Outline

- Intrafraction tumor motion
- Indirect motion monitoring
  - External surrogate
  - Internal surrogate (markers)
- Direct motion monitoring
- Summary

Challenge: tumors move
**Respiratory tumor motion**

<table>
<thead>
<tr>
<th>Site</th>
<th>Study</th>
<th>n</th>
<th>Normal breathing</th>
<th>Deep breathing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lung</td>
<td>Pathil et al.</td>
<td>20</td>
<td>5.3 - 14.6 / 7.6 - 16.8 / 9.5 - 14.9</td>
<td>6.4 - 12.6 / 24.6 / 9.5</td>
</tr>
<tr>
<td>Liver</td>
<td>Suramo et al.</td>
<td>30</td>
<td>25 (20-30)</td>
<td>55 (30-80)</td>
</tr>
<tr>
<td>Pancreas</td>
<td>Suramo et al.</td>
<td>50</td>
<td>20 (10-30)</td>
<td>43 (30-80)</td>
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<tr>
<td>Kidney</td>
<td>Suramo et al.</td>
<td>200</td>
<td>20 (10-40)</td>
<td>41 (20-70)</td>
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<tr>
<td>Diaphragm</td>
<td>Davies et al.</td>
<td>9</td>
<td>12/17 (7-17)</td>
<td>43/44 (25-52)</td>
</tr>
</tbody>
</table>

**Other intrafraction motion**

Fig. 3. Management of prostate displaceable motion using PROTEUS software.

**Challenge for RT simulation and treatment**

- We need to know where the tumor is for imaging, planning, and treatment
- TG-76 recommends to use motion management techniques for motion > 5mm
- We need to monitor motion
  - Indirect monitoring
    - External or internal surrogates — assume perfect surrogate/tumor motion correlation
  - Direct tumor motion monitoring
Philips Bellows pneumatic system

Varian RPM™

- Real-time position management
- Respiratory motion
- External surrogate signal
Surface image-guided RT (SIGRT)

- Non-invasive and non-ionizing imaging modality
- Compares the acquired image with a reference image
- External surrogate

C-rad's Sentinel – laser based

Current use of SGIRT in the United States

Surface Imaging


Internal fiducial tracking

- Use of IGRT
- Treatment precision depends on marker–tumour distance

Seppenwoolde et al. PMB 2011 (liver SBRT study)

Hokkaido system

Shirato et al., UROBP, 2000
• Fluoroscopy
  – Ionizing radiation
  – 30 fps

• Marker-based
  – 2mm gold marker

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<table>
<thead>
<tr>
<th>Voltage</th>
<th>Pulse width</th>
<th>Location</th>
<th>Dose rate ($10^{-6}$ Gy/min)</th>
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</thead>
<tbody>
<tr>
<td>70 kV</td>
<td>2 ms</td>
<td>Entrance</td>
<td>1.76</td>
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<tr>
<td>70 kV</td>
<td>2 ms</td>
<td>Isocenter</td>
<td>0.44</td>
</tr>
<tr>
<td>70 kV</td>
<td>2 ms</td>
<td>Exit</td>
<td>0.014</td>
</tr>
<tr>
<td>120 kV</td>
<td>4 ms</td>
<td>Entrance</td>
<td>10.8</td>
</tr>
<tr>
<td>120 kV</td>
<td>4 ms</td>
<td>Isocenter</td>
<td>5.6</td>
</tr>
<tr>
<td>120 kV</td>
<td>4 ms</td>
<td>Exit</td>
<td>0.8</td>
</tr>
</tbody>
</table>

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**Brainlab ExacTrac / Novalis**

- Internal / external
- External (IR) for continuous monitoring (respiratory)
Synchrony™ Respiratory Tracking System

- Optical camera (Synchrony)
- X-ray sources
- Cyberknife

- Synchrony™ vest & camera – external surrogate
- Synchronization with internal surrogate by means of x-ray
  - Periodically updates the internal (fiducial) /external correlation model
**Calypso**

- Implanted electromagnetic transponders
- Flat panel array – contains the source coils that emit EM
- 300-500 kHz

Belanger et al., JACMP 2016

**MRI/linac**

- Higher contrast than
  - Fluoroscopy
  - CBCT
  - 4DCBCT

Elekta - Unity

ViewRay - MRIdian
**Summary**

- There is a large variety of motion monitoring technologies being used in the clinic.
- External and internal surrogate monitoring assumes perfect correlation between surrogate and tumor motion.
  - Anzai, Calypso, RPM, ExacTrac, Hokkaido, Cyberknife, surface imaging.
- Direct monitoring with MRI does not add extra radiation and provides better contrast than other modalities.