State of the ART

*High Tesla MRgART*

Dan Hyer, PhD
Associate Professor
COI

• License revenue from IBA
• Consulting for Elekta
Agenda

• Technology overview
• Implementation timeline
  – Construction
  – Installation
  – Commissioning
• Workflow overview at our site
• How are we using the Unity
  – Statistics on what kind of cases we have treated
  – Case highlight
• Treatment throughput and machine reliability
TECHNOLOGY OVERVIEW
Commercial Implementations

- **Elekta Unity**: $B_{\text{field}} = 1.5 \, T$  
  $E = 7 \, MV$
- **Viewray MRIdian**: $B_{\text{field}} = 0.35 \, T$  
  $E = 6 \, MV$
- **MagnetTx Aurora RT**: $B_{\text{field}} = 0.5 \, T$  
  $E = 6 \, MV$

FDA 510k cleared
FDA 510k pending
Unity overview

- Beam Energy: **7 MV FFF**
- SAD: **143.5 cm**
- Maximum Field Size: **22x57.4 cm²**
- Treatment Delivery: **Step & Shoot IMRT**
- Dose Rate: **425 MU/min**
- Max Gantry Speed: **6 RPM**
- Leaf Speed: **6 cm/s**
- Collimator: **90°**
IMPLEMENTATION TIMELINE

Construction: ~6 months (Highly Variable)
Installation: ~6 months (~3 months for new installations)
Commissioning/training: ~3 months
Implementation timeline

- Aug
- Sep
- Oct
- Nov
- Dec
- Jan
- Feb
- Mar
- Apr
- May

2018

2019

[Images of various stages of a project, from August to May, with a team photo in May.]
MV isocenter, MR-MV alignment

COMMISSIONING: MECHANICALS
• Need to add copper plates to eliminate ERE
• Analyze spokes only within the central region
Radius of circle encompassing all intersections: 0.8 mm
Average distance to circle center = 0.5 mm
MR-MV alignment

- MRI and gantry are mechanically aligned during installation
- Any offset between the systems needs to be quantified and accounted for during treatment planning
MR-MV alignment phantom

• Alignment evaluated using the MR-MV isocenter phantom
  – 7 ZrO₂ spheres in a known geometry surrounded by copper sulfate solution
• EPID and MRI images are acquired without moving the phantom
• Analyzed using QA alignment software
  – 0.307 mm (lat), 0.998 mm (sup/inf), 0.015 mm (ant/post)
Absolute dose calibration

COMMISSIONING: DOSIMETRY
Dose calibration methodology

- Followed TG-51 formalism with modifications by Malkov et al\textsuperscript{1}

\[ D^Q_{W} = M k_Q k_B N_{D,W}^{60Co} \]

- Due to extended SAD, beam quality specifier was $TPR_{20,10}$
  - TG-51 requires $\%dd(10)_x$ for $k_Q$ determination
  - Conversion following the formalism of Kalach et al\textsuperscript{2}

- $K_B$ factor accounts for changes in chamber response due to the magnetic field
  - TN30013 chamber aligned parallel with the magnetic field
    - 0.994 (O’Brien et al)\textsuperscript{3}
    - 0.988 (Malkov et al)\textsuperscript{1}

- Output measured at 90° to remove dependence due to varying helium level

\textsuperscript{1} Malkov V N and Rogers D W O 2018 Monte Carlo study of ionization chamber magnetic field correction factors as a function of angle and beam quality Medical Physics 45 908-28
\textsuperscript{2} Kalach N I and Rogers D W 2003 Which accelerator photon beams are "clinic-like" for reference dosimetry purposes? Med Phys 30 1546-55
\textsuperscript{3} O’Brien D J, Roberts D A, Ibbott G S and Sawakuchi G O 2016 Reference dosimetry in magnetic fields: formalism and ionization chamber correction factors Med Phys 43 4915
Dose calibration validation

• Independent validation performed with UW Calibration Lab TLDs

• Construction of probes
  – 4 TLDs embedded in a solid water phantom with minimal air-gaps

• Result: 0.991 ± 5%
Geometric accuracy

MRI COMMISSIONING
Geometric accuracy

• Assessed using the vendor supplied 3D geometry phantom
  – Markers in 7 planes
    • 25 mm in-plane spacing
    • 55 mm plane spacing
  – Overall size
    • 500x375x330 mm³
Geometric accuracy – results

- Geometric accuracy is assessed within variable diameter spherical volumes

<table>
<thead>
<tr>
<th>Maximum distortion (mm) – Excluding 2% of markers with greatest values</th>
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<tbody>
<tr>
<td></td>
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<tr>
<td>------------------</td>
</tr>
<tr>
<td>Total</td>
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<tr>
<td>RL</td>
</tr>
<tr>
<td>AP</td>
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<td>FH</td>
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Distortion map for 350 mm DSV
ADAPTIVE THERAPY WORKFLOW
Workflow overview

Simulation CT images

Simulation MR images

Online treatment planning system

Adapted treatment plan

Reference contours and plan

Daily images

CT MRI

MR-Linac

Offline treatment planning system
Online treatment process

- Setup and image patient
- Register daily and planning datasets
- Re-contour and re-plan as needed
- Motion monitoring (3-planes) and radiation delivery

1 Physician
1 Physicist
2 RTT techs
Understanding the adaptive planning process

• Adapt to position
  – MLC position is shifted to account for daily setup errors
  – Plan is re-calculated with new MLC positions
    • No new contours are drawn!

• Adapt to shape
  – New contours are drawn to account for anatomical changes
  – Plan is re-optimized and re-calculated
Standard linac: Table shift
MRI linac: Adapt to Position
MRI linac: Adapt to Position
Adapt to shape: Adapted contours

- Prostate
- Seminal Vesicles
- Bladder
- Rectum
- Body
- Bone
Statistics and case highlights

HOW ARE WE USING THE UNITY?
Case highlight: Liver

• Potential benefits
  – Visualizing tumor
    • Far superior to CBCT
  – Visualizing adjacent OAR’s
    • Adapt plan if position of OAR’s change throughout treatment to achieve ablative doses
    • 3 fx RX: 45-60 Gy, Limit to bowel is 35 Gy

• Challenges
  – Motion
    • Typically can use abdominal compression to reduce motion
Standard planning strategy

• Unity
  – HCC: 45 Gy / 3fx
  – Mets: 54-60 Gy / 3 fx
  – 3-5 mm PTV around ITV
    • 8-10 mm with KV imaging
  – 11 coplanar beams
  – Step and shoot IMRT

• Unity imaging
  – T2 navigator triggered MRI
Standard of care – CBCT

Hard to visualize target
Original contours

Electron densities are overridden on structures that may be overlapped

GTV
Liver
Kidneys
Stomach
Great Vessel
Cord
Body
Bone
Adapted contours

Electron densities are overridden on structures that may be overlapped

GTV
Liver
Kidneys
Stomach
Great Vessel
Cord
Body
Bone
Treatment throughput and uptime

MR-LINAC
Planning and review time

Included
- Registration
- Contouring (if needed)
- Plan optimization
- Plan approval
- Second check

Not Included
- Patient ingress/egress
- Image acquisition
- Treatment delivery

Slide from David Dunkerley, PhD
# Machine uptime

<table>
<thead>
<tr>
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<th>Versa A</th>
<th>Versa B</th>
<th>Unity</th>
<th>GammaKnife</th>
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<td>5/20/2019</td>
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<td>3514</td>
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<td><strong>Up-Time [%]</strong></td>
<td>99.55%</td>
<td>98.21%</td>
<td>98.52%</td>
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Thanks!