MR in RT: MRI on a MR Guided RT system

Yingli Yang, PhD

Department of Radiation Oncology, UCLA

July 31st, 2017





- Introduction to tri-Cobalt-60 MRI guided radiotherapy system (MRgRT)
 - RT system and MRI system configuration
 - Clinical workflow
 - Treatment delivery with MRI
 - Adaptive RT
 - · Gated RT
- MRI Challenges for ViewRay MRgRT
 - Current imaging protocols (3D and 2D Cine)
 - Potentials with MRI techniques on 0.35T
 - Motion artifact free MRI
 - Breath hold MRI
 - Free breathing MRI
 - 4DMR
 - Treatment response with DWI



- Introduction to tri-Cobalt-60 MRI guided radiotherapy system (MRgRT)
 - RT system and MRI system configuration
 - Clinical workflow
 - Treatment delivery with MRI
 - Adaptive RT
 - Gated RT
- MRI Challenges for ViewRay MRgRT
 - Current imaging protocols (3D and 2D Cine)
 - Potentials with MRI techniques on 0.35T
 - Motion artifact free MRI
 - Breath hold MRI
 - Free breathing MRI
 - 4DMR
 - Treatment response with DWI



Introduction to ViewRay MRIdian[®] system

• RT components:

- 3 headed cobalt system, each 15,000Ci, dose rate around 500cGy/min at 105cm SAD
- 3 independent MLC systems (1cm leaf width, double focus, field size 27.3cm x 27.3cm)
- MRI components:
 - Split superconductor MRI (0.345 T)
 - 50cm FOV with 70cm bore size
 - Imaging isocenter matches with RT system





Patient Immobilization with coil











UCLA MRgRT Clinical workflow





Thorax and abdomen treatments on Viewray

- Challenges:
 - Mobile and easily deformed
 - Packed with soft tissue organs
- Advantages with MRgRT:
 - Adaptive radiation therapy
 - Soft tissue based gated treatment



7



- Introduction to tri-Cobalt-60 MRI guided radiotherapy system (MRgRT)
 - RT system and MRI system configuration
 - Clinical workflow
 - Treatment delivery with MRI
 - Adaptive RT
 - Gated RT
- MRI Challenges for ViewRay MRgRT
 - Current imaging protocols (3D and 2D Cine)
 - Potentials with MRI techniques on 0.35T
 - Motion artifact free MRI
 - Breath hold MRI
 - Free breathing MRI
 - 4DMR
 - Treatment response with DWI



Adaptive RT with MRI



Adaptive treatment after 15 fx



Online Adaptive Treatment Work Flow with MRI guidance



Intra-fractional Motion Management

- Free-breathing gated treatment
- Breath-hold gated treatment
- Free-breathing treatment with monitoring





- Introduction to tri-Cobalt-60 MRI guided radiotherapy system (MRgRT)
 - RT system and MRI system configuration
 - Clinical workflow
 - Treatment delivery with MRI
 - Adaptive RT
 - Gated RT
- MRI Challenges for ViewRay MRgRT
 - Current imaging protocols (3D and 2D Cine)
 - Potentials with MRI techniques on 0.35T
 - Motion artifact free MRI
 - Breath hold MRI
 - Free breathing MRI
 - 4DMR
 - Treatment response with DWI



Technical Considerations of 0.35T MRI

- Challenges
 - Nominal SNR loss of 4.3 fold when compared to 1.5T due to its lower spin polarization
 - Low SNR limits imaging acceleration using conventional SENSE and GRAPPA techniques
- Benefits:
 - Low SAR (Specific Absorption Rate)
 - Less spatial distortion
- Choice of basic sequence
 - Balanced steady-state free-precession (bSSFP)

Less dose distortion (electron Lorentz force) Less interaction between RT and MRI



bSSFP Signal at 0.35T

- Advantages :
 - High signal
 - Fast acquisition
- Disadvantages
 - banding artifacts signal void for off-resonance signal
 - · Sensitive to blood flow artifacts
 - Fat saturation could be problematic
- 0.35T
 - Better field homogeneity (<2ppm)
 - Native tissue T1 shortened by ~50% -> 50-60% SNR gain
 - + ~50% SNR efficiency gain by using longer TR





Current imaging protocols on ViewRay MRIdian® system

- Two basic acquisition modes:
 - 3D volume scan (static)
 - 2D sagittal cine imaging (dynamic): 4fps
- 3D volume scan:
 - 18 protocols with different image fields of view
 - Spatial resolution: 0.15x0.15cm or 0.15x0.3cm
 - Acquisition time: 17 -175 seconds







Issues with current 3D imaging protocol on ViewRay

- Breath hold MRI
 - Long acquisition time for breath hold MRI (17s 25s)
- Free breathing MRI
 - Motion artifact with free breathing MRI
- Sub-optimal soft tissue contrast with TrueFISP
 - T2/T1 weighting







Issues for current ViewRay 2D gated treatment

- Tracking motion through a slice in one plane
- sub-optimal tumor contrast/conspicuity
- Inadequate spatial coverage for retro. dose calculation





- Introduction to tri-Cobalt-60 MRI guided radiotherapy system (MRgRT)
 - RT system and MRI system configuration
 - Clinical workflow
 - Treatment delivery with MRI
 - Adaptive RT
 - Gated RT
- MRI Challenges for ViewRay MRgRT
 - Current imaging protocols (3D and 2D Cine)
 - Potentials with MRI techniques on 0.35T
 - Motion artifact free MRI
 - Breath hold MRI
 - Free breathing MRI
 - 4DMR
 - Treatment response with DWI



