Practical Aspects of Cyberknife Small Beam Dosimetry

Sonja Dieterich, PhD and Lei Wang, PhD
Stanford University Hospital
Conflict of Interest

Sonja Dieterich has a consulting agreement with Cyberheart, Inc.
Outline

- Reference dosimetry
  - TG-51
  - Detectors
  - Independent output check
- Relative Dosimetry
  - Output Factors
  - OARs
- Practical Comments on taking dosimetry data
  - Tools needed
  - Time required
  - Order of measurement
The IAEA concept

- CyberKnife: machine-specific static reference field
- 60 mm collimator, 80 cm SAD

Alfonso et al, Med Phys (2008), 5179
TG-51 for flattening filter only? No!

TPR^{20}_{10}  

TG51 is using %dd(10)_x

Kalach & Rogers, Med Phys 30 (2003) 1546
TG-51: Measuring $\%dd(10)_x$

$\%dd(10)_x$: the photon component of the photon beam percentage depth-dose at 10 cm depth in a $10 \times 10$ cm$^2$ field on the surface of a water phantom at an SSD of 100 cm (see Sec. VIII B).

- CK: 60 mm spherical collimator at 80 cm SAD
- Measure at 10 cm depth, 100 cm SSD, 60 mm collimator
- Calculate equivalent square
- Interpolate to 80 cm SAD using the BJR data
TG-51: Chamber selection

- Dose flatness insufficient for Farmer-type chamber
- Cavity length should be 1 cm or shorter
- Option: cross calibrate a short chamber with Farmer-type chamber

Independent Output Check

- Absolutely necessary before treating a patient!
- Same institute: cross-calibrate (TLD)
- Stand-alone site: TLD service
Outline

- Reference dosimetry
  - TG-51
  - Chambers
  - Independent output check
- Relative Dosimetry
  - Output Factors
  - OARs
- Practical Comments on taking Beam Data
  - Tools needed
  - Time required
  - Order of measurement
Goal: OF Uncertainty < 3%

- Francescon, Cora, Cavedon, Med Phys (2008) 504
- OF (= $s_{c,p}$) for 3 smallest cones:
  - 2 microchambers, PTW60012 diode, diamond detector
  - Measurements
  - Monte Carlo simulation

} } Consistency Check

- Dependency of OF on FWHM of electron beam
- MC correction factors for detector response
OF as Function of Electron-Beam FWHM

![Graph showing OF as a function of FWHM](image)

Table IV. Measured and MC-simulated $s_{c,p}$ for the four detectors and for the 5, 7.5, and 10 mm collimators, for the various FWHM of the Gaussian spatial distribution of the electron source.

<table>
<thead>
<tr>
<th>Coll 5 mm</th>
<th>FWHM 1.4 mm</th>
<th>FWHM 1.8 mm</th>
<th>FWHM 2.2 mm</th>
<th>FWHM 2.6 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>A16</td>
<td>0.614</td>
<td>0.669</td>
<td>0.643</td>
<td>0.611</td>
</tr>
<tr>
<td>PinPoint</td>
<td>0.613</td>
<td>0.661</td>
<td>0.636</td>
<td>0.607</td>
</tr>
<tr>
<td>Diode</td>
<td>0.710</td>
<td>0.757</td>
<td>0.732</td>
<td>0.704</td>
</tr>
<tr>
<td>Diamond</td>
<td>0.613</td>
<td>0.677</td>
<td>0.639</td>
<td>0.609</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Coll 7.5 mm</th>
<th>FWHM 1.4 mm</th>
<th>FWHM 1.8 mm</th>
<th>FWHM 2.2 mm</th>
<th>FWHM 2.6 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>A16</td>
<td>0.801</td>
<td>0.809</td>
<td>0.808</td>
<td>0.799</td>
</tr>
<tr>
<td>PinPoint</td>
<td>0.798</td>
<td>0.805</td>
<td>0.802</td>
<td>0.795</td>
</tr>
<tr>
<td>Diode</td>
<td>0.852</td>
<td>0.757</td>
<td>0.850</td>
<td>0.843</td>
</tr>
<tr>
<td>Diamond</td>
<td>0.815</td>
<td>0.833</td>
<td>0.818</td>
<td>0.813</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Coll 10 mm</th>
<th>FWHM 1.4 mm</th>
<th>FWHM 1.8 mm</th>
<th>FWHM 2.2 mm</th>
<th>FWHM 2.6 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>A16</td>
<td>0.859</td>
<td>0.874</td>
<td>0.870</td>
<td>0.860</td>
</tr>
<tr>
<td>PinPoint</td>
<td>0.858</td>
<td>0.867</td>
<td>0.865</td>
<td>0.860</td>
</tr>
<tr>
<td>Diode</td>
<td>0.895</td>
<td>0.909</td>
<td>0.896</td>
<td>0.890</td>
</tr>
<tr>
<td>Diamond</td>
<td>0.871</td>
<td>0.889</td>
<td>0.876</td>
<td>0.872</td>
</tr>
</tbody>
</table>

