Use of Volumetric Modulated Arc Therapy for Intra and Extra Cranial Stereotactic Radiosurgery

Initial Experience at UMASS Memorial Medical Center
Worcester, MA

Charles Mayo, Ph.D.

MO-SAM-SAM BRB -4
Monday 7:30 am – 9:25 am  BallRoom B
VMAT for SRS/SRT

• VMAT is relatively new, but quickly becoming widely used in conventional settings
• Growing recognition that it can offer particular advantage for SRS/SRT
• Session is intended to provide a broad view on use of this technology
• Speakers offer perspective using either Eclipse or Pinnacle
Why VMAT for SRS/SRT?

- Shorter treatment times are consistent with IGRT goals.
- Facilitates sparing proximal normal tissues, compared to fixed aperture techniques.
- Facilitates simultaneously treating multiple targets with a single isocenter (Sunesh, Verbekel)
On the learning curve

Remember a lesson learned during IMRT about perceptions of new technology:

Given that the technology is capable, probability that the planner gets a better Rapid Arc Plan.

\[ p(E) = p(E|Q) \cdot p(Q) \]

Probability that the planner gets a better Rapid Arc Plan:

Probability that RapidArc technology is capable of a better plan:

Not getting the plan we want could be \( p(Q) \) but it could also be \( p(E|Q) \).

Avoid temptation to judge a new technology, before staff have time to master it.
Beam Configuration in Eclipse

Input depth dose curves, profiles and output factor tables
Use dose analysis tools to compare calculated and measured depth doses and profiles.
Single lesion - Intracranial

- 7 Gy x 3 use two arcs: transverse + vertex
- 15Gy x 1 use three or four arcs in different planes to reduce base line low dose.
- Similar planning approach as used in conventional
Treatment Planning Templates
Optimization Structures
Acoustic Neuroma
80%/cm on Brain Stem Side
Normal Tissue Considerations
Optic Nerves/Chiasm

Need more data in intermediate dose regime

QUANTEC Radiation Induced Optic Neuropathy

- Model: LQ extrapolation from 1.8 Gy/fx, 59.4 Gy with $\alpha/\beta=3.3$
- Model: LQ extrapolation from 1.8 Gy/fx, 59.4 Gy with $\alpha/\beta=1.6$
- Model: Iso Neuret(NSD) = 60 Gy, 1.8 Gy/fx
- Model: Iso Optic RET = 8.9 Gy

Literature Findings:
- >10% Incidence RION
- 1-9% Incidence RION
- No Incidence RION

Majority of published data pre-date planning and treatment delivery technology that allows for steep dose gradients in or near optic structures. Effect on partial volume tolerance needs further exploration.

Lack of published data in hypofractionation region

Only a few detailed publications in SRS region

Normal Tissue Considerations

Brain Stem

Need more data in intermediate dose regime

Selected data on brain stem radiation tolerance

- LQ Extrapolation from 64.3 Gy, 1.89 Gy/Fraction using $\alpha/\beta = 3.3$
- LQ Extrapolation from 64.3 Gy, 1.89 Gy/Fraction using $\alpha/\beta = 2.5$
- LQ extrapolation from 14.2 Gy in 1 using $\alpha/\beta = 2.1$

- Complications
- Dose Constraints
- Cut Point
- No Complication
- Other Reference

Debus, Noel, Wenkel, Nishimura (Surface)
Debus (Dmax)
Weber (Surface)
Debus (0.9 cc)
Nishimura (Dmax)
Uy (Dmax)
Debus, Noel, Wenkel, Nishimura (Center)
Deus, Noel, Wenkel, Nishimura (Center)
Schoenfeld (0.1 cc)
Daly (1% of BS)
Meeks (calculated 3% iso-complication for 0% partial volume)
Clark (~Dmax)
Foote (Tumor Margin)
Foote (Peripheral Dose)
Foote (Prescribed Dose)

Results from Article in Press in IJORBP Mayo, Ding, Adessa, Kadish, Moser and Fitzgerald

Using RapidArc for frameless SRT is new.

Can we demonstrate that it is reasonable compared to other frameless SRT technologies that have been in use for a while?

