## MR-guided RT: Commissioning and Quality Control

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Radiation Oncology UNIVERSITY OF TORONTO TECHNA UHN Princess Margaret Cancer Centre

### Disclosure

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
  - Spatial accuracy: system/scanner-related distortions
  - Spatial accuracy: patient-induced (tissue susceptibility)
  - Quantification of motion
- ❑ MR-guided RT systems: design specific
  - RF noise
  - Magnetic field coupling
  - MR & radiation source: iso-to-iso registration
- ❑ System performance monitoring & Reporting
  - Database record: in-house, commercial, cloud solutions

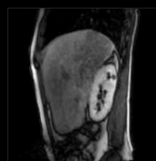
MRI Guidance

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

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



- Organ motion present → 4D composite distortion field
- The distortions can be treated as separate problems
  - practically, no coupling b/w system and patient specific distortions

MRI Guidance

**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 × 40 × 30 $cm^3$ | ≤2 ppm | 1.2 ppm |
| 45 × 45 × 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 × 40 × 40 $cm^3$ | ≤5 ppm* | |

- 70 cm bore
- 120 cm long

MRI Guidance

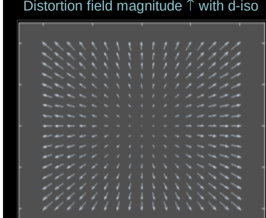
**MR data for RT planning – System-related distortions**

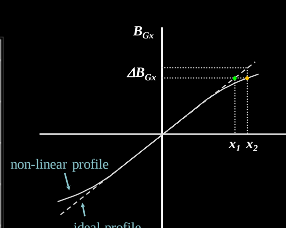
MR images suffer of intrinsic distortions → affect geometric accuracy

**2. Gradient non-linearity**

- Most significant source of geometric distortions

Distortion field magnitude ↑ with d-iso





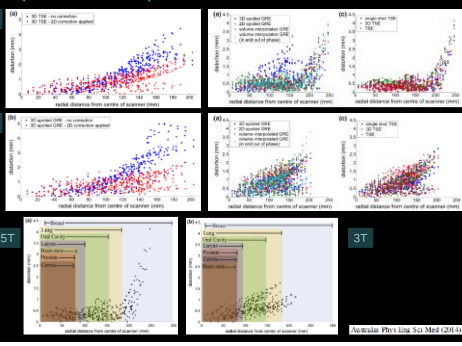
MRI Guidance

## 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 → 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: measurements & harmonic analysis

## System-related distortions

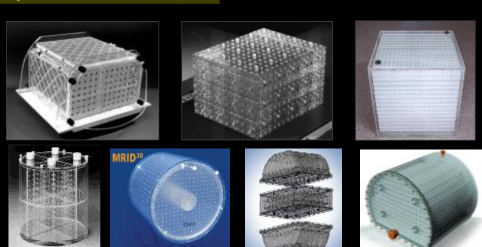
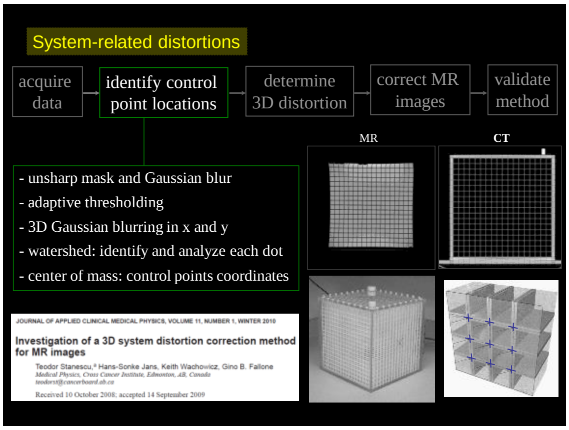
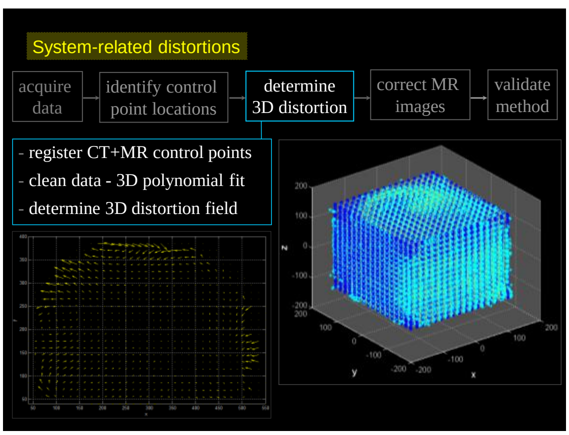
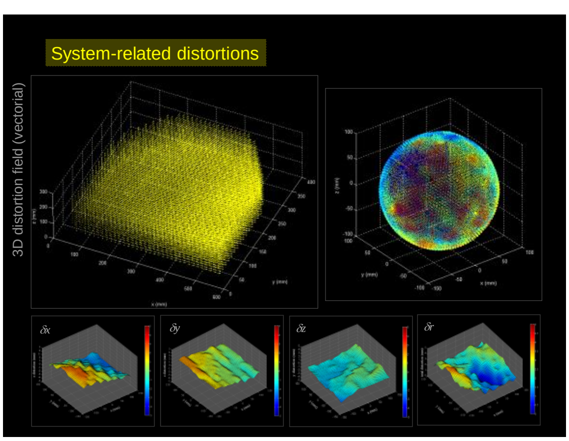


