The Physics of Skin Brachytherapy: The Manchester Approach

Sally Baker
Principal Brachytherapy Physicist
The Christie
Overview

- Different radiation modalities for skin
- Advantages of brachytherapy
- Principles of Manchester System for skin
- Dosimetric assessment of Manchester System
- Image guided optimisation
- Dose and Fractionation
Radiation modalities for skin - kV

- Commonly radiotherapy for skin cancer is given with superficial X-ray machines.
  - Only useful for small tumours
  - Now mostly used for bcc on faces of elderly patients
  - Dosimetric issues with curved treatment areas

Image taken from http://www.gulmaymedical.com/xstrahl300.htm
Radiation modalities for skin - electrons

- High-energy electron (linear accelerator) treatments are increasingly being used.
- Even lowest energy still gives significant dose at depth.
- Only really beneficial for deep tumours.
- 4x4cm minimum treatment area.
- Cannot account for curvature in treatment area.
- Dosimetric planning uncertainties.
Radiation modalities: depth dose

% Depth Dose for different modalities

- 40kV Superficial 4cm
- 6MeV Electrons 10cm
- Brachytherapy mould
Brachytherapy

- Can position source to precisely cover treatment area
- Conformal dose distribution with small effective penumbra
- Relative dose at depth can be controlled by adjusting height of source dwells above skin surface
- Due to close source to skin distance, depth dose profile falls off quickly sparing tissue at depth.
- Can account for surface curvature
The Manchester System

- Started with Radium sources
- Published rules from Paterson-Parker, compiled in *Radium Dosage: The Manchester System* (Meredith 1938)
- Distribution rules to obtain uniform dose distribution
- Tabulated data for calculating treatment time
The Manchester system

- Aim is deliver uniform skin surface dose
- Regular source positions around circumference of area
- For large area need % activity in centre
Source distribution rules

Aims to give a uniform dose (+-10%) across skin surface
Calculating treatment time

- Look up area and treatment height in table
- Obtain amount of radium to get prescribed dose to skin surface
- This table was later converted to more modern units of microGy of RAK / Gy of prescription dose

Leads to a calculation of the treatment time.
Treatment depth

- Expressed as ‘80% depth’
- 100% is the average dose across skin surface
- 80% should cover disease plus a 1mm depth margin
The Manchester System

Height above skin to place sources determined by the treatment depth required

- Governed by the inverse square law
- Sources placed higher above skin to achieve greater relative dose at depth

<table>
<thead>
<tr>
<th>Source height</th>
<th>Separation of 100 and 80% isodoses</th>
</tr>
</thead>
<tbody>
<tr>
<td>5mm</td>
<td>0.6mm</td>
</tr>
<tr>
<td>10mm</td>
<td>1.3mm</td>
</tr>
<tr>
<td>20mm</td>
<td>2.5mm</td>
</tr>
</tbody>
</table>
Manchester system 80% depth dose (mm)

<table>
<thead>
<tr>
<th>Distance, $h$, to surface, in mm</th>
<th>Area of mould, in cm$^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>1.4</td>
</tr>
<tr>
<td>10</td>
<td>2.2</td>
</tr>
<tr>
<td>15</td>
<td>2.6</td>
</tr>
<tr>
<td>20</td>
<td>3.3</td>
</tr>
</tbody>
</table>

i.e. If you need to treat to greater depth, place the sources at a greater treatment height
Adapted for HDR afterloading

Position HDR source in plastic catheters according to distribution rules around circumference and centre spot if needed

Ensure HDR source height and spacing positioned accurately
Manchester system dosimetry review

- Geometric circular arrangements of sources created
- Catheter axes defined in plane above skin surface
- Dose profile at skin surface assessed
Findings for flat treatment areas

• For a flat surface the dose across the skin surface calculated on Oncentra Brachy TPS is within 10% of 100% (for most small areas is within 5%)
• The uniformity depends upon area and height but for flat areas and regular geometry works well.
Curved treatment areas

- Manchester system ‘can be used’ for curvature less than $\frac{1}{2}$ cylinder

Convex surface results in sources splaying at treatment height
Surface dose profile from centre to periphery

Dose profile (mm)

% Surface dose (cGy)

Flat geometry
Curved surface

Centre  Periphery
Clinical treatment areas

- Standard flat(ish) areas e.g. shin, scalp
- Curved treatment areas e.g. finger-tip, ear
  - Regular spacing of posts on circumference leads to irregular dwell positions
Individualised planning approach

