MRI-Guided Tracking and Gating

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Disclosures

- Honoraria and travel grants from ViewRay, Inc.

Learning Objectives

- Currently and soon-to-be available MRI-guided systems
- Clinical workflow for MRI-guided tracking and gating
- Limitations of MRI-guided tracking and gating
- Quality assurance for gating process on MR-IGRT systems

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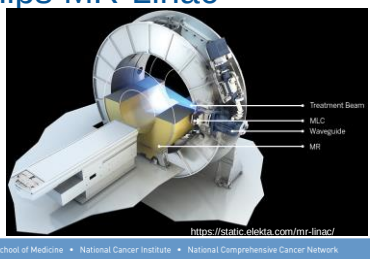
Elekta-Philips MR-Linac

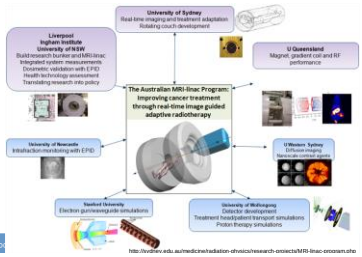
- 1.5 Tesla
- 6-MV linac
- Installed at Uttrecht (Netherlands) and MD Anderson
- Not yet clinical



https://static.elekta.com/mr-linac/

The Australian MRI-Linac

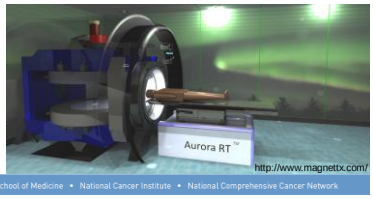
- 1.0 Tesla
- 6-MV linac
- Not commercial
- Not yet clinical



http://sydney.edu.au/medicine/radiation-physics/research-projects/MRI-linac-program.php

MagnetTx Aurora-RT

- 0.5 Tesla
- 6-MV linac
- Developed at Cross Cancer Center, Canada
- Not yet clinical



http://www.magnettx.com/

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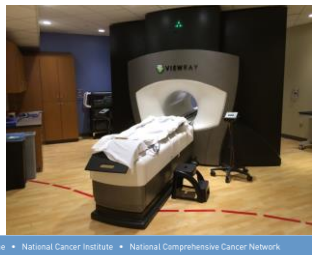
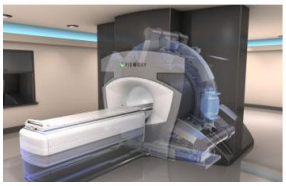
ViewRay MRIdian

- 0.35 Tesla
- Co-60 x 3
- First clinical use in January of 2014
- 6 centers world-wide currently treating patients



ViewRay MRIdian

- Pneumatic system for source motion
- 30 pairs of tungsten MLC leaves under each source
- 4 frames per second in the sagittal frame
- Up to 50 cm field of view
- True Fast Imaging with Steady State Free Precession (TRUFI) sequence
- Volumetric scans from 17 sec to 3 min depending of field of view and resolution



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Clinical Workflow

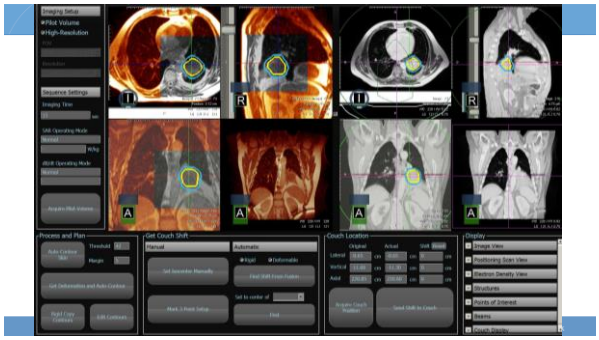
- Patient identification
  - Necessity for MRI guidance
    - Large (>2 cm) tumor motion
    - Online adaptation with subsequent gating
    - SBRT for anatomy otherwise poorly visualized on CBCT or on-board fluoroscopy
    - Inability to have fiducial markers inserted
  - MRI clearance via questionnaire and medical history
- Simulation
  - CT image dataset for accurate electron density
    - MRI-only is an option for non-adaptive cases
  - MRI dataset acquired on MR-IGRT system
    - Evaluation of tumor visualization and tracking accuracy
    - Primary image in treatment planning

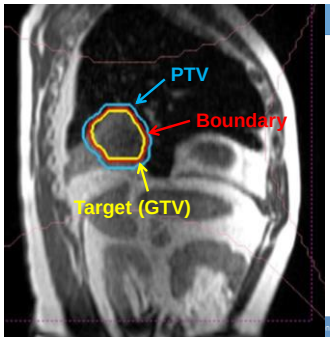
Clinical Workflow

- Treatment planning
  - ITV may not be necessary depending on approach
    - Breath-hold: inhale breath-hold scan, treatment only during inhale breath hold, continuous patient coaching
    - Exhale-phase gating: exhale breath-hold scan, treatment with patient breathing freely, system used to gate on exhale phase
    - Free-breathing: ITV necessary (caution!)
  - Determination of approach should be made prior to simulation

