History of Dosimetry Audit in the UK

Andrew Nisbet

Department of Medical Physics
St Luke’s Cancer Centre, Royal Surrey County Hospital NHS Foundation Trust, Guildford
& Department of Physics, Surrey University
What can we learn from audit results in the literature?

- What benefits have been derived?
- What is the currently achieved consistency in radiotherapy dosimetry?
- Can dosimetry audits be used to assure accuracy of advanced radiotherapy treatments?
- Do dosimetry audits benefit clinical trials?
- What should the methodology for future national dosimetry intercomparisons entail?
Timeline

- IAEA postal dosimetry service 1966/7 using (LiF) TLD. The WHO joined the programme in 1968

- RPC funded since 1968 by the NCI for QA of dosimetry of patients entered into clinical trials

- Worsnop B R 1968 Phantom thermoluminescent dosimeter comparison for a co-operative radiotherapy trial Radiology 91 541-53

- Almond P R, Law J and Svenson H 1972 Comparison of radiation dosimetry between Houston (USA), Edinburgh (UK) and Umea (Sweden) Phys. Med. Bid 17 64-70
Timeline


Timeline


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• 1st comprehensive national dosimetry intercomparison in the UK carried out in the late 1980s. (Thwaites et al. PMB 37, 445, 1992)
Thwaites et al 1992

- 15 regions
- Jan 1987-Jan 1991
- 63 centres
Reference Dosimetry Results

Table 6. Summary of results (ratios of measured-to-stated dose) of recent photon dosimetry intercomparisons in reference conditions.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Region/study</th>
<th>No.</th>
<th>Av.</th>
<th>sd</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Johansson et al (1982)</td>
<td>Scandinavia</td>
<td>22</td>
<td>1.001</td>
<td>0.014</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>Co-60</td>
<td>50</td>
<td>1.017</td>
<td>0.023</td>
<td>0.10</td>
</tr>
<tr>
<td></td>
<td>x-rays</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Johansson et al (1986) (EORTC)</td>
<td>Europe</td>
<td>59</td>
<td>1.001</td>
<td>0.019</td>
<td>0.10</td>
</tr>
<tr>
<td></td>
<td>Co-60</td>
<td>16</td>
<td>1.024</td>
<td>0.033</td>
<td>0.14</td>
</tr>
<tr>
<td></td>
<td>x-rays</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wittkämper et al (1987)</td>
<td>Netherlands</td>
<td>11</td>
<td>0.994</td>
<td>0.006</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>Co-60</td>
<td>40</td>
<td>1.008</td>
<td>0.020</td>
<td>0.10</td>
</tr>
<tr>
<td></td>
<td>x-rays</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hanson et al (1991)</td>
<td>International (mainly USA)</td>
<td>740</td>
<td>1.008</td>
<td>0.019</td>
<td>0.14</td>
</tr>
<tr>
<td></td>
<td>Co-60 and x-rays</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>This work</td>
<td>UK</td>
<td>61</td>
<td>1.002</td>
<td>0.014</td>
<td>0.08*</td>
</tr>
<tr>
<td></td>
<td>Co-60</td>
<td>100</td>
<td>1.003</td>
<td>0.015</td>
<td>0.10</td>
</tr>
<tr>
<td></td>
<td>x-rays</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Omitting centre 163.
## Multi Beam Situations

**Table 7. Summary of results (ratios of measured-to-calculated dose at the centre of target volume) of dosimetry intercomparisons in multi-beam situations (with acknowledgements to Johansson 1987).**

<table>
<thead>
<tr>
<th>Reference</th>
<th>Region/study</th>
<th>Site</th>
<th>No.</th>
<th>Mean</th>
<th>sd</th>
</tr>
</thead>
<tbody>
<tr>
<td>Worsnop (1968)</td>
<td>US 1968</td>
<td>lung</td>
<td>16</td>
<td>—</td>
<td>0.069</td>
</tr>
<tr>
<td>Johansson (1987)</td>
<td>Sweden 1984</td>
<td>bladder</td>
<td>15</td>
<td>1.002</td>
<td>0.031</td>
</tr>
<tr>
<td>Wittkämper <em>et al</em> (1987)</td>
<td>Netherlands 1985</td>
<td>prostate</td>
<td>18</td>
<td>1.015</td>
<td>0.015</td>
</tr>
<tr>
<td>SSRBMP (1984)</td>
<td>Switzerland 1984</td>
<td>lung</td>
<td>13</td>
<td>1.005</td>
<td>0.062</td>
</tr>
<tr>
<td>Present work</td>
<td>UK</td>
<td>3-field (homogeneous) (with lung inhomogeneity)</td>
<td>62</td>
<td>1.008</td>
<td>0.027</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>62</td>
<td>1.011</td>
<td>0.034</td>
</tr>
</tbody>
</table>
Timeline

- Dosimetry audit network evolved in the early 1990s (e.g. Bonnett et al BJR 67, 275, 1994)
  - UK national audit network established in 1993
  - Network co-ordinated by the IPEM and comprises eight co-operative regional groups
  - Basic audit methodology and phantom design followed that of the original national intercomparison

Results for Electron Beam Calibrations

No. of Beams 156
Mean 0.994
Std Dev 1.8%
Max Positive Dev. 4.6%
Max Negative Dev. 5.1%
Timeline

- NPL, at the invitation of IPEM, started conducting reference dosimetry audits in 1995.
  - The NPL is involved in the network and carries out reference beam calibration audits to link the groups.

