Clinical approaches, experiences and lessons learned from a large SBRT program

Grace Tang, PhD
Department of Medical Physics
Memorial Sloan Kettering Cancer Center

AAPM annual meeting 2020
About me

• No conflict of interest
About MSKCC

- Eight locations/sites across New York and New Jersey
- Total number of linacs = 29+
  - 22 TrueBeams
    - 1 HD MLC
  - 7 C-series
  - 1 MR linac (Elekta Unity)
- 1 ExacTrac
- 2 Calypso
- 18 AlignRT
- All TBs have 6DOF couch except 2 machines with Calypso
Overview of SBRT at MSKCC

• Wide range of disease sites
  ➢ Brain, lung, GI, prostate, paraspinal

• Intrafractional motion management strategies
  ➢ Treatment techniques
    ❖ Respiratory gating
      o Limited
    ❖ Compression
    ❖ Deep inspiration breath-hold (DIBH, most frequently used)
      o Can be reliable if patient can tolerate
  ➢ Monitoring techniques
    ❖ 2D kV imaging
    ❖ ExacTrac
    ❖ Calypso
    ❖ Intrafractional motion review (IMR)
    ❖ Simultaneous MV/kV imaging (in-house)
## Intrafractional motion monitoring for SBRT

<table>
<thead>
<tr>
<th></th>
<th>Motion monitoring method</th>
<th>Matching structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>SBRT paraspinal/bone</td>
<td>ExacTrac IMR</td>
<td>Hardware (if available) Anterior of vertebral body</td>
</tr>
<tr>
<td>SBRT prostate</td>
<td>MV/kV IMR 2D kV</td>
<td>Fiducials</td>
</tr>
<tr>
<td>SBRT lung</td>
<td>Calypso 2D kV</td>
<td>Beacons/fiducials</td>
</tr>
<tr>
<td>Ablative/SBRT GI</td>
<td>IMR 2D kV</td>
<td>Fiducials/stent</td>
</tr>
</tbody>
</table>
2D kV imaging

- Only on non-TrueBeams
- kV pairs during treatment
  - Every other partial or full arc for VMAT
  - Every other gantry angle for IMRT
- Manually match on structure by therapists
  - Shift if needed
- Not very efficient
ExacTrac

- A pair of kV imaging units (sources “on” the floor and imagers mounted on the ceiling)
- kV images auto-matched to images created from planning CT
- Provides 6DOF shift
- At MSK
  - Manually trigger of kV imaging
    - No fixed number of triggers, approximately 1-2 times per arc/between gantry angles at therapists’ discretion
  - Relative monitoring only (not used for setup)
  - No automatic beam-hold
ExacTrac and paraspinal

- N = 1019 treatment sessions
  - 194 patients
- Rx
  - 24 Gy × 1
  - 9-10 Gy × 3
  - 6 Gy × 5
- All sim’ed with myelogram unless contraindicated
  - MRI can be used instead of myelogram
- Immobilization: CDR
- Initial setup: CBCT
- Intrafractional motion monitoring: ExacTrac
  - ~3-5 image pairs triggered per tx session
  - Stop tx when x/y/z > 2 mm or rotation >1.5°
  - CBCT re-acquired and couch shifted
- > 2 mm shift occurred in 6 out of 1019 treatment sessions (~0.6%)
  - All shifts occurred in second half of the treatment sessions
- While >2 mm shift occurrence appears to be low, it does happen and does not seem to be predictable

<table>
<thead>
<tr>
<th>Patient</th>
<th>Treatment time (min)</th>
<th>Time to correction (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td># 1: Single fraction</td>
<td>38.9</td>
<td>30.7</td>
</tr>
<tr>
<td># 2: Fraction 2 of 5</td>
<td>26.5</td>
<td>22.7</td>
</tr>
<tr>
<td># 2: Fraction 5 of 5</td>
<td>12.3</td>
<td>9.9</td>
</tr>
<tr>
<td># 3: Fraction 3 of 5</td>
<td>31.9</td>
<td>23.8</td>
</tr>
<tr>
<td># 4: Single fraction</td>
<td>38.1</td>
<td>25.4</td>
</tr>
<tr>
<td># 5: Fraction 3 of 5</td>
<td>23.4</td>
<td>12.6</td>
</tr>
</tbody>
</table>

Frequency of large intrafractional target motions during spine stereotactic body radiation therapy. Wu et al. Practical radiation oncology 2020 (10) e45-49
Intrafractional motion review (IMR)

- Varian TrueBeams (v2.7 MR3)
- 2D kV imaging
- Imaging trigger can be based on time, MU, gantry angle or RPM gating (start or end of gate)
- Matching based on fiducials or bony structures
  - Typically with a 2 mm margin
  - No matching done on soft tissue
- Therapist monitors matching and interrupt treatment if
  - Matching is significantly off on a single image
  - Matching is about 1-2 mm off on a few successive images

<table>
<thead>
<tr>
<th>IMR trigger settings for SBRT tx</th>
</tr>
</thead>
<tbody>
<tr>
<td>VMAT</td>
</tr>
</tbody>
</table>
| IMRT                      | Non-FFF: every 200 MU  
                          | 6FFF: every 300-500 MU |
IMR and GI

- N = 8 patients
- VMAT with DIBH using RPM (gating window: 3 mm)
- Fiducials (i.e. marker, clips, stents)
- IMR triggered every 20º- 40º
- Based on over 5000 IMR images, relative from initial CBCT setup, fiducial displacement (sup-inf)
  - < 3 mm, 78.5% of the time
  - < 5 mm, 90.1% of the time
  - > 1 cm, 0.6% of the time
  - Average 0.6 mm, Std 2.9 mm
- Demonstrates residual motion within gating window
  - Random
  - Internal motion ≠ external motion