Can use 3D scans of empty shell to:
• reconstruct source positions
• assess coverage of surface dosimetry and dose at depth
<table>
<thead>
<tr>
<th><strong>Manchester System</strong></th>
<th><strong>Image Guided Planning</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Experience since 1930s</td>
<td>Knowledge needed of acceptable dose distributions</td>
</tr>
<tr>
<td>Tables used to calculate doses/depths</td>
<td>Dosimetry across volume can be assessed</td>
</tr>
<tr>
<td>Assumes regular geometry and flat surface</td>
<td>Geometry of source dwell positions can be reconstructed on CT</td>
</tr>
</tbody>
</table>
| Inverse square law correction only | TG43 dose formalism  
• assumes water equivalence for modelling attenuation and scatter  
• Models source anisotropy |
| Fit of shell to patient assumed to be perfect | Air gaps between shell and patient can be seen (CT scan in treatment setup) |
Array style treatments

- Activate dwells above whole treatment area and with a margin as needed to cover target area
- Adjust dwell weightings to achieve uniform dose distribution across skin surface
- More flexible optimisation
- 80% depth doses altered from Manchester system, dependent on relative weightings within array
Array-style plan

Create source dwell positions on catheters spaced 1cm apart
## Optimised weightings

- optimise to give uniform dose to skin surface
- Within an individual catheter the dwell weightings are lowest in the centre
- Mimics peripheral loading of classical Manchester System

<p>| | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>11</td>
<td>-75.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.54</td>
</tr>
<tr>
<td>4</td>
<td>12</td>
<td>-72.5</td>
<td>0.0</td>
<td>0.0</td>
<td>0.31</td>
</tr>
<tr>
<td>4</td>
<td>13</td>
<td>-70.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.21</td>
</tr>
<tr>
<td>4</td>
<td>14</td>
<td>-67.5</td>
<td>0.0</td>
<td>0.0</td>
<td>0.03</td>
</tr>
<tr>
<td>4</td>
<td>15</td>
<td>-65.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.00</td>
</tr>
<tr>
<td>4</td>
<td>16</td>
<td>-62.5</td>
<td>0.0</td>
<td>0.0</td>
<td>0.00</td>
</tr>
<tr>
<td>4</td>
<td>17</td>
<td>-60.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.00</td>
</tr>
<tr>
<td>4</td>
<td>18</td>
<td>-57.5</td>
<td>0.0</td>
<td>0.0</td>
<td>0.00</td>
</tr>
<tr>
<td>4</td>
<td>19</td>
<td>-55.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.04</td>
</tr>
<tr>
<td>4</td>
<td>20</td>
<td>-52.5</td>
<td>0.0</td>
<td>0.0</td>
<td>0.21</td>
</tr>
<tr>
<td>4</td>
<td>21</td>
<td>-50.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.31</td>
</tr>
<tr>
<td>4</td>
<td>22</td>
<td>-47.5</td>
<td>0.0</td>
<td>0.0</td>
<td>0.53</td>
</tr>
</tbody>
</table>
Dose at depth

% dose at depth (4cm diameter circle)

Source height above skin surface
- 10mm
- 15mm
- 20mm

% of skin surface dose

Depth (mm)
Array-style depth doses

- Minimal differences seen with different step sizes
- Slight differences in depth doses compared with Manchester System (due to source/dwell weighting arrangement)

The array is positioned at a height using thermoplastic bolus material
Array-style 80% depth doses

<table>
<thead>
<tr>
<th>Distance, h, to surface, in mm</th>
<th>3</th>
<th>7</th>
<th>10</th>
<th>20</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 (e.g. Flap + shell)</td>
<td>1.7</td>
<td>2.1</td>
<td>2.7</td>
<td>2.9</td>
<td>3.0</td>
</tr>
<tr>
<td>12 (e.g. Flap + 5mm Thermoplast + shell)</td>
<td>2.1</td>
<td>2.7</td>
<td>2.9</td>
<td>3.3</td>
<td>3.9</td>
</tr>
<tr>
<td>17 (e.g. Flap + 10mm Thermoplast + shell)</td>
<td>2.5</td>
<td>3.0</td>
<td>3.5</td>
<td>3.9</td>
<td>3.9</td>
</tr>
<tr>
<td>22 (e.g. Flap + 15mm Thermoplast + shell)</td>
<td>2.9</td>
<td>3.3</td>
<td>3.9</td>
<td>4.3</td>
<td>5.0</td>
</tr>
</tbody>
</table>

- Values are for flat treatment areas
- A curved surface achieves greater dose at depth
Treatment planning

