Application of Implanted Markers in Proton Therapy

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Course Outline

- Brief review of protons characteristics that apply to fiducials
- Why different materials are needed for fiducial markers in proton therapy as compared to x-ray therapy
- What are the requirements for fiducial markers in proton therapy
- The impact of choice of fiducial material on dosimetry
- The impact of choice of fiducial material on radiopacity
- Fiducial marker options for proton therapy

Accelerated proton beams are used for the treatment of cancer
Range uncertainties in proton therapy are the biggest challenge and can be substantial.

Range Uncertainties in Proton Therapy

- Treatment Planning
  - CT noise, artifacts, resolution
  - HU – Stopping power conversion (CT calibration)
  - Dose calculation algorithm
- Treatment Delivery
  - Setup and positioning errors
  - Organ motion
  - Anatomical/Physiological change
Influence of lipiodol on proton therapy for HCC

Lipiodol is an iodine compound and it is used with an embolizing agent for HCC patients during TACE treatment.

HU values of partially lipiodolized lesions inside the PTV should be replaced by the average HU value of surrounding normal liver.

Without correction of HU value

Corrected CT image with HU value

<table>
<thead>
<tr>
<th></th>
<th>UFL 33</th>
<th>UFL 1%</th>
<th>Pt #1</th>
<th>Pt #2</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>UFL 22</td>
<td>UFL 76</td>
<td>546</td>
<td>880</td>
</tr>
<tr>
<td></td>
<td>UFL 33</td>
<td>UFL 76</td>
<td>546</td>
<td>880</td>
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Internal motion induced reduction of dose in proton therapy

- Separate PTV with different margins transversely and along the direction of the beam.
- Determine the beam parameters (field setup) using the CTV or GTV.
- Add appropriate margin for range modulation.

Tumor shrinkage in proton therapy

- Planning CT
- CT after 5 weeks

S Mori, G Chen, MGH
Organ motion in proton therapy

Free breathing Treatment

Tsunashima/Dong

Courtesy of Lei Dong

CT Artifacts

Fiducial Markers

- Originally developed in the pre-conformal radiotherapy era to verify the position of tissue
- Ensure target localization of tumors and organs
- Often made of high density materials such as gold to increase visibility in X-ray imaging
- Used for a variety of sites (prostate, liver, lung, breast, eye, etc)
- Will impact dose delivery, this effect is more pronounced in proton therapy
Ideal characteristics of fiducial markers in Proton Therapy

- Good radiographic visibility in diagnostic X-rays
- No distortion of the delivered dose
- Minimal artifact in the CT images used for treatment planning
- No migration during treatment

Dose Perturbations in Proton Therapy: MC Simulations

Dose Perturbations for Ni-Ti markers in Carbon Ion and Proton Therapy
Impact of distance from the distal end of the beam on dosimetric impact

An opposed pair of proton beams

Radiographic images of the carbon coated ZrO₂ and PEEK encapsulated stainless steel fiducials
Dose Perturbations for the carbon coated ZrO$_2$ and PEEK encapsulated stainless steel fiducials

Key Elements to consider the Markers for Proton Therapy

- Material composition
- Size
- Orientation
- Location

Biological effect of dose distortion by fiducial markers in spot-scanning proton therapy

- 1.5 and 2 mm spherical gold markers were recognized by fluoroscopy
- 1.5 mm gold marker does not affect TCPs
- For 2 mm gold marker, it is safe to use two or more fields
Microscopic gold particle-based fiducials in proton therapy

- X-ray Radiographs: Good Visibility
- a) gold fiducial  
- b) silicone  
- c) 2.5 wt% Au  
- d) 4.9 wt% Au  
- e) 7.2 wt% Au


Film Dosimetry: Gafchromic EBT film

- a) gold fiducial  
- b) 2.5 wt% Au  
- c) 4.9 wt% Au  
- d) 7.2 wt% Au


Depth dose profiles for a) parallel b) perpendicularly aligned markers

Injectable fiducial markers with BaSO$_4$ and polymer for proton therapy

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### Material component ratio

<table>
<thead>
<tr>
<th></th>
<th>B1</th>
<th>B2</th>
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<tbody>
<tr>
<td>Polymer</td>
<td>10%w%</td>
<td>10%w%</td>
</tr>
<tr>
<td>PBS</td>
<td>90%w%</td>
<td>90%w%</td>
</tr>
<tr>
<td>BaSO$_4$</td>
<td>5%w%</td>
<td>5%w%</td>
</tr>
<tr>
<td>Polymer</td>
<td>10%w%</td>
<td>20%w%</td>
</tr>
</tbody>
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CBCT OBI Fluoroscopy

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<th>Orientation</th>
<th>Parallel</th>
<th>Perpendicular</th>
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<tbody>
<tr>
<td>GOLD</td>
<td>-15.05%</td>
<td>-9.77%</td>
</tr>
<tr>
<td>STAINLESS</td>
<td>-7.92%</td>
<td>-4.43%</td>
</tr>
<tr>
<td>TITANIUM</td>
<td>-6.92%</td>
<td>-0.78%</td>
</tr>
<tr>
<td>BaSO$_4$</td>
<td>-3.79%</td>
<td>-0.53%</td>
</tr>
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Commercially available fiducial markers

- Viscoil (IBA)
- FlexiCoil (Civco)
- Carbon Markers (Civco)
- Beammarks (Beampoint)
Summary

- The physical characteristics of proton beams show a very favorable dose distribution in depth by spread out Bragg peak
- However, PT is more sensitive to uncertainties in treatment planning and beam delivery compared to x-ray therapy
- Implanted markers for proton therapy should have
  1) No or minimal dose distortion
  2) Good radiographic visibility in diagnostic X-rays
  3) Minimal artifacts in the CT images
  4) No migration during treatment
- Key factors for fiducial markers in proton therapy:
  - Material, Size, Orientation, and Location

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