![Histogram of the tumor displacements relative to the initial position determined at the beginning of each fraction for all patients.](image)

IMR and paraspinal

- No preferential motion axis
- IMRT/VMAT
  - Usually all posterior beams/arcs
- IMR may miss motion in certain axes, e.g. ant-post
Simultaneous MV/kV imaging at MSK

- MV images and kV images are acquired simultaneously during treatment.
- Treatment plan is post-processed to add imaging control points:
  - Minimum added dose
  - May renormalize plan if needed
  - Matching template created every 20 degrees

- Acquired MV and kV images are transferred to in-house software (Sequence Reg) for analysis via iTools Capture.
- Instantaneous analysis done online.
- Auto-registration on markers.

Simultaneous MV-kV imaging for intrafractional motion management during volumetric modulated arc therapy delivery. Hunt et al. 2015. JACMP 17(2) pp473-486.
Simultaneous MV/kV imaging and prostate

• Alarm triggered when >1.5 mm shift is recorded for two consecutive control points
• Occurs ~1.2 times per patient on average
• MV/kV pair acquired to confirm
  ➢ Similar shift observed unless patient drastically changes breathing pattern
  ➢ Shift patients based on MV/kV pair
In development: markerless MV/kV

- Varian MRA project (PIs: Tianfang Li, Xiang Li, Perry Zhang)
- Simultaneous MV and kV image acquisition during paraspinal treatment
- MV images are accumulated over the sliding window delivery until a bony structure is visible in the image
In development: markerless MV/kV

- kV images are taken at a frequency based on the MV image accumulation
- Acquired images are transferred to an in-house software for analysis via iTools Capture
- Preliminary phantom study shows matching accuracy of <0.5 mm
- To further improve robustness, machine learning-based algorithm is in investigation for image registration

AAPM 2020: ePoster
Markerless Motion Tracking with Treatment Beam Imaging in Spine SBRT Treatment: A Phantom Study. Li et al
Calypso

- Non-ionizing radiation
- Automatic beam-hold
- Continuous target motion monitoring
- “Direct” tumor motion
- Implant with 2-3 beacons
- At MSK
  - Not used for GI/prostate
  - Two lung protocols
    - DIBH
      - Only eligible for patients capable of at least 5 breath-holds, with more than 20 seconds for each breath-hold
    - Free-breathing
      - Gate at end-expiration
<table>
<thead>
<tr>
<th>Frequency</th>
<th>Test</th>
<th>Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily</td>
<td>Laser localization — only if using SRS techniques relying on lasers for target localization (e.g., frame-based SRS without X-ray IGRT)</td>
<td>1 mm</td>
</tr>
<tr>
<td></td>
<td>Collimator size indicator for clinically relevant aperture</td>
<td>2 mm total</td>
</tr>
<tr>
<td></td>
<td>Radiation isocentricity test (limited gantry and couch positions) — maximum deviation in center of target object relative to each projection's beam central axis</td>
<td>1.0 mm SRS, 1.5 mm SBRT</td>
</tr>
<tr>
<td></td>
<td>IGRT positioning/repositioning</td>
<td>1 mm SRS, 2 mm SBRT</td>
</tr>
<tr>
<td></td>
<td>Imaging subsystem interlocks</td>
<td>Functional</td>
</tr>
<tr>
<td></td>
<td>Stereotactic interlocks — cone size, backup jaws</td>
<td>Functional</td>
</tr>
<tr>
<td></td>
<td>Accelerator output constancy</td>
<td>±3%</td>
</tr>
<tr>
<td>Monthly</td>
<td>Radiation isocentricity test — covering complete range of gantry, couch, collimator positions used clinically — maximum deviation in center of target object relative to each projection's beam central axis *Note: If both MLC and fixed conical collimators are used, both must be evaluated at least monthly</td>
<td>1.0 mm SRS, 1.5 mm SBRT</td>
</tr>
<tr>
<td></td>
<td>Treatment couch position indicators: relative over the maximum clinical range</td>
<td>1 mm/0.5°</td>
</tr>
<tr>
<td></td>
<td>Output constancy at relevant dose rates</td>
<td>2%</td>
</tr>
<tr>
<td>Annually</td>
<td>SRS arc rotation mode (if used clinically)</td>
<td>1 MU, 1°</td>
</tr>
<tr>
<td></td>
<td>MU linearity (≥5 MU to highest MU used clinically)</td>
<td>±2%</td>
</tr>
<tr>
<td></td>
<td>Accelerator output</td>
<td>±1.5%</td>
</tr>
<tr>
<td></td>
<td>Coincidence of radiation and mechanical isocenter</td>
<td>±1.0 mm maximum 3-D displacement from center of target object</td>
</tr>
<tr>
<td></td>
<td>Verification of small-field beam data — relative output factors for cones and/or MLC</td>
<td>±2% from baseline for &gt;1.0 cm apertures, ±5% from baseline for ≤1.0 cm apertures</td>
</tr>
<tr>
<td></td>
<td>E2E localization assessment “hidden target test” using SRS frame and/or IGRT system</td>
<td>1.0 mm</td>
</tr>
<tr>
<td></td>
<td>E2E dosimetric evaluation using SRS frame and/or IGRT system</td>
<td>±5% measured vs. calculated</td>
</tr>
</tbody>
</table>
Acknowledgement

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