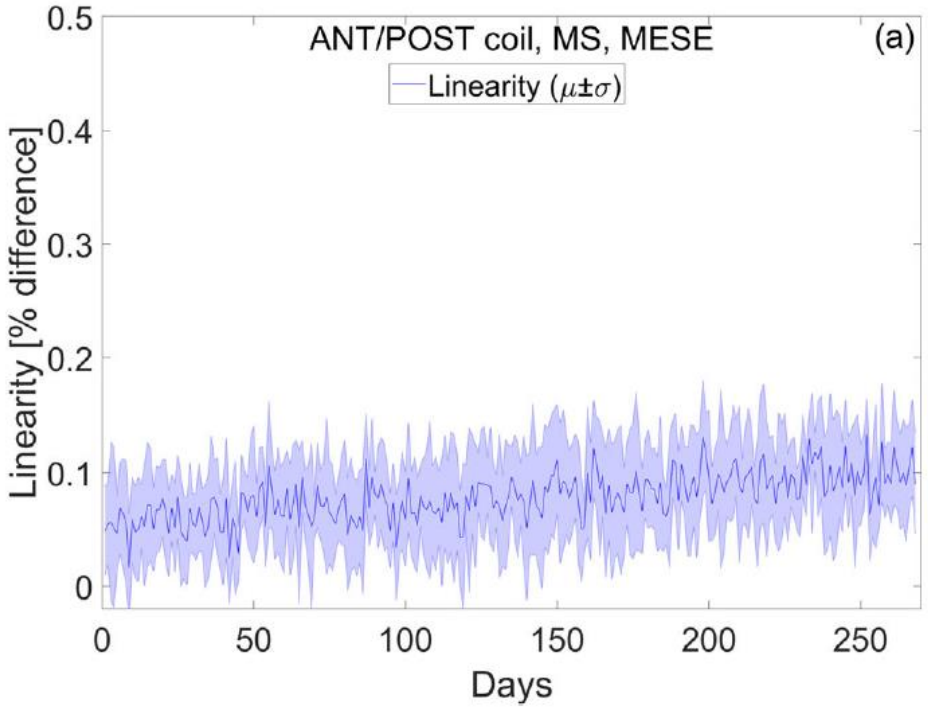


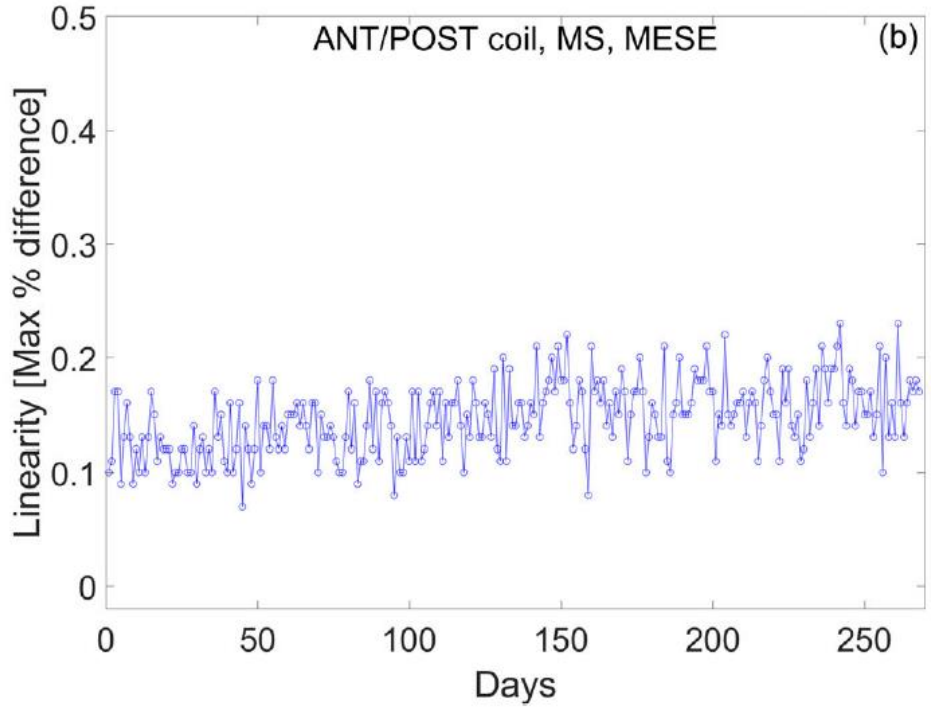
$$\text{Uniformity} = \frac{\max - \min}{\max + \min} \times 100\%$$