- Patient treatments are planned on CT datasets:
  - Mould fitted to the patient so skin surface can be seen
  - Catheters fixed in position above the skin surface
  - Catheters threaded with wire to enable reconstruction of path
  - Treatment area marked out using wire
  - Can determine which dwell positions are needed and optimise the plan to best cover the treatment area
Preparing for Treatment Planning: Defining Catheter Tip

- Catheter Tip on Plan = most distal dwell position
- We define it on the proximal side of the button

- This point is easily visible on the CT scans
- Metal wires are positioned inside the catheters for the CT scan
MicroSelectron – Distal Length

- Position tip of check cable at proximal side of button and read out position from Handheld Terminal

Distal reference length for HDR in Treatment Plan

N.B. As catheter ends after the button, cannot use dwell positions in last 5mm of catheter
Numbering the catheters

- The catheters are numbered prior to CT scanning
- Correspond to the transfer tube and channel numbers for treatment
- We use numbers from RS used for electrical cables
Marking the treatment area

- A thin wire is taped to the inside of the shell underneath the clinician’s target outline
- Easy to mark out target area on planning system

Treatment Planning with the CT scan will be covered in the afternoon session.
Treatment depths achievable

- Treatment depth (of 80% isodose) depends on:
  - curvature of treatment area
  - height of sources above surface

- Coverage of the target volume is good at 11mm source height
- If the sources are too close to the skin surface, it is also hard to generate a uniform dose distribution at skin surface
Image guided skin brachytherapy patients treated at the Christie

- All skin brachytherapy treatments planned on Oncentra Brachy since March 2012
- 59 patients so far

<table>
<thead>
<tr>
<th>Location</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Finger</td>
<td>18</td>
</tr>
<tr>
<td>Lower leg</td>
<td>15</td>
</tr>
<tr>
<td>Hand</td>
<td>12</td>
</tr>
<tr>
<td>Scalp</td>
<td>7</td>
</tr>
<tr>
<td>Angio Sarcoma of scalp</td>
<td>3</td>
</tr>
<tr>
<td>Pinna</td>
<td>2</td>
</tr>
<tr>
<td>Arm</td>
<td>1</td>
</tr>
<tr>
<td>Shoulder</td>
<td>1</td>
</tr>
</tbody>
</table>
Derivation of dose and fractionation

- Historically, continuous low dose rate:
  - Radium/radon moulds 6000 Roentgen over 10 days
  - Cobalt moulds 5250cGy/ 8 consecutive days
• At introduction of HDR afterloader in 1980s:
  • Fundamental shift from continuous LDR to fractionated HDR
    • Assume insignificant repair during treatment
    • 6h minimum time between fractions (assuming 1.5h repair half time this gives ~94% repair)
  • Due to the radiobiological uncertainties of LDR to HDR, the Px dose was taken from EBRT experience of radical 8 fraction treatments of 4000-4500cGy for small areas

Table 2

<table>
<thead>
<tr>
<th>Total dose (Gy)/no. of fractions</th>
<th>BED early responding tissues ($\alpha/\beta = 10$ Gy)</th>
<th>BED late responding tissues ($\alpha/\beta = 3$ Gy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>45/8</td>
<td>70</td>
<td>129</td>
</tr>
<tr>
<td>22/1</td>
<td>70</td>
<td>183</td>
</tr>
<tr>
<td>52.5/15</td>
<td>71</td>
<td>114</td>
</tr>
<tr>
<td>60/30</td>
<td>72</td>
<td>100</td>
</tr>
</tbody>
</table>

Many assumptions in the radiobiological calculations….
Since the 80’s: 4000 – 4500cGy in 8# with HDR
Sometimes dose is reduced to 3750cGy (poorly perfused areas)
**Prescribed to skin surface** as per classical Manchester System for skin with manual sources
Treated bi-daily with at least a 6 hour gap
8# delivered over 4/5 days

Treatment times ~10 mins per # depending on area, treatment height and age of source (range 2 – 60 mins)
Dose at depth

- 80% = min dose to target volume = 3000-3600 cGy/8#
Prescription depth

- Our convention is to prescribe to skin surface
  - (as with superficial x-ray)
- In some centres the dose is prescribed to depth
- -> report the depth as well as the dose prescribed
- Be wary of prescribing the dose to a single point
  - Dose varies significantly with a small change in depth
  - Dose varies across the area even with an optimised plan
  - Need to review coverage of whole target volume
Summary

- Brachytherapy for skin treatments at the Christie:
  - Long history of treatment, now modified to use image guidance and plan optimisation
  - Suitable to treat shallow depths
  - Conformal to target area, using CT scan to reconstruct source catheters and define target volume to guide optimisation
  - Can be targeted to cover the treatment depth by adjusting source height above treatment surface
Any Questions ?