Overview of MLC-based Linac Radiosurgery

Grace Gwe-Ya Kim, Ph.D. DABR
MLC based Linac SRS

• Better conformity for irregular target
• Improved dose homogeneity inside the target
• Comparable dose fall-off outside the target
• Less time-consuming treatment planning
• Shorter treatment time
• Machine is not limited for cranial treatment
• Patient comfort
• Ease of treatment / workflow
• Comparable positioning accuracy
• Hypofractionated treatments
SRS vs. SRT

- The prescribed dose and dose fractionation in stereotactic dose delivery depend upon:
  - Volume
  - Location
  - Disease

M Linskey et al. J Neurosurg (Suppl 3) 2000;93:90-95
SRS vs. SRT

- Risk factors to developing edema (Meningioma)
  - Dose
  - Volume
  - Location
  - Pre-existing edema etc.

Gagnon et al., Neurosurgery, (2012), 70 (3) 639-645
SRS vs. SRT

C Brennan et al., IJROBP, 88 (1) 130–136, (2014)

A Phase 2 Trial of Stereotactic Radiosurgery Boost After Surgical Resection for Brain Metastases
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G Minniti et al., IJROBP, 86 (4) 623–629, (2013)

Multidose Stereotactic Radiosurgery (9 Gy × 3) of the Postoperative Resection Cavity for Treatment of Large Brain Metastases
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Claudia Scaringi, MD, * Gaetano Lanzetta, MD, § Maurizio Salvati, MD, §,
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- 49 patients
- SRS boost: Significant lower local failure
- Tumors ≥ 3 cm with superficial: higher risk of local failure
- 101 patients
- > 3 cm cavities
- the most effective tx. option for large radioresistant brain met
- V24Gy: radionecrosis
Imaging

- **Metastatic**
  - MRI with Gadolinium
    - T1 post contrast (thin slice)
    - Small non-enhancing lesions may be seen on T2
  - CT Head with contrast – If MRI unavailable
    - May miss small posterior fossa lesions

- **AVM**
  - CTA, DSA, MRA

- **Trigeminal Neuralgia**
  - T1 post, FIESTA
TG-54
“MRI contains distortions which impede direct correlation with CT data at the level required for SRS”

TG-117
Use of MRI data in Treatment Planning and Stereotactic Procedures – Spatial Accuracy and Quality Control Procedures

Gradient nonlinearity distortion, Siebert et al, ASTRO 2014
IMRS vs. VMAT

JZ Wang et al, Medical Dosimetry 37 (2012) 31-36
MLC leaf width

54 patients, DCA & IMRT techniques
No significant diff. 3 mm vs. 5 mm
Narrow leaf: Sparing small OARs

43 patients, DCA technique
<1.1 cm³ : aver. CI diff. 11%

Annes Dhabaan et al., JACMP, Vol. 11, No.3 (2010)
Plan optimization

- Constraints
- Normal Tissue Objective
- Tuning Structures
- MU constraint

- Target structure resolution
- Calc. grid size
## Constraints

### TG-101

<table>
<thead>
<tr>
<th>Serial Tissue</th>
<th>Max vol. (cc)</th>
<th>One fraction</th>
<th>Three fraction</th>
<th>Five fraction</th>
<th>End point</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Threshold dose (Gy)</td>
<td>Max point dose (Gy)</td>
<td>Threshold dose (Gy)</td>
<td>Max point dose (Gy)</td>
</tr>
<tr>
<td>Optic pathway</td>
<td>&lt;0.2</td>
<td>8</td>
<td>10</td>
<td>15.3</td>
<td>17.4</td>
</tr>
<tr>
<td>Cochlea</td>
<td></td>
<td>9</td>
<td>17.1</td>
<td>25</td>
<td>Cranial neuropathy</td>
</tr>
<tr>
<td>Brainstem (not medulla)</td>
<td>&lt;0.5</td>
<td>10</td>
<td>15</td>
<td>18</td>
<td>23.1</td>
</tr>
<tr>
<td>Spinal cord and medulla</td>
<td>&lt;0.35</td>
<td>10</td>
<td>14</td>
<td>18</td>
<td>21.9</td>
</tr>
<tr>
<td></td>
<td>&lt;1.2</td>
<td>7</td>
<td>12.3</td>
<td>14.5</td>
<td></td>
</tr>
</tbody>
</table>

