Part 2: Motion management for pancreatic radiotherapy
Monitoring, mitigation, and impact of intrafraction tumor motion

Bernard (Tripp) Jones, Ph.D.

University of Colorado Anschutz Medical Campus
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- **Conflicts of Interest**
kV monitoring during pancreatic SBRT

- Periodic monitoring of tumor position
- Using the on-board kV imager
  - Tumor or surrogate must be visible on kV
- Goal: understand how to establish a kV monitoring program
  - Requires careful coordination between simulation, planning, pre-treatment setup, and monitoring!
Pancreatic SBRT

- **Clinical rationale for dose escalation**
  - More dose improves local control but increases toxicity

- **Motion inhibits escalation**
  - Difficult to mitigate
  - 4DCT underestimates pancreatic tumor motion
  - Increased dose to bowel

*Jones et al, Green Journal 2014*

*Brunner et al, Green Journal 2015*
Treatment and Motion

- CBCT projection images from two patients
  - Some patients show consistent breathing
- Patients with inconsistent breathing are much harder to treat
- Respiratory gating reduces motion
  - 5 mm average motion range
  - Still high
Triggered imaging and Panc SBRT

- Images taken with on-board kV imager
  - It’s OK that imaging axis and treatment axis are different
  - Majority of motion is in the head-toe direction (fully sampled)
  - Arc delivery – any shifts will be detected a max of 90\(^\circ\) later
- Soft-tissue contrast not required
  - Quickly localize the fiducials
Implementing a kV monitoring program: Major considerations
Choosing a surrogate

- Must be visible on kV imaging
  - High-contrast – quickly visible
  - Not soft-tissue based

- Gold fiducial markers
  - 3+ markers implanted 1-2 weeks prior to simulation
    - Impact of migration small

- Surrogates for other tumor sites
  - Lung tumor
    - Not visible from all angles
  - Diaphragm
    - Useful for liver or inferior lung tumors
Establish a reference position
- What is the timing of kV monitoring?
- Capture the surrogate position at a time point corresponding to kV monitoring

Other motion management concerns
- If gating, match plan CT to treatment position

Our workflow
- End-exhale breath hold planning CT
  - High-quality image for contouring
  - Pre-treatment setup using breath hold CBCT
  - Treatment with end-exhale gating
- 4DCT
  - Determine respiratory gating thresholds
  - Contour fiducial markers at 30% phase (when kV imaging occurs)
    - Reference location for kV monitoring
Initial patient setup

AP Fluoro
- See entire motion range
- Set longitudinal shift accurately
  - Allows for detection of bad breath hold

Exhale breath-hold CBCT
- Coached and controlled by therapists
- Excellent image quality, soft tissue contrast
- Align to fiducials
kV Monitoring - Workflow

- **Baseline drift** – images are taken too early (or too late)
  - Pause - Adjust amplitude gating thresholds
- **Tumor shift** – target moves from tx location
  - Shift - Re-localize target

![Image showing treatment window, Max Exhale, Ref Pos 30%, Max Inhale, Correct, Baseline drift, Tumor shift]
Causes of error

- What to do when fiducial markers are observed outside the expected location?
  - Cause #1: Image was taken at the wrong time
  - Cause #2: Tumor has shifted
Cause #1: Image taken at the wrong time

- Respiratory baseline drift
- Changes to the breathing trace can change the timing of imaging
- Can be caused by physical changes or an artifact of the breathing monitoring system
- To fix: pause treatment, reset breathing monitoring system, or adjust gating thresholds

1. Baseline drift of breathing trace
2. kV monitoring occurs too early (or too late)
3. Treatment window becomes too wide

Cause #2: Tumor has shifted

- Can be due to
  - Gross patient shifts
  - Changes in respiratory pattern
  - Internal motion
    - Small bowel changes
    - ~1 cm interfraction shifts are common

- To fix:
  - 2D->3D shifts using kV monitoring image
  - re-do initial setup imaging
    - Fluoro, CBCT
QA of kV monitoring

- Not a recommendation, just my experience
- Commissioning
  - End-to-end test with a moving phantom
    - We used a 3D programmable motion platform, phantom with OSLD inserts
    - Also possible – phantom with repetitive motion and imaging features on kV
- Periodic QA
  - kV imaging accuracy
    - Covered by daily imaging QA
  - Gating system
    - Covered by monthly QA of gating system
What is the benefit?
Pilot study

- What is the impact of kV monitoring on
  - Clinical workflow?
  - Treatment accuracy?
  - Tumor dose?

- 68 pancreatic SBRT patients
- Chart review of all in-treatment imaging actions
  - Pauses to adjust for breathing
  - Shifts to adjust for motion

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<th>Cohort</th>
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<tr>
<td>All Patients</td>
<td>68</td>
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<tr>
<td>Gating</td>
<td>53 (78%)</td>
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<tr>
<td>Compression</td>
<td>15 (22%)</td>
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<table>
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<tr>
<th></th>
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<tr>
<td>Dose per Fraction</td>
<td>660 cGy</td>
<td>500 – 900 cGy</td>
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<tr>
<td>Number of Fractions</td>
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<td>3 – 5</td>
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<tr>
<td>Number of Fiducials</td>
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<td>1 – 7</td>
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<td>Treatment Time</td>
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<td>137 – 1331 s</td>
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<td>PTV Volume</td>
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<td>16 – 349 cm³</td>
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<tr>
<td>BMI</td>
<td>23</td>
<td>17 – 40</td>
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Results

- **Average “pause rate” of 0.81/fx**
  - Roughly 4 pauses total during a 5 fraction treatment
  - Pause time: $1.9 \pm 1.8$ minutes

- **Average “shift rate” of 0.32/fx**
  - 1-2 shifts per patient over 5 fractions
  - Median shift of 5.2 mm
    - Mostly in the SI direction
  - Shifts larger in longer treatments
    - 5.3 v 4.7 mm average
Dosimetric effect

- 45% of shifts resulted in dosimetric differences
  - Of these, average was 23% of rx
- Identified a potential for margin reduction
- Results tied to the fiducial contour margin
  - Shift threshold
  - 3 mm

Conclusions

- kV monitoring is feasible for pancreatic SBRT
  - Significant benefits to treatment accuracy
  - Potential dosimetric benefits

- Moderate changes in workflow
  - Small but not insignificant
  - Introduce 2-5 minute pauses

- Key workflow points
  - Identify a suitable surrogate
  - Understand timing of kV monitoring
  - Measure surrogate position during simulation
  - Not every error means tumor shift
    - Understand the impact of respiratory baseline drift
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My email: bernard.jones@cuanschutz.edu