Dosimetry Audits in Radiotherapy

Basic principles - Establishment of DA center – IAEA network – IAEA activities

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Introduction

- One of the greatest risks for a patient undergoing radiotherapy treatment is that inaccurate dose delivery has implications for tumor control, treatment morbidity and toxicity impacting upon patient survival and quality of life in the immediate and longer terms.
- Variation between the dose prescribed to that delivered can have direct impact on the treatment outcomes.
It is recognized internationally [e.g. IAEA GSR Part 3, EU BSS 2013/59 BSS] that an effective quality management program involve an independent dose assessment.

An external dosimetry audit (DA) program is to ensure the accurate dose delivery to radiotherapy patients.

Every radiotherapy center should have access to an independent dosimetry audit.

Dosimetry audits should be conducted under an independent dosimetry audit center (DAC).
2.2.4.1 Operation of TLD audits and results for radiotherapy centres

Dosimetry Audits

Remote audits (TLD, film)  On-site audits (IC, film)

Dosimetry Audit

- DA is a tool for quality and for improvement for dose accuracy.
- DA is performed on voluntary basis. RT should seek for it.
- DA is a “second” eye, independent from RT center procedures and common habits.
- DA should identify gaps in procedures and methodologies, errors in routine work and RT system operation. Understanding the “errors” are part of the work and common to many RT center, they should be identified.
- DA identify “good practices”. DA contribute to the avoidance of incidents, accidents and near misses.
- DA tests should be conducted according to routine work and procedures
- DA is confidential. DA is NOT an inspection and should NOT impose enforcements, penalties, sanctions.
- DA is a place for exchange of knowledge, expertise, expertise and dissemination of information.
2.2.4.1 Operation of TLD audits and results for radiotherapy centres

**Dosimetry Audit**
- Management
- Medical Practitioners
- Medical Physicists
- Technologists
- Administrative staff
- External stakeholders

**Dosimetry Audit Center (DAC)**
- **DAC scope:** perform radiotherapy dosimetry audits.
- **DAC aim:**
  - **ensure quality** radiotherapy treatments to patients at local radiotherapy centers by increasing the accuracy and reducing uncertainty in the dosimetry of clinical radiotherapy beams
  - improve **patient safety**, by detecting inaccuracies, malpractices, threats
  - provide **guidance**, advises, recommendations to RT dissemination of information
  - contribute to **harmonization** of processes and cooperation
  - strengthening **confidence** of RT and BT centers

**Clinical Audit**
- Medical Practitioners
- Medical Physicists
- Technologists
2.2.4.1 Operation of TLD audits and results for radiotherapy centres

**Dosimetry Audit Center (DAC)**

- DAC should obtain the approval and endorsement by the national radiation oncology and medical physics community.
- DAC should be recognized to provide dosimetry audits in radiotherapy by the national competent authority or other relevant governmental body (e.g., Ministry of Health).
- Funding should be made available that will ensure that the audit activities are sustained and proper resources are allocated to support this audit program.
- Human resources: enough trained staff to implement the planned audit schedule (Chief MP, MPs, Scientific and technical staff, administrative staff).
- Training
- Infrastructure – Equipment
2.2.4.1 Operation of TLD audits and results for radiotherapy centres

- **I option**
  - **Dosimetry Audit Centre (DAC)**
  - Measuring Centre
  - Medical Physics Group
  - Radiation Oncologist
  - Local Radiotherapy Centre

- **II option**
  - **Dosimetry Audit Centre (DAC)**
  - Measuring Centre
  - Medical Physics Group
  - Radiation Oncologist
  - Local Radiotherapy Centre

- The clinical **Medical Physics Group** (MPG): one or several medical physicists with extensive experience in clinical dosimetry from working in a radiotherapy department.

- **Measuring Centre (MC)**: provides reliable and accurate measurements that are traceable to primary standards

- **SSDL**: calibration & reference irradiations

- Close cooperation with other stakeholders
Dosimetry Audits under DAC

- **Level 1**: Beam output under reference conditions
- **Level 2**: Beam’s relative dosimetry parameters under non-reference conditions, on- and off-central axis
- **Level 3**: Verification of individual dosimetry parameters within advanced treatment modality paths by comparing treatment planning system calculations with DAC measurements.
- **Level 4**: Verification of advanced treatment modalities, e.g. for example intensity modulated radiation therapy (IMRT), stereotactic radiosurgery (SRS) and stereotactic body radiation therapy (SBRT), using an end-to-end anthropomorphic phantom that approximates patient treatment, including targets, organs at risk and heterogeneities.