image processing algorithm

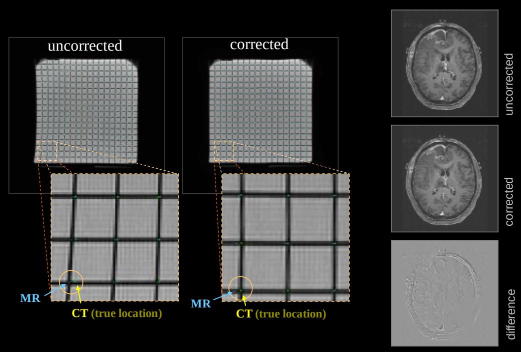
acquire data → identify control point locations → determine 3D distortion → correct MR images → validate method


System-related distortions
acquire data
identify control point locations
determine 3D distortion
correct MR images
validate method
MR
CT
- 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
JOURNAL OF APPLIED CLINICAL MEDICAL PHYSICS, VOLUME 11, NUMBER 1, WINTER 2010
Investigation of a 3D system distortion correction method for MR images
Received 10 October 2008; accepted 14 September 2009


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


System-related distortions
3D distortion field (vectorial)
δx
δy
δz
δr

## 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]

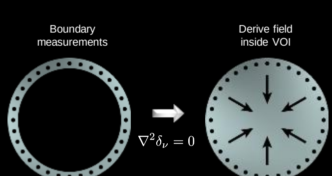
Phys. Med. Biol. **50** (2005) 1343–1361

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

- *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: phantom measurements + harmonics analysis




**Dirichlet problem:**
Laplace equation with boundary conditions

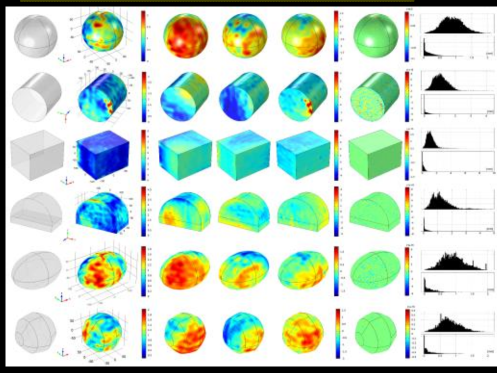
$\Delta u(\mathbf{r}) = 0,\ \mathbf{r} \in \mathcal{D}$
$u(\mathbf{r}) = g(\mathbf{r}),\ \mathbf{r} \in \partial\mathcal{D}$
$u: \mathcal{D} \to \mathbb{R}$
$u \in C(\bar{\mathcal{D}}) \cap C^2(\mathcal{D})$ where $\bar{\mathcal{D}} = \mathcal{D} \cup \partial\mathcal{D}$
$g \in C(\partial\mathcal{D})$ is a continuous function