Examine characteristics of first 12 patients (14 targets)

CTV volume

\[ 1.2 \pm 3.96 \ (0.1 \ – \ 12.6) \ cm^3 \]

PTV volume

\[ 2.35 \pm 6.0 \ (0.6 \ - \ 19.3) \ cm^3 \]
Single Lesion Intracranial Experience
Conformality Index – How tightly does the prescription isodose conform to the pTV?

- **ICRU Conformality Index**:
  \[
  CI_{ICRU} = \frac{V_{Rx}}{V_{PTV}}
  \]

- **95% Conformality Index**:
  \[
  CI_{95\%Rx} = \frac{V_{95\%Rx}}{V_{PTV}}
  \]

- **Paddick Inv Conformality Index**: 
  \[
  CI_{Inv-Paddick} = \frac{V_{Rx} \times V_{PTV}}{V_{Rx \cap PTV}^2}
  \]

<table>
<thead>
<tr>
<th>Institution</th>
<th>Technique</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colombo</td>
<td>CyberKnife</td>
<td>1.18 (1.01-1.48)</td>
</tr>
<tr>
<td>Mayo</td>
<td>RapidArc</td>
<td>1.13 ± 0.11</td>
</tr>
<tr>
<td>Bolsi</td>
<td>IMRT protons (ps)</td>
<td>2.8 ± 0.6</td>
</tr>
<tr>
<td>Cozzi</td>
<td>Helical Tomo</td>
<td>1.8 ± 0.6</td>
</tr>
<tr>
<td></td>
<td>CyberKnife</td>
<td>1.8 ± 0.3</td>
</tr>
<tr>
<td>Mayo</td>
<td>RapidArc</td>
<td>1.51 ± 0.34</td>
</tr>
<tr>
<td>Han</td>
<td>NCP IMRT (9-12 flds)</td>
<td>1.35 ± 0.15</td>
</tr>
<tr>
<td></td>
<td>Helical Tomo</td>
<td>1.26 ± 0.15</td>
</tr>
<tr>
<td>Colombo</td>
<td>CyberKnife</td>
<td>1.29 (1.14-1.52)</td>
</tr>
<tr>
<td>Collins</td>
<td>CyberKnife</td>
<td>1.64 (1.04 – 3.11)</td>
</tr>
<tr>
<td>Mayo</td>
<td>RapidArc</td>
<td>1.24 ± 0.2</td>
</tr>
</tbody>
</table>
Gradient Index – How steeply does the dose fall off away from the ptv?

\[ \text{CGIg} = 100 - \left\{ 100 \times \left[ \left( R_{\text{Eff}, 50\% Rx} - R_{\text{Eff}, Rx} \right) - 0.3 \right] \right\} \]

\[ R_{\text{Eff}, 50\% Rx} = \frac{3}{4 \pi} \sqrt[3]{\frac{3V_{50\% Rx}}{\text{cm}^3}} \]

\[ R_{\text{Eff}, Rx} = \frac{3}{4 \pi} \sqrt[3]{\frac{3V_{Rx}}{\text{cm}^3}} \]

\[ Gr_{\text{Eff}} = \frac{50\%}{R_{\text{Eff}, 50\% Rx} - R_{\text{Eff}, Rx}} \]

- Wagner Static MLC 60-80
- Han NCP IMRT 22.32 ± 19.2
- Helical Tomo 43.28 ± 13.78
- Mayo RapidArc 66.6 ± 14.1
- Mayo RapidArc 83.8 ± 15.8 %/cm
Homogeneity Index – How uniform is the dose in the PTV?

\[ HI_{Max} = \frac{D_{Max}}{D_{Rx}} \]

\[ HI_{STD} = 1 + \frac{D_{STD}}{D_{Rx}} \]

\[ HI_{Overall} = \sqrt{HI_{Max} \times HI_{STD}} \]

- Han (NCP IMRT) \( 1.13 \pm 0.04 \)
- Tomo \( 1.18 \pm 0.06 \)
- Colombo (CyberKnife) \( 1.35 (1.18 - 2.01) \)
- Collins (CyberKnife) \( 1.19 (1.11 - 1.54) \)
- Mayo (RapidArc) \( 1.08 \pm 0.03 \)
- Mayo (RapidArc) \( 1.016 \pm 0.005 \)
- Mayo (RapidArc) \( 1.049 \pm 0.014 \)
Static MLC with 0.25 cm leaves
Dose gradient for RapidArc with 0.5 cm leaves is a bit sharper than static with 0.25 cm leaves and dose is much more homogeneous.
Going back, taking a look at Static MLC plans for those patients to see What effect a smaller MLC would have. (Preliminary results, 8/14 static mlc plans)