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Longitudinal Spatial Linearity



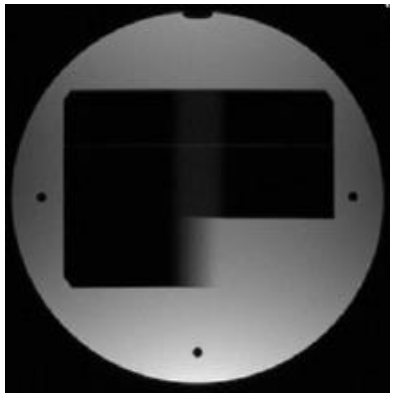


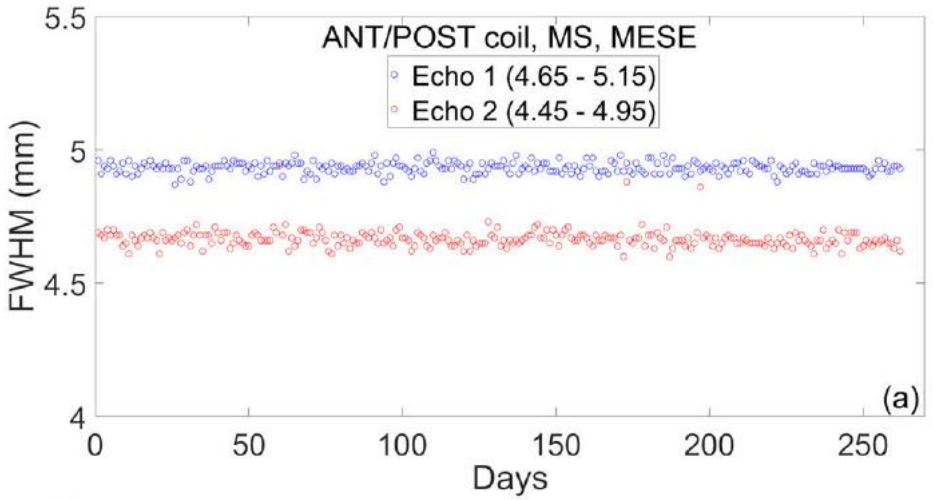


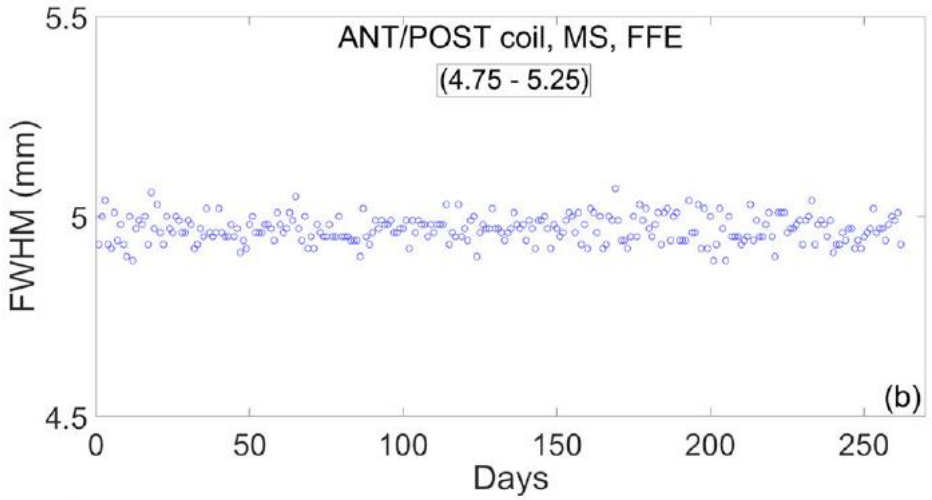
$$\text{Linearity} = \frac{d_{\text{Measured}} - d_{\text{Actual}}}{d_{\text{Actual}}} \times 100\% \quad \text{(tolerance: < 0.5\%)}$$