- Use of the harmonic properties of the 3D distortion vector field
- Distortions are measured on the surface of the VOI
- Laplace's equation is solved to derive the full 3D field within the entire VOI

Med. Phys. 41 (11), November 2014

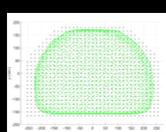
SU-F-J-154

System-related distortions – Harmonic analysis

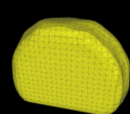


System-related distortions – Harmonic analysis

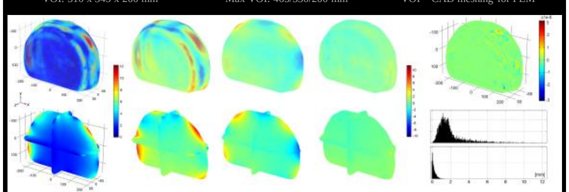
VOI: 510 x 345 x 200 mm$^3$



Max VOI: 465/330/200 mm



VOI – CAD meshing for FEM



System-related distortions

MRI Guidance

Summary

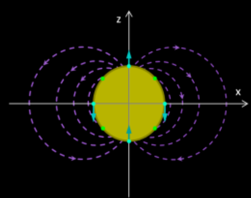
- Manufacturers provide a 1st order correction (2D/3D)
  - Correction should be enabled in the protocols
- Detailed quantification of residual distortions needed
  - MR commissioning
  - Clinical implementation of clinical protocols
- Limited standardization and lack of user friendly solutions
  - Most of vendors offer phantoms with various features
  - In-house developments: reliability, efficient workflows
  - Routine monitoring, report & document

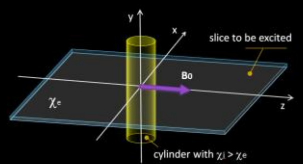
## Patient-induced distortions

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



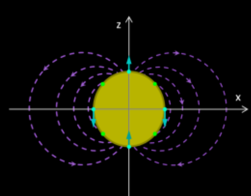



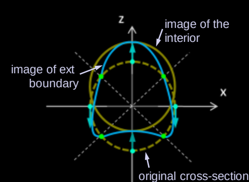

Cylinder geometry: interior and exterior mapped diff
Interior: const field offset, no shape distortion along Gr

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

## Patient-induced distortions

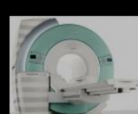
Tissue magnetic susceptibility




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

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



## Patient-induced distortions

**Methods for quantifying the distortion field:**

1. Measurement of B0 field distortion map
   - double-echo GE sequence → 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)

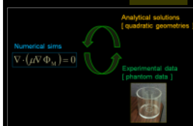
**Characterization of tissue magnetic susceptibility-induced distortions for MRIgRT**

T. Stanescu[a)] — Med. Phys. 39 (12), December 2012
*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*

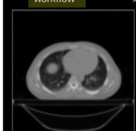
K. Wachowicz
*Division of Medical Physics, Department of Oncology, University of Alberta, Cross Cancer Institute, 11560 University Avenue, Edmonton, Alberta T6G 1Z2, Canada*

D. A. Jaffray
*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

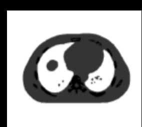
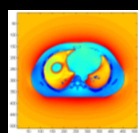


