HDR Applicators and Dosimetry*

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*with a ‘too much’ radiobiology
Objectives

- Review the radiobiology of brachytherapy-linear quadratic model.
- Understand how to convert LDR dose prescriptions to HDR treatments.
- Understand some of the differences between LDR and HDR planning and treatment methods.
Radiobiology of Cell Death

- **Single Strand Breaks (SSB)**
  - easily repaired DNA damage

- **Double Strand Breaks (DSB)**
  - less frequent and less easily repaired DNA damage

- **Hypothesis**
  - unrepaired DSB lead to cell death-inactivation
Radiobiology-LQ Model

- \( S = \exp(-\alpha D + \beta D^2) \)
  - \( \alpha \) single event coefficient of a DSB
  - \( \beta \) double event coefficient of a DSB
  - \( S \) is the surviving fraction or overall probability of survival
  - High dose rate delivery with respect to repair
Radiobiology-Fractionation

- Late responding normal tissue cells versus tumor cells
  - shallower initial slope
  - steeper final slope
- Crossover point
  - $\alpha D = \beta D^2$
- Dose/fraction below the crossover point
  - higher survival of late responding tissues
Radiobiology-Dose Rate

- **Low Dose Rate (LDR)**
  - similar in effect to low dose per fraction below crossover point

- **High Dose Rate (HDR)**
  - possible to be above crossover point in effect

- **Equivalence?**
Radiobiology-the effect

- **Biological Effect-E**
  - single acute dose = $\alpha D + \beta D^2$
  - $n$ well separate fractions = $n(\alpha D + \beta D^2)$
  - $E = (nD)(\alpha + \beta D)$
  - $E/\alpha = \alpha(nD)(1 + D/(\alpha/\beta))$

- **Biological Effective Dose (BED)**
  - Extrapolated Response Dose (ERD)
  - $BED = E/\alpha = \text{Total Dose} \times \text{Relative Effectiveness}$
Prescriptions-Equivalence

↓ total dose, ↓ fraction size, ↑ fraction number to minimize complications

To determine a reasonable dose for HDR treatments, based upon a continuous LDR treatment, the BED’s or ERD’s are assumed to be equal.

\[
\text{HDR: } \quad E_{\text{RD}} \cdot N d (1 + \frac{d}{\alpha/\beta}) \quad [1]
\]

\[
\text{LDR: } \quad E_{\text{RD}} \cdot N R t \left(1 + \frac{2R}{\mu(\alpha/\beta)} \left(1 - e^{-\frac{\mu t}{\alpha/\beta}}\right) \right) \quad [2]
\]

where:

- \( N \) = number of fractions (for HDR or LDR);
- \( d \) = dose/fraction (for HDR) in Gy;
- \( R \) = dose rate (for LDR) in Gy/hour;
- \( t \) = time for each fraction (for LDR) in hours;

and \( \alpha/\beta \) (in Gy) and \( \mu \) (in h\(^{-1}\)) are tissue-specific parameters.
Equate and solve for HDR dose, spreadsheet math…

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value of V</th>
<th>ERD LDR</th>
</tr>
</thead>
<tbody>
<tr>
<td>N_LDR</td>
<td># of LDR fxs</td>
<td>1</td>
</tr>
<tr>
<td>Rate (LDR Rate)</td>
<td>60</td>
<td>R 0.60 Gy/hr</td>
</tr>
<tr>
<td>t (time)</td>
<td>83.3</td>
<td>T 83.33 hours</td>
</tr>
<tr>
<td>mu (1.4 hr)</td>
<td>1.4</td>
<td>N 5 fractions</td>
</tr>
<tr>
<td>alpha/beta</td>
<td>10</td>
<td>d 6.55 Gy/HDR fraction</td>
</tr>
<tr>
<td>Dose</td>
<td>5000</td>
<td></td>
</tr>
<tr>
<td>N_HDR</td>
<td># of HDR Fractions</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>ERD HDR Dose</td>
<td>6.55 Gy</td>
</tr>
</tbody>
</table>
Treatment Goals

- Deliver the dose to the target
  - LDR limited source strengths, limited variability
  - HDR can ‘tune’ the dose distribution
- Spare normal tissues
  - LDR: pull applicator or sources early as needed
  - HDR: adjust position and optimization points pre treatment
HDR Planning-Matching

- Exact matching of an individual isodose is possible, but ...
  - You may not always want a perfect match
  - Using BED, the DOSE relationship is NOT linear between HDR and LDR isodoses
HDR Planning - Considerations

- LDR classic pear shape
  - tapered near tip of tandem because of source placement
  - clinical outcome based upon cervix target
- HDR mimic classic pear shape
  - tapered near tip via optimization
  - planned outcome to mimic LDR shape
- How is this done...
Various HDR Applicators
Various HDR Applicators
Prescription Points Vs Dose Optimization Points (Vs DVH?)

