# Novel methods and tools for MR Commissioning and Quality Control

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## Disclaimer

License agreement with Modus Medical Devices Inc. to develop a phantom for the quantification of MR image system-related distortions.

# Topics for MR-guided RT system Commissioning & QC

## MR data for RT planning and in-room guidance

- MR image distortion: system/scanner-related
- MR image distortion: susceptibility-induced
- Quantification of motion

## MR-guided systems: design specific

- RF noise
- Magnetic field coupling
- MR-radiation source system: iso-to-iso registration

## System performance monitoring & Reporting

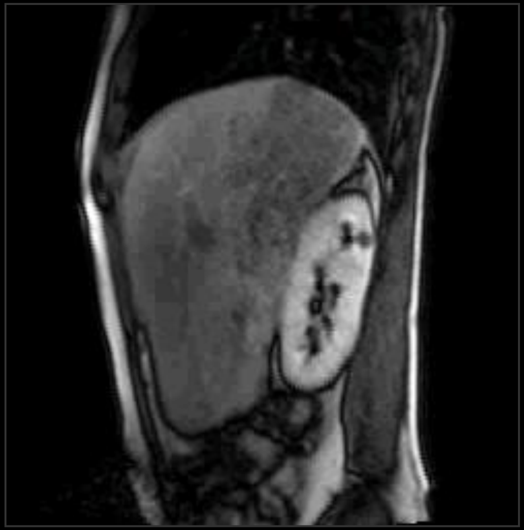
- Open-source software for semi/auto-QC monitoring
- Data base record: in-house, commercial, cloud solutions

## MR data for RT planning

MR images suffer of intrinsic distortions → affect geometric accuracy

**> System | scanner - related:**
- B0 field inhomogeneities
- Imaging gradients non-linearity

**> Patient | object - induced:**
- Tissue magnetic susceptibility
- Chemical shift



- The distortions can be treated as separate problems
- Organ motion present → 4D composite distortion field

## MR data for RT planning – System-related distortions

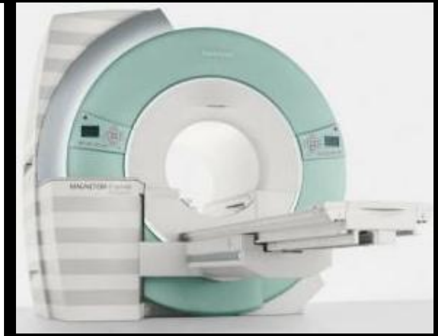
MR images suffer of intrinsic distortions → affect geometric accuracy

### 1. B0 field inhomogeneities

- High field homogeneity required for the static magnetic field
- Typical value: a few ppm in a 40-50 cm spherical volume

Siemens Espree 1.5T - B0 field homogeneity specs

| Homogeneity | | |
|---|---|---|
| **Volume** | **Guaranteed** | **Typical** |
| 10 cm DSV | ≤0.05 ppm | 0.01 ppm |
| 20 cm DSV | ≤0.2 ppm | 0.08 ppm |
| 30 cm DSV | ≤1 ppm | 0.8 ppm |
| $40 \times 40 \times 30$ cm$^3$ | ≤2 ppm | 1.2 ppm |
| $45 \times 45 \times 30$ cm$^3$ | ≤4 ppm | 2.8 ppm |
| | Standard deviation Vrms (Volume root-mean square) measured with highly accurate 24 plane plot method (20 points per plane). | |
| $40 \times 40 \times 40$ cm$^3$ | ≤5 ppm* | |



- 70 cm bore
- 120 cm long

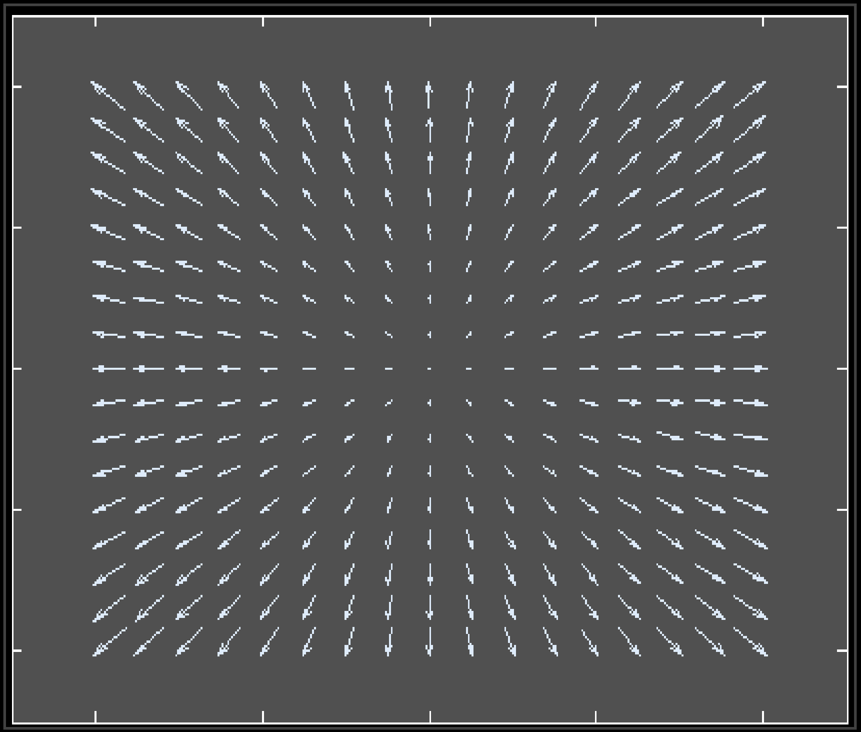
## MR data for RT planning – System-related distortions

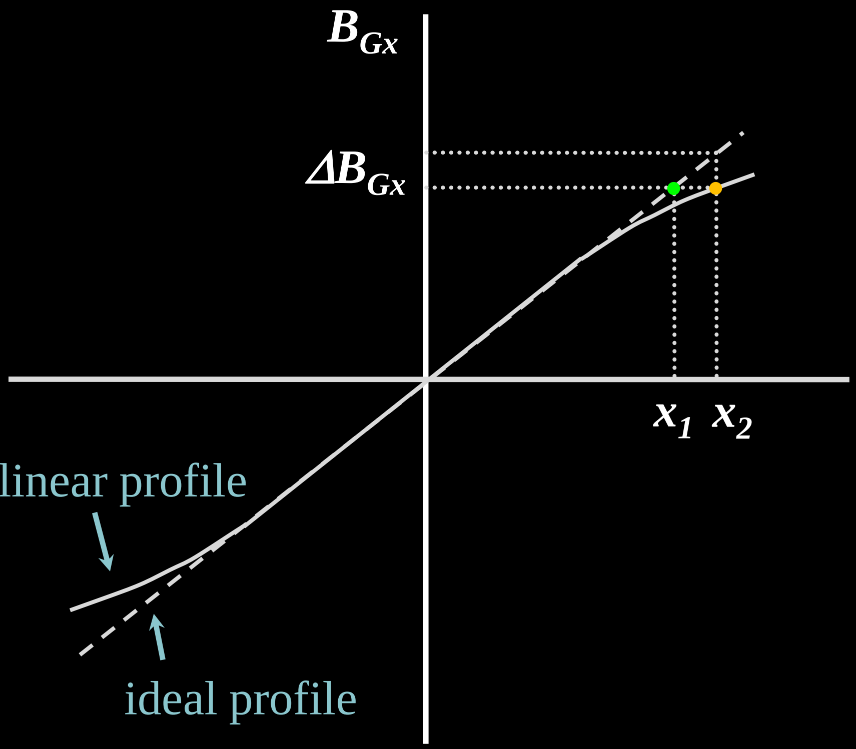
MR images suffer of intrinsic distortions → affect geometric accuracy

### 2. Gradient non-linearity

- Most significant source of geometric distortions

Distortion field magnitude ↑ with d-iso

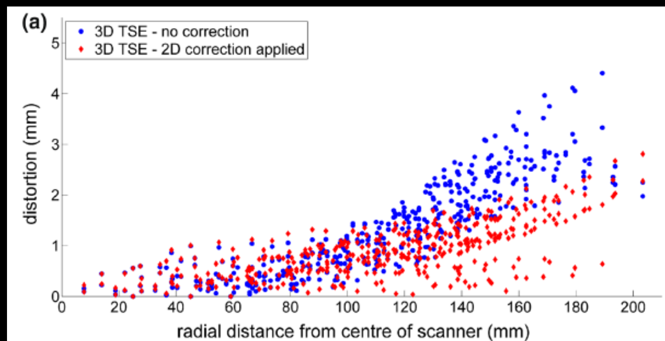


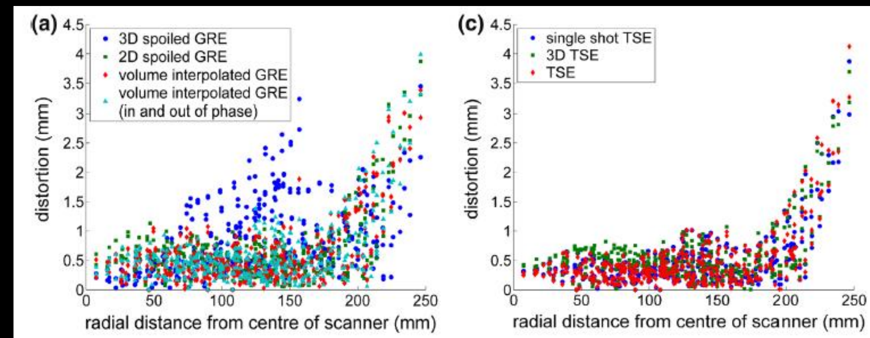


# System-related distortions

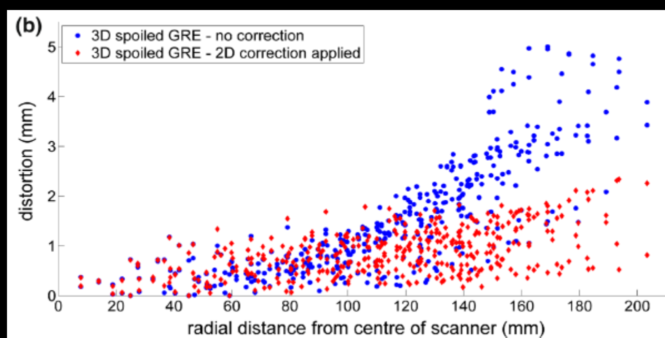
## Multiple MR scanner quantification

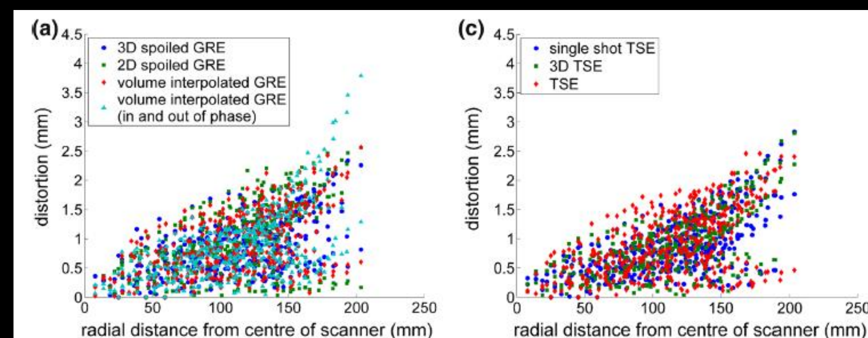
1.5T



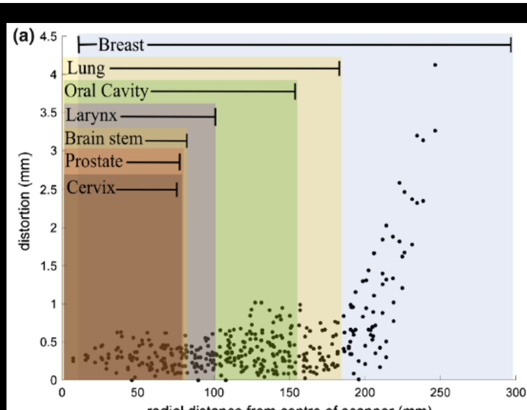



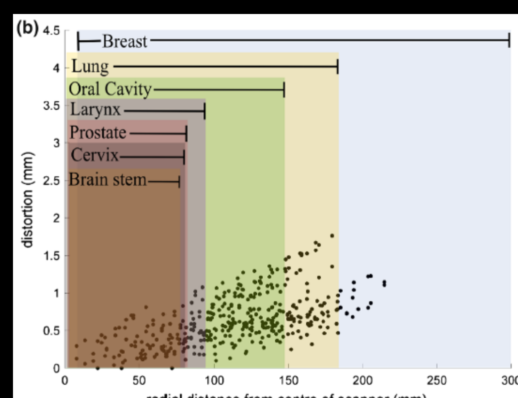

3T




1.5T




3T

Australas Phys Eng Sci Med (2014) 37:103–113

## MR data for RT planning – System-related distortions

MR images suffer of intrinsic distortions $\rightarrow$ affect geometric accuracy

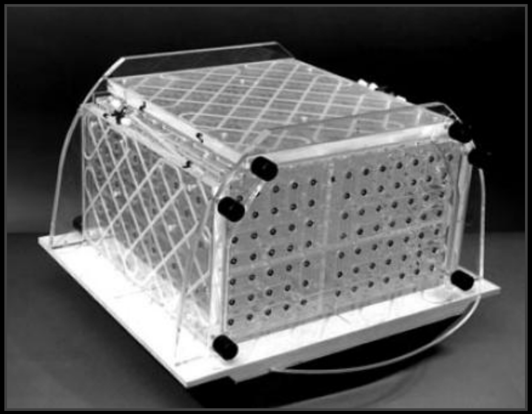
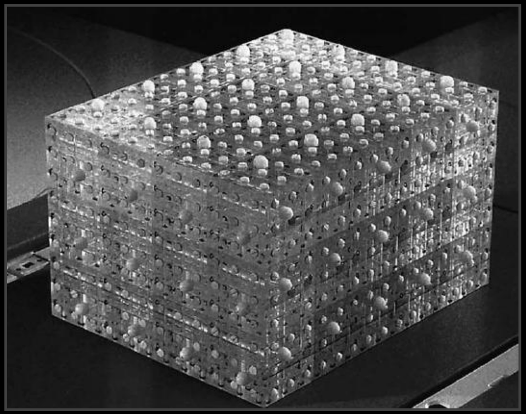
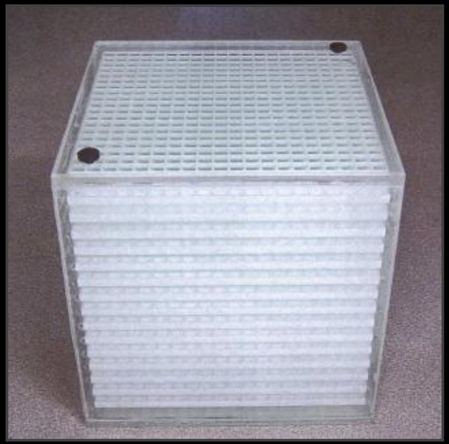
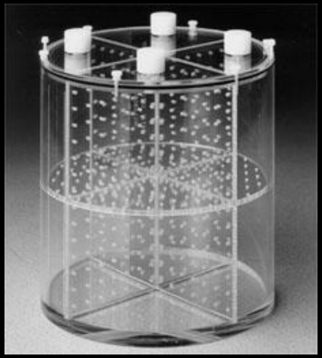
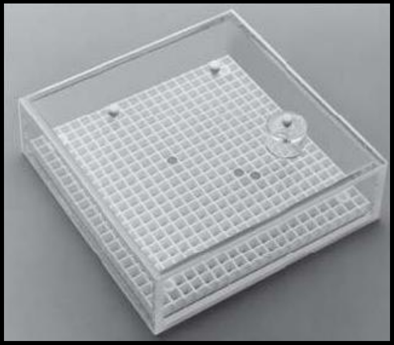
### Methods for quantifying the 3D distortion field

a. Measurements using phantoms or linearity objects

b. Theoretical evaluation using spherical harmonics

c. Hybrid approach

# System-related distortions

## image processing algorithm

acquire data → identify control point locations → determine 3D distortion → correct MR images → validate method

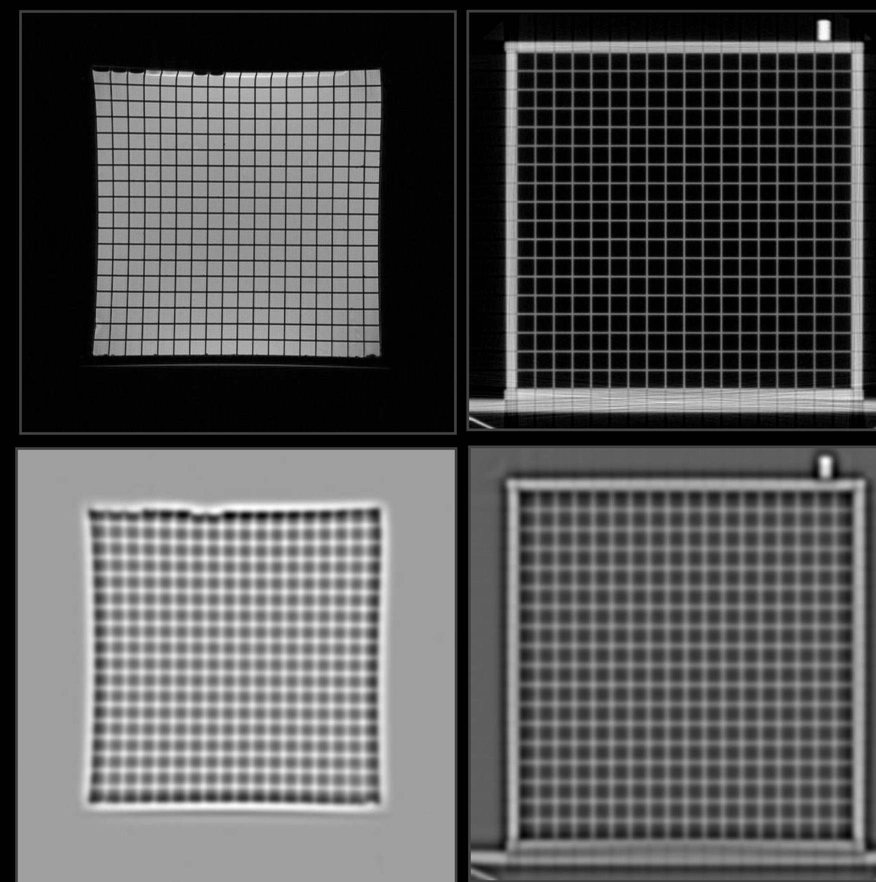
MRI Guidance

# System-related distortions

acquire data → identify control point locations → determine 3D distortion → correct MR images → validate method