<table>
<thead>
<tr>
<th>Applicable dosimetry equipment</th>
<th>Level 1 Ref. conditions</th>
<th>Level 2 Non-ref conditions</th>
<th>Level 3 Complex</th>
<th>Level 4 Adv.</th>
</tr>
</thead>
<tbody>
<tr>
<td>TLD</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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</tr>
<tr>
<td>OSLD</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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<tr>
<td>RPLD</td>
<td>✓</td>
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<tr>
<td>Alumox</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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<tr>
<td>Ion chamber</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Films</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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<tr>
<td>Diode</td>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>2D area</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>3D area</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>3D dosimetry (ph)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

| Planarities                  |                         |                           |                 |             |
| Wires                        | ✓                       | ✓                         | ✓               | ✓           |
| Geometric-solid              | ✓                       | ✓                         | ✓               | ✓           |
| Spherical-anthropomorphic    | ✓                       | ✓                         | ✓               | ✓           |

*require appropriate dosimeter readout device

2.2.4.1 Operation of TLD audits and results for radiotherapy centres
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DAN: Remote DA

1. Dosimetry audit methodologies for national dosimetry audit networks (DAN) were developed through IAEA consultants meetings in 4 CRPs in 1996-2017.
2. Feasibility studies were conducted by the IAEA staff in co-operation with the Medical University of Vienna.
3. Multicentre pilot studies were organized by the IAEA with project participants to test the methodology internationally.
4. Pilot audit runs were organized by national audit networks with a few local RT centres to test the methodology locally.

Dose audits for RT centres

Years 1969-2017:
- 133 countries
- 2280 hospitals
- 12858 audits
2.2.4.1 Operation of TLD audits and results for radiotherapy centres

The IAEA TLD system: used till 2017

- PCL3, automatic (Fimel, France)
- LiF powder, type TLD-100, Harshaw
- Standard polyethylene capsules
- Standard perspex holders for TLD irradiation

The IAEA RPLD system consists of the FGD-1000 Dose Ace reader and GD-302M glass dosimeters, Asahi Glass Co.

- GD-302M dosimeter: silver activated phosphate glass in the form of rods of 1.5 mm Ø×12 mm
- Glass rods are encapsulated in customized plastic capsules fitting the IAEA standard TLD holder
2.2.4.1 Operation of TLD audits and results for radiotherapy centres

**DAN: Remote DA**

- Cost-free dose audits are offered for h.e. photon beams in reference conditions for RT centres in LMI countries worldwide.
- Regular participation: 3 beams/RT centre every 2nd year; these restrictions will be relaxed in 2018 due to efficiency gains occurring with the introduction of RPLDs.
- New installations or RT units after major repair are offered immediate audit after the beam commissioning and before starting patient treatments.
- At present 600-700 beam checks per year in 9 irradiation runs with average turnover time of 1-3 months.
- Follow-up dosimetry checks provided when deviations outside 5% acceptance limit are detected.
- Follow-up on-site visits by national experts, SSDLs or IAEA experts when deviations persist.

**Increase in the IAEA/WHO postal dose audit for radiotherapy hospitals**

Provision of dosimetry audits by the IAEA increased significantly in the last 20 years.

- **Years 1969-2017**
  - 133 countries
  - 2289 hospitals
  - 12858 audits
2.2.4.1 Operation of TLD audits and results for radiotherapy centres

**IAEA/WHO audit results for Co-60 and high energy X rays, 1969-2017**

- Number of beam checks:
  - Co-60: 6105
  - High energy X-rays: 6753

- First check:
  - Mean: 1.007
  - SD: 0.076
  - Results within 5%: 85.3%

- After follow-up:
  - Mean: 1.007
  - SD: 0.057
  - Results within 5%: 90.6%

**IAEA/WHO TLD results for hospitals**

- Number of beam checks:
  - Co-60: 6105, 2016-2017: 185
  - High energy X-rays: 6753, 2016-2017: 1126

- First check:
  - Mean: 1.007, 2016-2017: 1.000
  - SD: 0.076, 2016-2017: 0.031
  - Results within 5%: 85.3%, 2016-2017: 97.0%

- After follow-up:
  - Mean: 1.007, 2016-2017: 1.000
  - SD: 0.057, 2016-2017: 0.024
  - Results within 5%: 90.6%, 2016-2017: 98.9%

For the results outside the acceptance limits:
- repetitive dosimeter irradiations (38 beams in 2016-2017)
- if deviation persists, on-site visits:
  - by local experts (SSDLs, radiotherapy centres)
  - by IAEA experts (QUATRO-reactive)
2.2.4.1 Operation of TLD audits and results for radiotherapy centres

Approx. 99% acceptable TLD results after follow-up in 2016-2017

Follow-up of deviations outside ±5%

Of 208 f-up TLD/RPLDs sent in 2012-2017, 46% were sent to:
UKR (35), RUS (20), KAZ (12), PRC (18), IND (11)
2.2.4.1 Operation of TLD audits and results for radiotherapy centres

Dose determination from RPLD signal

\[ D = M \times N \times SCF \times f_{\text{lin}} \times f_{\text{en}} \times f_{\text{hol}} \times f_{\text{fad}} \]

- \( M \) – dosimeter reading (corrected for the readout position)
- \( N \) – dosimetry system calibration coefficient
- \( SCF \) – dosimeter sensitivity correction factor
- \( f_{\text{lin}} \) – dose response non-linearity correction factor
- \( f_{\text{en}} \) – energy correction factor
- \( f_{\text{hol}} \) – holder correction factor
- \( f_{\text{fad}} \) – fading correction factor.

