Non-Coplanar Rotational Therapy
w/ High Efficient Unflattened Beams

Hansen Chen, M.S.
NewYork-Presbyterian Hospital, NY

Speed of an Unflattened High Dose Rate Beam

- 6 MV Flat Beam
  - For 300 MU/Min Dose Rate
  - 100 MU Beam On Time = 20 Sec

- 7 MV Unflattened Beam
  - For 2000 MU/Min Dose Rate
  - 100 MU Beam On Time = 3 Sec

Rotational Therapy (VMAT) Helps the Speed

- Static IMRT (FF)
  - 414 MU, 7 beams,
  - ~5 seg/beam
  - Tx Time ~5 min

- VMAT (FFF)
  - 515 MU, 9-29 MU/OP,
  - Min Gantry Speed 2 deg/sec
  - Tx Time ~2 min

[Images and diagrams showing the comparison]
Published Beam-on-Time Comparison

Don’t Worry, this is NOT Proton Symposium
But We Don’t Usually Use Single Photon Beam

Bi-Lateral Beams
Coronal Plane Dose

Typical Photon Dose Distribution
Prostate SBRT Case
Prescribed Dose of 4000 cGy w/ 800 cGy / Fraction

7 Field Static IMRT
VMAT (Rotational Therapy)
Non-Coplanar Rotational
with Unflattened Beams

3 Non-Coplanar Arcs
Couch 0, +30 and -30 Degrees

Sampling the Isocenter Planar Dose

7 Field Static IMRT
VMAT (Rotational Therapy)
Non-Coplanar Rotational
with Unflattened Beams
Isn’t This What We Are Fighting For?

But How?

Machines Deliver Non-Coplanar Beams

And don’t forget how high dose rate unflattened beam can help...
C-Shape Linac Non-Coplanar VMAT

Head and Neck Case  Prostate Case

Prostate with 2 Non-Coplanar Arcs

- Dose Spreading to Avoid Femoral Heads
- 11 MV Unflattened Beams
- Table at +/- 15°
- Rx Dose: 200 cGy per Fraction
- Total of 320 MU per Fraction, 350° Arcs
- Gantry Speed ~2°/sec
- Tx Delivery Time ~ 3 min

H&N with 2 Non-Coplanar Arcs

- Dose Spreading to Avoid Parotid Glands
- 7 MV Unflattened Beams
- Table at +/- 20°
- Rx Dose: 200 cGy per Fraction
- Total of 462 MU per Fraction
- Gantry Speed ~2.5°/sec
- Tx Delivery Time ~ 4 min

Slide courtesy of Ali Bani-Hashemi
C-Shape Linac Potential Collision Issue

- Patient Safety
- Time Efficiency

Searching for Non-Collision Sub-Arcs

GammaKnife Non-Coplanar Beams
A New Design of Non-Coplanar Rotational Linac

Joined efforts from Columbia University, Cornell University and NewYork-Presbyterian

Beam Directed by Two Rotational Rings

Double-Ring Mechanism Front View
The plane of treatment system outer gantry is mounted at an oblique angle \( \theta \), with respect to the plane normal to the axis of the patient bore.

Slide courtesy of John Cheeseborough.

---

Conical Non-Coplanar Rotational Beams

Slide courtesy of John Cheeseborough.
Preliminary Machine Geometry

Monte Carlo Beam Data Simulation

Taking Advantage of Unflattened Beam
Lung Cancer Case Study

- Prescription: 18 Gray for 3 Fractions
- Lung Volume: 2844.7 cm$^3$
- Tumor Volume:
  - Pt 1: PTV ~ 36.42 cm$^3$ (1cm GTV, ±1cm ITV, ±0.5cm PTV)
  - Pt 2: PTV ~ 114.65 cm$^3$ (3cm GTV, ±1cm ITV, ±0.5cm PTV)
  - Pt 3: PTV ~ 268.1 cm$^3$ (5cm GTV, ±1cm ITV, ±0.5cm PTV)
- Plans to be Compared:
  - Static Field IMRT (FF)
  - Coplanar VMAT (FF)
  - Non-Coplanar VMAT (FFF)

