Introduction of MRgRT: What, How and Why?

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AAPM, Tu-MW 301-1, July 16th, 2019

Inter-fraction anatomic changes:

Problems in current CT/CBCT-based IGRT

- Insufficient image quality
  - Lack of soft-tissue contrast
  - Incapable of visualizing tumor
  - Only can see organ/anatomy so far
- Incapable of assessing treatment response during the course of RT delivery
  - Lack of functional/biologic information

MRI
Why MRI-guided RT

- Better image quality (high SNR, soft tissue contrast)
- No imaging dose
- Possible fast imaging
- Able to provide all anatomy and biological data
- Real-time imaging (intrafraction motion)
  - Treat the patient simultaneously while being imaged by MRI
- Capable of online adaptive planning
- Possible adaptation based on treatment response

Cont......Why MRgRT?

High soft tissue contrast improves:
- target/OAR delineation
- auto-segmentation
- Deformable registration
- Workflow and throughput

Motion management with real-time MRI reduces:
- margins account for motion and delineation uncertainty

High-field MRI allows:
- Adaptation based on tumor and/or normal tissue responses

Integrated MRgRT systems

- ViewRay (0.35T, Co-60 or 6MV Linac)
- Elekta Unity MR-Linac (1.5T, 7MV)
- Aurora RT MR-Linac (Edmonton) (0.5T, 6MV)
- Australian MR-Linac (1.0T, 6MV)
**ViewRay MR-Linac system**

- **RT components:**
  - Un-flattened nominal 6MV beam
  - Double stack double focused 138 leaf MLC

- **MRI components:**
  - Split superconducting MRI (0.345 T)
  - 50cm FOV with 70cm bore size
  - Imaging isocenter matches with RT system
  - Zero boil-off

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**ViewRay: Real-Time Motion Management**

- Revolutionary targeting accuracy
- What you see is what you get
  - 4 Frames per second
  - bSSFP sequence (T2/T1) weighting
  - Imaging a single sagittal plane (you choose the plane)
  - Future: 8 frames per second (FDA cleared, not yet installed for any customer)

Courtesy James Lamb, UCLA

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**Clinical uses of ViewRay systems**

- **Clinical uses:**
  - > 5 years
  - 4500 patients
  - 6500 on-table adaptation fractions
  - 50 disease sites

Courtesy Yingli Yang
**Elekta Unity MRI-Linac**

**Fully integrated three subsystems**
- State of the art radiotherapy delivery system
  - Linac rotates around the MRI magnet
  - Modified to make it compatible with the MR environment
  - Delivery of radiotherapy conformal to MRI-defined anatomy
- 1.5T MRI system
  - Modified to make it compatible with Linac based radiotherapy
  - 3D/4D pre-treatment MRI, 2D/3D beam-on MRI
- Real-time and Online adaptive workflow
  - Real-time motion management
  - Online adaptive replanning

**Specially designed MR magnet**
- Designed to maintain normal 1.5T operation in the imaging volume
- Minimize material in the beam path and ensure it is homogeneous
- Minimize magnetic field at the Linac
- Built using ‘normal’ process to ensure manufacturability and reliability

**Electron Return Effect (ERE)**

Cross plane beam profiles: measurements vs. beam model


Technical note: Dose effects of 1.5T transverse magnetic field on tissue interfaces in MRI-guided radiotherapy.

Chen X, Pitar P, Chen Y, Schultz C, Li XA.

Dose difference maps w/o 1.5T

Dose effect of 1.5T can be substantially reduced or eliminated, by including B-field in plan optimization, resulting in no deterioration in plan quality.
Clinical highlights
From Aug 2018 – June 2019

>230 patients completed treatment
>50% SBRT adoption
16 min minimum session time
12 different indications treated

For internal use only.