- unsharp mask and Gaussian blur
- adaptive thresholding
- 3D Gaussian blurring in x and y
- watershed: identify and analyze each dot
- center of mass: control points coordinates

MR CT



JOURNAL OF APPLIED CLINICAL MEDICAL PHYSICS, VOLUME 11, NUMBER 1, WINTER 2010

**Investigation of a 3D system distortion correction method for MR images**

Teodor Stanescu,[a] Hans-Sonke Jans, Keith Wachowicz, Gino B. Fallone
*Medical Physics, Cross Cancer Institute, Edmonton, AB, Canada*
*teodorst@cancerboard.ab.ca*

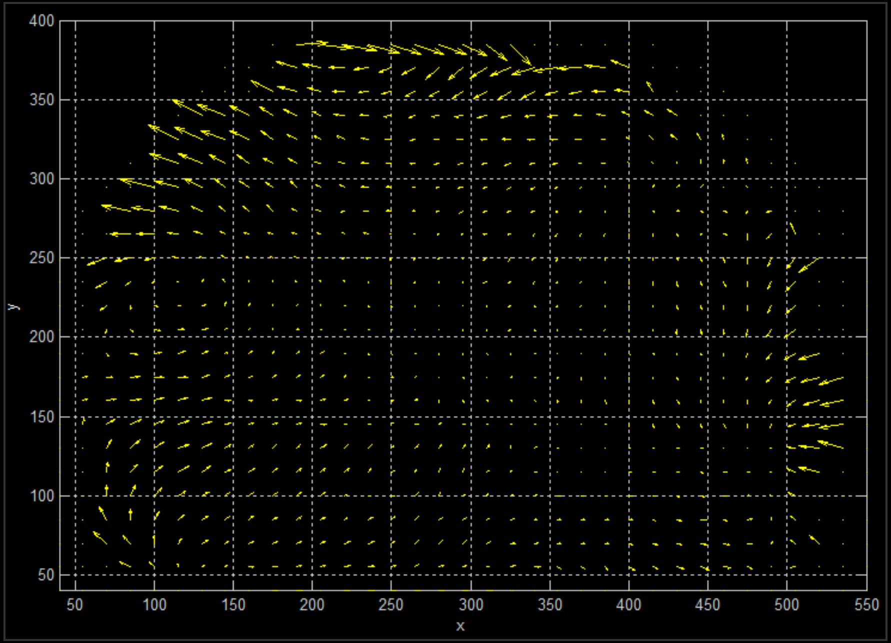
Received 10 October 2008; accepted 14 September 2009

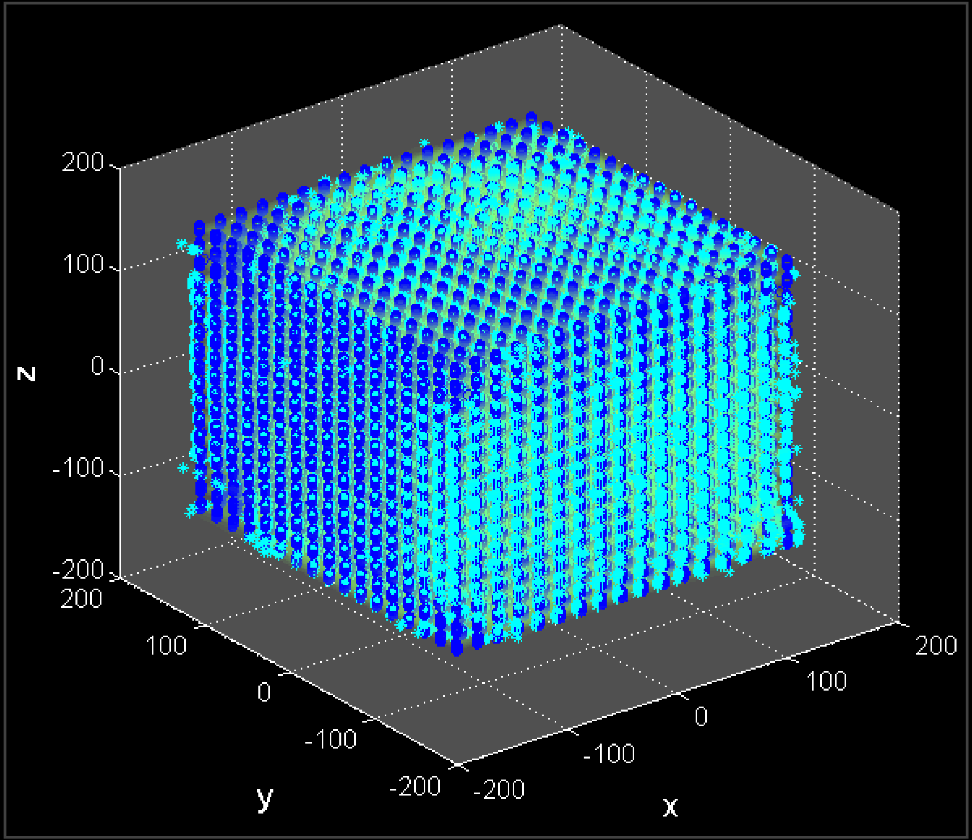
MRI Guidance

# System-related distortions

acquire data → identify control point locations → **determine 3D distortion** → correct MR images → validate method

- register CT+MR control points
- clean data - 3D polynomial fit
- determine 3D distortion field

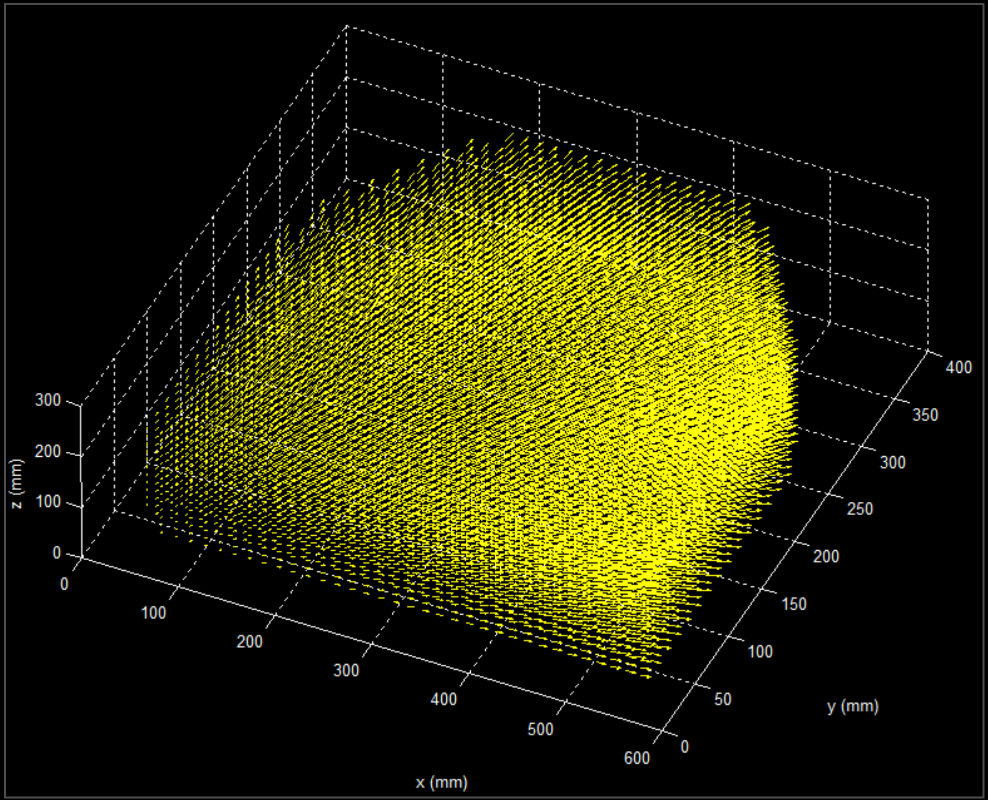


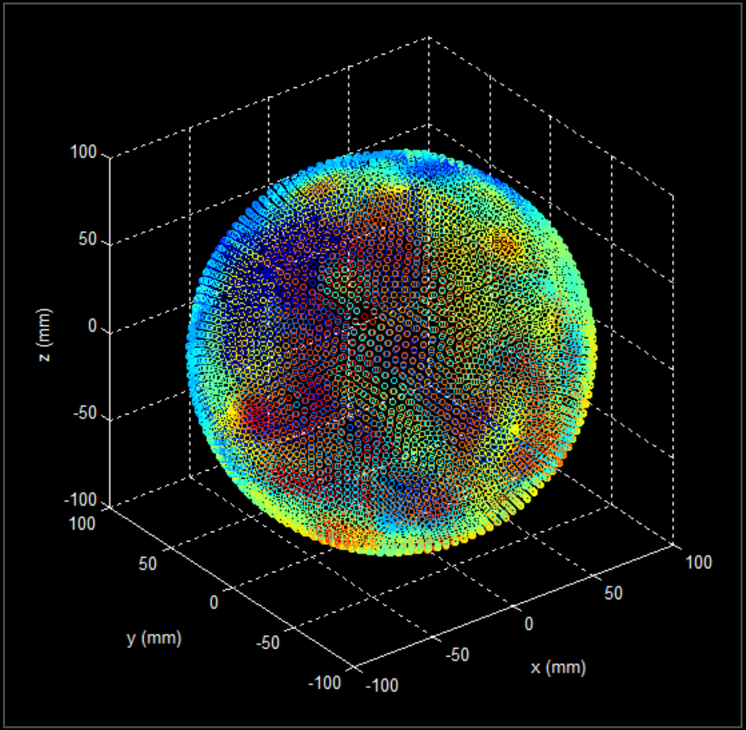



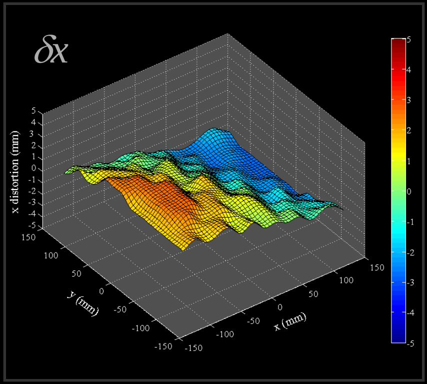
MRI Guidance

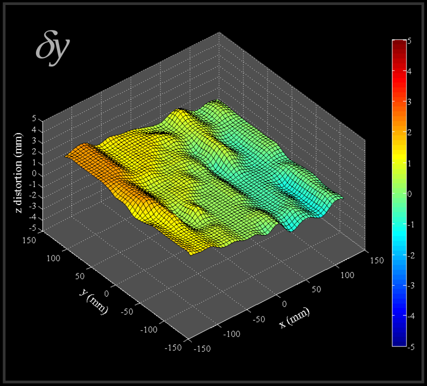
# System-related distortions

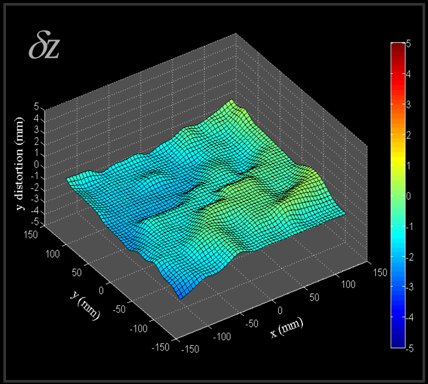
3D distortion field (vectorial)

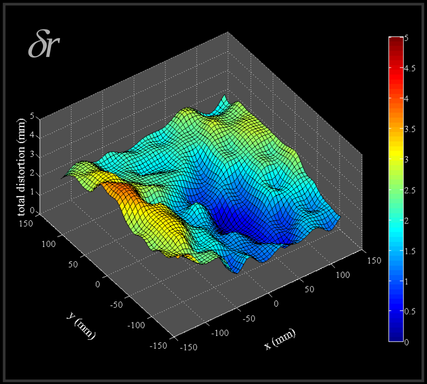


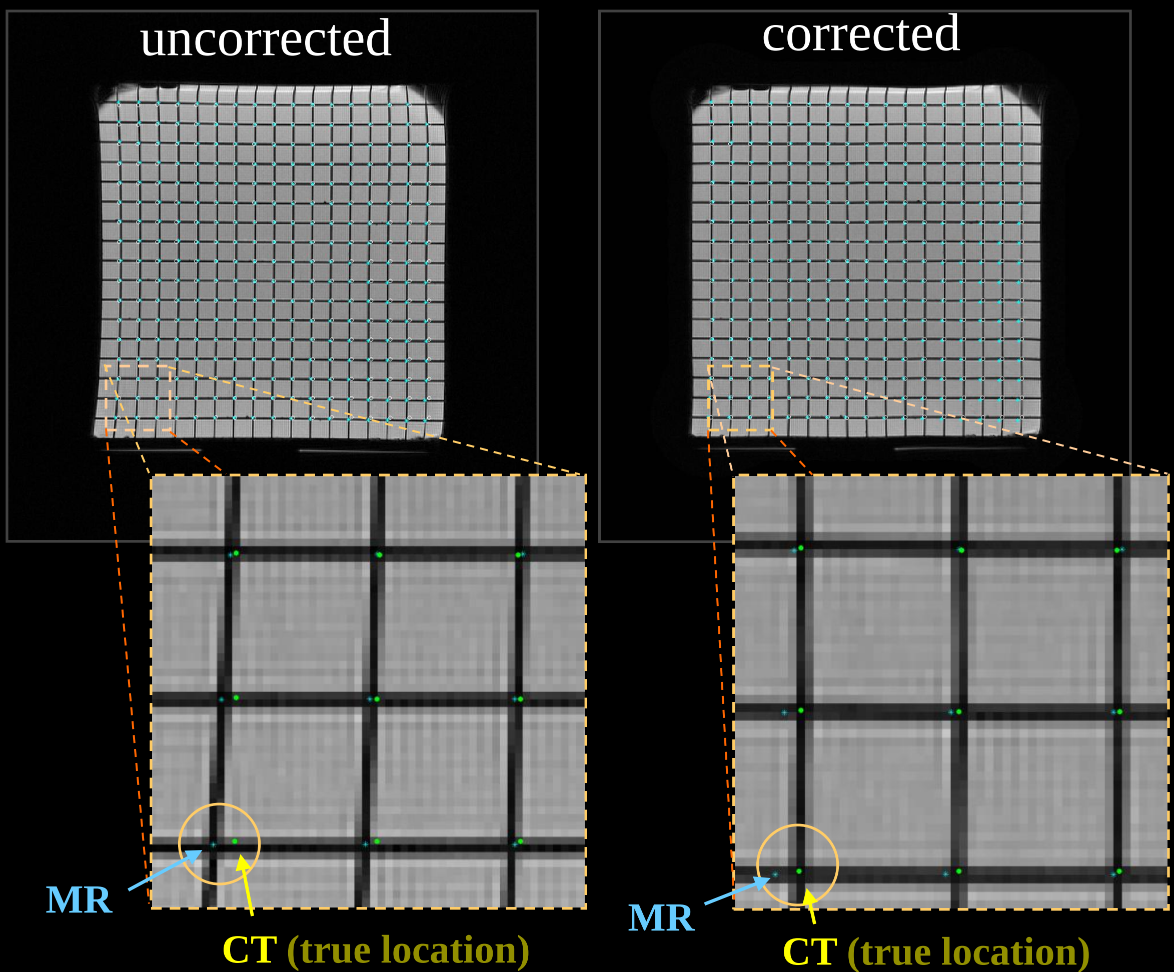



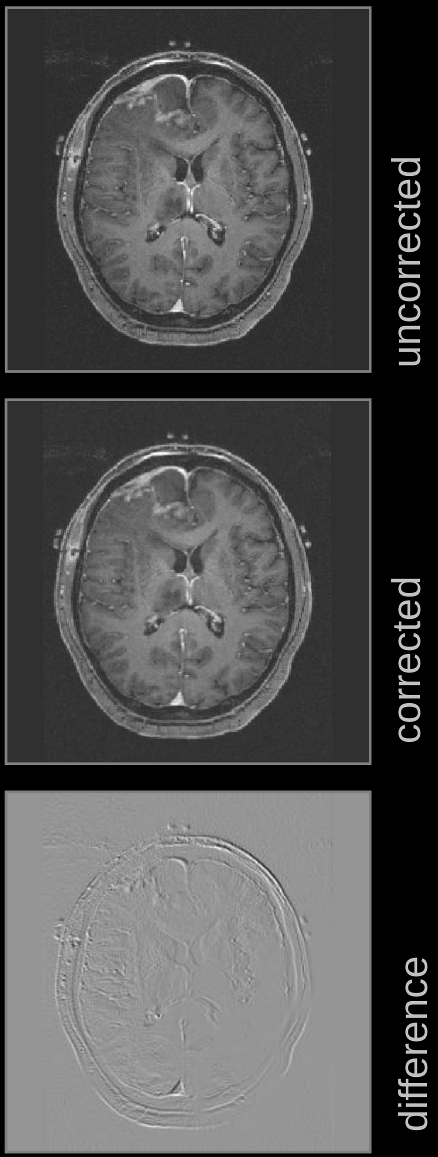



MRI Guidance

# System-related distortions



# System-related distortions

## Spherical harmonics analysis

**A complete distortion correction for MR images: I. Gradient warp correction**

Simon J Doran[1], Liz Charles-Edwards[2], Stefan A Reinsberg[2] and Martin O Leach[2]

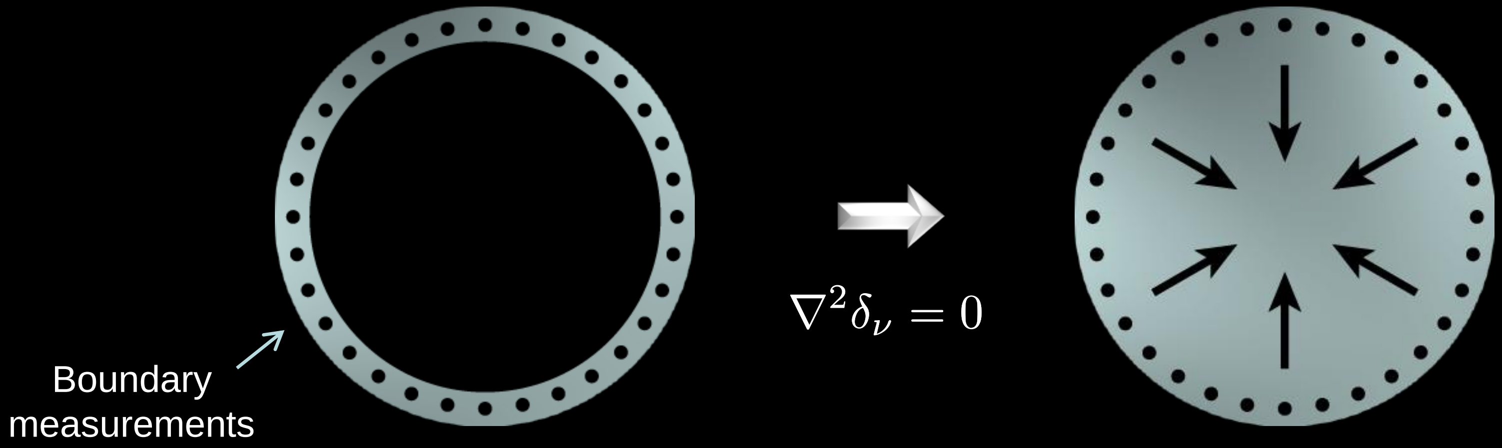
Phys. Med. Biol. **50** (2005) 1343–1361

$$B(r,\theta,\phi) = \sum_{n=0}^{\infty}\sum_{m=0}^{n}\left(\frac{r}{r_0}\right)^n P_{nm}(\cos\theta)[A_{nm}\cos m\phi + B_{nm}\sin m\phi],$$