Tx Plan Comparison

- Single Coplanar VMAT
- Multiple Non-Coplanar VMAT
Butterfly Shaped Isodose Distribution

Plan Quality Quantitative Evaluation

- **RTOG CI** = PV/TV, where PV is the prescription volume, and TV is the target volume (=1 is a perfect plan)
- **Paddick CI** = (TVPV)^2/(TV x PV), where PV is the prescription volume, TVPV is the target volume within the prescribed isodose surface, and TV is the target volume (< 1, closer to unity is better)
- **Paddick GI** = PV50%/PV, where PV50% is 50% of the prescription volume isodose line, and PV is the prescription volume (lower is better)

Plan Quality Comparison Table

<table>
<thead>
<tr>
<th>PTV = 36.4 cm³</th>
<th>IMRT</th>
<th>Coplanar VMAT</th>
<th>Non-Coplanar VMAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>TV³</td>
<td>33.99</td>
<td>33.54</td>
<td>33.55</td>
</tr>
<tr>
<td>RTOG CI</td>
<td>1.00</td>
<td>0.99</td>
<td>0.97</td>
</tr>
<tr>
<td>CI</td>
<td>0.87</td>
<td>0.86</td>
<td>0.86</td>
</tr>
<tr>
<td>GI</td>
<td>5.65</td>
<td>5.43</td>
<td>4.36</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PTV = 114.7 cm³</th>
<th>Coplanar VMAT</th>
<th>Non-Coplanar VMAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>TV³</td>
<td>108.86</td>
<td>108.45</td>
</tr>
<tr>
<td>RTOG CI</td>
<td>0.98</td>
<td>0.97</td>
</tr>
<tr>
<td>CI</td>
<td>0.90</td>
<td>0.90</td>
</tr>
<tr>
<td>GI</td>
<td>4.65</td>
<td>4.09</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PTV = 268.1 cm³</th>
<th>Coplanar VMAT</th>
<th>Non-Coplanar VMAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>TV³</td>
<td>255.69</td>
<td>253.32</td>
</tr>
<tr>
<td>RTOG CI</td>
<td>1.33</td>
<td>1.12</td>
</tr>
<tr>
<td>CI</td>
<td>0.80</td>
<td>0.71</td>
</tr>
<tr>
<td>GI</td>
<td>3.71</td>
<td>3.56</td>
</tr>
</tbody>
</table>
Using DCR to Evaluate Dose Fall-Off

Lung Dose Volume Histogram

Biological Lung Irradiation Response

Dose response of interstitial pneumonitis after whole lung irradiation for TBI

Sampath et al. IJROBP 2005, 63:378
Very Few 2nd Cancers Attributable to Radiotherapy in Adults

- 647,672 adult (>20 y/o at diagnosis) cancer survivors in US SEER registries.
- Survived >5 years
- Survivors of 15 types of cancers
- Over 30 years of follow-up
- 60,271 (9%) developed 2nd cancers
- 3,266 (0.001%) of them might be related to RT

Non-Coplanar Rotational Therapy

- The rationale for unflattened beam – the Speed!
- The rotational VMAT delivery increases the speed even more
- For the time saved, we propose to do non-coplanar VMAT to gain more dose distribution advantage
- The non-coplanar rotational beam has reduced the mid-dose volume with larger low dose spread
- Not every facility can afford the built-up cost for proton therapy, non-coplanar VMAT might provide an affordable solution as to the similar dose fall-off

Conclusion
Non-Coplanar Rotational Therapy

- The non-coplanar techniques has been discussed
- The hurdles by using C-Shaped Linac for non-coplanar rotational delivery has ben discussed
- A new design for non-coplanar conical rotational Tx delivery technique – ArcKnife has been introduced
- The ArcKnife Tx plan evaluation and dose distribution has been presented
- Biological and clinical implication of sun tan zone (low dose bath) and sun burn zone (hot spot) for both NTCP and 2nd cancer incidence has been addressed

Acknowledgement

- Physicists
  - Dr. Rompin Shih
  - Dr. Muhammad Afghan
  - Dr. Arun Gopal
  - Dr. Pin Yang
  - Dr. Yu Chen
  - Michael Schweizer
- And special thanks to Dr. Clifford Chao, MD

Thank You