Commissioning and Radiobiology of the INTRABEAM System
Susha Pillai and Junan Zhang

Scheme

• INTRABEAM System.
• Physics Commissioning, QA, and Radiation Protection
• Radiobiology
Disclosure

- OHSU is an INTRABEAM user but does not receive any financial support from Carl Zeiss, Inc.

INTRABEAM: a portable kV accelerator

- Small accelerator that generates electrons and produces x-rays.
- The accelerator itself is quite small. (175mmx110x70 mm, 1.62 kg)
- Probe is 10 cm long with 3 mm diameter
- X-rays are 50 kV in energy;
- No additional shield is needed for OR room.
INTRABEAM: breast treatment

Surgical removal of the tumor

Applicator with X-ray probe positioned in the lumpectomy site. Treatment lasts for about 20 to 50 minutes to deliver 20 Gy in single fraction to the applicator surface.

Depth Dose Curve

Sharp dose falls off (approx. $r^{-3}$) in tissue.
Scheme

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• Radiobiology

INTRABEAM Quality Assurance Tools

• Manufacturer provided full set of radiation shielded QA instruments.
• PDA (Photodiode Array)
  • Contains five photodiodes at orthogonal positions
  • Isotropy check
• PIACH (Probe adjuster/ionization chamber holder)
  • Measures and adjusts the straightness of the probe manually
  • Inbuilt thermometer for temperature/pressure correction
  • Mount for ion chamber
• High precision water phantom (optional/send back to factory to QA)
  • To perform independent verification of the depth dose and dose distribution
  • Radiation shielded with lead glass.
  • Mechanical positioning accuracy of +/- 0.1mm
**Annual Calibration**

Factory Annual Calibration

- Dose Rate in Water
- PTW chamber
- Dose Rate in Air
- Dose Rate Conversion Factor

PAICH Applicator

**Customer Output Check**

Factory Annual Calibration

- Dose Rate In Water
- Factory Chamber
- Dose Rate in Air
- Dose Rate Conversion Factor (DRCF)

Customer Output Check

- Dose Rate in Water w/o Applicator
- Customer Chamber (Calibrated every 2 years)
- Dose Rate in Air
- \( \times \) DRCF
Pre-Tx Output Check: ATF & IRM

- Clinical Dose Rate
- Dose Rate per IRM count (Gy/count)
- Dose Rate in Water w/o Applicator
- Dose Rate in Air
- Applicator Transfer function
- STOP
- ∆ >10% from baseline
- OR Primary
- OR Back-up
- Accumulated IRM counts
- IORT Tx
- Within 36hrs.

Applicator Transfer function takes into account the attenuation and scatter from the applicator.

Where to calibrate the PTW parallel-plate chamber?

- Choice 1: PTW Lab
  - Pros:
    - Recommended by Carl Zeiss, Inc.
    - Factory chamber is calibrated over there
  - Cons:
    - International shipping takes a little bit time
    - Traceable to national standards of the German National Lab. No to US standards.
An ADCL Lab (UW), traceable to NIST

<table>
<thead>
<tr>
<th>Beam Quality</th>
<th>HVL in Al (mm)</th>
<th>Air Kerma (Gy/C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UW50-L</td>
<td>0.760</td>
<td>1.151 x 10^9</td>
</tr>
<tr>
<td>UW40-L</td>
<td>0.503</td>
<td>1.165 x 10^9</td>
</tr>
</tbody>
</table>

50kV INTRABEAM beam quality

<table>
<thead>
<tr>
<th>Tube Voltage</th>
<th>HVL in Al (mm)</th>
<th>Interpolated Air Kerma (Gy/C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50kV</td>
<td>0.64</td>
<td>1.165 x 10^9</td>
</tr>
</tbody>
</table>

1. TG-61: Both tube potential and HVL shall be used to specify the air-kerma calibration factor.
2. TG-61: Interpolation may only be performed within the same series (e.g. for L series. But not between L series and M series.)

Where to calibrate the PTW parallel-plate chamber?

PTW Air Kerma (Gy/C): 1.174 x 10^9

Where to calibrate the PTW parallel-plate chamber?

1. TG-61: Both tube potential and HVL shall be used to specify the air-kerma calibration factor.
2. TG-61: Interpolation may only be performed within the same series (e.g. for L series. But not between L series and M series.)
Radiation Protection

- No additional shield is needed for OR room.
- Two tungsten-rubber shields (0.1mm lead equivalent. 95% reduction) to put over the breast.
- Two lead mobile barriers (>0.5mm lead equivalent). One for anesthesiologist and one for physicist, therapist and radiation oncologist, all wearing lead aprons.
- All other OR people have to leave the room.

Calibrated OSLDs used to monitor skin doses
Radiation Survey

Scheme

- INTRABEAM System
- Physics Commissioning, QA, and Radiation Protection
- Radiobiology
References

- Liu, Qi, et al. "Relative Biologic Effectiveness (RBE) of 50 kV X-rays measured in a phantom for intraoperative tumor-bed irradiation." *International Journal of Radiation Oncology* *Biology* *Physics* 85.4 (2013): 1127-1133

Single Fraction, High dose

- INTRABEAM delivers high single dose (typical 20Gy) to tumor bed. Similar to SRS.
- Linear-quadratic model has limitations in predicting the effects of single dose in the range of 15 Gy and higher.

• No proliferation of tumor cells between surgery and initiation of radiotherapy
  – Delaying the beginning of radiotherapy was estimated to be responsible for a loss in local control of about one-third (local recurrence rate of about 6\% vs. 9\%) when the delay exceeded 8 weeks. (Huang et al. 2003).