- *Anm*, *Bnm* are the spherical harmonic coefficients
- Provided by the manufacturer for a certain region of interest
- Example: 29 coeff for Gx and Gy | 7 coeff for Gz

# System-related distortions

## Hybrid technique: harmonics analysis + phantom measurements




- Make use of the harmonic nature of the 3D distortion vector field
- Distortions measured on a volume boundary
- Laplace's equation is solved to reconstruct the full 3D distortion field within the entire VOI (volume of interest)

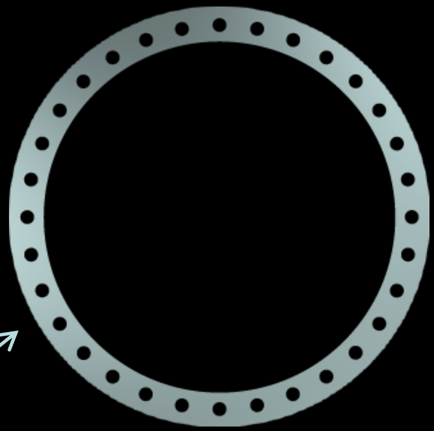
$$\delta_\nu = \sum_{i=1}^{N} c_{i,\nu} \Delta B_i(\vec{r}) \qquad \nu \in \{x, y, z\} \quad \longrightarrow \quad \nabla^2 \vec{B} = 0 \Rightarrow \nabla^2 \vec{\delta}(\vec{r}) = 0$$

Med. Phys. 41 (11), November 2014

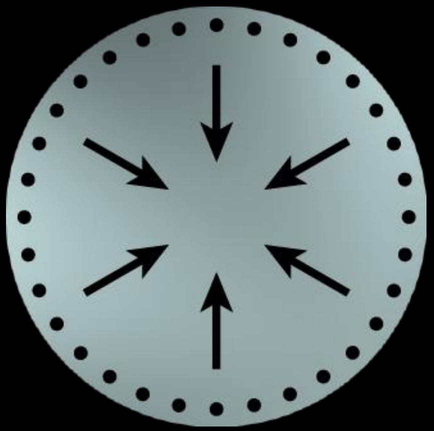
# System-related distortions

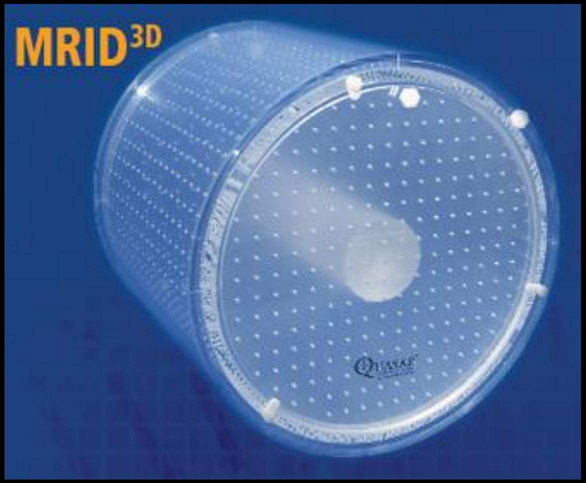
## Hybrid technique: harmonics analysis + phantom measurements

Boundary measurements



$$\nabla^2 \delta_\nu = 0$$





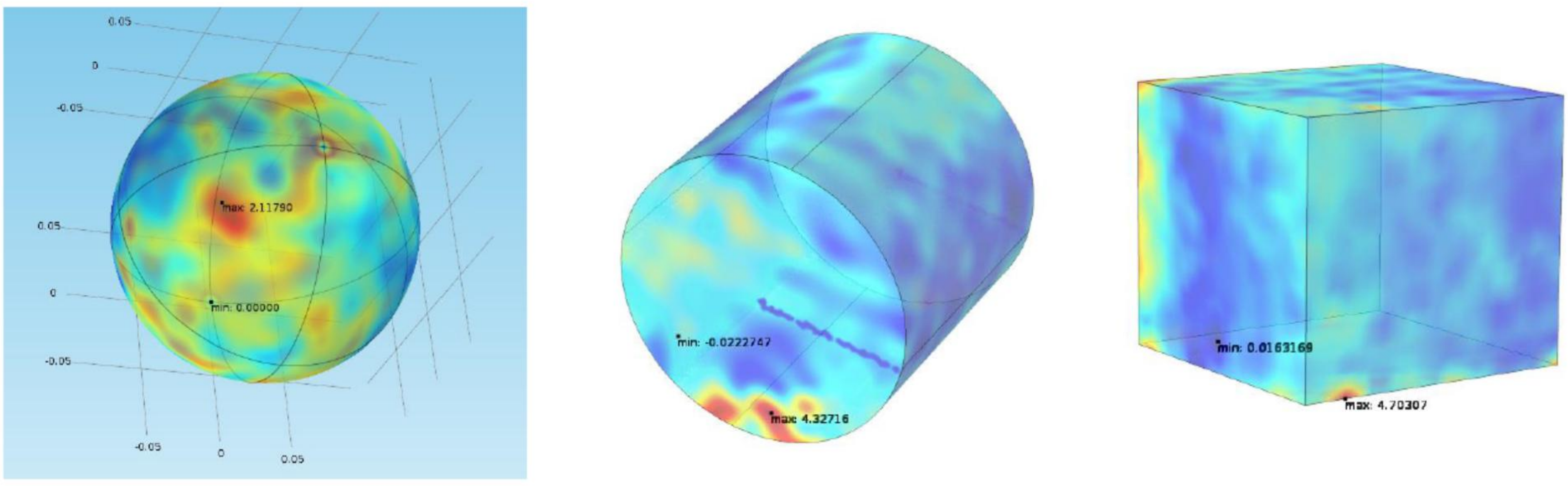

Collaboration with Modus Medical Devices

- Large field 3D distortions
- Harmonic analysis
- 38 diameter, 32 long
- Light weight, hollow, <17 Kg
- Option for inserts

# System-related distortions

## Harmonics analysis can be extended to arbitrary geometries

- Solver validated using reference data from a large FOV grid phantom
- Agreement with reference data: 0.1-0.5% of sampling points
- Validation for arbitrary surfaces ongoing - Workflow
    - Source surface – e.g. cylinder + grid extensions (incomplete MR coverage)
    - Surface parametrization – volume meshing, set Dirichlet BC
    - Solver: solution for entire volume
    - Post-processing




sphere cylinder block

# System-related distortions

## Summary

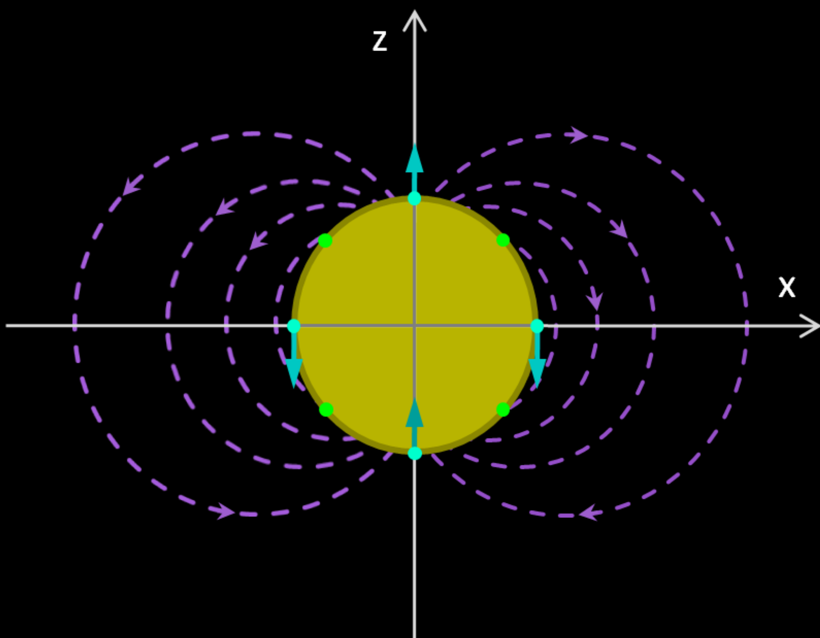
- Manufacturers provide a 1st order correction (2D/3D)
- Detailed quantification depends on clinical applications
  - MR used for diagnostic
  - MR-only planning
- Limited standardization and lack of user friendly solutions

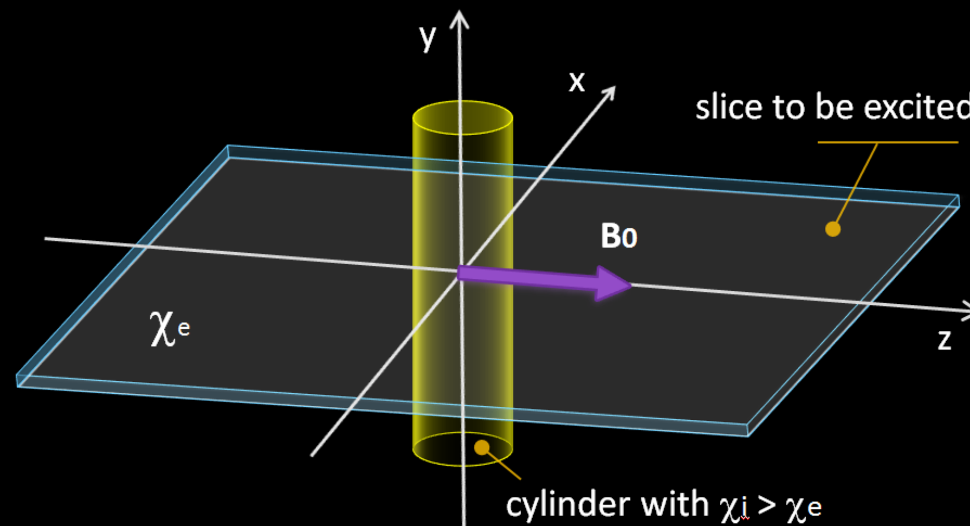
# Patient-induced distortions

## Tissue magnetic susceptibility

**SUSCEPTIBILITY ARTEFACTS IN NMR IMAGING**

K. M. Lüdeke, P. Röschmann and R. Tischler
Philips GmbH Forschungslaboratorium Hamburg, D-2000 Hamburg 54, FRG



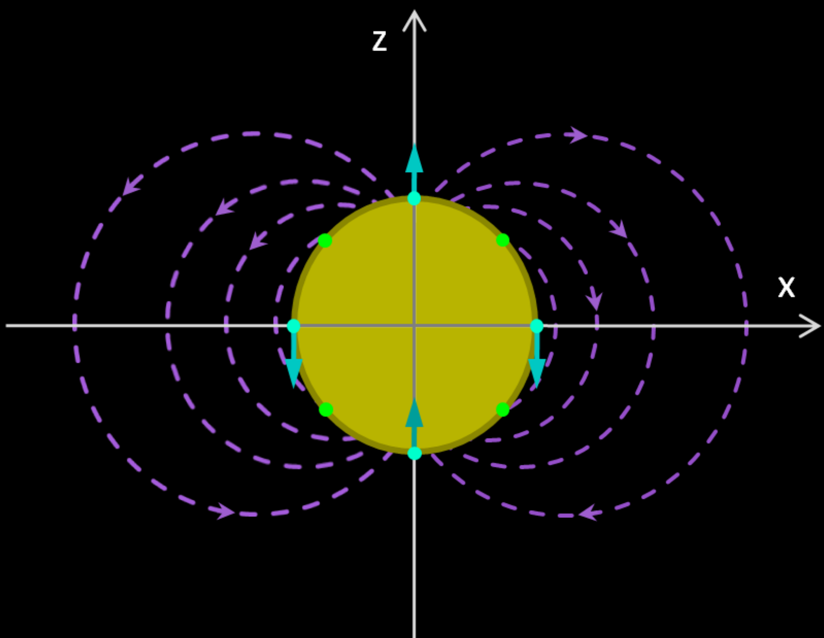



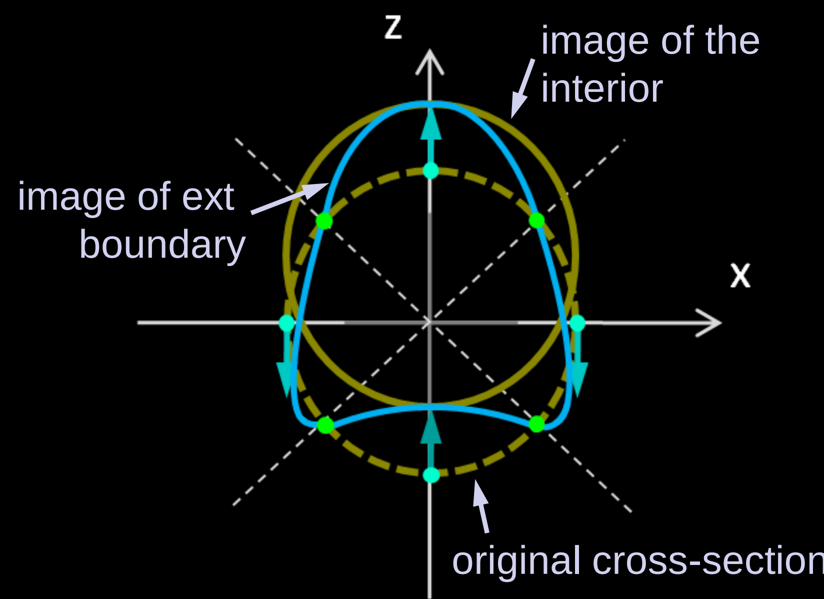

Cylinder geometry: interior and exterior mapped diff
Interior: const field offset, no shape distortion along Gr

Exterior: (∃) inhomogeneous dipole field
\ shape distortions
\ arrows indicate magnitude & direction of warp

# Patient-induced distortions

## Tissue magnetic susceptibility




Cylinder geometry: interior and exterior mapped diff
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Exterior: (∃) inhomogeneous dipole field
\ shape distortions
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Patient-induced distortions

## Methods for quantifying the distortion field:

1. Measurement of B0 field distortion map
   - double-echo GE sequence $\rightarrow$ phase diff of the 2 echoes

2. Correlating at least 2 images of the same sample
   - without calculating or measuring the field

3. Numerical computations of the magnetic field on datasets converted into tissue susceptibility maps

# Patient-induced distortions

## Tissue magnetic susceptibility (~ mm)

**Characterization of tissue magnetic susceptibility-induced distortions for MRIgRT**

**Med. Phys. 39 (12), December 2012**

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*Radiation Medicine Program, Princess Margaret Hospital, 610 University Avenue, Toronto, Ontario M5G 2M9, Canada and Department of Radiation Oncology, University of Toronto, 610 University Avenue, Toronto, Ontario M5G 2M9, Canada*

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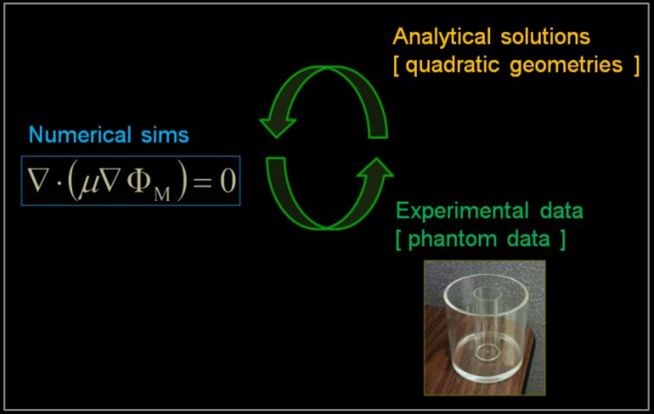
*Radiation Medicine Program, Princess Margaret Hospital, 610 University Avenue, Toronto, Ontario M5G 2M9, Canada and Department of Radiation Oncology, University of Toronto, 610 University Avenue, Toronto, Ontario M5G 2M9, Canada*

validation




workflow - - - - →

CT raw image

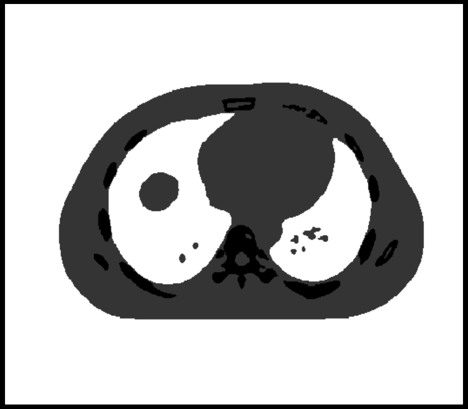
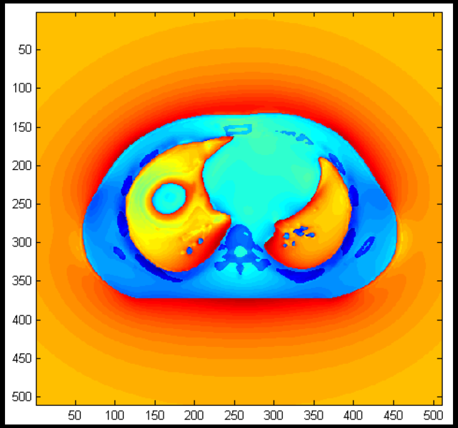
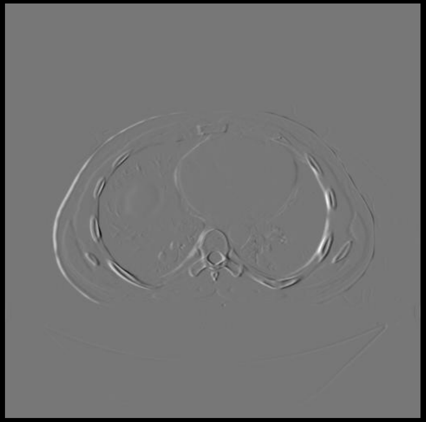