Clinical Workflow

- Pre-treatment
  - Volumetric MRI scan under appropriate conditions
    - Inhale breath-hold
    - Exhale breath-hold
    - Free-breathing
  - Patient alignment
  - Selection of sagittal slice for gating
  - Preview of tracking accuracy and efficiency
- Treatment with tracking and gating





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- Target
  - Region of anatomy to be tracked
  - May be GTV or drawn from scratch at time of patient pre-treatment setup
- Boundary
  - Numerical expansion of the target
  - PTV (caution!)
- User-selected parameters
  - Region of Interest (ROI)
    - Percent area of target outside boundary
  - Delay time
    - Amount of time target can be outside boundary

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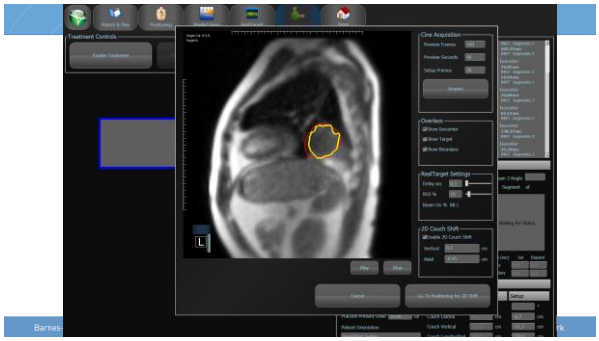
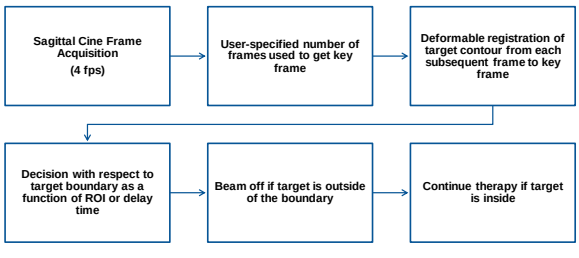
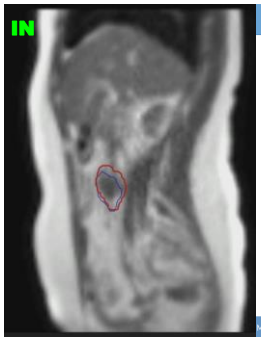



Sagittal Cine Frame Acquisition (4 fps)
User-specified number of frames used to get key frame
Deformable registration of target contour from each subsequent frame to key frame
Decision with respect to target boundary as a function of ROI or delay time
Beam off if target is outside of the boundary
Continue therapy if target is inside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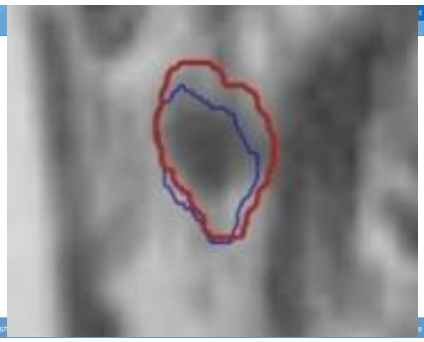

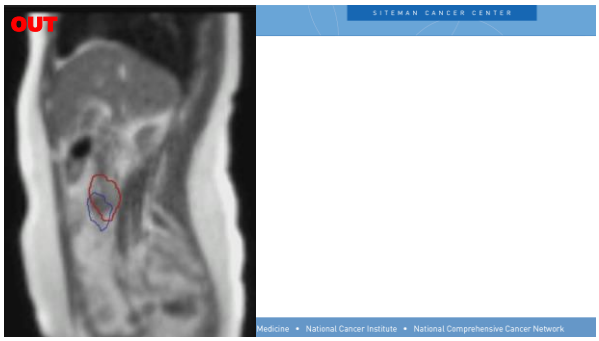
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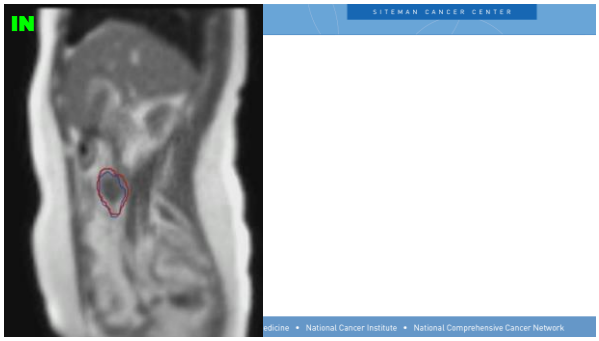
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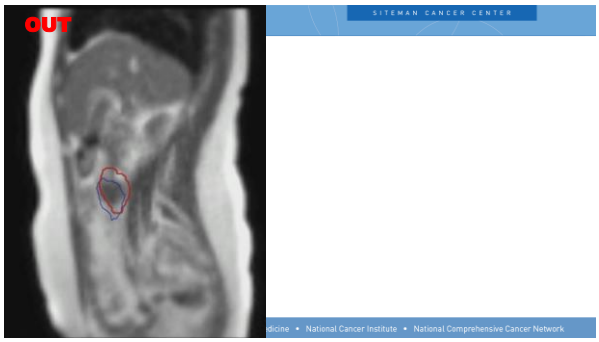
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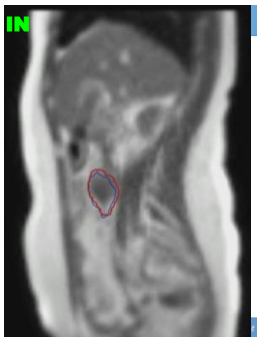