- Introduction to tri-Cobalt-60 MRI guided radiotherapy system (MRgRT)
 - RT system and MRI system configuration
 - Clinical workflow
 - Treatment delivery with MRI
 - Adaptive RT
 - Gated RT
- MRI Challenges for ViewRay MRgRT
 - Current imaging protocols (3D and 2D Cine)
 - Potentials with MRI techniques on 0.35T
 - Motion artifact free MRI
 - Breath hold MRI
 - Free breathing MRI
 - 4DMR
 - Treatment response with DWI



Accelerated 3D Balanced SSFP Imaging

- Current planning protocol for abdominal tumors on the MRgRT system
 - GRAPPA 2 × 2, an effective under-sampling rate of 7.5-fold (7.5x).
 - Inadequate resolution (1.5x1.5x3mm3) for SBRT/SRS
 - Long breath-holding time (25s)
- Goal:
 - To accelerate RT planning/setup MRI protocol on the 0.35T
 MRgRT system for shorter breath-holds and/or improved resolution





Method

- Sampling pattern: Variable-density Poisson-Disk (VDPD)
- Reconstruction: L1-ESPIRiT reconstruction[1]
 - Offline recon. ~1 minute per 3D volume

$$\hat{x} = \arg\min\sum_{i=1}^{N} \|DFS_i x - m_i\|_2^2 + \lambda \|Wx\|_1$$

- Comparison under two under-sampling rates
 - GRAPPA 7.5x (Clinical sequence): GRAPPA 2 × 2, partial Fourier(6/8), elliptical scanning
 - PDVD 15x (Proposed sequence): center 22 × 16 region fully sampled
- Ten patients with abdominal tumors





[1] Uecker et al. MRM, 2014

Patient Study

• Two patients failed the GRAPPA-25s breath hold. All VDPD-12.5s were successfully tolerated.



- Introduction to tri-Cobalt-60 MRI guided radiotherapy system (MRgRT)
 - RT system and MRI system configuration
 - Clinical workflow
 - Treatment delivery with MRI
 - Adaptive RT
 - Gated RT
- MRI Challenges for ViewRay MRgRT
 - Current imaging protocols (3D and 2D Cine)
 - Potentials with MRI techniques on 0.35T
 - Motion artifact free MRI
 - Breath hold MRI
 - Free breathing MRI
 - 4DMR
 - Treatment response with DWI



Compensated Free-Breathing 3D MRI for MRgRT

- K-space sampling
 - Golden-angle (GA) rotated stack-of-stars (SOS) sampling trajectory
- Key features:
 - Insensitive to motion (radial trajectory)
 - Better K space coverage (in-plane and through-plane GA rotation)





Zhou et al., MRM 2017

Patient study 1

Malignant neoplasm of peripheral nerves of right lower limb Patient has involuntary motion during acquisition



Standard Cartesian Acquisition

Proposed Acquisition



Patient study 2

Intrahepatic bile duct carcinoma Patient fails to hold his breath during acquisition



Clinical Protocol

Proposed Protocol



- Introduction to tri-Cobalt-60 MRI guided radiotherapy system (MRgRT)
 - RT system and MRI system configuration
 - Clinical workflow
 - Treatment delivery with MRI
 - Adaptive RT
 - Gated RT

MRI Challenges for ViewRay MRgRT

- Current imaging protocols (3D and 2D Cine)
- Potentials with MRI techniques on 0.35T
 - Motion artifact free MRI
 - Breath hold MRI
 - Free breathing MRI
 - 4DMR
 - Treatment response with DWI



4DMRI on Viewray

- 4D-CT the current clinical standard
- **Over-sampled** •
- Images sorted •



More flexible k-space sampling and image reconstruction •



•

[Cai et al., Med Phys 2011]

4DMRI on Viewray

- 3D encoding has SNR advantages
- Higher slice resolution
- More flexible sampling design
- Established theories to retrieve missing k-space lines

Exhaust over-sampling

Smart under-sampling





Patient study



64 y. o. female with liver metastases



Patient study Phase 1/8 3/8 6/8 8/8 4D-MRI

4D-MRI has better tumor contrast and less motion artifacts than 4D-CT



- Introduction to tri-Cobalt-60 MRI guided radiotherapy system (MRgRT)
 - RT system and MRI system configuration
 - Clinical workflow
 - Treatment delivery with MRI
 - Adaptive RT
 - Gated RT

MRI Challenges for ViewRay MRgRT

- Current imaging protocols (3D and 2D Cine)
- Potentials with MRI techniques on 0.35T
 - Motion artifact free MRI
 - Breath hold MRI
 - Free breathing MRI
 - 4DMR

Treatment response with DWI



Treatment response assessment - Diffusion MRI

- Measures tissue cellularity
 - tumors -> higher cellular density -> lower ADC (Apparent Diffusion Coefficient)
- Extensively studied at high field (>=1.5T)
 - may be an early imaging biomarker for tumor response to treatment



Ongoing project – DWI imaging

(1)





(2)



recurrence



Geometric Distortions of Conventional EPI-based Diffusion MRI





Summary

- MRI offers superior soft-tissue contrast for MRgRT
- Low field MRI has its potentials and advantages for a MRgRT system
- Real-time MRI provides effective methods for motion management for RT
- MRI-guided adaptive: a new RT paradigm?
 - Functional imaging in assessment of treatment response
- Comprehensive MRI acquisition: different MRI pulse sequences