image mask

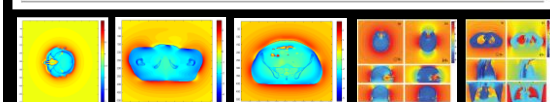

magnetic field


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 | |



MRI Guidance

## Organ / target motion: lung

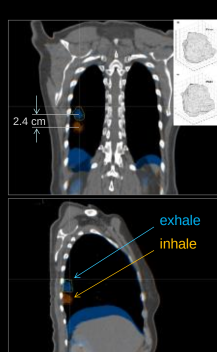
Case study: lung patient, 10 bins 4D CT

**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

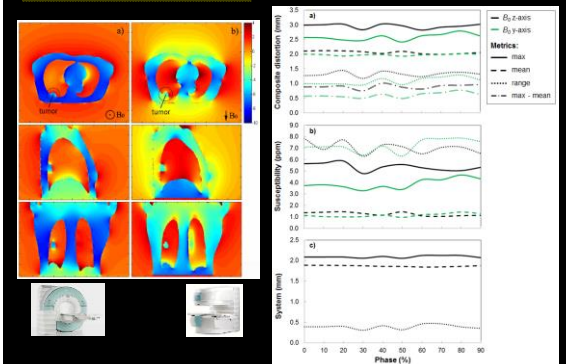
2. Magnetic susceptibility
- numerical methods
- anatomy specific
- dynamic distortion field

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



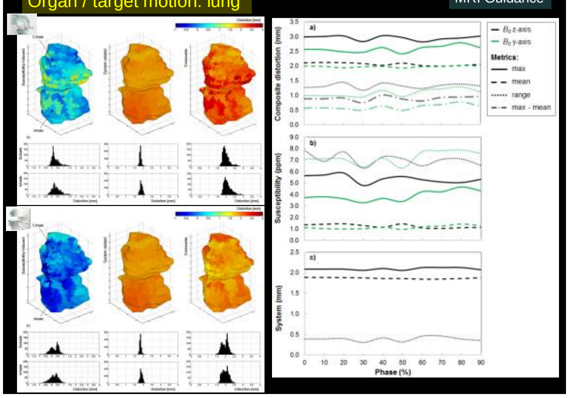
## Organ / target motion: lung

MRI Guidance




## Organ / target motion: lung

MRI Guidance




MRI Guidance

## Organ / target motion: lung

B0 z-axis

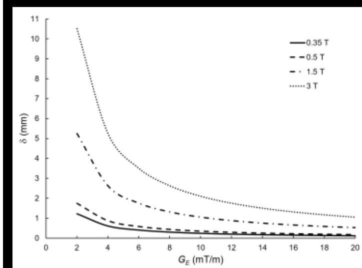
| | | Scanner-related field | χ-induced | χ-induced field | | | Composite Field | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 0.35 T | 0.5 T | 1.5 T | 0.35 T | 0.5 T | 1.5 T |
| | | [mm] | [ppm] | [mm] | [mm] | [mm] | [mm] | [mm] | [mm] |
| Exhale | max | 2.13 | 5.29 | 0.37 | 0.53 | 1.59 | 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 |

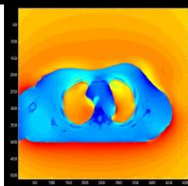
B0 y-axis

| | | Scanner-related field | χ-induced | χ-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 |

## Patient-induced distortions

Tissue magnetic susceptibility (~ mm) – Protocol optimization



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

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MRI Guidance

### ❑ 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

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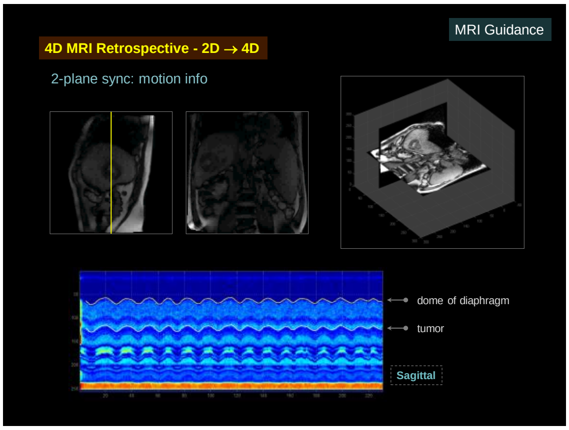
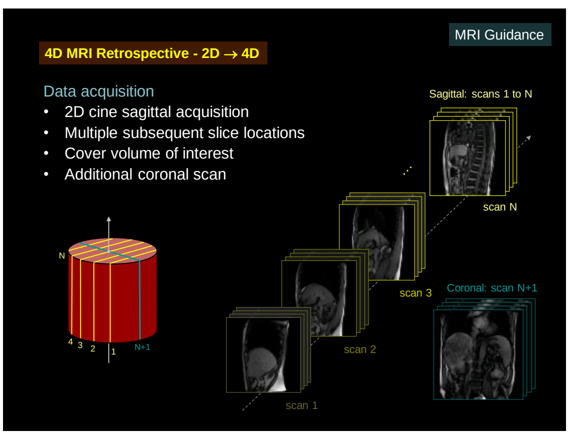
MRI Guidance