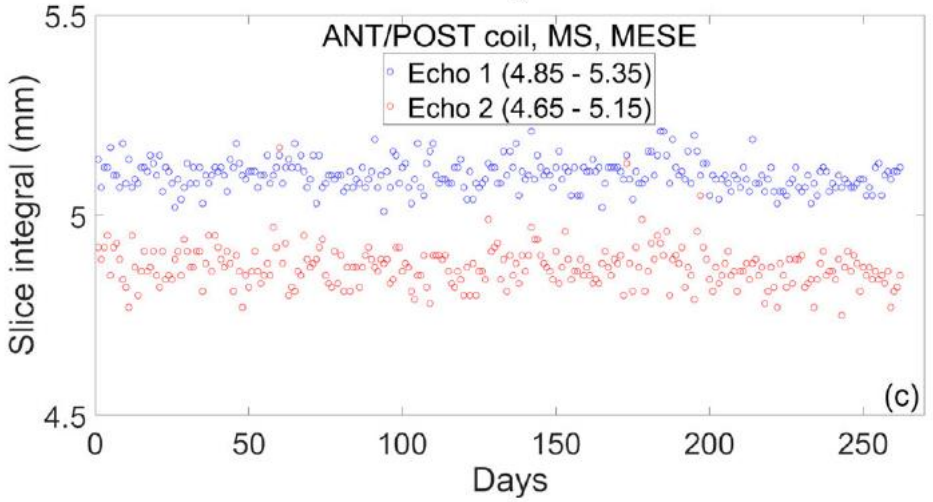
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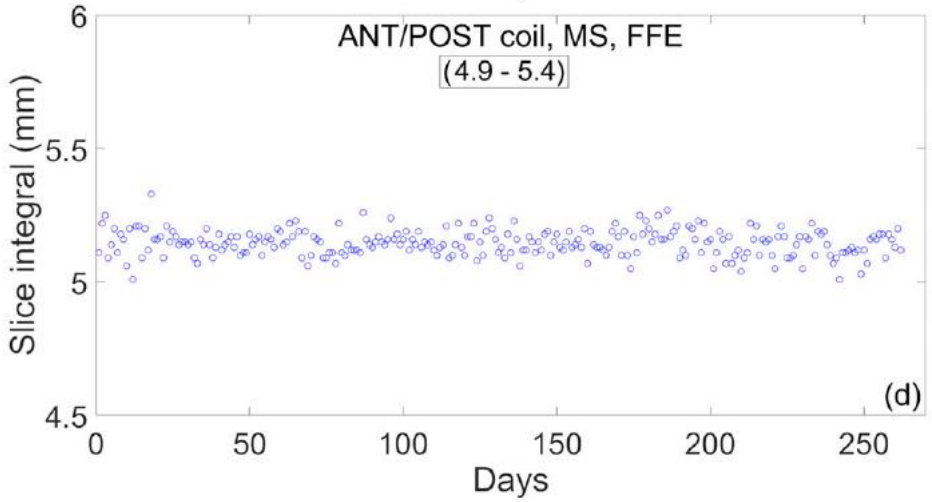
Longitudinal Slice Profile