image mask




magnetic field

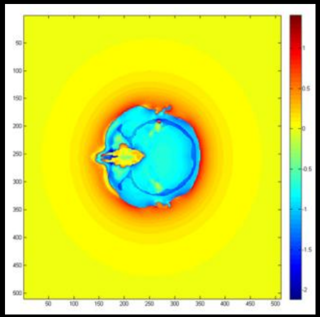
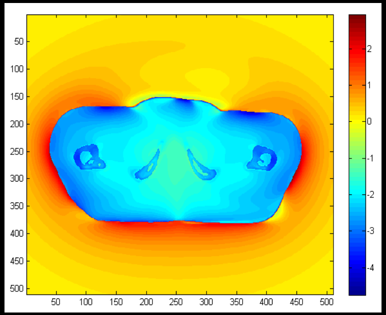
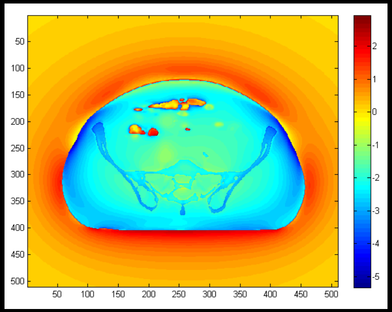
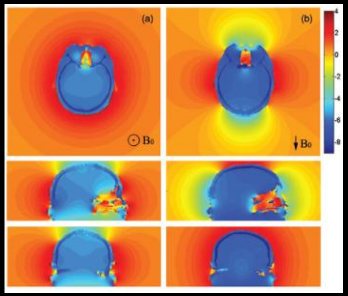
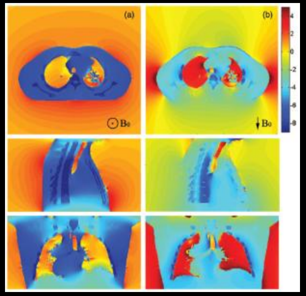


geometric distortion

# Patient-induced distortions

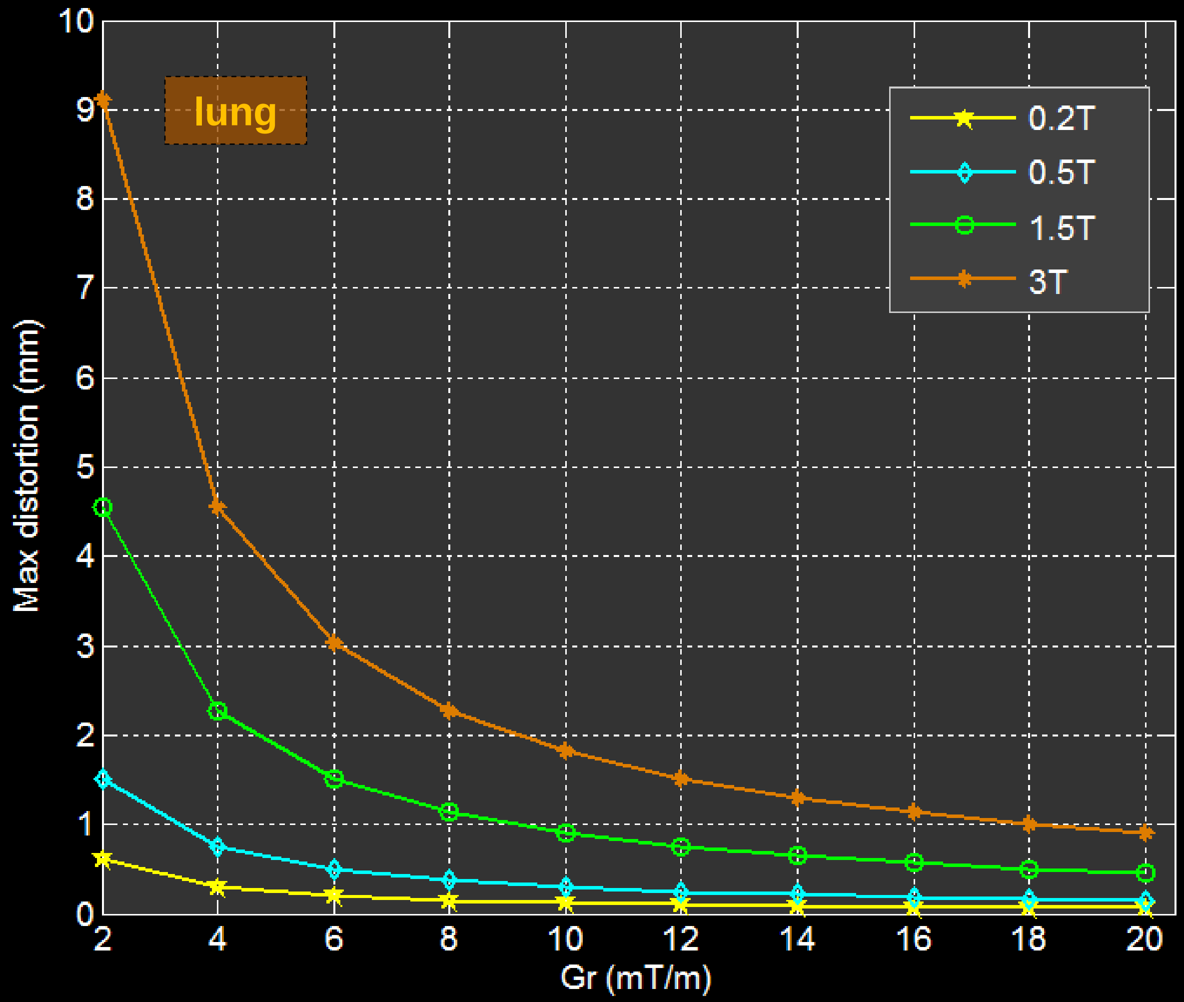
## Tissue magnetic susceptibility (~ mm)

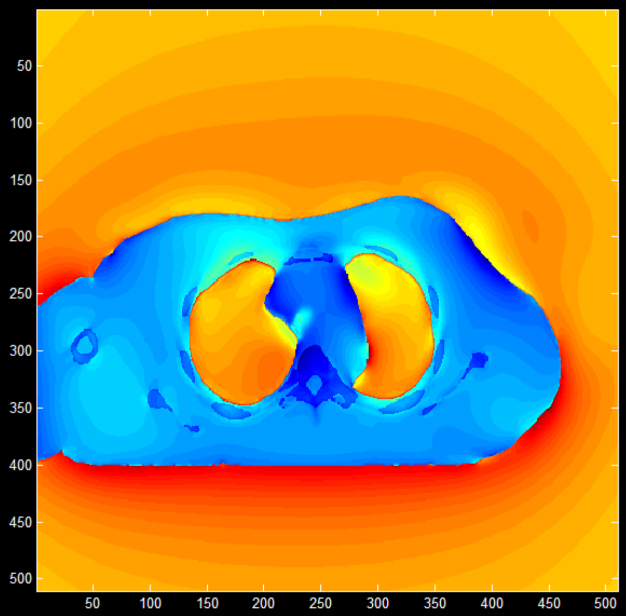
| | | | | | 0.5 T (5 mT/m) | | | 3.0 T (5 mT/m) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Anatomical site | Structure | Max distortion (ppm) | Mean distortion (ppm) | Range of distortion (ppm) | Max distortion (mm) | Mean distortion (mm) | Range of distortion (mm) | Max distortion (mm) | Mean distortion (mm) | Range of distortion (mm) | ppm offset |
| Brain | Body | 5.48 | 0.43 | 9.36 | 0.55 | 0.04 | 0.94 | 3.29 | 0.26 | 5.62 | −5.81 |
| | Bone | 3.36 | 0.25 | 6.37 | 0.34 | 0.03 | 0.64 | 2.02 | 0.15 | 3.82 | |
| | Air cavities | 5.66 | 0.92 | 9.96 | 0.57 | 0.09 | 1.00 | 3.40 | 0.55 | 5.98 | |
| Lung | Body | 2.99 | 0.41 | 5.37 | 0.30 | 0.04 | 0.54 | 1.79 | 0.25 | 3.22 | −6.79 |
| | Bone | 4.96 | 0.64 | 7.71 | 0.50 | 0.06 | 0.77 | 2.98 | 0.38 | 4.63 | |
| | Lung | 5.56 | 0.71 | 8.85 | 0.56 | 0.07 | 0.89 | 3.34 | 0.43 | 5.31 | |
| Prostate | Body | 3.98 | 0.54 | 6.42 | 0.40 | 0.05 | 0.64 | 2.39 | 0.32 | 3.85 | −6.07 |
| (no air pockets) | Bone | 2.48 | 0.41 | 3.03 | 0.25 | 0.04 | 0.30 | 1.49 | 0.25 | 1.82 | |
| Pelvis | Body | 3.91 | 0.46 | 5.91 | 0.39 | 0.05 | 0.59 | 2.35 | 0.28 | 3.55 | −6.12 |
| (air pockets) | Bone | 2.54 | 0.47 | 4.02 | 0.25 | 0.05 | 0.40 | 1.52 | 0.28 | 2.41 | |
| | Air pockets | 4.85 | 0.68 | 7.27 | 0.49 | 0.07 | 0.73 | 2.91 | 0.41 | 4.36 | |

# Patient-induced distortions

Tissue magnetic susceptibility (~ mm)




$$\Delta r = ppm \frac{B_0[T]}{Gr[mT/m]}$$

# Organ / target motion: lung

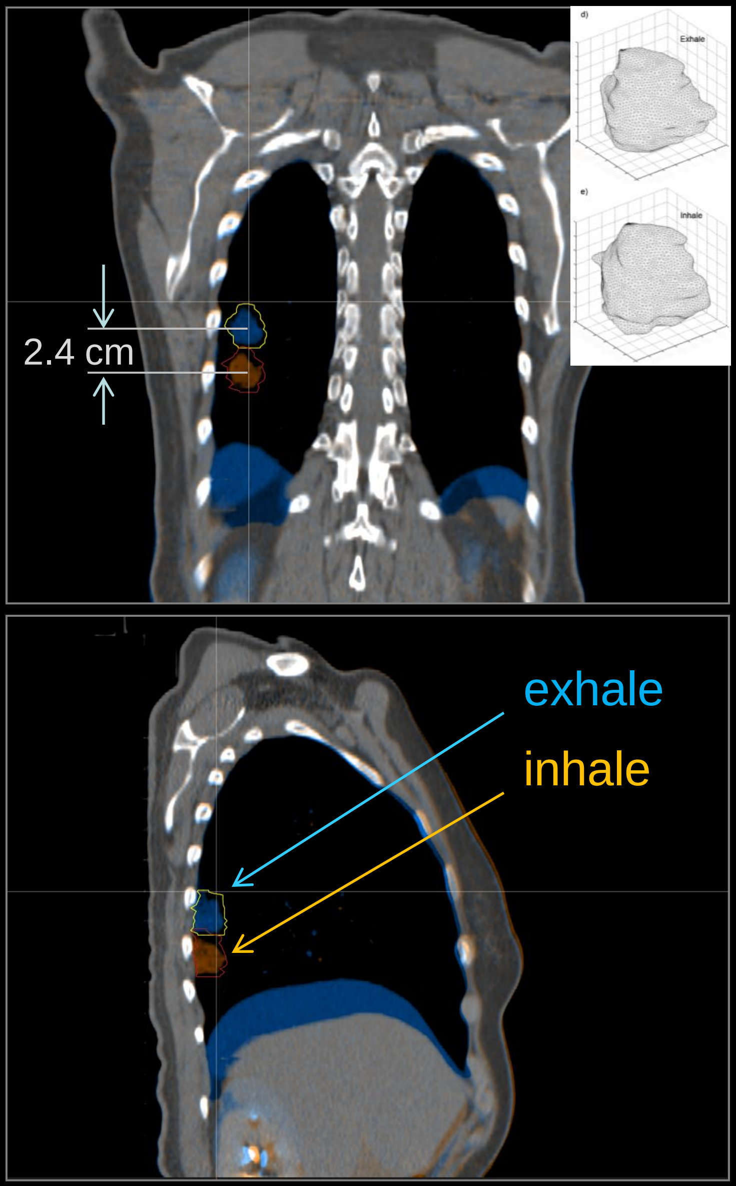
Case study: lung patient, 10 bins 4D CT

**4D distortion field associated with organ motion:**
- 2 independent steps

1. System distortions
- register anatomy to 3D field
- track dist as local target/organs move
- static field - measured with phantom

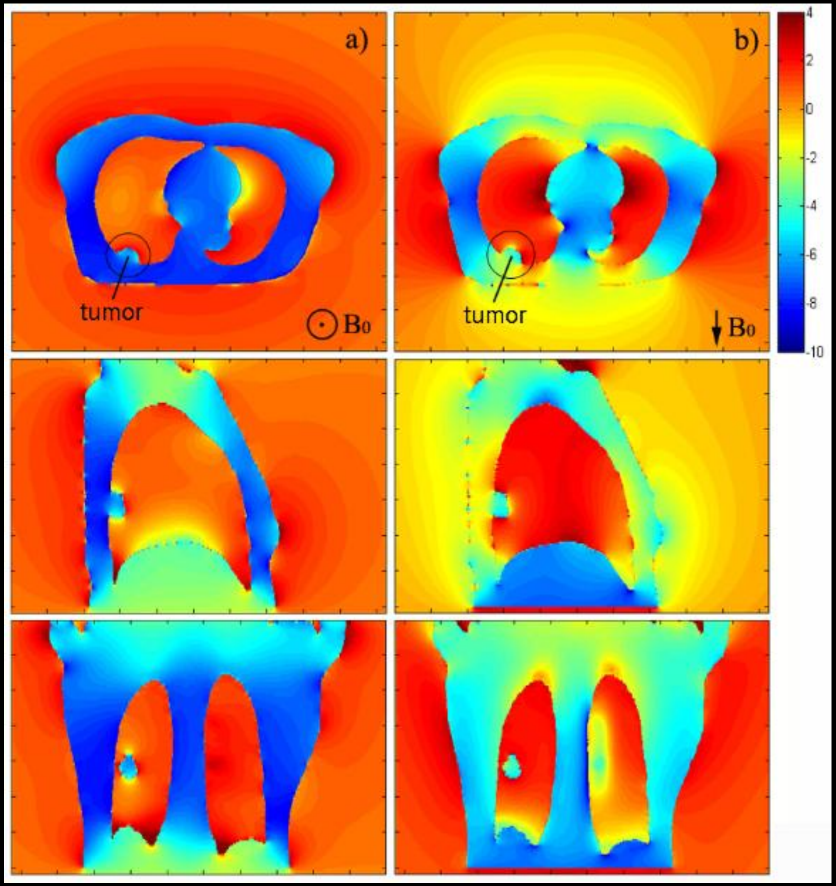
2. Magnetic susceptibility
  - numerical methods
  - anatomy specific
  - dynamic distortion field

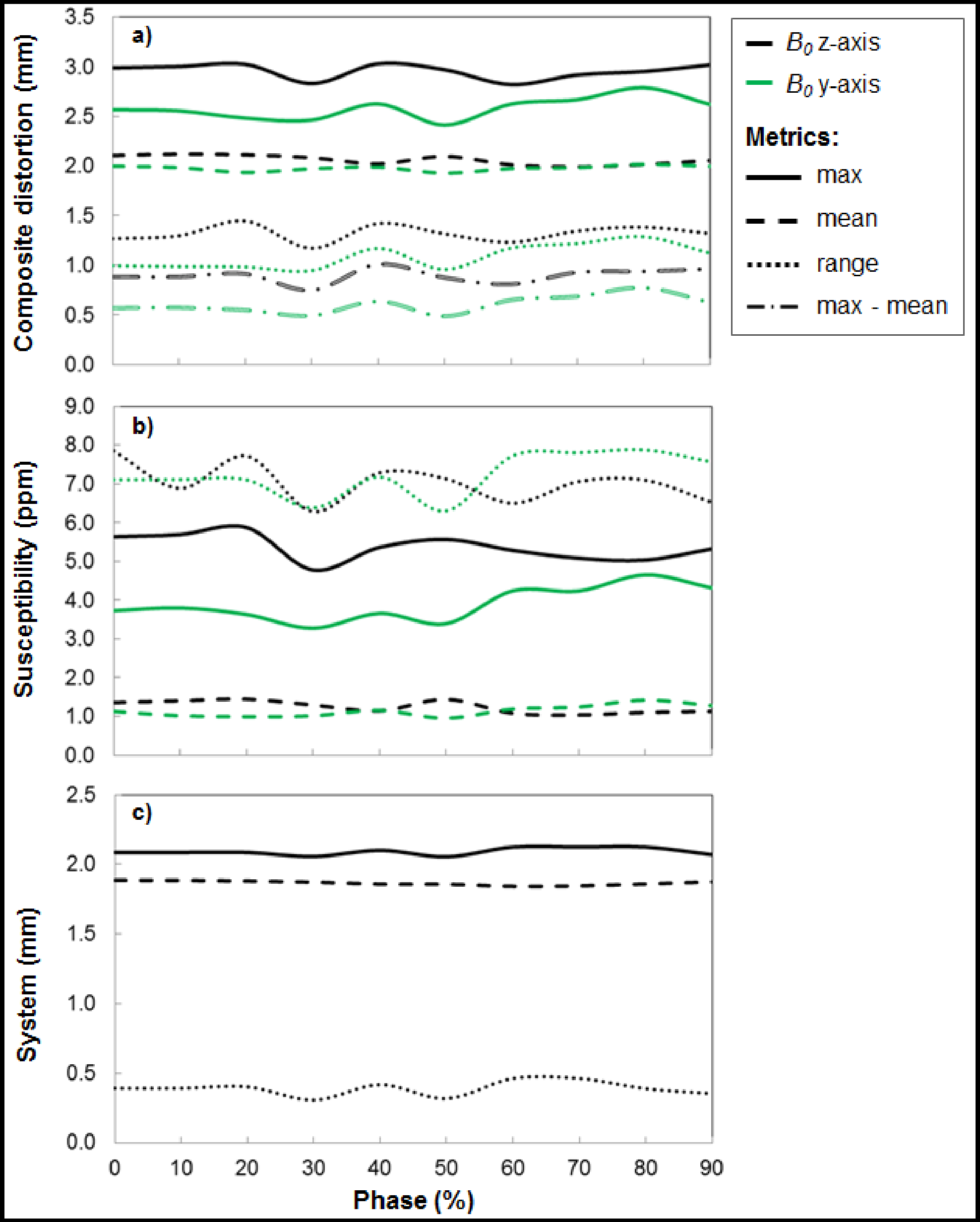
**Total:** combine contributions from 1 & 2



