Historical Reconstruction of Co-60 Radiotherapy Doses to Patients with Hodgkin’s Lymphoma

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Background

• What is Hodgkin’s Lymphoma (HL)?
  – Cancer of the lymphocytes

• Why are we interested in HL?
  – Correlating mean organ dose with late radiation effects
    • “Health Risks from Exposure to Low Levels of Ionizing Radiation: BEIR VII”
  – Benefits of the study
    • Known delivered tumor doses
    • Relatively large field sizes
  – Negatives of the study
    • Radiation therapy as well as chemotherapy were used
    • Genetic predisposition to certain diseases
    • Historically, treatment planning did not include 3D image sets
Correlating Dose with Late Radiation Effects

- Secondary cancers are the leading cause of death in 15 years survivors of HL (Hoppe et al 1997)

- Goal of creating more accurate risk models

- University of Florida cohort
  - 55 patients with at least 40 years of potential follow-up
  - 24 second malignancies identified in 19 patients
  - 22 in-field second malignancies in 17 patients

5 year OS: 79.7% (95% CI; 66.9-88.4%)
10 year OS: 64.9% (95% CI; 51.4-76.3%)
20 year OS: 55.5% (95% CI; 42.2-68.1%)
Organs at Risk

Mantle Field

- Thyroid (hypothyroidism, multinodular goiter, thyroid cancer)
- Heart (coronary artery disease, valvular insuff./sten., cardiomyopathy)
- Lungs (lung cancer, pulmonary fibrosis)
- Breast (invasive carcinoma and DCIS)
- Peripheral Vasculature (subclavian steal syndrome, carotid dz)
- Spinal Cord (transverse myelitis)

Inverted Y Field

- Small and large bowel (radiation enteritis, colonic polyps)
- Gonads (ovarian dysfunction, infertility)
- Peripheral Vasculature (renal artery stenosis, mesenteric angina)
Previous Dosimetry Methods

1. Calculations in 3-D mathematical computer models using an extensive database of out-of-beam doses
2. Measurements in anthropomorphic phantoms constructed of tissue-equivalent material
3. Calculations using 3-D treatment planning

<table>
<thead>
<tr>
<th>Modality</th>
<th>Dose reconstruction organ site</th>
<th>Mean organ dose, Gy (range)</th>
<th>Dosimetry method</th>
<th>Number of patients</th>
<th>Reference(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hodgkin lymphoma</td>
<td>Lung</td>
<td>(0.5–4.9)</td>
<td>1 (with correction for lung blocking)</td>
<td>Cases = 98, Controls = 259</td>
<td>Kaldor et al. (82)</td>
</tr>
<tr>
<td>External beam</td>
<td>Lung</td>
<td>7.2 (&lt;1–15.2) cases</td>
<td>1, 3</td>
<td>Cases = 29, Controls = 82</td>
<td>van Leeuwen et al. (83)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6.7 (&lt;1–21.0) controls</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>External beam</td>
<td>Lung</td>
<td>27.2 (median 33.8) cases</td>
<td>1, 3</td>
<td>Cases = 222, Controls = 444</td>
<td>Travis et al. (41)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>21.8 (median 29.4) controls</td>
<td></td>
<td></td>
<td>Gilbert et al. (42)</td>
</tr>
</tbody>
</table>

Monte Carlo Methods

- Large differences between doses reported from treatment planning system (TPS) doses and measured values
  - TPS underestimates dose up to 55% at 11.25 cm from the treatment field border (Howell et al. 2010)
  - Large differences in mean doses between TPS and Monte Carlo calculations, up to 70% (Joosten et al. 2013)

- Lack of 2D & 3D image sets creates a need for computational phantoms

- In-field and out-of-field doses can be considered with Monte Carlo methods

"The UF Family of Reference Hybrid Phantoms for Computational Radiation Dosimetry" (Lee et al. 2004)
### Overview of Anthropomorphic Data