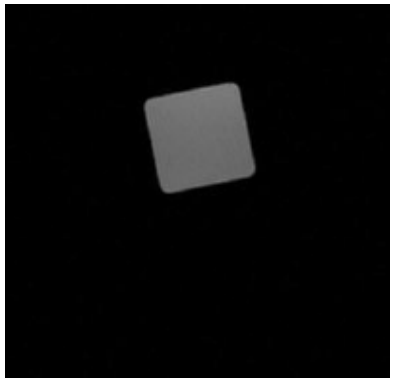


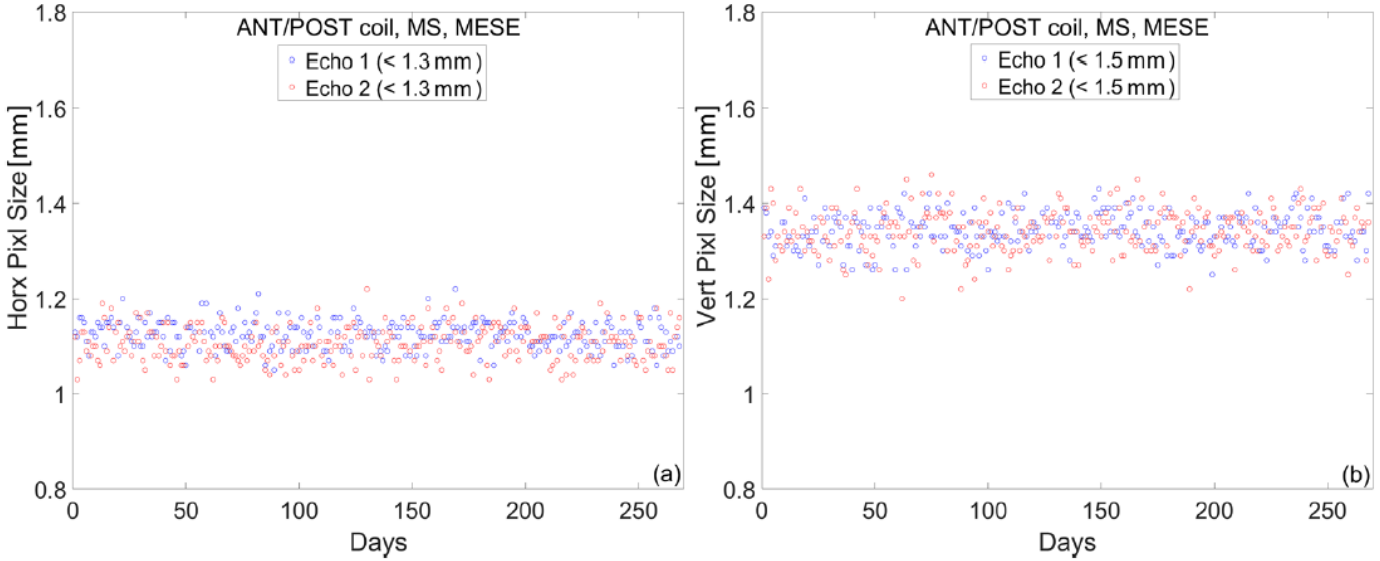


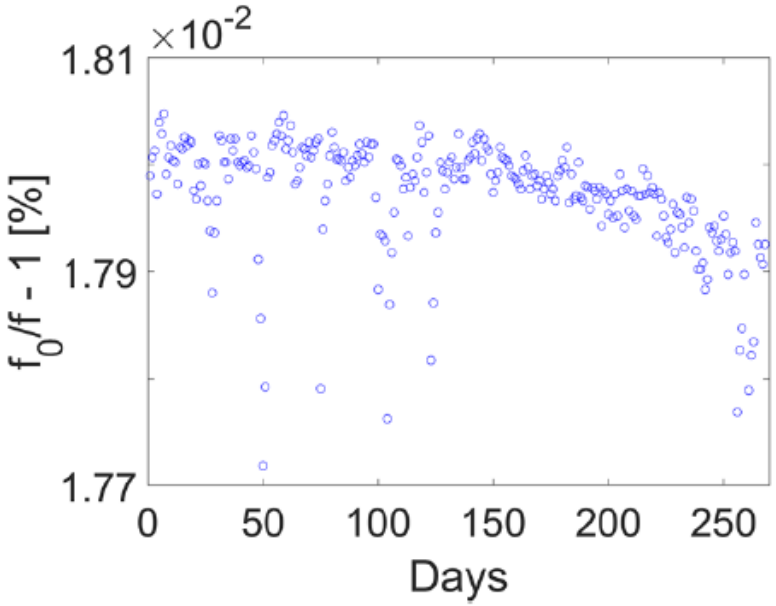


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Spatial Resolution & Center Frequency







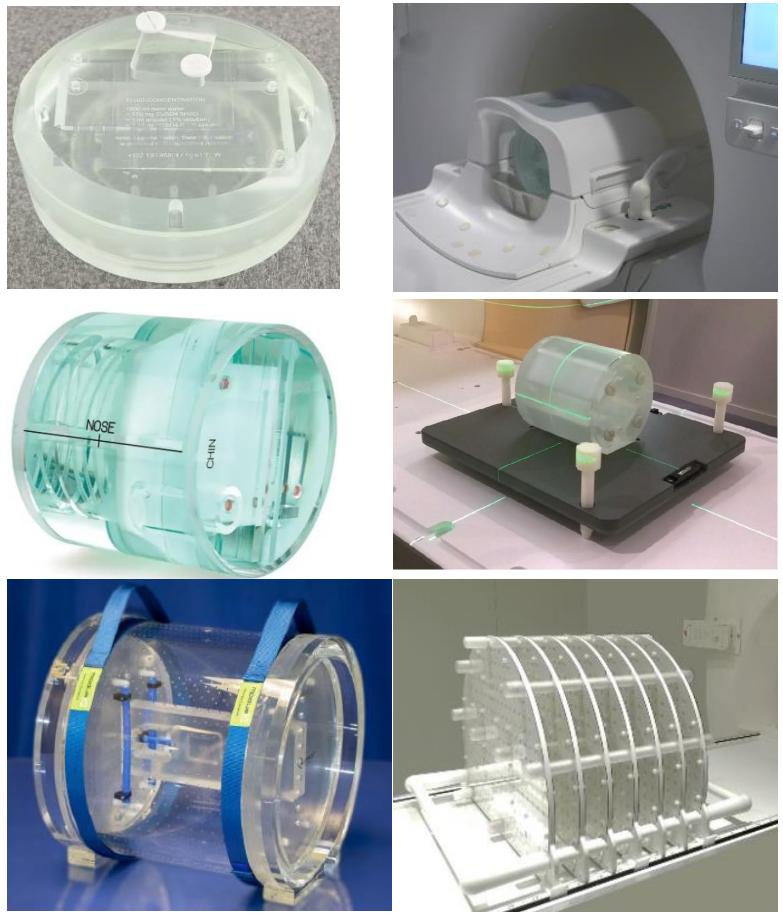
Center frequency:
inspection for drift

$$f = \frac{\gamma}{2\pi} B_0$$

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Summary

- **Therapeutic MRI QA Tests**
  - PIQT QA (daily, weekly)
  - ACR QA (monthly, annually)
  - ELPS QA (monthly)
  - Geometric QA (monthly)
  - Longitudinal QA (trend)



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References

- Philips Healthcare (user manual, educational materials)
- Elekta (user manual, training materials)
- IBA QUASAR (user manual)
- **Subashi E**, Dresner A, Tyagi N. Longitudinal assessment of quality assurance measurements in a 1.5 T MR-Linac: Part II – Magnetic resonance imaging. ***J Appl Clin Med Phys*** 2022; 23:e13586.

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Thank You!



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