# Organ / target motion: lung

MRI Guidance



# Organ / target motion: lung

**B0 z-axis**

| | | Scanner-related field | $\chi$-induced | $\chi$-induced field | | | Composite Field | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 0.35 T | 0.5 T | 1.5 T | 0.35 T | 0.5 T | 1.5 T |
| | | [mm] | [ppm] | [mm] | [mm] | [mm] | [mm] | [mm] | [mm] |
| Exhale | max | 2.13 | 5.29 | 0.37 | 0.53 | 1.59 | 2.11 | 2.11 | 2.82 |
| | mean | 1.84 | 1.08 | 0.08 | 0.11 | 0.32 | 1.87 | 1.89 | 2.01 |
| | range | 0.46 | 6.50 | 0.46 | 0.65 | 1.95 | 0.45 | 0.46 | 1.23 |
| Inhale | max | 2.09 | 5.64 | 0.39 | 0.56 | 1.69 | 2.20 | 2.29 | 2.99 |
| | mean | 1.89 | 1.36 | 0.10 | 0.14 | 0.41 | 1.92 | 1.94 | 2.10 |
| | range | 0.40 | 7.85 | 0.55 | 0.79 | 2.36 | 0.50 | 0.58 | 1.27 |

**B0 y-axis**

| | | Scanner-related field | $\chi$-induced | $\chi$-induced field | | | Composite Field | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 0.35 T | 0.5 T | 1.5 T | 0.35 T | 0.5 T | 1.5 T |
| | | [mm] | [ppm] | [mm] | [mm] | [mm] | [mm] | [mm] | [mm] |
| Exhale | max | 2.13 | 4.24 | 0.30 | 0.42 | 1.27 | 2.15 | 2.18 | 2.62 |
| | mean | 1.84 | 1.19 | 0.08 | 0.12 | 0.36 | 1.86 | 1.87 | 1.97 |
| | range | 0.47 | 7.72 | 0.54 | 0.77 | 2.32 | 0.49 | 0.57 | 1.17 |
| Inhale | max | 2.09 | 3.73 | 0.26 | 0.37 | 1.12 | 2.08 | 2.11 | 2.57 |
| | mean | 1.89 | 1.13 | 0.08 | 0.11 | 0.34 | 1.90 | 1.91 | 2.00 |
| | range | 0.40 | 7.11 | 0.50 | 0.71 | 2.13 | 0.39 | 0.43 | 0.99 |

## MR data for RT planning

**Issue:** MR images suffer of intrinsic distortions → affect geometric accuracy

**Strategies:** **S**everal methods proposed claiming adequate accuracy

**Limitations and Challenges:**

- Vendor and application specific
- Large FOVs still posing practical issues for distortion field mapping
- Susceptibility-induced distortions minimized via protocol optimization
- Real-time correction limited
- Streamlining and clinical integration

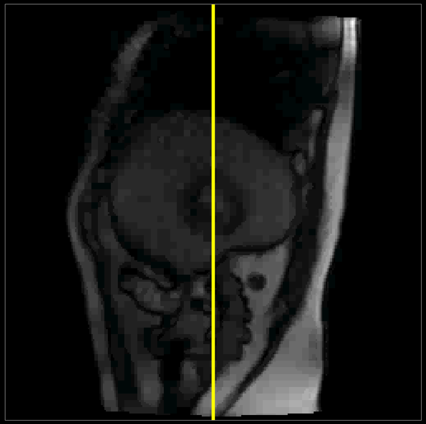
## MR data for Treatment Delivery - Patient setup verification & Tracking/Gating

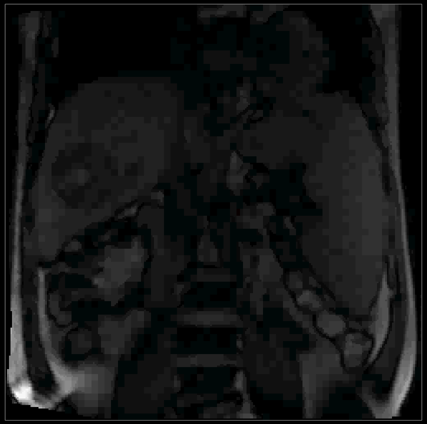
**Aim:** Reliable quantification and validation of methods used for organ motion assessment (real-time or retrospective data availability)

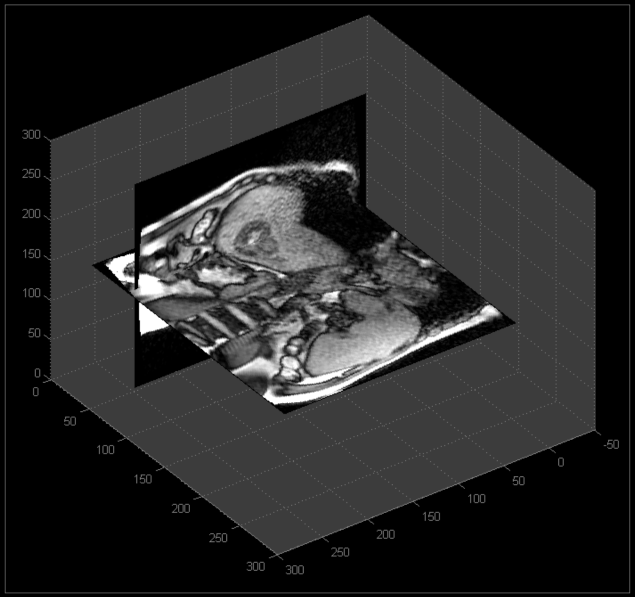
- **Real-time imaging:**
  - 1D / 2D readily available, platform specific
  - 3D $\rightarrow$ 4D (3D+time): most techniques under development
- **Retrospective 4D image data binning and image reconstruction**
  - Available, implementation is vendor specific
  - Growing literature: 2D $\rightarrow$ 4D, 3D $\rightarrow$ 4D

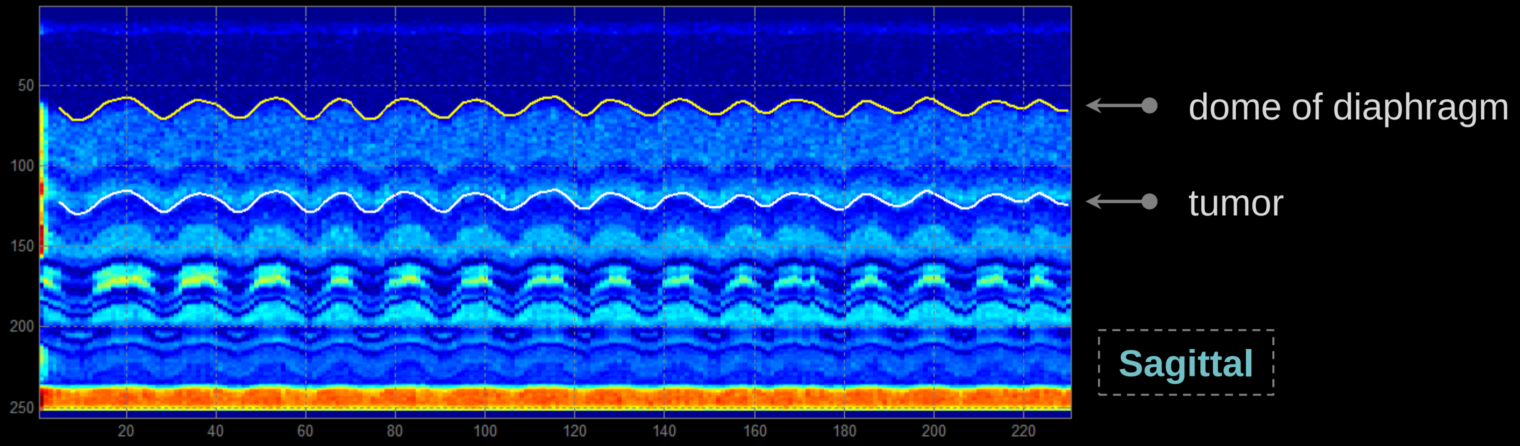
# 4D MRI Retrospective - 2D → 4D

## 2-plane sync: motion info





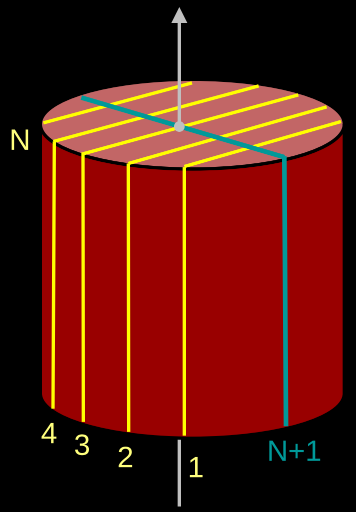


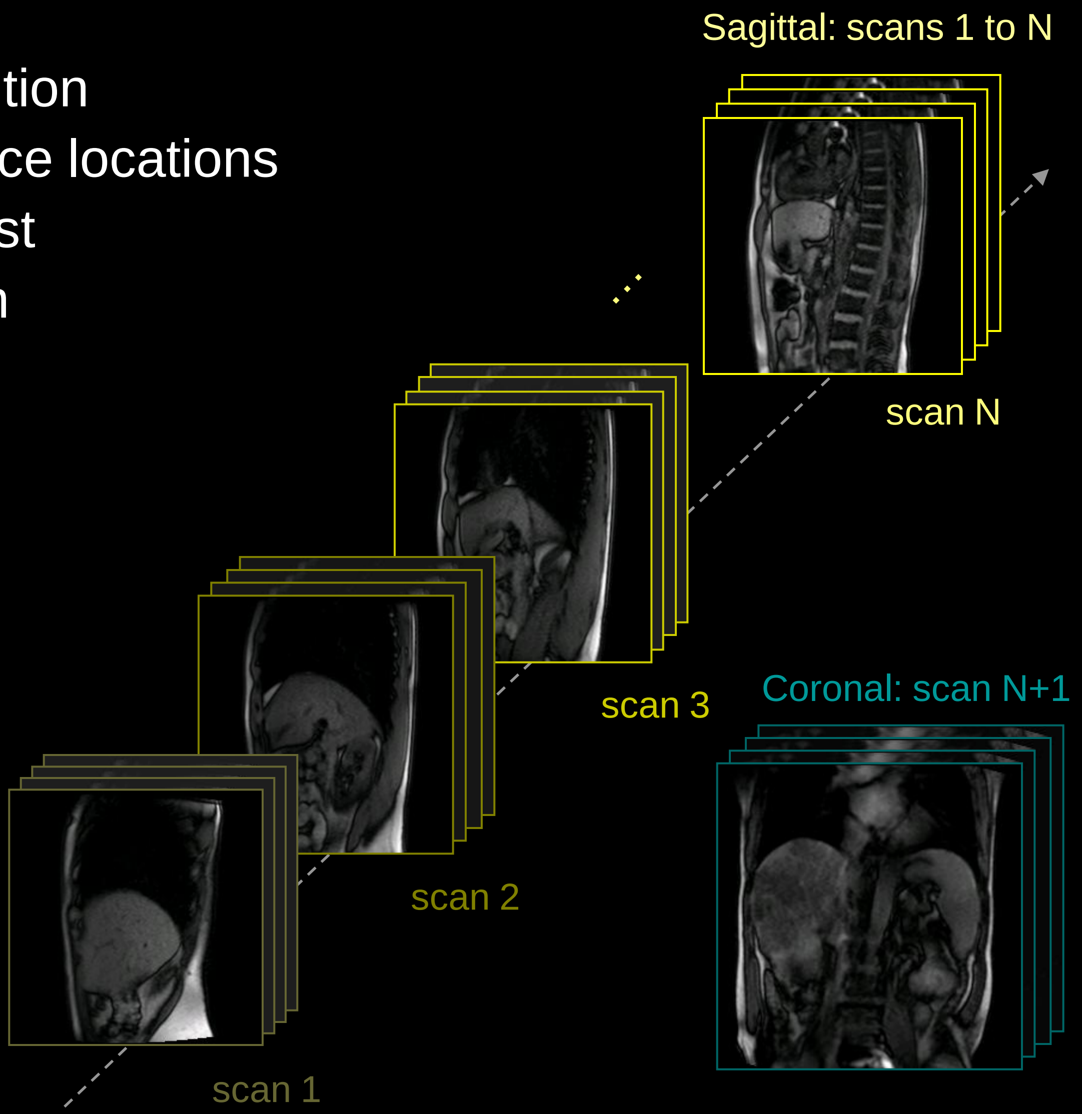



## 4D MRI Retrospective - 2D → 4D

### Data acquisition

- 2D cine sagittal acquisition
- Multiple subsequent slice locations
- Cover volume of interest
- Additional coronal scan

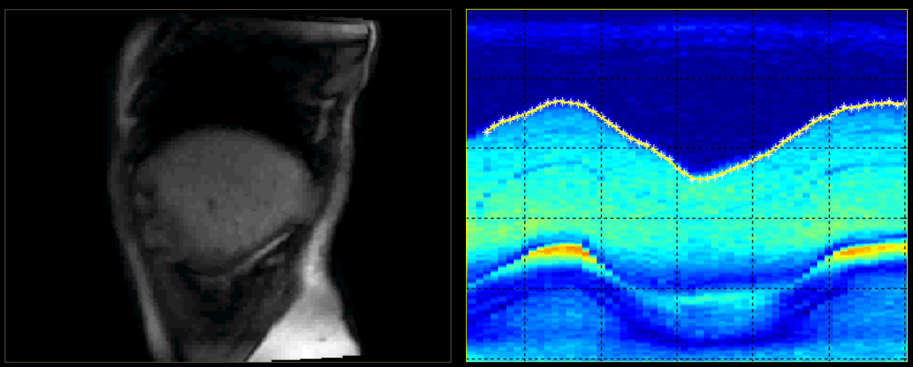


# 4D MRI Retrospective - 2D → 4D

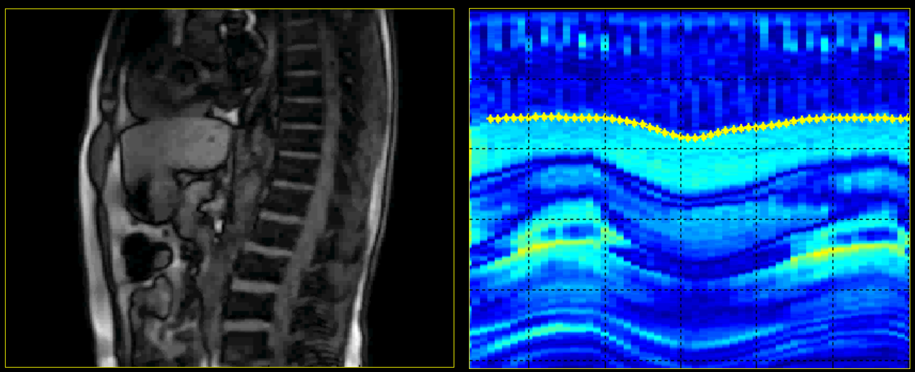
## Organ motion curves & 4D data bining

scan 1

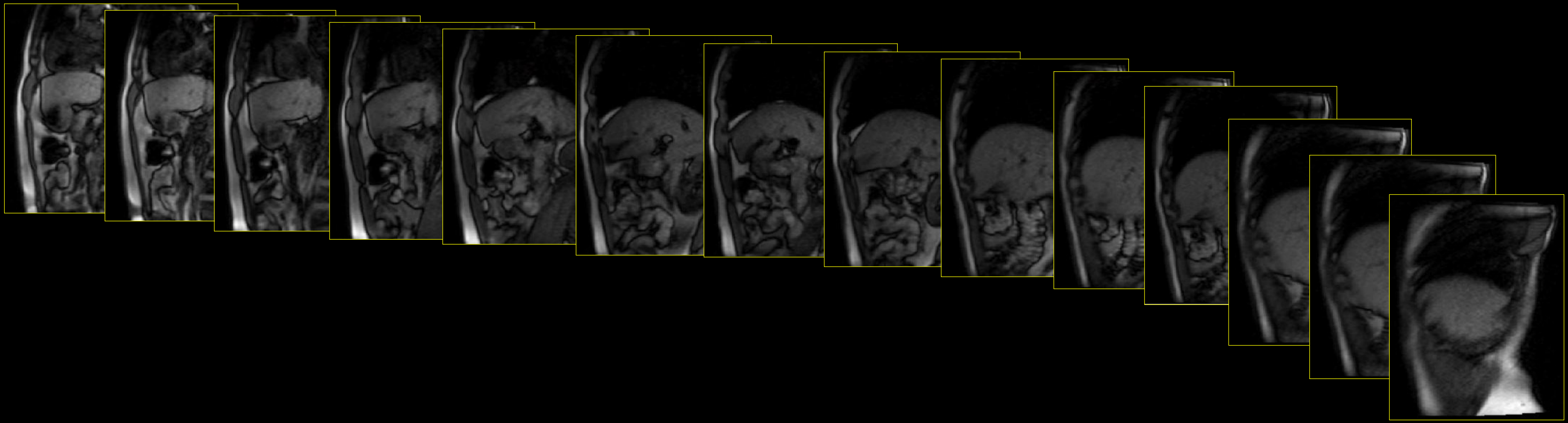


…

scan 14



## Exhale phase – 3D volume, slice-by-slice



# 4D MRI Retrospective - 3D → 4D

- 3D fast acquisition with 4D image data sorting and reconstruction
- Similarity with 4D CBCT → potential solution for motion quantification

**Strategies:**

- Breathhold + multiple 3D acquisitions (< 15s) at diff respiratory phases
- Free breathing - Continuous acquisition (radial sampling) + post processing

## 4D MRI Retrospective - 3D → 4D

- 3D fast acquisition with 4D image data sorting and reconstruction
- Similarity with 4D CBCT → potential solution for motion quantification

**Strategies:**

- Breathhold + multiple 3D acquisitions (< 15s) at diff respiratory phases
- Free breathing - Continuous acquisition (radial sampling) + post processing

## 4D MRI Dynamic

**Strategies:**

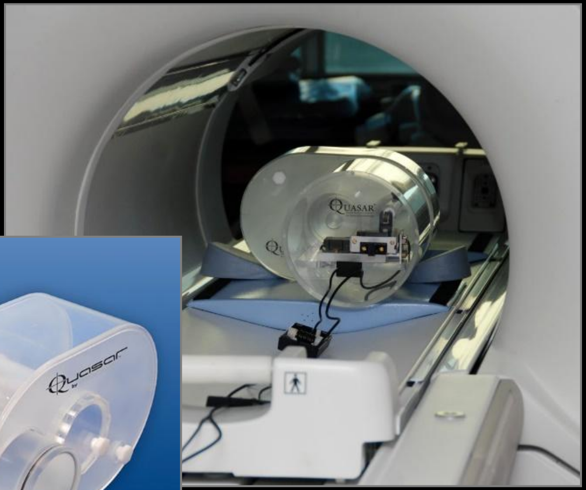
- Free breathing - Multiple 3D scans with ~s time sampling, low image resolution
- Sparse/parallel imaging 3D acquisitions, good temporal sampling (?)