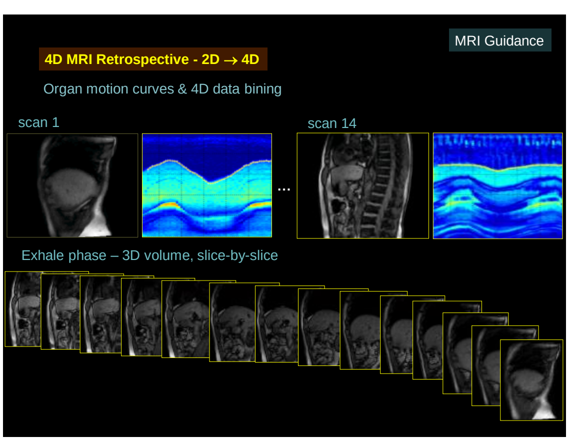
### MR data for Treatment Delivery - Patient setup verification & Tracking/Gating

**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(?) → 4D (3D+time): most techniques under development
- **Retrospective 4D image data binning and image reconstruction**
  - Available, implementation is vendor specific
  - Growing literature: 2D → 4D, 4D


MRI Guidance
4D MRI Retrospective - 2D → 4D
2-plane sync: motion info
dome of diaphragm
tumor
Sagittal


MRI Guidance
4D MRI Retrospective - 2D → 4D
Data acquisition
• 2D cine sagittal acquisition
• Multiple subsequent slice locations
• Cover volume of interest
• Additional coronal scan
Sagittal: scans 1 to N
scan N
scan 3
Coronal: scan N+1
scan 2
scan 1
N
4 3 2 1
N+1


MRI Guidance
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

MRI Guidance

- 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 + post processing

## 4D MRI Retrospective - 3D → 4D

MRI Guidance

- 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

MRI Guidance


*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")

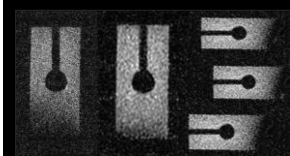
ViTAL

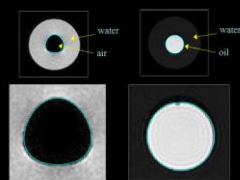
modus

CIRS

MRI Guidance

## Phantom data analysis



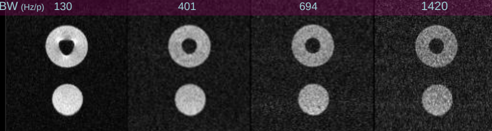



Prototype provided by Modus Medical Devices

MRI Guidance

## Phantom data analysis

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



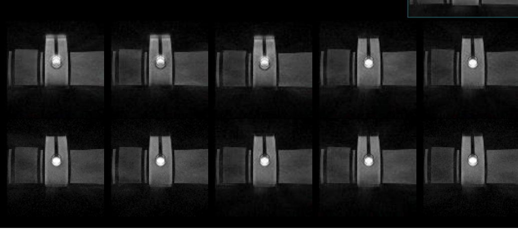
| SNR (%) | 100 | 53 | 41 | 26 |
|---|---|---|---|---|
| Time (s) | 1.6 | 0.9 | 0.7 | 0.5 |

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 1.3 x 1.3 x 3.0
Mid/High BW
View sharing mode: golden angle, total acquisition time < 1 min



MRI Guidance

**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?

| | | |
|---|---|---|
| 20% | 1. | MR main field (B0) inhomogeneity |
| 20% | 2. | Chemical shift |
| 20% | 3. | Tissue susceptibility |
| 20% | 4. | Imaging gradient non-linearities |
| 20% | 5. | Motion |