- Lens: Max. dose <10 Gy (1 fx)
- Normal Brain: V10 < 12 cc or V12 < 10 cc
- Cranial Nerves: (fifth, seventh and eighth CN) 12.5-15 Gy

(Flicker et al., IJROBP 2004)
• V10 and V12 volumes greater than 4.5-7.7 and 6.0-10.9 cc carry >10% risk of symptomatic radiation necrosis, respectively

G Minniti et al, Radiation Oncology 2011, 6:48
Multi-metastases

M Yamamoto et al., Lancet Oncol, March 10, 2014

L Ma et al., Int. J CARS, 20 April 2014
L Cozzi et al., Rad Onc., 9:118 2014
Tuning Structures

- Individual target(s) (not the composite PTV_total): lower = 100% of the target to receive 102% of prescription, no upper constraint
- Inner control max dose = 98% of prescription dose
- Middle control max dose = 50% of prescription
- Outer control max dose = 40% of prescription

G. Clark et al., Practical Radiation Oncology (2012) 2, 306–313
Plan optimization – MU

<table>
<thead>
<tr>
<th>Field</th>
<th>Arc 1</th>
<th>Arc 2</th>
<th>Arc 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plan A</td>
<td>4116</td>
<td>2105</td>
<td>2105</td>
</tr>
<tr>
<td>Plan B</td>
<td>3488 (18% ↓)</td>
<td>1794 (17% ↓)</td>
<td>1794 (17% ↓)</td>
</tr>
</tbody>
</table>
Surface Imaging System

- **Stereo photogrammetry**
  - 3 cameras & visible light projector
  - Reference image
    - Contours from DICOMRT
    - Previous captured image

- **Registration algorithm**
  - Minimize distance between reference image & real-time surface
  - Rotations & translations
Clinical Work Flow

CT Simulation
- Patient Simulation
- Create mask & head cushion

Planning
- Plan and isocenter
- Create body contour

Surface image registration
- Importing plan & body str.
- Select ROI

Initial setup
- Manual head adjuster
- Start from bridge of nose

Capturing new-reference Image
- CBCT image registration
- Capture new reference

Treatment
- Monitoring
- Adjust if needed
Patient Setup
Capture New Reference

- kV/kV match to check for rotations (e.g., pitch)
- CBCT-indicated shifts are used to put patient in their final Tx position
- New reference image is captured with AlignRT (zero offsets)
- Monitor patient’s position during treatment
- Discontinue treatment and reposition if offsets exceed ~1 mm
- Couch angle changed in AlignRT for beams utilizing couch rotations
Quality Assurance

- **Daily QA**
  Cal. verification

- **Monthly QA**
  Camera calibration

- **Isocenter Cal.**
  Allows AlignRT isocenter to be calibrated to MV isocenter
Clinical Results

- 44 patients
  - 115 intracranial metastatic lesions

- Median follow-up of 4.7 months
  - 1 year actuarial local control rate was 84%
    - 95% confidence interval: 69-99%

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**RESEARCH—HUMAN—CLINICAL STUDIES**

Pan et al., Neurosurgery, pp. 844-852, October 2012

Frameless, Real-Time, Surface Imaging-Guided Radiosurgery: Clinical Outcomes for Brain Metastases
## Clinical Results

Comparison of local control & survival for retrospective studies of brain metastases treated with radiosurgery

<table>
<thead>
<tr>
<th>Treatment System</th>
<th>Pts (n)</th>
<th>Actuarial 1y LC* (%)</th>
<th>Actuarial 1y Survival (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frame-based linac</td>
<td>80</td>
<td>89</td>
<td>33</td>
</tr>
<tr>
<td>Frame-based Gamma Knife</td>
<td>205</td>
<td>71</td>
<td>37††</td>
</tr>
<tr>
<td>Frameless linac</td>
<td>53</td>
<td>80</td>
<td>44</td>
</tr>
<tr>
<td>Frameless linac</td>
<td>65</td>
<td>76</td>
<td>40</td>
</tr>
<tr>
<td>Frameless, surface-imaging guided linac</td>
<td>44</td>
<td>84</td>
<td>37</td>
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</tbody>
</table>

*LC: local control; †: not reported; ††estimated from Kaplan-Meier curve
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