Circa 2000 NCRI Radiotherapy Clinical Trials: Quality Assurance Group
Venables et al  *Phys Med Biol.* 2001 Jul;46(7):1937-48 The mean ratio of measured to calculated dose at the START reference point was found to be 0.981 for the breast phantom and 0.978 for the chest wall phantom. A number of departments had deviations of greater than 4%

Venables et al  *Radiother Oncol.* 2004 Jun;71(3):303-10 TLD measurements were performed on 429 patients from 33 hospitals. The average ratio of dose measured using TLD to that prescribed was 0.99+/-0.04. Eight patients had initial measurements more than 10% different to the prescribed dose.
Semi Anatomic phantom Scottish+ audits (Thwaites et al 2003)

- MV calibration 1.001 (SD 1.1%)
- Other single field parameters 0.998 (SD 1.5%)
- Geometric parameters 1.00 (SD 1mm)
- $e^{-}$ calibration 0.997 (1.8%)
- KV 1.001 (SD 1.6%)
- Breast 0.978 (2.3%) 96% within 5% tolerance
- Thorax 0.991 (1.1%) 100%
- H&N 0.993 (1.6%) 97% within tolerance
Timeline

- Dosimetry audit for a multi-centre IMRT head and neck trial. Clark et al Radiother Oncol 2009
- A national dosimetric audit of IMRT. Budgell et al Radiother oncol 2011
- A methodology for dosimetry audit of rotational radiotherapy using a commercial detector array. Hussein et al Radiother Oncol 2013
- A national dosimetry audit of intraoperative radiotherapy Eaton et al BJR 2013
Comparison between all results

<table>
<thead>
<tr>
<th>2003</th>
<th>1996</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>22</td>
</tr>
<tr>
<td>Mean</td>
<td>0.995</td>
</tr>
<tr>
<td>Std Dev</td>
<td>0.7%</td>
</tr>
<tr>
<td>Max Pos Dev</td>
<td>0.5%</td>
</tr>
<tr>
<td>Max Neg Dev</td>
<td>2.0%</td>
</tr>
</tbody>
</table>
## Comparison between relevant centres 1996 and 2003 results

<table>
<thead>
<tr>
<th></th>
<th>2003</th>
<th>1996</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>22</td>
<td>15</td>
</tr>
<tr>
<td>Mean</td>
<td>0.995</td>
<td>0.995</td>
</tr>
<tr>
<td>Std Dev</td>
<td>0.7%</td>
<td>2.2%</td>
</tr>
<tr>
<td>Max Pos Dev</td>
<td>0.5%</td>
<td>2.6%</td>
</tr>
<tr>
<td>Max Neg Dev</td>
<td>2.0%</td>
<td>4.9%</td>
</tr>
</tbody>
</table>
EQUAL results >5% (Ferreira et al 2003)

- Reference
  - 1998-1999 3.1%
  - 1998-2002 1.2%

- Beam output variations
  - 1998-1999 4.7%
  - 1998-2002 1.8%

- Wedge
  - 1998-1999 10.4%
  - 1998-2002 3.3%
On site visits

- Clinically significant discrepancies in most studies
- Remote TLD audits less resource intensive –
- Site visits with ionisation chambers less uncertainty & more likely to find root cause
Cost Effective?

- Radiotherapy and Oncology
  Volume 86, Issue 2, Pages 195-99 Quality assurance of dosimetry and the impact on sample size in randomized clinical trials, Pettersen, Aird, and Olsen

- “The number of patients required in an Randomised Clinical Trial may be reduced by introducing appropriate dosimetry QA as the risk of under-powering the study is minimized. Dosimetry QA in clinical studies is therefore cost-effective”.

Royal Surrey County Hospital
NHS Foundation Trust
RPC Head & Neck Phantom

<table>
<thead>
<tr>
<th>Phantom</th>
<th>Head and neck</th>
<th>Prostate</th>
<th>Thorax</th>
<th>Liver</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irradiations</td>
<td>250</td>
<td>64</td>
<td>24</td>
<td>4</td>
</tr>
<tr>
<td>Pass</td>
<td>179</td>
<td>55</td>
<td>17</td>
<td>3</td>
</tr>
<tr>
<td>Fail</td>
<td>71</td>
<td>9</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>Year introduced</td>
<td>2001</td>
<td>2004</td>
<td>2004</td>
<td>2005</td>
</tr>
</tbody>
</table>
RPC Credentialing


- Gynae Oncology Group 165, HDR cervix
  - Credentialed centres
    - major deviations 0, minor 15 (no 70)
  - Non-Credentialed
    - major deviations 57, minor 87 (no 275)
Benefits (&disadvantages) of credentialing

• Benefits
  • Primary role – reduce deviation rate for data submitted for clinical trials
  • Education
  • Reassurance
  • Some evidence deviations less in credentialed centres

• Disadvantages:
  • Resources needed
  • A deterrent to trial recruitment (Note: funds are available locally)
Conclusions

- Clinically significant discrepancies discovered in many (inter)national studies, particularly in developing world and under-resourced centres.
- Clinically significant discrepancies discovered for advanced technologies in USA.
- Deviations less in credentialed centres.
- Cost effective.
Conclusions

• Standard Deviations decrease with repeated intercomparisons
• Incidence of discrepancies decrease
• Standard deviations increase as complexity of intercomparison increase

• Results indicate consistency for photon and electron beam dosimetry at the level of beam calibration in the UK at tolerances applied (SD within 1.0%)
Options for Audit Groups

• Tighten tolerances for standard audits (diminishing returns)

• OR

• When it is observed that the tolerances for reference levels are met continually develop to include more complex treatments / modalities / levels of dosimetry chain / imaging / patient measurements.