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

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

MRI Guidance

## MR-linac systems

Radiofrequency (RF) interference

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


MRI Guidance

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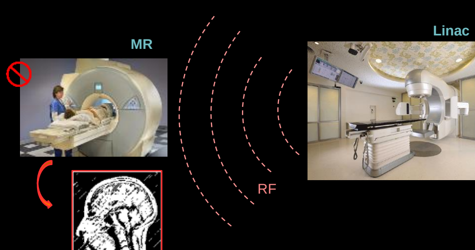
- Linac is a significant source of RF




MRI Guidance

## MR-linac systems

Radiofrequency (RF) interference

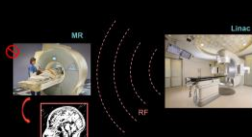
- MR needs to be isolated | Collects weak signal from patient
- Linac is a significant source of RF

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

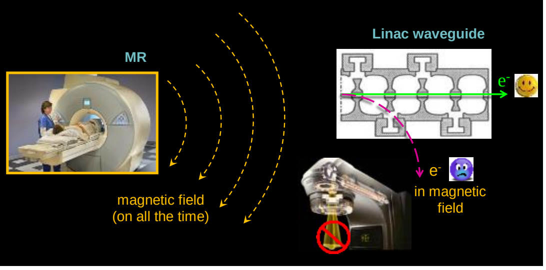


MRI Guidance

## 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)

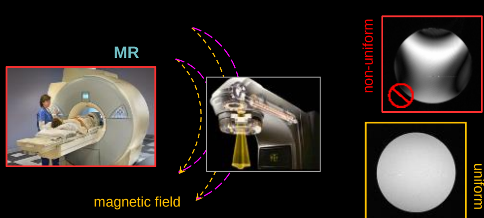



MRI Guidance

## MR-linac systems

Magnetic field mutual interaction: MR magnet → Linac

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




MRI Guidance

## MR-linac systems

Magnetic field mutual interaction: MR magnet → Linac

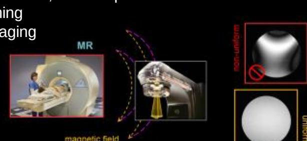
- Linac is a large metallic structure, ferromagnetic components
  - » MR imaging field homogeneity affected

Solutions:

- Passive and/or active shielding
- Physical separation

QC monitoring:

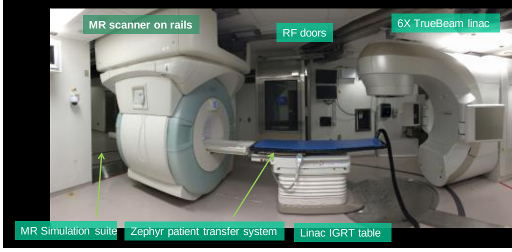
- Simulation environment: baseline, monitor perturbations
- MR: B0 mapping & Shimming
- Linac: treatment beam, imaging



## Princess Margaret MRgRT Project

QC monitoring:

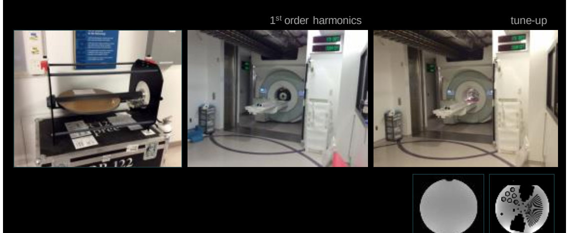
- Simulation environment: baseline for B0 fringe field mapping
- Establish margins of tolerance for sub-components
  - MR scanner: active imaging field homogeneity
  - Linac: beam optimal specs
  - Couch: safety margins on pull forces, upgradability impact on MR