# QC of motion sequences: 2D/4D

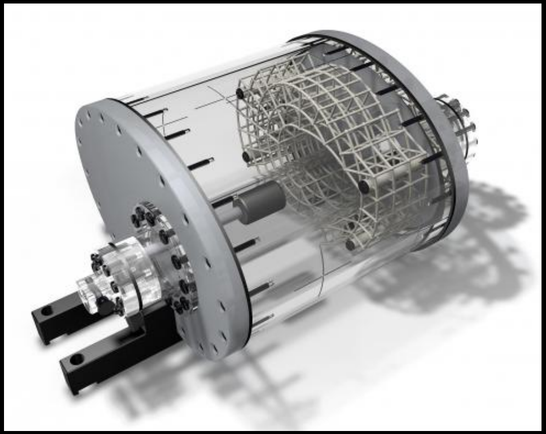

*Motion Stage*

- Accuracy in reaching a fixed position: 0.1 mm
- Maximum NRMSE for dynamic motion with frequency < 1 Hz: 6.0%
- Max speed: > 30 mm/sec
- Max force: ~> 20 N
- Max phantom weight/load: 6 kg
- Dimensions: 134 mm W X 72 mm H (90 mm with phantom adapter) X 287 mm L
- Carriage: 102 mm W X 95 mm L
- Range of motion: 50 mm (2.0")

ViTAL BIOMEDICAL TECHNOLOGIES

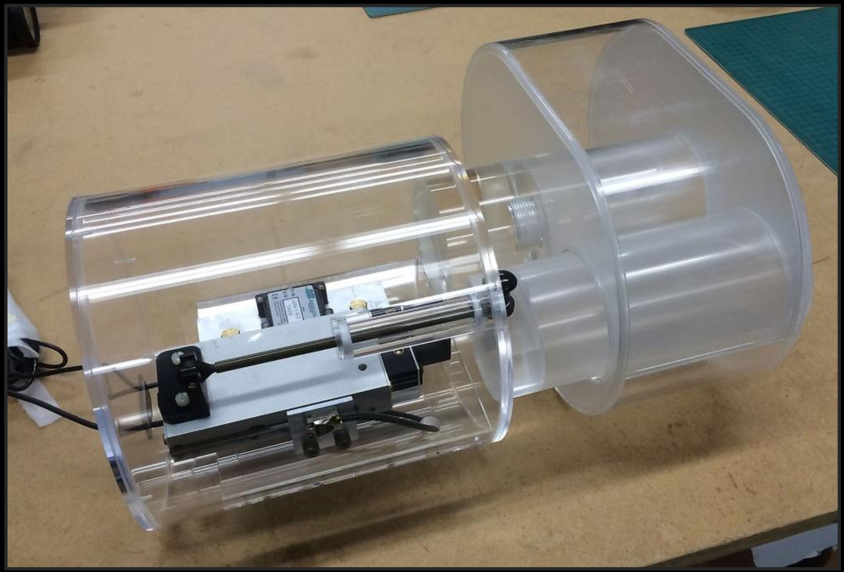



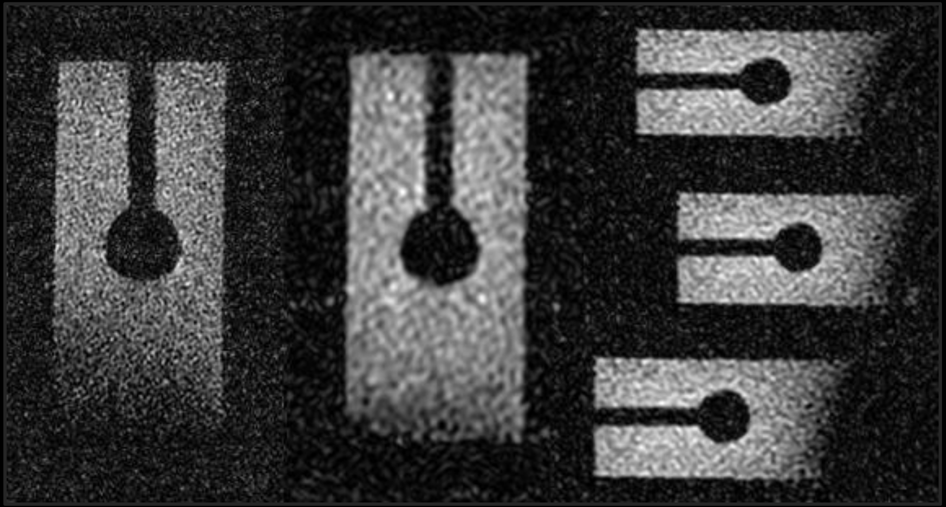
modusQA

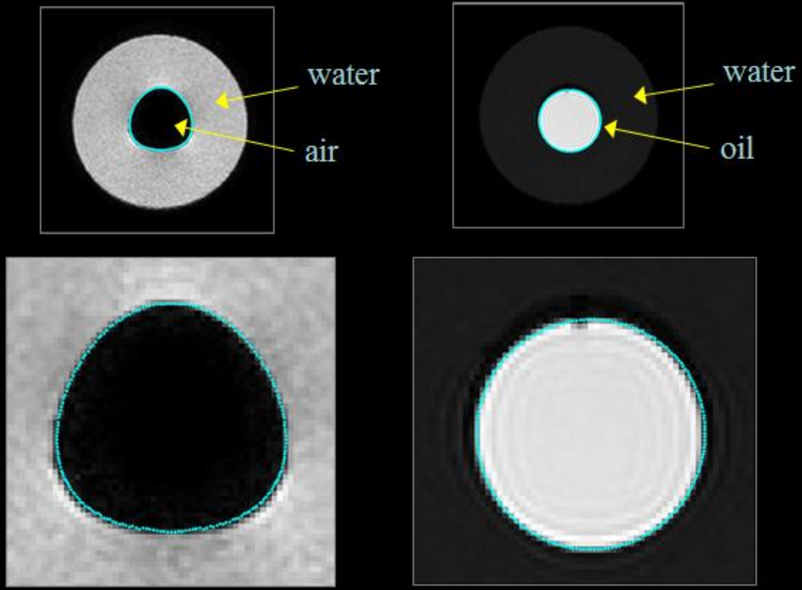


CIRS Tissue Simulation & Phantom Technology

# Phantom data analysis



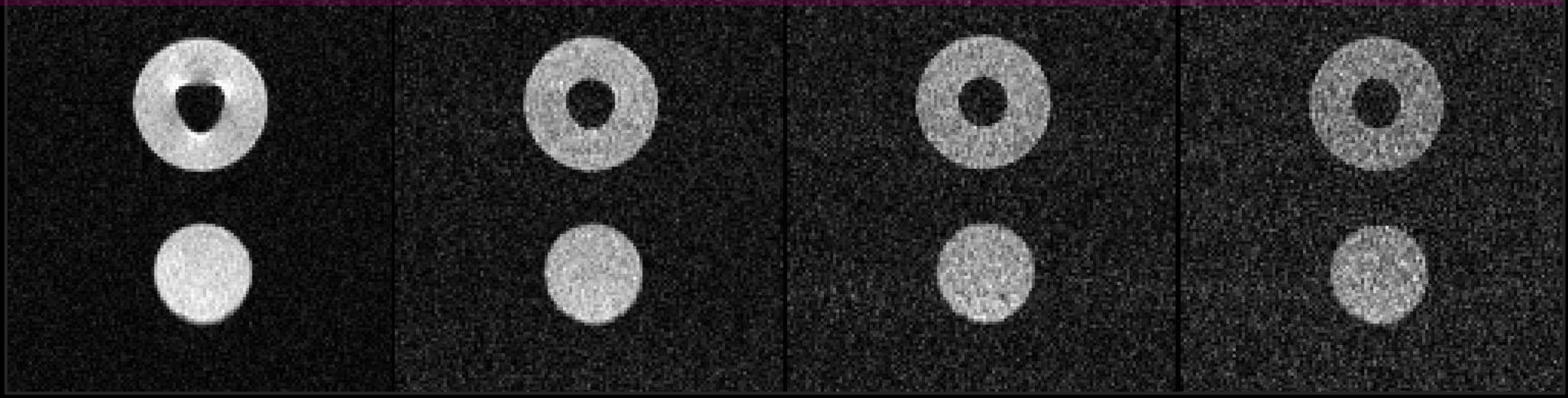





Prototype provided by Modus Medical Devices

# Phantom data analysis

| BW (Hz/p) | 130 | 401 | 694 | 1420 |
|---|---|---|---|---|



| | | | | |
|---|---|---|---|---|
| SNR (%) | 100 | 53 | 41 | 26 |
| Time (s) | 1.6 | 0.9 | 0.7 | 0.5 |

→

Increased BW
Decreased SNR
Decreased Susceptibility effects → better geometric accuracy
Decreased acquisition time/frame → faster imaging

**TurboFLASH** - 1.9x 1.9 x 8 mm | FOV 300 | min TE/TR

# Phantom data analysis

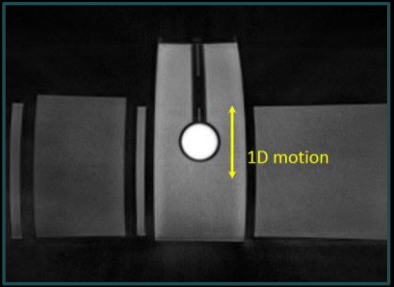
**RadialVIBE:**

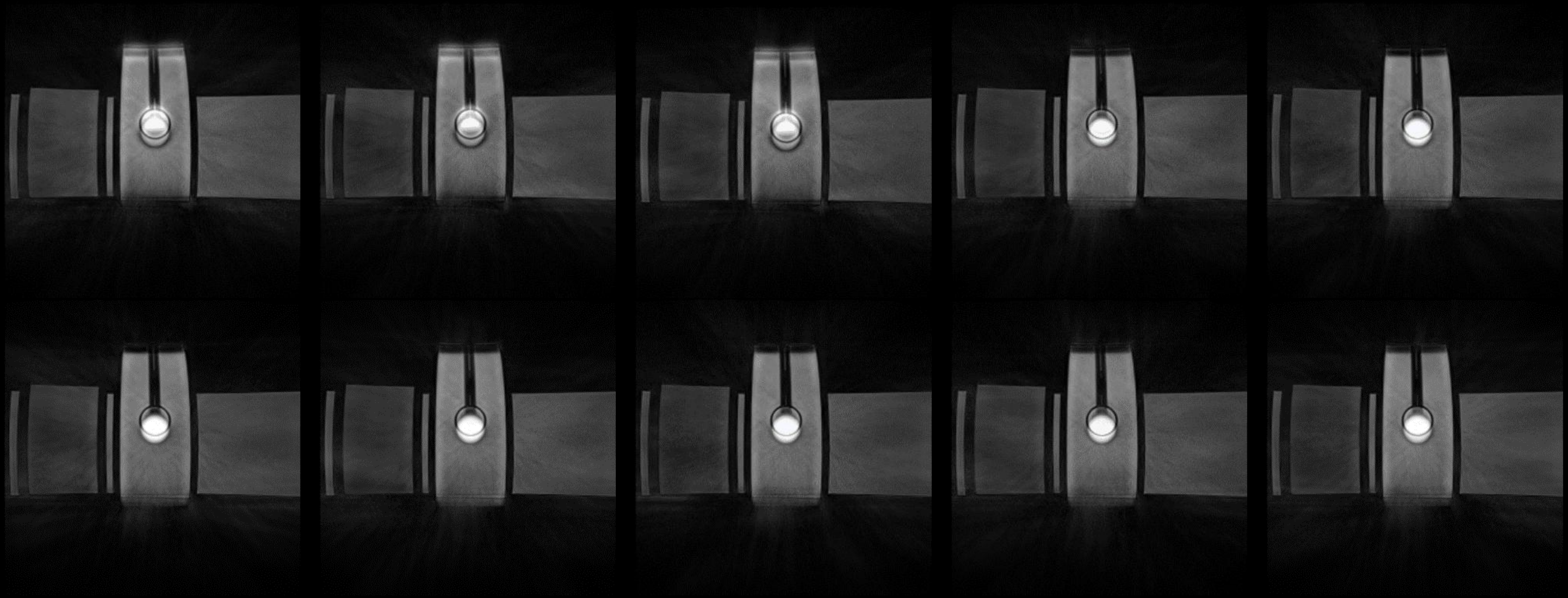
FOV: 310x310

Voxel resolution 1.3x.1.3x3.0

Mid/High BW

View sharing mode: golden angle, total acquisition time < 1 min



## MR data for Treatment Delivery - Patient setup verification & Tracking/Gating

**Aim:** Reliable quantification and validation of methods used for organ motion assessment (real-time or retrospective data availability)

**Strategies:** 1D / 2D available, several proposed 4D techniques

**Limitations and Challenges:**

- Vendor implementation and application specific
- 4D motion - quantification of distortions still to be investigated
- Motion phantoms & QA methods still to be developed
- Motion data integration in clinical workflows

# Which is the main contributor to the MR image distortion field for RT applications?

| | | |
|---|---|---|
| 27% | 1. | MR main field (B0) inhomogeneity |
| 6% | 2. | Chemical shift |
| 8% | 3. | Tissue susceptibility |
| 32% | 4. | Imaging gradient non-linearities |
| 27% | 5. | Motion |

# Which is the main contributor to the MR image distortion field for RT applications?

Answer: Imaging gradient non-linearities

Ref: Doran et al, Phys Med Biol 50, 1343-1361, 2005

# Topics for MR-guided RT system Commissioning & QC

System performance monitoring

- Open-source software for semi/auto-QC monitoring
  - ACR guidelines, AAPM, NEMA, etc.

MR data for RT planning and in-room guidance

- MR image distortion: system/scanner-related
- MR image distortion: susceptibility-induced
- Quantification of motion

MR-guided systems: design specific

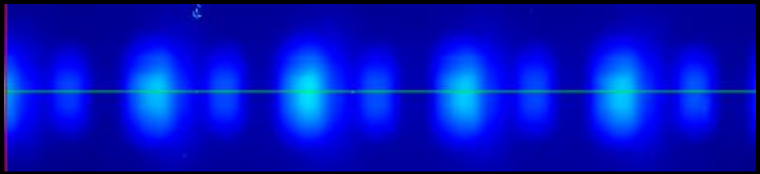
- MR-radiation source system: iso-to-iso registration
- RF noise
- Magnetic field coupling

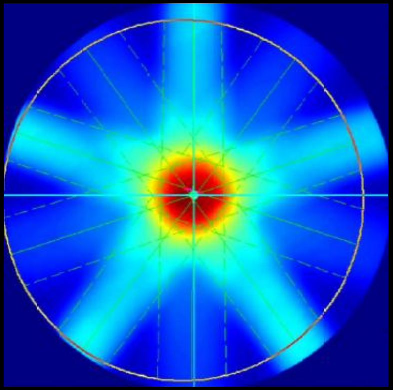
Reporting

- Data base record: in-house, commercial, cloud solutions

# MR-to-Radiation source isocenter registration

- Cylindrical phantom filled with water
- Scribe lines for alignment to lasers
- Circular film between two halves of phantom
- Wrap-around film strip
- Once MLC accuracy is established, imaging this phantom provides information about MR-RT isocenter alignment
- Once RT isocenter is established, MR isocenter coordinate shift is implemented in software

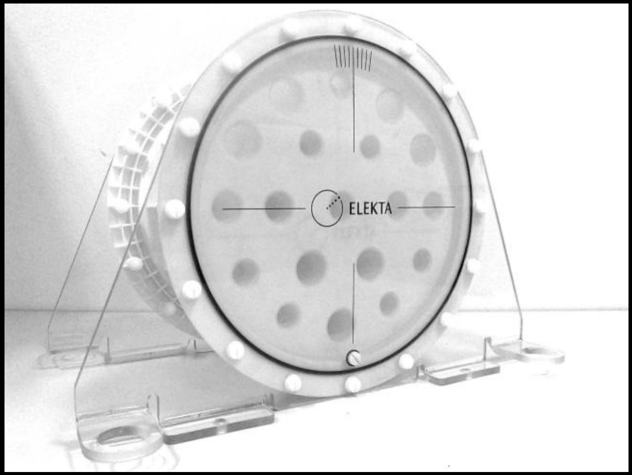




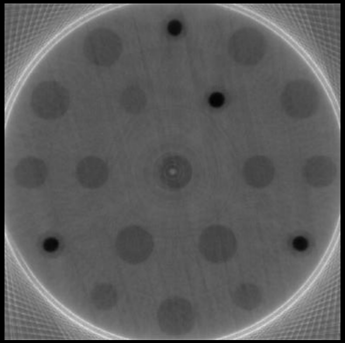
Courtesy of Olga Green, Washington University, St. Louis

# MR-to-Radiation source isocenter registration

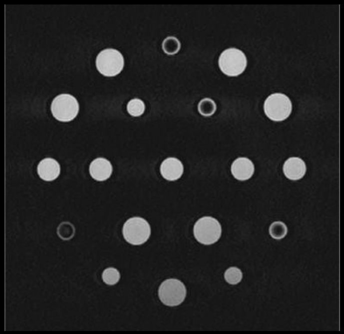
- Designed for Elekta’s Atlantic system
- MR-to-MV alignment
- Ceramic, non-conductive markers for MV
- 3D analysis to locate markers
- Automatic co-registration MR/MV
- Testing done at UMC, Utrecht
- MR image res: 1x1x1 mm3
- MV image res: 0.5x0.5x0.5 mm3
- Analysis mean error: ~0.3 mm