<table>
<thead>
<tr>
<th>Patient #</th>
<th>Sex</th>
<th>Age</th>
<th>Height</th>
<th>Weight [lbs]</th>
<th>Arm Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>F</td>
<td>16</td>
<td>5' 7&quot;</td>
<td>158</td>
<td>up</td>
</tr>
<tr>
<td>2</td>
<td>M</td>
<td>16</td>
<td>5' 10&quot;</td>
<td>138.8</td>
<td>down</td>
</tr>
<tr>
<td>3</td>
<td>F</td>
<td>12</td>
<td>5' 3&quot;</td>
<td>111.7</td>
<td>down</td>
</tr>
<tr>
<td>4</td>
<td>M</td>
<td>14</td>
<td>6' 2&quot;</td>
<td>199.6</td>
<td>down</td>
</tr>
<tr>
<td>5</td>
<td>F</td>
<td>21</td>
<td>5' 5&quot;</td>
<td>136</td>
<td>up</td>
</tr>
<tr>
<td>6</td>
<td>F</td>
<td>20</td>
<td>5' 5&quot;</td>
<td>107</td>
<td>down</td>
</tr>
<tr>
<td>7</td>
<td>F</td>
<td>36</td>
<td>5' 6&quot;</td>
<td>187.5</td>
<td>down</td>
</tr>
<tr>
<td>8</td>
<td>M</td>
<td>22</td>
<td>6' 2&quot;</td>
<td>172</td>
<td>up</td>
</tr>
<tr>
<td>9</td>
<td>F</td>
<td>57</td>
<td>5' 6&quot;</td>
<td>179.3</td>
<td>down</td>
</tr>
<tr>
<td>10</td>
<td>F</td>
<td>17</td>
<td>5' 5&quot;</td>
<td>154.7</td>
<td>down</td>
</tr>
</tbody>
</table>

- Modeled Cobalt-60 teletherapy unit
- Matched subjects to UF/NCI phantom library
- Generated “Historical” information
- Subjects matched to a mantle field treatment
- Calculated relative organ doses
Cobalt-60 Teletherapy Unit

- Source Capsule & Housing
- Primary Definer
- Moveable Collimators
- Trimmer Bars
- Cerrobend block

SSD = 80 cm
Validation for In-Field and Out-of-Field Doses

- **In-field**
  - Agrees with British Journal of Radiology Supplement 25 percent depth dose (PDD) data with in ~1%

- **Out-of-field**
  - Agrees with AAPM Radiation Therapy Committee Task Group No. 36 “Fetal dose from Radiotherapy with photon beams” within 8.8%
Phantom Patient matching

Variations of phantoms for Subject 10

LEAST

Library (LIB)

Progression of Refinement

MOST

Caliper-Scaled Hybrid (CSH)

Photo-Caliper-Scaled Hybrid (PCSH)

Patient Specific Voxel (PSV)
Phantom Patient matching

Variations of phantoms for Subject 10

LEAST

Library (LIB)
Caliper-Scaled Hybrid (CSH)

Progression of Refinement

Photo-Caliper-Scaled Hybrid (PCSH)
Patient Specific Voxel (PSV)

MOST
Phantom Patient matching

Progression of Refinement

LEAST

Library (LIB) | Caliper-Scaled Hybrid (CSH) | Photo-Caliper-Scaled Hybrid (PCSH) | Patient Specific Voxel (PSV)

MOST

Caliper-Scaled Hybrid (CSH) → Photo-Caliper Scaled Hybrid (PCSH)

Variations of phantoms for Subject 10
Phantom Patient matching

Variations of phantoms for Subject 10

LEAST

Library (LIB)

Caliper-Scaled Hybrid (CSH)

Photo-Caliper-Scaled Hybrid (PCSH)

Patient Specific Voxel (PSV)

Progression of Refinement

MOST
Mantle Field Recreation

- Co-60 unit is paired with variations of phantoms for estimating mean organ dose
- Reconstruction
  - AP/PA fields
  - 80 cm SSD
  - 35 Gy prescribed to midline at suprasternal SSN
  - 3:2 anteriorly weighted
## Results

### A.

**Average Percent Difference for all Organs**

<table>
<thead>
<tr>
<th>Type</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSV/LIB</td>
<td>27.9%</td>
</tr>
<tr>
<td>PSV/CSH</td>
<td>24.8%</td>
</tr>
<tr>
<td>PSV/PCSH</td>
<td>24.2%</td>
</tr>
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</table>

### B.

**Average Percent Different for all In-Field Organs**

<table>
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<th>Type</th>
<th>Percentage</th>
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<tbody>
<tr>
<td>PSV/LIB</td>
<td>14.3%</td>
</tr>
<tr>
<td>PSV/CSH</td>
<td>11.6%</td>
</tr>
<tr>
<td>PSV/PCSH</td>
<td>11.0%</td>
</tr>
</tbody>
</table>

### C.

**Average Percent Different for all Out-of-Field Organs**

<table>
<thead>
<tr>
<th>Type</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSV/LIB</td>
<td>49.1%</td>
</tr>
<tr>
<td>PSV/CSH</td>
<td>48.9%</td>
</tr>
<tr>
<td>PSV/PCSH</td>
<td>47.1%</td>
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</table>
Acknowledgements

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• ALRADS Group