## 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




## MR testing & commissioning

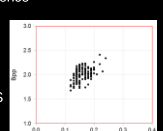
**MRgRT: MR Shimming Study**

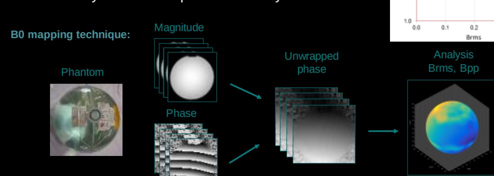
**Methods:**

- 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



## 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

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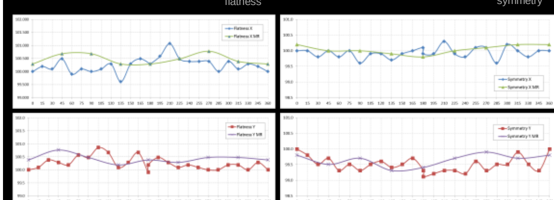
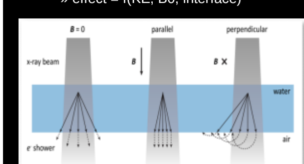
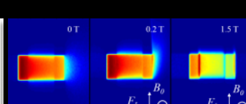


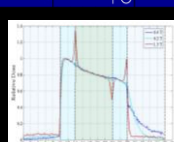

## Dosimetry in magnetic field

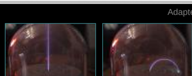
- Electron trajectories perturbed by the presence of B0 → Lorentz force
  - » effect = f(KE, B0, interface)




Adapted from B. Murray





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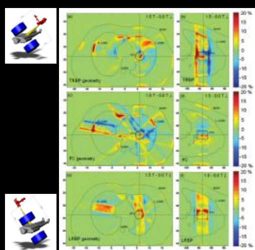
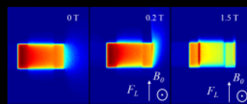

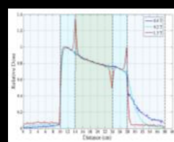



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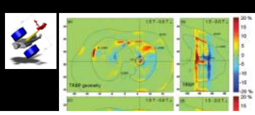
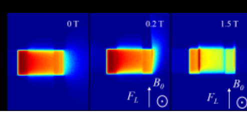
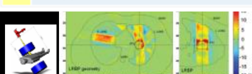
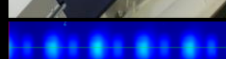
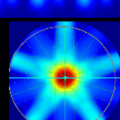




| | |
|---|---|
| **MRgRT Dosimetry** | Thursday - 8/4/2016 |
| Therapy Scientific Session | 10:00 AM - 12:00 PM |



## MR-to-Radiation source isocenter registration

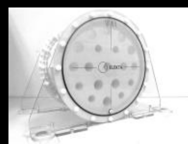
- Cylindrical phantom filled with water
- Scribe lines for alignment to lasers
- Circular film between two halves of phantom
- Wrap-around film strip
- Once MLC accuracy is established, imaging this phantom provides information about MR-RT isocenter alignment
- Once RT isocenter is established, MR isocenter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

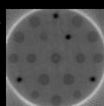
Courtesy of Olga Green

## MR-to-Radiation source isocenter registration

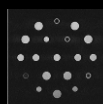
- Designed for Elekta's Atlantic system
- MR-to-MV alignment
- Ceramic, non-conductive markers for MV
- 3D analysis to locate markers
- Automatic co-registration MR/MV
- Testing done at UMC, Utrecht
- MR image res: 1x1x1 mm3
- MV image res: 0.5x0.5x0.5 mm3
- Analysis mean error: ~0.3 mm



MV CBCT



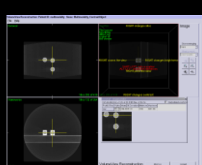
MR

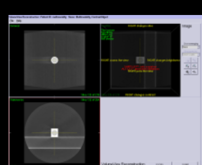


Images & info courtesy of M. Sell, M. Luzzaro (Elekta)

## 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





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

| | | |
|---|---|---|
| 20% | 1. | Magnetic field drift |
| 20% | 2. | Imaging-to-treatment isocenter co-registration |
| 20% | 3. | Center frequency |
| 20% | 4. | Image uniformity |
| 20% | 5. | Ghosting |

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

**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