11 Unity machines in clinical operation

Unity @ F-MCW

Pancreas

Arterial T1-weighted Resectable
Arterial T1-weighted Unresectable
DWR
Motions: respiration and peristalsis in abdomen

Oct 10, 2017
Starting imaging patients

1st patient

Prostate: Pre-Beam and Beam-On
Pancreatic adenocarcinoma, 5x6.6Gy SBRT, daily 4D MRI, adapt to shape, beam-on motion monitoring, started treating on March 22, 2019.
**Daily 4DMRI**

- Motion Averaged
- Mid Position
- Respiratory Binned

**Adapt to Shape: Contour editing**

- Motion Averaged 4D
- Respiration triggered 3D T2
Parallel contour editing

- MR Philips control
- MD MIM
- Phys MIM
- RTT MIM
- Monaco
- Online

- Image Reg
- Contour Identification
- Contour Initialization
- Editing CTV/CTV
- Editing OAR inside
- Editing OARs
- Editing bone
- External contour
- Identifying air
- Checking Syn CT

Time reduction >50%

Paulson E, Ahunbay E, Chen X, Erickson B, Hall W, Li XA, presenting at ASTRO 2019.

Case A: Pancreas / Ref vs daily plans

Sample case: Pancreas: Pre-beam motion adaptation
RADIATION ONCOLOGY

QA: ArtQA software

Planning CT/MRI
Offline Monaco
Check of plan integrity & data transfer
Check of delivery parameters from log file

Online Monaco & TSM

Mosaiq & Unity

dose calc considering 1.5T

Pre-Tx QA

Post-Tx QA

Planning CT/MRI

QA: ArtQA software

ArtQA: Pre-Tx 30 sec

Sample case: Pancreas / beam-on cine
Post-Treatment IMRT QA

Post-Tx dose reconstruction

Daily DWI

Changes of ADC during RT (SBRT, 5 fr)

NCT03500081, STIM, Bill Hal, PI
Sample case /GBM: / Daily (fx 4) image + plan

WHO Grade IV GBM, Initial RT 23x2Gy=46Gy, boost 30x2Gy=60Gy
Daily T1 and FLAIR, Adapt to Position. On-table time 28 min, started treating on 2/20/2019

Sample case /GBM: Weekly quantitative Panel

Ktrans kep T1 Map T2 Map ADC Dslow (IVIM)

Courtesy of John Christodouleas
Response-guided adaptive dose painting

T1
T2
DWI

Tumor definition

Dose prescription
Plan
Treat

Adopted from: Uulke van der Heide

Different PTV expansions into duodenum from pancreatic tumor, yellow represents a tighter PTV volume enabled by real-time MRI utilization

Hall et al, EJC 2019

Pancreatic cancer RT

Not just an IGRT
Disruptive Innovation

• Improve tumor definition and characterization and management of motion and response, leading to adaptive dose painting, increasing local control.
• Improve OAR definition, better avoidance, decreasing toxicities.
• More SBRT, hypofractionation, ablative RT, transferring the success of SBRT for lung and liver to other tumor sites.
• Online planning and real-time image guided dose delivery, making RT as an intervention.
• Replace surgery with radiotherapy for more situations.
• More affordable RT

• Re-define RT (margin, fractionation, dose homogeneity, tumor heterogeneity, response-based adaptation, …)
  ➢ Varying daily radiation dose based on tumor/OAR location
  ➢ Varying total radiation dose based on early response assessment during treatment by MR
  ➢ Adjusting therapy during treatment based on early markers of disease response
  ➢ Monitoring normal tissue damage during RT from MR changes
• Possibility to treat novel diseases (e.g. kidney, cardiac)
Acknowledgements

F-MCW Unity Clinical Team

MRgRT research team

Adaptive Radiation Therapy Program

MCW Radiation Oncologists
W. Hall, B. Erickson, C. Lawton, M. Straza, M. Awan, A. Currey, E. Gore

Funding Supports:
Elekta, Siemens, Manteia, Fotsch

Paul Knechtges, MD
Kiyoko Oshima, MD
Entesar Dalah, Ph.D
Mei Feng, MD
Hui Wu, MD
Wei Huang, MD
Dingjie Li
Taly Schmidt, Ph.D
Cheng Zheng, Ph.D
H Zhong
P. Prior
Y. Liang
A. Amjad