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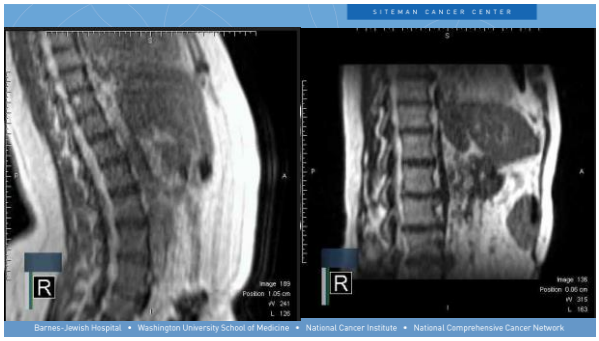
Limitations

- Organ motion is not simple
  - While majority of motion is in the superior-inferior direction, both motion and deformation can go out of plane
  - Volumetric imaging will be available on future systems, but currently only the sagittal plane is clinically used
  - Tracking accuracy must be carefully evaluated when several sources of motion are observed in vicinity of target
    - Cardiac motion
    - Fluids pumping

Limitations

- A high-quality pre-treatment image is key
  - Key frame selection depends on it
  - Target contour should be delineated to an accuracy at least corresponding to the resolution of the image
- Not all patients are able to hold their breath for even 17 seconds
  - MRI navigators or bellows systems may be used, but these have limitations similar to 4DCT (i.e., not "real") and may take a long time to acquire



Limitations

- Treatment efficiency
  - Inhale breath-hold: depends on patient's ability
  - Free-breathing end-exhale: depends on
    - breathing pattern
    - organ motion
    - Average duty cycles of 85% since February of 2015

Limitations

- System latency
  - 4 frames per second means each image takes 250 milliseconds to acquire
    - Already half the recommended maximum latency (AAPM TG-76)
  - There will always be additional processing time and radiation beam termination time
    - For Co-60: source transit time
- Tracking accuracy
  - No deformable registration algorithm is perfect
    - supervision is still important during delivery
    - post-treatment analysis may need to be done to optimize the next fraction

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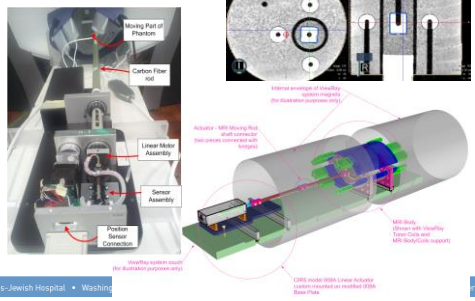
MR-IGRT Quality Assurance

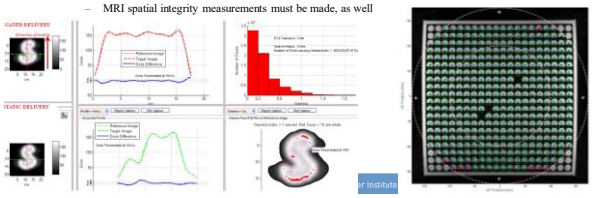
- Key issues
  - What sort of phantom to use?
    - There are no surrogates or fiducials
    - Tracking accuracy depends on image quality which in turn depends on composition of matter being scanned
      - A homogeneous water phantom is not equivalent to any relevant part of a patient's anatomy
  - How to set appropriate boundary?
    - Latency
    - Imaging resolution
    - Tracking accuracy

CIRS Motion Phantom for MRI



MR-IGRT Quality Assurance

- Dosimetric and spatial accuracy
  - Ionization chamber measurements allow evaluation of dosimetric effect of latency
  - Film measurements allow evaluation of spatial effect of latency and tracking accuracy
  - MRI spatial integrity measurements must be made, as well



Summary

- MRI allows real-time, real-anatomy tracking that has the potential for greater accuracy and efficacy of treatment
- Workflow and planning issues specific to MRI guidance must be considered and their mitigation planned for prior to patient treatment

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