A novel deliver sequence and efficiency optimization algorithm for Spot-Scanning Proton Arc therapy (SPArc)

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Disclosure

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  – Ion Beam Application S.A.
  – Beaumont Herb and Betty Fisher Research Seed Grant Award

• A patent related to the proton arc
Dosimetric limitations?

- Uncertainties
  - Range, setup, motion, etc.

- Long delivery time
  - Limits the beam number per fx

- Larger Penumbra (Spot size)

Proton Arc Therapy

3D/4D Robustness optimization
  (Liu et al)
  RaySearch Raystation
  Varian Eclipse 13

Delivery Efficiency engine
  (Cao et al, Van de Water et al)

Dynamic Collimation system
  (Hyer et al, U of Iowa)
Spot-Scanning Proton Arc (SPArc)

• A robust, delivery efficient and potential for continuous arc delivery advanced IMPT optimization algorithm
  – Prostate (PTCOG 2017)
  – Brain Hippocampus sparing (AAPM 2017)
  – Cranial SRS (ASTRO 2017)
  – Spine SRS (ASTRO 2017)
  – Bilateral Head & Neck (AAPM 2017)
  – Advanced staged lung cancer (NA-PTCOG 2016)
  – Mobile tumor – interplay (AAPM 2017)
  – ....

Ding X & Li X IJROBP 2016
Whole Brain Radiotherapy with Hippocampal and cochlea sparing

Figure: A representative CT slice of a patient contours and dose distribution and DVHs

Ding et al. AAPM 2017
Brain SRS

Table 1: Comparisons of various dosimetric parameters. SPArc = Spot-scanning proton arc. GKRS = Gamma Knife radiosurgery. IMPT = intensity modulated proton therapy (PTCOG annual scientific meeting 2017)

<table>
<thead>
<tr>
<th></th>
<th>SPArc</th>
<th>GKRS</th>
<th>3-field IMPT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conformity Index (ICRU)</td>
<td>1.97</td>
<td>2.01</td>
<td>2.48</td>
</tr>
<tr>
<td>Gradient Index</td>
<td>2.58</td>
<td>2.84</td>
<td>6.681</td>
</tr>
<tr>
<td>Brain mean dose Gy [RBE]</td>
<td>0.54</td>
<td>0.98</td>
<td>0.75</td>
</tr>
<tr>
<td>V1Gy (cc)</td>
<td>114.7</td>
<td>317.2</td>
<td>134.9</td>
</tr>
<tr>
<td>V2Gy (cc)</td>
<td>62.1</td>
<td>137.1</td>
<td>112.7</td>
</tr>
<tr>
<td>V5Gy (cc)</td>
<td>31.2</td>
<td>43.2</td>
<td>74.4</td>
</tr>
<tr>
<td>V12Gy (cc)</td>
<td>14.7</td>
<td>14.7</td>
<td>38.3</td>
</tr>
</tbody>
</table>
Interplay effects for proton therapy

- The motion of the beam could interfere with the motion of target
- May result in distortion of the planned dose distribution, local over- and under-dosage
- One of the major concerns for treating lung cancer with scanning beam proton
Single-fraction 4D dynamic dose

Patient 6, ITV volume of 402cc, S-I motion of 1.2 cm

Li et al. Radiation Oncology 2018
Dosimetric limitations?

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  – Range, setup, motion .etc.

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Proton Arc Therapy
Clinical Feasibility?

- *Principles and Practice of Stereotactic Radiosurgery* by Lawrence S. Chin and William F. Regine 2015 p 87. Proton arc therapy is **not feasible nor is it necessary** to generate conformal plans.
- Dr. Yu: “intensity modulated proton arcs **would be harder, if not impossible**, to achieve with the current spot scanning technology”.
- Realistic SPArc Treatment Delivery time
- SPArc Treatment Delivery Accuracy
- Machine/Software Limitations
Magnetic Hysteresis

• Energy switching time
  – Switching from high to low energy is much faster than switching from low to high energy

Examples:
  – Takes 1s from 220MeV to 180MeV
  – Takes 4s from 180MeV to 220MeV
Original Proposal – iterative robust optimized approach

Ding X & Li X IJROBP 2016
A new approach – Energy sequence optimization

Split Control point and energy layers

Beam 1a (5°)
- 220 MeV
- 210 MeV
- 200 MeV
- 190 MeV

Beam 1 (10°)
- 220 MeV
- 210 MeV
- 200 MeV
- 190 MeV
- 180 MeV
- 170 MeV
- 160 MeV
- 150 MeV
- 140 MeV
- 130 MeV
- 120 MeV
- 110 MeV

Beam 1b (15°)
- 180 MeV
- 170 MeV
- 160 MeV
- 150 MeV
- 140 MeV
- 130 MeV
- 120 MeV
- 110 MeV

New sub-control point 1a with half of total energy layers

Remove original control point

New sub-control point 1b with another half of total energy layers
Machine limitation Small MU spots

• IBA ProteusONE clinical threshold 0.02MU per spots
• Sensitive to the noise? Delivery accuracy?
• More beam pauses

Ding et al. under review
Study design - Planning

• 5 Prostate patients
• SPArc coarse sampling = 18 beam angles
• SPArc final sample frequency = 72 sub control points
• Minimum MU per spot = 0.02 MU
• Using same objective function
  – SPArc orig
  – SPArc seq
SPArc Plan comparison
QA Experiment design

• Project and calculate the 72 sub-control points into a fix gantry
• 5cm solid water; deliver the SPArc at fixed Gantry 90
• Deliver the control point based on the CW arc sequence

Total Delivery time/
# Beam Pause
Measurements and QA results

- 5cm solid water depth
- Majority of proximal end of 2D dose
  - Absolute dose comparison
    - Within 3% difference
  - 2D gamma analysis (3%/3mm)
    - Range from 95% - 100%
Total Delivery Time

Beam Pauses are around 0-10 times per delivery in both groups
Conclusion

• The new energy sequence optimization could significantly reduce the total treatment time while providing an equivalent plan quality compared to the SPArc orig.
• The current existing clinical proton system could deliver the lower MU weighting spots with minimal interruption.
• Delivery accuracy at fix gantry meets the existing QA criteria.
• To be continued...
Have we reached dosimetric limitation yet?

• Let’s spin our gantry first

How to deliver the proton arc therapy safely, accurately and efficiently?

LETTER TO THE EDITOR

Have we reached proton beam therapy dosimetric limitations? – A novel robust, delivery-efficient and continuous spot-scanning proton arc (SPArc) therapy is to improve the dosimetric outcome in treating prostate cancer

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