- **Dose Optimization Points**
  - control the shape of the isodose distribution
  - assign relative weights to the points
  - e.g. 140% to ring surface

- **Prescription Points**
  - define the absolute value of the isodose lines
  - scale the entire dose distribution

- **Equivalence**
  - dose is prescribed to a ‘Point’
  - isodose shape is described by optimization
  - dose is delivered to a ‘Volume’
Dosimetry Methods - Tandem and Ring

- Dose optimization points are tapered along the tandem axis.
- Applicator points entered based on classic distances.
- Dwell locations down to ring, but not past.
Dosimetry Methods-Tandem and Ring

- Dose optimization points can also be used to modify the classic location of dose specification (Point A)
- 1.8 cm, 1.5 cm, 1.2 cm
- Use CT scan information to get uterine wall thickness
Dosimetry Methods-Tandem and Cylinder

- Dose optimization points along the tandem
- Dose optimization points along the cylinder surface
- When vaginal vault will not accept ovoids or ring geometry
Dosimetry Methods - Cylinders

- Simplest geometry
- Vaginal surface target
  - or depth
- follow the shape of the cylinder
- decide upon a treatment length
Conclusion

There are lots of details to keep track of during brachytherapy. Document your thoughts and rationales for any planning decisions. Communicate…

<table>
<thead>
<tr>
<th>HDR PLANNING SHORTCUTS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tandem and Ring:</strong> (step size 2.5 mm, dummy spacing 1.0 cm)</td>
</tr>
<tr>
<td>Digitizing Collar 1 (Ring): 1, 1.9, 27, 40, 85</td>
</tr>
<tr>
<td>Digitizing Collar 2 (Tandem): 1, 5, 9, 13, 17, 21, 25</td>
</tr>
<tr>
<td>(If using film, try tracking OR describing, whichever works. If using CURE-CEVO tracking)</td>
</tr>
</tbody>
</table>

**Tandem Table:** (Tandem dwell times active every 5.0 mm up to level of ring plane but not protruding into ring) DOSE POINTS @ 100% |

<table>
<thead>
<tr>
<th>Tandem Dwell Position along +X axis</th>
<th>4 cm hazards</th>
<th>6 cm hazards</th>
<th>8 cm hazards</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12 mm</td>
<td>12 mm</td>
<td>12 mm</td>
</tr>
<tr>
<td>3</td>
<td>10 mm</td>
<td>14 mm</td>
<td>14 mm</td>
</tr>
<tr>
<td>5</td>
<td>20 mm</td>
<td>16 mm</td>
<td>14 mm</td>
</tr>
<tr>
<td>7</td>
<td>20 mm</td>
<td>18 mm</td>
<td>16 mm</td>
</tr>
<tr>
<td>9</td>
<td>20 mm</td>
<td>20 mm</td>
<td>18 mm</td>
</tr>
<tr>
<td>11+</td>
<td>20 mm</td>
<td>20 mm</td>
<td>20 mm</td>
</tr>
</tbody>
</table>

**Ring Table:** (adjust for symmetry or prescription)

<table>
<thead>
<tr>
<th>Active Dwell 26 mm Ring</th>
<th>40 mm Ring</th>
<th>44 mm Ring</th>
</tr>
</thead>
<tbody>
<tr>
<td>(4-dwell each side)</td>
<td>(5-dwell each side)</td>
<td>(6-dwell each side)</td>
</tr>
<tr>
<td>Left Side Dwell 21,25,29</td>
<td>25,29,33,37,39</td>
<td>25,29,33,37,39</td>
</tr>
</tbody>
</table>

**Ring optimization point placed relative to catheter axis @ 6 mm in the +U axis all active dwell in ring with DOSE POINTS @ 100%**

**Cylinder:** (step size 5.0 mm, dummy spacing 1.0 cm) DOSE POINTS @ 100% |

**Digitize using tracking for easiest method.**

<table>
<thead>
<tr>
<th>Dwell Position along +X axis</th>
<th>2 cm diameter</th>
<th>2.5 cm diameter</th>
<th>3 cm diameter</th>
<th>3.5 cm diameter</th>
<th>4 cm diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9</td>
<td>11</td>
<td>12</td>
<td>13</td>
<td>15</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
<td>12.5</td>
<td>14</td>
<td>16</td>
<td>18</td>
</tr>
<tr>
<td>3</td>
<td>10</td>
<td>12.5</td>
<td>15</td>
<td>17.5</td>
<td>20</td>
</tr>
<tr>
<td>4</td>
<td>10</td>
<td>12.5</td>
<td>15</td>
<td>17.5</td>
<td>20</td>
</tr>
</tbody>
</table>

**Tip Dwell along +X axis**

<table>
<thead>
<tr>
<th>Tip Dwell Position along +X axis</th>
<th>2 cm diameter</th>
<th>2.5 cm diameter</th>
<th>3 cm diameter</th>
<th>3.5 cm diameter</th>
<th>4 cm diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>51 mm</td>
<td>49 mm</td>
<td>43 mm</td>
<td>43 mm</td>
<td>39 mm</td>
</tr>
</tbody>
</table>