**Relative Biological Effectiveness (RBE)**

\[
RBE = \frac{\text{Dose of Reference Radiation}}{\text{Dose of Test Radiation}} 
\]

for a given effect
Relative Biological Effectiveness (RBE)

- Depends on LET and beam hardening
  - $\text{RBE(kV)} > \text{RBE(MV)}$
  - Deeper depth $\Rightarrow$ Beam Hardening $\Rightarrow$ Lower RBE

- Depends on radiation dose and survival level
  - Deeper depth $\Rightarrow$ Lower dose $\Rightarrow$ Higher Survival $\Rightarrow$ Higher RBE (based on LQ model)

- Depends on dose rate and treatment time

RBE varies with LET

<table>
<thead>
<tr>
<th>Radiation</th>
<th>LET of secondary electrons (keV/μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6-18 MV X-ray</td>
<td>0.2</td>
</tr>
<tr>
<td>Intrabeam (Avr. E=20 kV)</td>
<td>2</td>
</tr>
</tbody>
</table>
Beam hardening

Spherical breast applicator absorbs lower energy photons and harden the beam.

RBE decreases with beam hardening

Table 1. Estimated low-dose RBEs (α/β; see equation (1)) and clinically relevant RBEs (23 min irradiation, 12.5 GY) for low-energy x-rays as shown in figure 2, for a miniature photon radiosurgery system (Dinsmore et al 1996, Cosgrove et al 1997), operated at 40 kV.

<table>
<thead>
<tr>
<th>Depth (mm)</th>
<th>Low dose</th>
<th>Clinical</th>
<th>Low dose</th>
<th>Clinical</th>
<th>Low dose</th>
<th>Clinical</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>5.05</td>
<td>1.55</td>
<td>2.11</td>
<td>1.38</td>
<td>1.23</td>
<td>1.12</td>
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<tr>
<td>5</td>
<td>2.67</td>
<td>1.44</td>
<td>1.85</td>
<td>1.29</td>
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<tr>
<td>10</td>
<td>1.54</td>
<td>1.41</td>
<td>1.76</td>
<td>1.27</td>
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<td></td>
</tr>
<tr>
<td>15</td>
<td>2.48</td>
<td>1.40</td>
<td>1.72</td>
<td>1.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>2.44</td>
<td>1.40</td>
<td>1.69</td>
<td>1.24</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Estimated based on LQ model, for a fixed 20Gy

Relative Biological Effectiveness (RBE)

- Depends on LET and beam hardening
  - RBE(kV) > RBE(MV)
  - Deeper depth => Beam Hardening => Lower RBE
- Depends on radiation dose and survival level
  - Deeper depth => Lower dose => Higher Survival
    => Higher RBE (based on LQ model)
- Depends on dose rate and treatment time

RBE changes with cell survival level

- \( \text{Survival level} = 0.8 \)
- \( \text{Survival level} = 0.1 \)
- \( \text{Survival level} = 0.01 \)

Figure 4.1: Variation of RBE with LET for survival of mammalian cells of human origin. The RBE rises to a maximum at an LET of about 50 keV/\mu m, and subsequently falls for higher values of LET. Curves 1, 2, and 3 refer to cell survival levels of 0.8, 0.1, and 0.01, respectively. Observing that the absolute value of the RBE is not unique but depends on the level of biological damage and, therefore, on the dose level. (From Biomedicine 69: Cell Trop Radiat Res 1 239-356, 1969)

E. Hall, Radiobiology for the Radiologist
### Relative Biological Effectiveness (RBE)

- **Depends on LET and beam hardening**
  - $RBE(\text{kV}) > RBE(\text{MV})$
  - Deeper depth $\Rightarrow$ Beam Hardening $\Rightarrow$ **Lower RBE**

- **Depends on radiation dose and survival level**
  - Deeper depth $\Rightarrow$ Lower dose $\Rightarrow$ Higher Survival $\Rightarrow$ **Higher RBE** (based on LQ model)

- **Depends on dose rate and treatment time**

### LQ model predicts that RBE increases with depth

- Estimated (LQ model), Late-reacting normal tissue 200Gy to surface

  “The decrease in RBE with depth due to beam hardening is more than compensated for by the increase in RBE with depth due to the decreasing dose.”


Relative Biological Effectiveness (RBE)

- Depends on LET and beam hardening
  - RBE(kV) > RBE(MV)
  - Deeper depth => Beam Hardening => Lower RBE
- Depends on radiation dose and survival level
  - Deeper depth => Lower dose => Higher Survival => Higher RBE (based on LQ model)
- Depends on dose rate and treatment time

Repair of normal tissue cell during treatment

Cell survival curves with INTRABEAM. (Liu et al. 2013)


Experiment showed that RBE may decrease with depth


RBE(INTRABEAM, 8.1mm, 15.1 Gy/h)  
Probably due to different tx time and beam hardening  
> RBE(INTRABEAM, 12.7mm, 9.8 Gy/h)  
> RBE(6 MV, 360 Gy/h)
Correlation between RBE and dose level is not statistically significant.


Acknowledgements and Future Directions

- OHSU INTRABAM team
  - Surgeons, Nurses, Radiation Oncologists, Medical Physicists, Therapists, Dosimetrists

- Upcoming Task Group Report: No. 182 - AAPM Recommendations on Electronic Brachytherapy Quality Management