Point source assumption starts breaking down for 5 mm collimator!
OF Correction Factor $F_{corr}$

- No lateral electron equilibrium
- Detector response: $F_{corr} = \frac{OF\ (MC)}{OF\ (measured)}$
- Combine detector correction with FWHM correction to get $s_{c,p}^*$

| TABLE III. Estimated values of $F_{corr}^*$ and $s_{c,p}^*$ for the 5, 7.5, and 10 mm collimators, for the four detectors. |
|---|---|---|---|
| | 5 mm | 7.5 mm | 10 mm |
| | $F_{corr}^*$ | $s_{c,p}^*$ | $F_{corr}^*$ | $s_{c,p}^*$ | $F_{corr}^*$ | $s_{c,p}^*$ |
| A16 | 1.098 | 0.675 | 1.021 | 0.818 | 1.010 | 0.867 |
| PinPoint | 1.107 | 0.679 | 1.027 | 0.819 | 1.014 | 0.870 |
| Diode | 0.957 | 0.679 | 0.966 | 0.823 | 0.978 | 0.875 |
| Diamond | 1.104 | 0.677 | 1.006 | 0.820 | 1.000 | 0.871 |
| Mean $s_{c,p}$ | 0.677 | 0.820 | 0.871 |
| $\pm 2\sigma$ | $\pm 0.004$ | $\pm 0.008$ | $\pm 0.008$ |
OF Corrections: Results

- Vicenza study results in low uncertainty of OFs if all corrections apply
- **Pantelis Med Phys (2008) 2312** BANG gel measurement strong indication for OF correction factor
OF corrections: What now?

- Convince me to change the 5 mm OF for my machines:
  - # of published papers agreeing on factor?
  - Doing my own, independent simulation? (Time, resources)
  - CyberKnife-wide consensus? (“Lets all decide on a number”)

- **IF** we change, how do we account for it in medical literature (e.g. trigeminal neuralgia)?
  - OF is usually not mentioned in physicians’ papers
  - Potential for errors in retrospective analyses

- We will have to discuss soon!
OAR Width vs. Detector Size

- Width of PTW60012 diode compared to small collimator OARs
- Use film as alternative? Other issues ...
- Do we need to de-convolve?
- No published literature (yet)
Outline

• Reference dosimetry
  • TG 51
  • Detectors
  • Independent output check

• Relative Dosimetry
  • Output Factors
  • OARs

• Practical Comments on taking Beam Data
  • Tools needed
  • Time required
  • Order of measurement
Tools needed

- **Water phantom:**
  - 3D tank with CAX correction
  - Be able to program star-pattern for IRIS

- **Detectors:**
  - (Farmer chamber)
  - Chamber with length < 1 cm
  - Diode & Reference Diode
    - PTW60012 (current standard)
    - Sun Nuclear Edge detector (hear lots of good things about it)
    - Other diodes

- **Other Detectors** (Bang gels, Diamond detectors, film ...)

---

**STANFORD SCHOOL OF MEDICINE**
Stanford University Medical Center

---
How much time is required?

<table>
<thead>
<tr>
<th></th>
<th>1 Fixed Collimator</th>
<th>1 IRIS collimator</th>
<th>Total/nozzle (hours)</th>
<th>Total (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OF (3 SADs)</td>
<td>10 min</td>
<td>10 min</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>TPR*</td>
<td>1.5 – 2 hrs</td>
<td>1.5 – 2 hrs</td>
<td>18 - 24</td>
<td>36 - 48</td>
</tr>
<tr>
<td>OCR*</td>
<td>1.5 – 2 hrs</td>
<td>1.5 – 2 hrs</td>
<td>18 - 24</td>
<td>36 - 48</td>
</tr>
<tr>
<td>MC data acqu.</td>
<td>N/A</td>
<td>N/A</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>TG 51</td>
<td>0.5-1</td>
<td>N/A</td>
<td>0.5 - 1</td>
<td>0.5 - 1</td>
</tr>
<tr>
<td>Total</td>
<td>3.5 - 5</td>
<td>3-4</td>
<td>40 - 51</td>
<td>78.5 - 103</td>
</tr>
</tbody>
</table>

- No automated tool to move robot 😞
- Time depends on position of robot teach pendant (outside room vs. inside room for each depth change)
- NOT Accuray recommended to watch by camera only ...
Order of Measurement

1. OF first!
   - Most difficult
   - Check inverse square law first (diodes go bad ...)

2. TPR, PDD, OCR
   - Fixed collimators first, then IRIS
   - TPRs for all cones
   - Then PDD for annual/quick reference!
   - OCRs for each cone

3. Process fixed cone data (ready to go live!)

4. Then process IRIS during the day, fixed cone MC during night

5. Last comes IRIS MC

6. Most efficient way to treatment!
Conclusion

- We have learned how to do TG 51 for CK
- The smallest cones remain a challenge, but ...
- ... we have several published papers on OF now
- Follow the literature
- Evaluate new detectors for suitability
- Definitely need more efficient beam data taking tools