MV CBCT



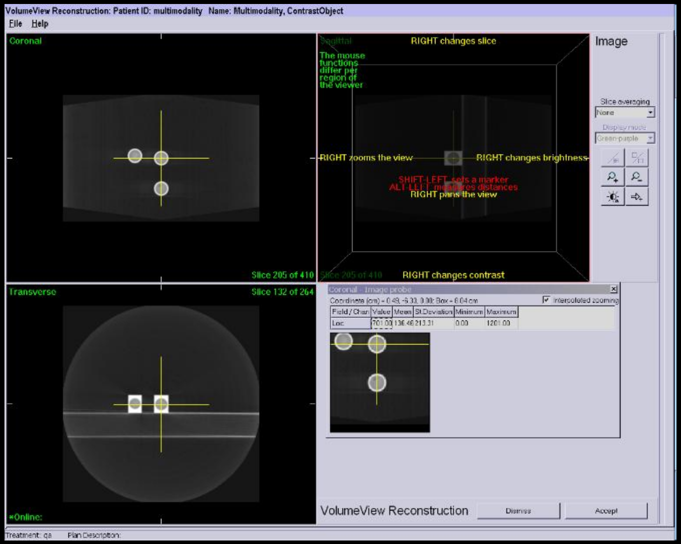
MR

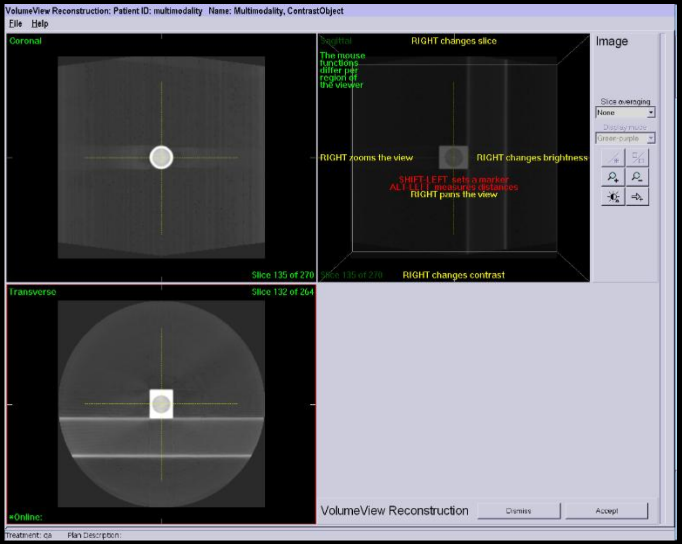


Images & info courtesy of M. Sell, M. Luzzaro (Elekta/Philips)

# MR-to-Radiation source isocenter registration

- Designed for IMRIS MR-linac system
- In collaboration with Modus Medical Devices
- MR-to-kV and  MV alignment
- Daily QA
- 3D analysis to locate markers
- Automatic co-registration
- Ongoing testing



# MR-linac systems

## Radiofrequency (RF) interference

- MR needs to be isolated | Collects weak signal from patient
- Linac is a significant source of RF

MR

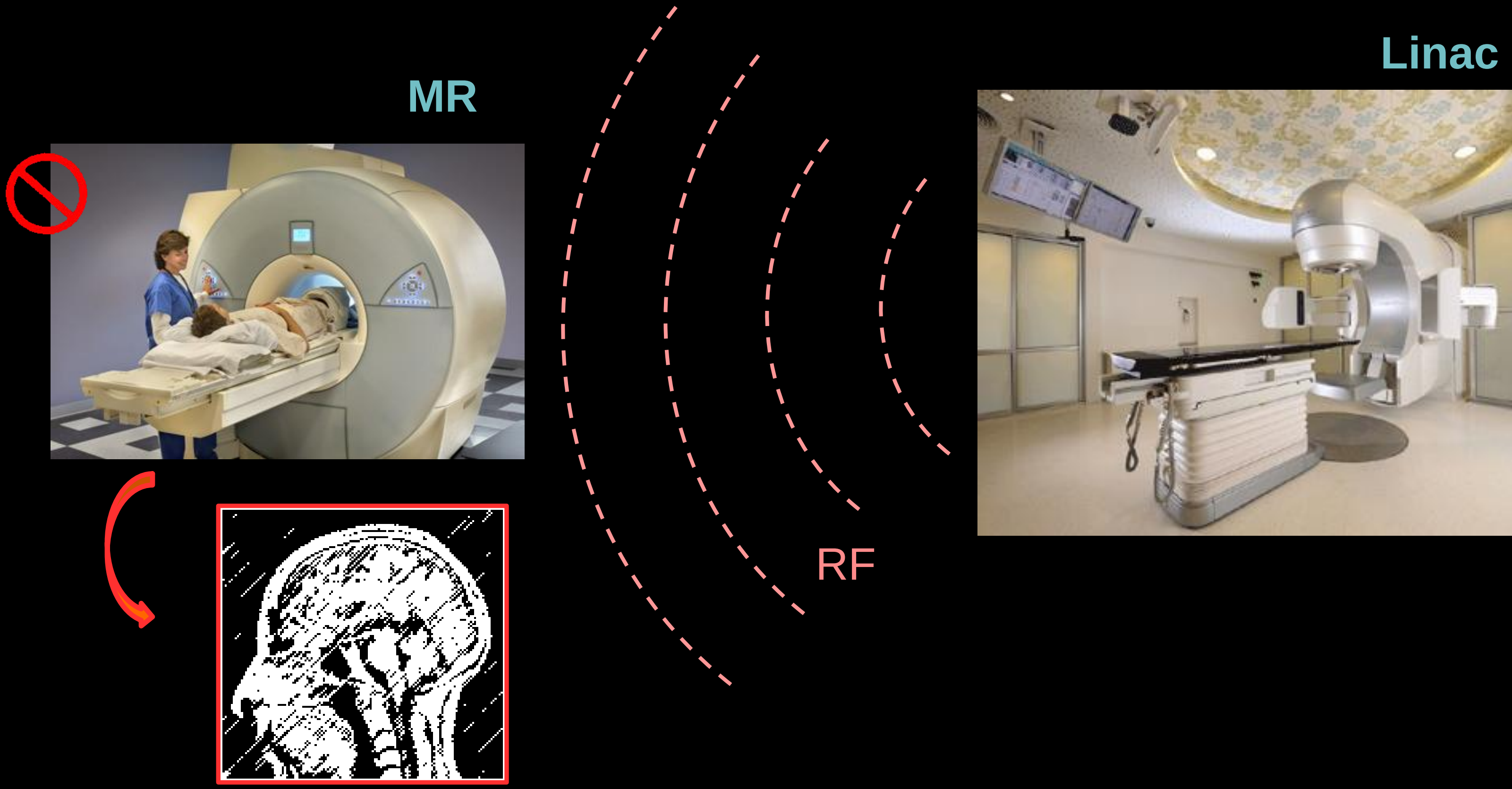
RF shield

Linac

# MR-linac systems

## Radiofrequency (RF) interference

- MR needs to be isolated | Collects weak signal from patient
- Linac is a significant source of RF



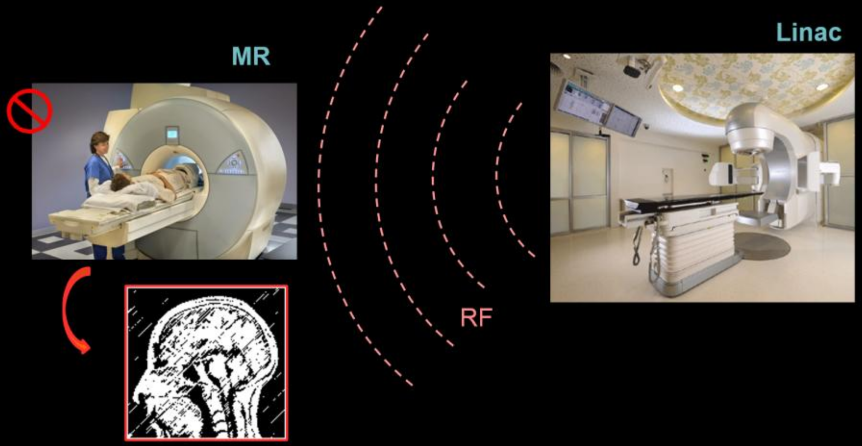
# MR-linac systems

## Radiofrequency (RF) interference

- MR needs to be isolated | Collects weak signal from patient
- Linac is a significant source of RF

Solutions:
- Relocate linac main RF sources in adjacent rooms
- Enclose linac head or MR in a Faraday cage

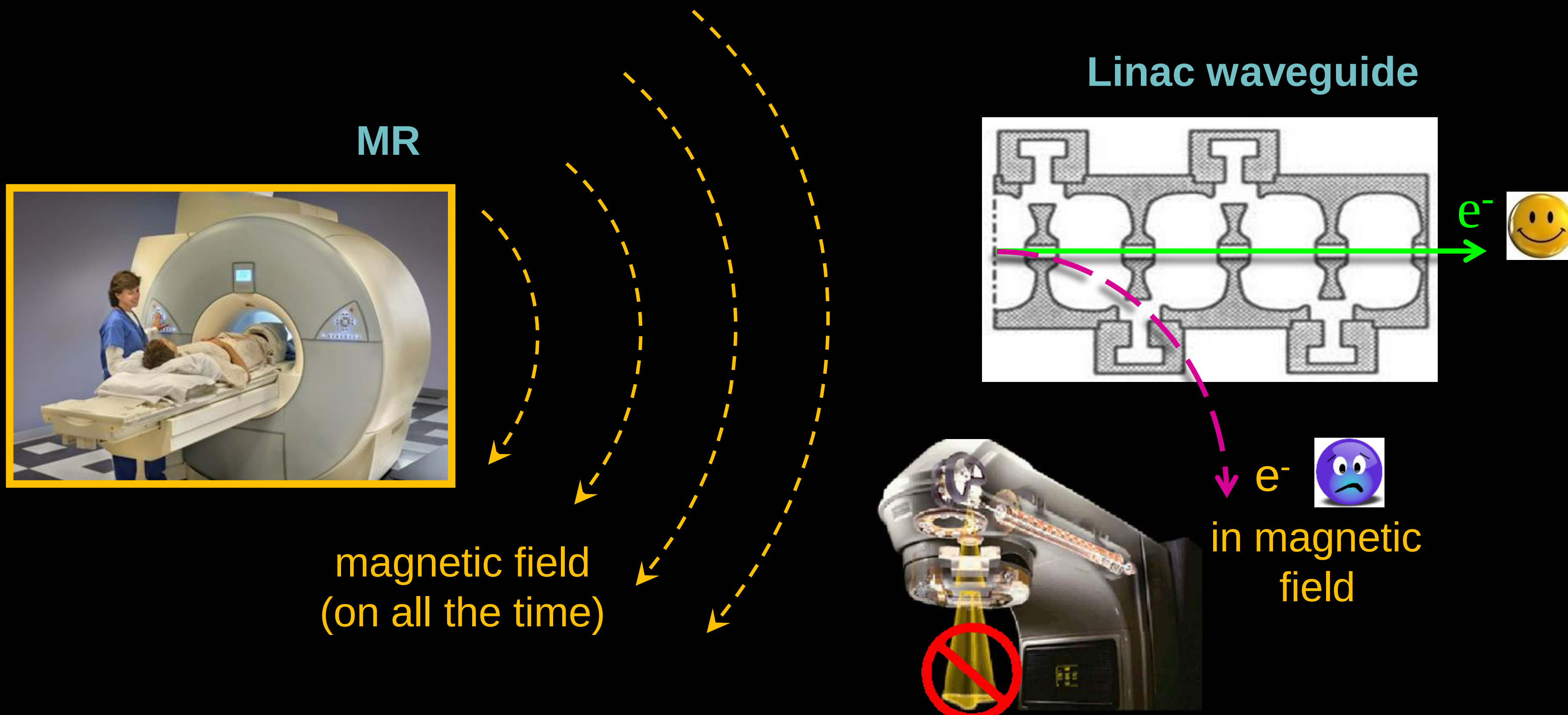
QC monitoring:
- MR scanner RF noise tests
- RF sniffer kit for troubleshooting



# MR-linac systems

## Magnetic field mutual interaction: MR magnet → Linac

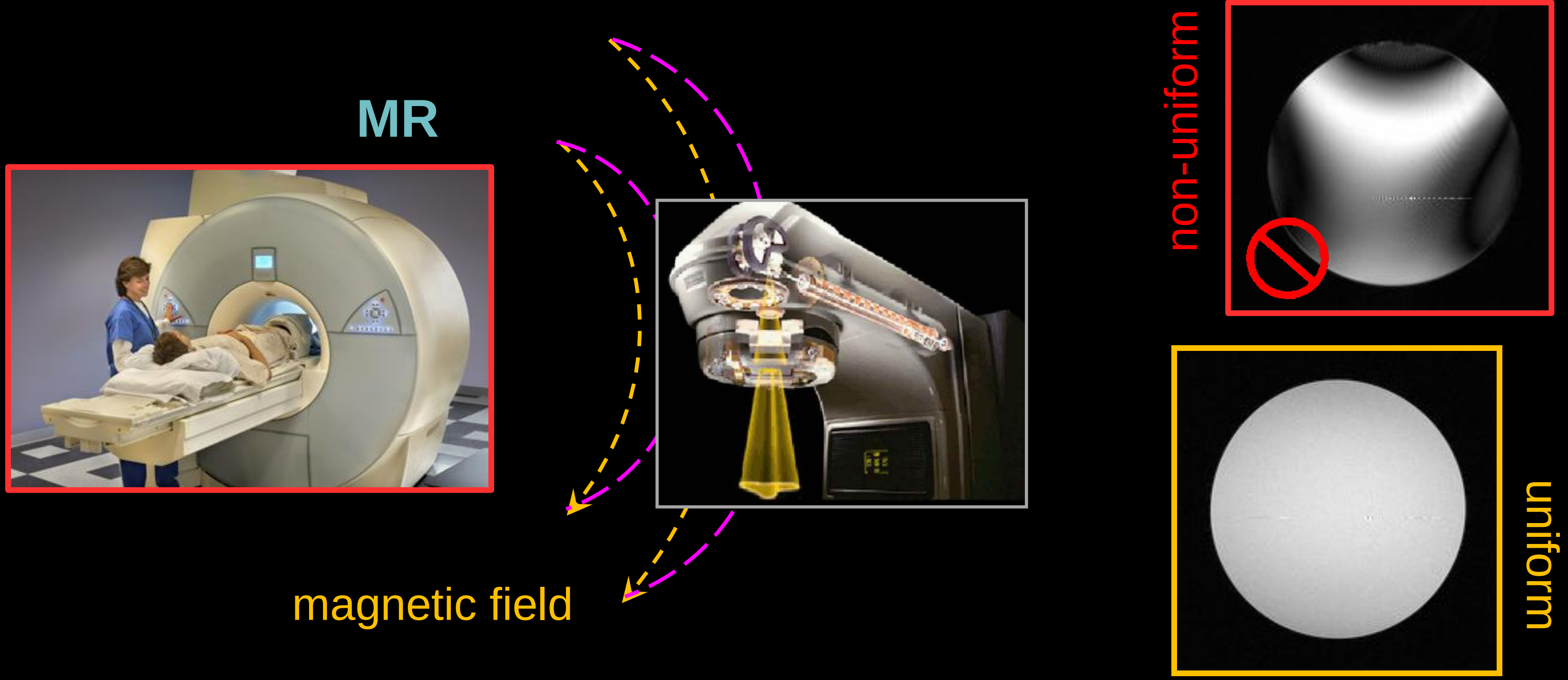
- B0 fringe field of MR scanner reaching the Linac structure
- Linac performance affected | Beam output = f(fringe B-field)



# MR-linac systems

## Magnetic field mutual interaction: MR magnet → Linac

- Linac is a large metallic structure, ferromagnetic components
  - » MR imaging field homogeneity affected



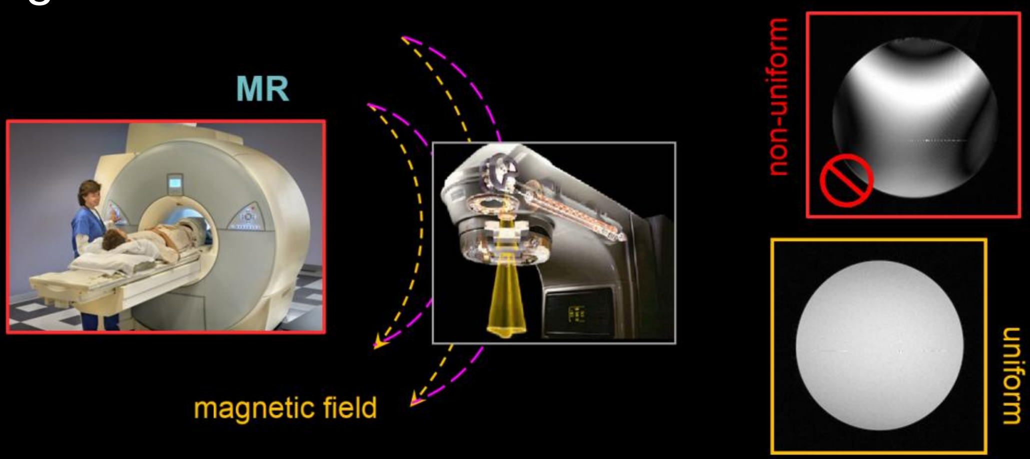
# MR-linac systems

## Magnetic field mutual interaction: MR magnet → Linac

- Linac is a large metallic structure, ferromagnetic components
  - » MR imaging field homogeneity affected

**Solutions:**
- Passive and/or active shielding
- Physical separation

**QC monitoring:**
- Simulation environment: baseline, monitor perturbations
- MR: B0 mapping & Shimming
- Linac: rad beam, imaging

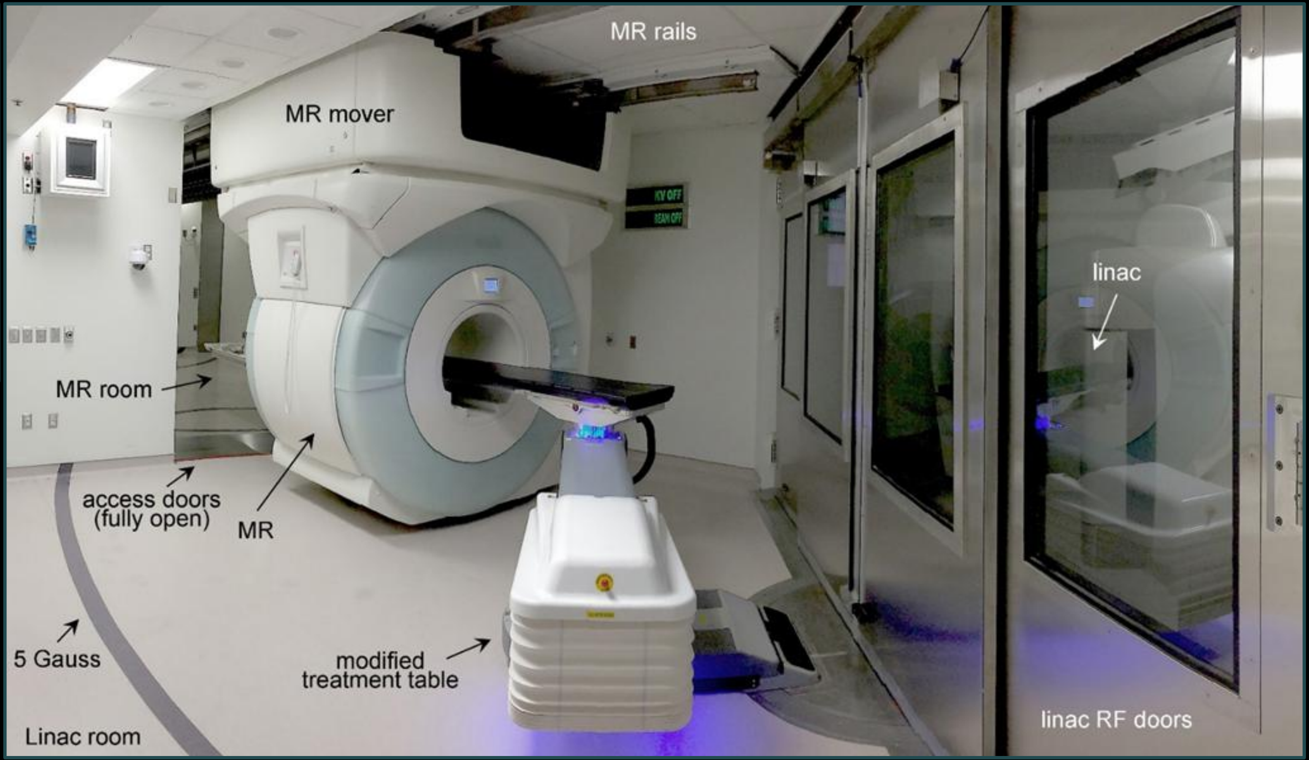


# Princess Margaret MRgRT Project

## QC monitoring:

- Simulation environment: baseline for B0 fringe field mapping
- Establish margins of tolerance for sub-components
  - MR scanner: active imaging field homogeneity
  - Linac: beam optimal specs
  - Couch: safety margins on pull forces, upgradability impact on MR