<table>
<thead>
<tr>
<th>Measure</th>
<th>RapidArc (0.5 mm)</th>
<th>Static MLC (0.25 mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DHI Max</td>
<td>1.083 ± 0.026</td>
<td>1.095 ± 0.10</td>
</tr>
<tr>
<td>DHI Overall</td>
<td>1.049 ± 0.014</td>
<td>1.059 ± 0.01</td>
</tr>
<tr>
<td>IC ICRU</td>
<td>1.13 ± 0.11</td>
<td>1.02 ± 0.11</td>
</tr>
<tr>
<td>IC 95%</td>
<td>1.51 ± 0.34</td>
<td>1.56 ± 0.21</td>
</tr>
<tr>
<td>CGI</td>
<td>66.3 ± 14.1</td>
<td>65.9 ± 6.9</td>
</tr>
<tr>
<td>Measured Gradient</td>
<td>83.8 ± 15.8</td>
<td>83.9 ± 8.5</td>
</tr>
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Demonstrating that RapidArc dose distribution is not doing worse than would be done with a more conventional approach.
For hypo-fractionation, the time to deliver the dose has the potential to be

7 Gy/45 min
7 Gy/4.5 min

"Sweet spot" for improvement in biological effect is larger for moving from conventional dose delivery rates to RapidArc with 1000 MU/min for hypo-fractionation protocols.

Paganetti, Changes in tumor cell response due to prolonged dose delivery times in fractionated radiation therapy, IJORBP 2005(63) 892-900
Treatment time – Reducing treatment time improves patient comfort, enables treating more SRT per machine/FTE and (maybe) potentiates the treatment

<table>
<thead>
<tr>
<th></th>
<th>System</th>
<th>Time Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Han</td>
<td>Tomotherapy</td>
<td>42 ± 16 min Treatment</td>
</tr>
<tr>
<td>Collins</td>
<td>CyberKnife</td>
<td>?</td>
</tr>
<tr>
<td>Colombo</td>
<td>CyberKnife</td>
<td>?</td>
</tr>
<tr>
<td>Mayo</td>
<td>Fixed MLC Radionics</td>
<td>~ 40 min</td>
</tr>
<tr>
<td>Mayo</td>
<td>RapidArc</td>
<td>16.6 ± 9 min Setup</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.8 ± 1.7 min Treatment</td>
</tr>
</tbody>
</table>
Single RapidArc for small volume lung target

Turn 100% isodose into a structure. Use Boolean operators to create two sub-volumes. Optimize outer portion of PTV not covered, to a higher dose. Optimize inner covered portion to Rx dose.

Inner = PTV AND 100%  
Outer = PTV SUB 100%

1st try- 100% doesn’t cover PTV

2nd try- 100% does cover PTV

Notice the dose uniformity in the PTV.

No need to accept big hot spots.
Lung Case - 3 targets, 3 RapidArcs

Palliative care
Need short treatment time for patient
Need low dose to uninvolved lung

C. Mayo, Ph.D.
Do you need to normalize to 80% to get a steep gradient?

Dose to proximal rib is higher for 11 field static (80% norm) than for 2 field VMAT (93% norm).
Do you need to normalize to 80% to get a steep gradient?

Distance from Rx to 50% of Rx isodose line is 1.2 cm for 11 field static plan and 1.3 cm for 2 field VMAT.
Low normalization makes little improvement in dose gradient, if objective is really dose painting, then that is more easily controlled with VMAT.
Between-Target Buffer: 1 cm inner margin IMRT PTV
On the learning curve
Revised RapidArc plan is better than IMRT plan.
On the learning curve
Revised RapidArc plan is better than IMRT plan.
Summary

• Many institutions have successfully used VMAT for SRS/SRT for 1-2 years.

• Dose distribution metrics compare favorably with other treatment modalities.

• For single or hypo-fractionated treatments reduced treatment time may have implications for radiobiological response.