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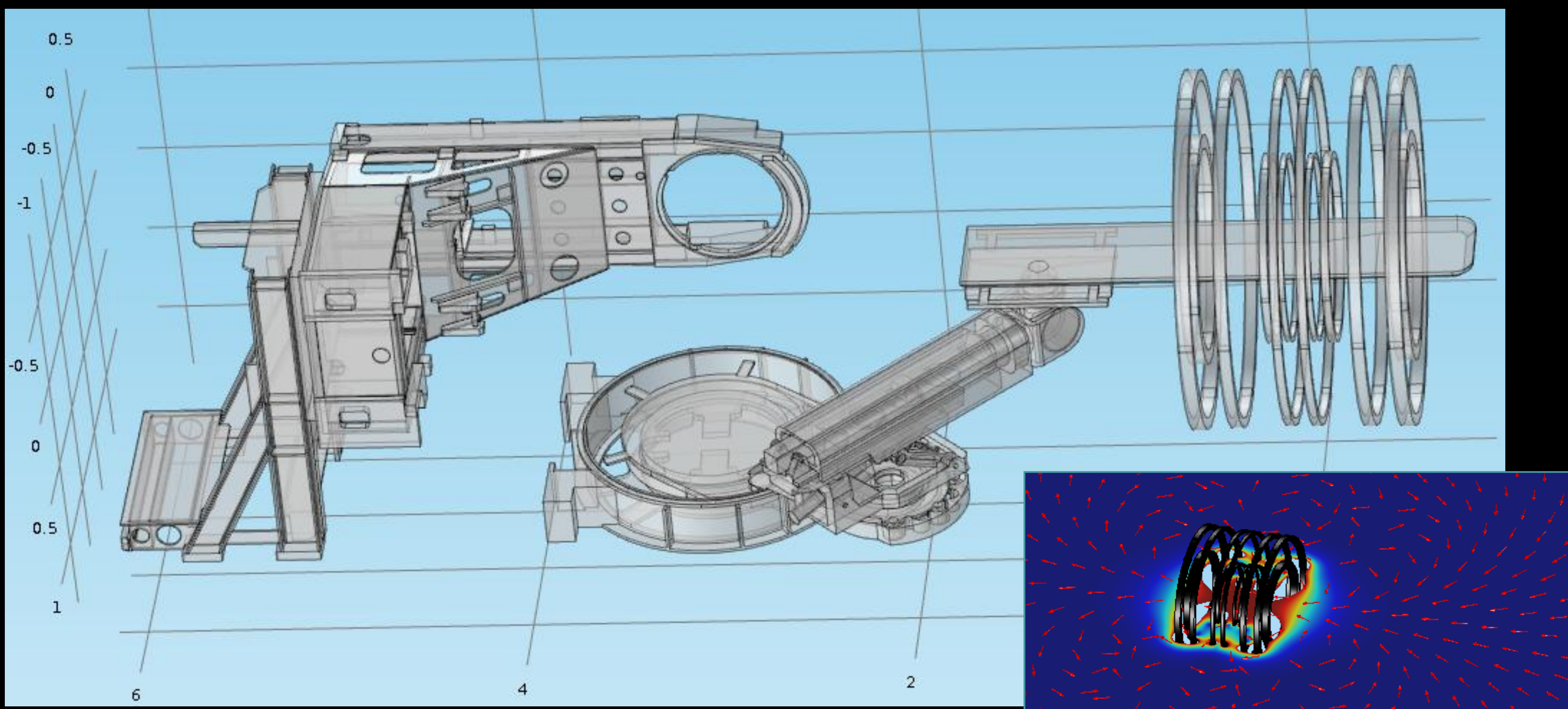


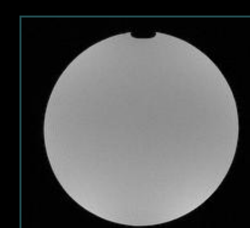
# Princess Margaret MRgRT Project

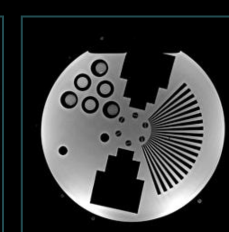
## QC monitoring:

- B0 mapping for testing system performance
- Direct measurements to ensure B-field decoupling
  - MR should stay within specs over time, all intended configurations
  - Negligible impact from hysteresis/residual B-field related effects
  - Measurements more often than for a standalone MR implementation

1st order harmonics


tune-up



# MR testing & commissioning

## MRgRT: MR Shimming Study

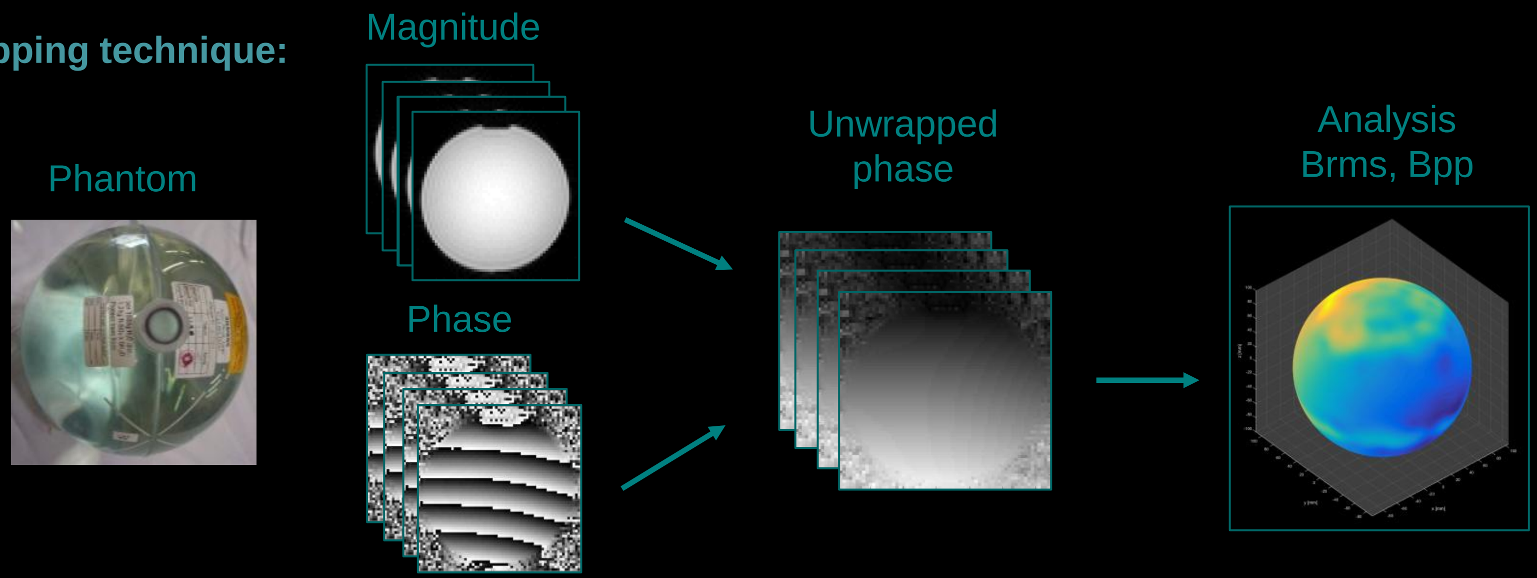
**Methods:**

- Siemens service procedures: Phantom Shim & Phantom Shim Check
- B0 mapping technique: dual-echo GRE field mapping sequence
- Metrics: Brms, Bpp, FWHM water spectral peak

**Results:**

- Transient effects due to B-field priming of the environment
- The effects are reproducible
- MR shim stays within the specs outlined by Siemens/IMRIS

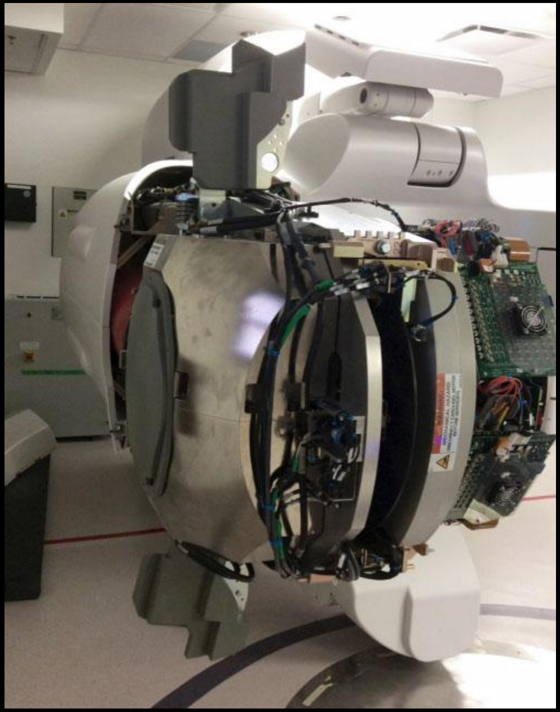
**B0 mapping technique:**



# Princess Margaret MRgRT Project

QC monitoring:

- Linac beam: Flatness & Symmetry v. Gantry angle rotation
- Direct measurements to ensure B-field decoupling
  - Beam stirring servos turned on/off
  - IC Profiler mounted on linac head via custom built accessory
  - Look for remnant magnetization and transient effects

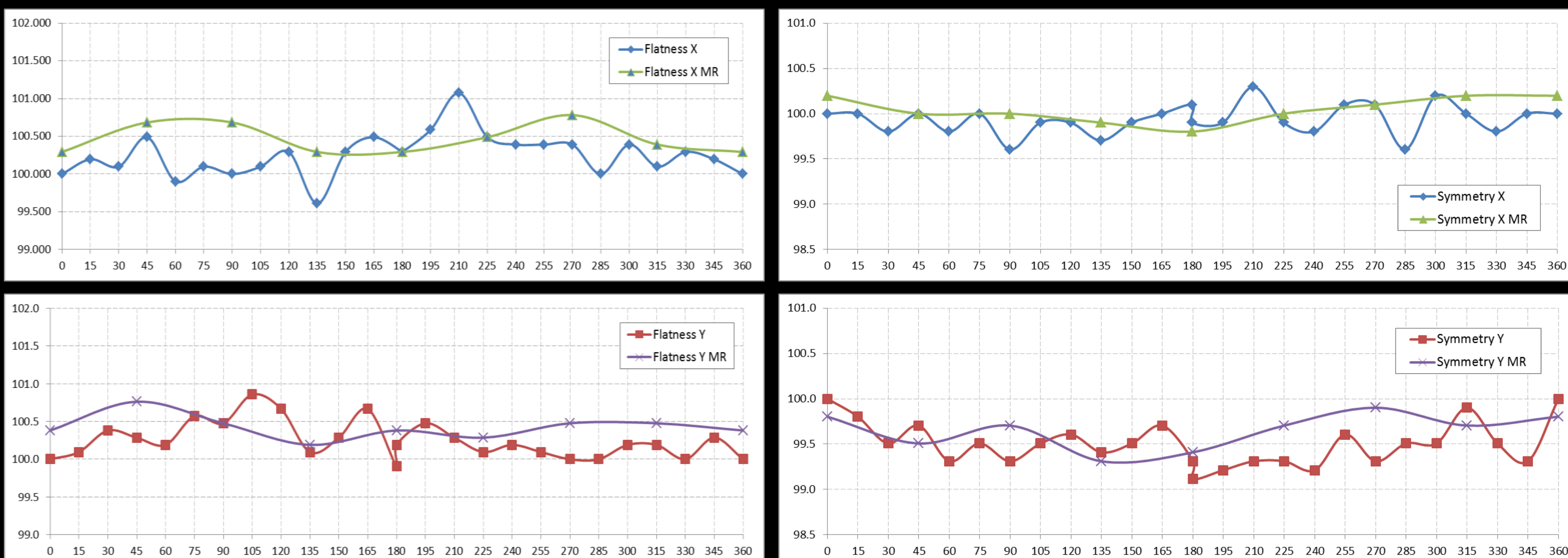


# Princess Margaret MRgRT Project

## QC monitoring:

- Linac beam: Flatness & Symmetry v. Gantry angle rotation
- Direct measurements to ensure B-field decoupling
  - Beam stirring servos turned on/off
  - IC Profiler mounted on linac head via custom built accessory
  - Look for remnant magnetization and transient effects

flatness symmetry



# For MR-guided RT systems, which MR-related test is new and has to be added to the QC routine?

| | | |
|---|---|---|
| 10% | 1. | Magnetic field drift |
| 81% | 2. | Imaging-to-treatment isocenter co-registration |
| 4% | 3. | Center frequency |
| 3% | 4. | Image uniformity |
| 3% | 5. | Ghosting |

# For MR-guided RT systems, which MR-related test is new and has to be added to the QC routine?

Answer: Imaging-to-treatment isocenter co-registration

Ref: Lagendijk et al, Phys Med Biol 59, R349-R369, 2014

## Topics for MR-guided RT system Commissioning & QC

MR data for RT planning and in-room guidance

- MR image distortion: system/scanner-related
- MR image distortion: susceptibility-induced
- Quantification of motion

MR-guided systems: design specific

- RF noise
- Magnetic field coupling
- MR-radiation source system: iso-to-iso registration

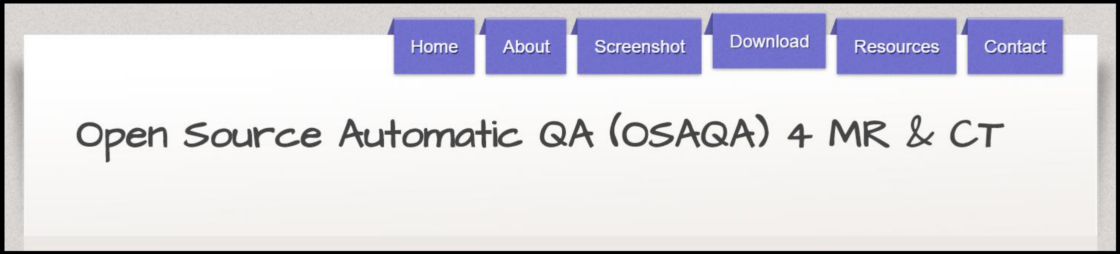
System performance monitoring & Reporting

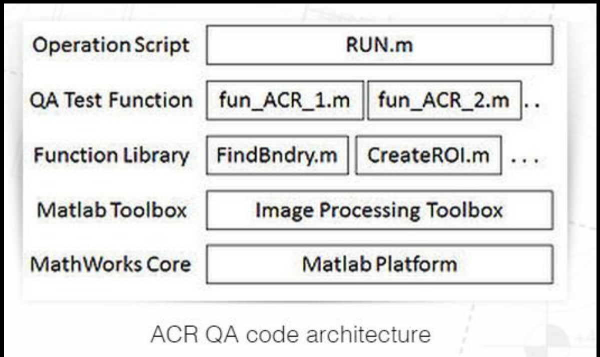
- Open-source software for semi/auto-QC monitoring
- Data base record: in-house, commercial, cloud solutions

# Topics for MR-guided RT system Commissioning & QC

## System performance monitoring

- Open-source software for semi/auto QC analysis
  - Developed by J. Sun *at el* - Calvary Mater Hospital, NSW
  - Supports ACR, MagPhan and MagIQ phantoms
  - Matlab code
  - Can be configured for broader purpose



ACR QA code architecture

http://qa-4-mr.webs.com/download
http://jidisun.wix.com/osaqa-project

**An open source automatic quality assurance (OSAQA) tool for the ACR MRI phantom**

Jidi Sun · Michael Barnes · Jason Dowling · Fred Menk · Peter Stanwell · Peter B. Greer

Australas Phys Eng Sci Med (2015) 38:39–46

# Topics for MR-guided RT system Commissioning & QC

## Data record and Reporting

**In-house:**

- AAPM 2015 presentation: TU-G-CAMPUS-I-15
  - Developed by J. Yung et al  at MD Anderson
  - Semi-automatic QC program
  - Analyze and record measurements
  - Built on open-source software (Linux, Apache, MySQL, Python)
  - Analysis performed on 27 MR scanner: 1.5/3T, GE/Siemens
  - Tests: geometric accuracy/linearity, position accuracy, image uniformity, signal, noise, ghosting, transmit gain, center frequency, magnetic field drift

# Topics for MR-guided RT system Commissioning & QC

## Data record and Reporting

**In-house / Commercial:**

- AQUA
    - Developed at Princess Margaret (Toronto)
    - Initially aimed for linac QC
    - Can be configured to include MRI tests
    - Analysis is semi-automatic
    - Data record is manual
    - Allows for data trending, control charts
    - The software is currently developed by Acumyn (www.acumyn.com)

# Topics for MR-guided RT system Commissioning & QC

## Data record and Reporting

**Commercial / Cloud:**

- QUMULATE
  - Developed by Varian for linac QA
  - Store, visualize, manage QC data
  - Arbitrary tests can be configured
  - Potential platform for MRI
  - Monthly/annual fee for service

# MR-guided RT system Commissioning & QC

## Summary

- Quantify and mitigate for system-related and patient-induced image distortions
- QC of motion sequences may be required, especially for new techniques
- MR-guided RT systems new tests may be required
    - RF noise
    - Magnetic field coupling
    - MR iso to radiation source iso co-registration
- Establishing a QC program including data reporting