Uncertainties

<table>
<thead>
<tr>
<th>Uncertainty component</th>
<th>TLD system</th>
<th>RPLD system</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Uncertainty, %</td>
<td>Uncertainty, %</td>
</tr>
<tr>
<td></td>
<td>(k=1)</td>
<td>(k=1)</td>
</tr>
<tr>
<td>Calibration of the system</td>
<td>0.60</td>
<td>0.80</td>
</tr>
<tr>
<td>Dosimeter readout</td>
<td>0.48</td>
<td>0.54</td>
</tr>
<tr>
<td>Individual dosimeter sensitivity factor</td>
<td>-</td>
<td>0.42</td>
</tr>
<tr>
<td>Dosimeter positioning during readout</td>
<td>-</td>
<td>0.42</td>
</tr>
<tr>
<td>Non-linearity dose response correction</td>
<td>0.90</td>
<td>0.55</td>
</tr>
<tr>
<td>Energy correction</td>
<td>0.95</td>
<td>0.81</td>
</tr>
<tr>
<td>Fading correction</td>
<td>0.02</td>
<td>0.01</td>
</tr>
<tr>
<td>Holder correction</td>
<td>0.10</td>
<td>0.14</td>
</tr>
<tr>
<td>Combined standard uncertainty (k=1)</td>
<td>1.60</td>
<td>1.51</td>
</tr>
</tbody>
</table>
2.2.4.1 Operation of TLD audits and results for radiotherapy centres

**Training video**

- **TLD Irradiation Tutorial**
  - IAEA/MWO TLD portal dose quality audit for Cs-137 and megavoltage X ray beams
- 18 minutes, HD quality
- Step-by-step explanation with example of operation
- 3 languages (ENG, SPA, RUS)
- Initially prepared for TLD; also suitable for RPLD

**DA for advanced RT dose delivery**

 Implemented in 2015-2016:
 TLD and film quality audit for photon beam ‘end-to-end’ IMRT treatment delivery.

‘End-to-end’ phantom for IMRT audit.
2.2.4.1 Operation of TLD audits and results for radiotherapy centres

**DA for advanced RT dose delivery**

- Aim of performing this exercise is to verify the dose delivery for an end-to-end clinical IMRT treatment,
- Acceptance limits:
  - ±5% for TLD in PTV, dose for TLD OAR must be lower than 2.8 Gy,
  - EBT3 film: 90% of points passing gamma criteria (3 mm, 3%, 20% threshold).
- Assessment of positioning uncertainties by shifting the isocentre by 1 mm.

**DAN: Support to End-to-End DA**

- The audit methodology was developed in a consultants meeting in 2014.
- Based on IAEA specifications CIRS developed a phantom prototype called SHANE (Shoulders, Head and Neck, End-to-End).
- The methodology was further developed and feasibility tested at AKH, Vienna, in 2015.
- SHANE was circulated among consultants for a multicentre pilot study in 2016-2017.
- Training of auditors was provided in 2017.
- Implementation at national levels started in 2018 with TC support.
2.2.4.1 Operation of TLD audits and results for radiotherapy centres

**DAN: Support to On-Site DA**

Set of practical tests for dosimetry calculations reflecting basic treatment techniques in a typical radiotherapy hospital

**IAEA**

**TLD audits for SSDLs (radiotherapy)**

**Organization**
- service started in 1981
- 77 SSDLs participate in this service
- at present ~ 35 beam checks per year
- 1 irradiation run per year (average turnover time 1-2 months)
- since 1998, follow-up dosimetry checks for deviations larger than 3.5% acceptance limits

**IAEA**
2.2.4.1 Operation of TLD audits and results for radiotherapy centres

- **TLD audits for SSDLs (radiotherapy):**
  - 1997-2017
  - N=1340 (972 Co-60, 368 X-rays)
  - Mean = 1.006
  - SD=1.7%
  - 97.5% results within acceptance limits

- **Dosimetry audits for SSDLs (radiotherapy):**
  - 2016-2017
  - N=74 (61 Co-60, 13 X-rays)
  - Mean = 1.006 (SD 1.1%)
Summary

- EU-BSS and IAEA BSS requires DA, as an independent quality tool.
- A DAC requires a strong positive engagement with the local radiation oncology and medical physics societies as well as with national authorities and government bodies.
- DAC participation in IAEA DAN is essential.
- Secured funding for DAC operations is essential. Without the secured funding, the DAC cannot exist.
- Engaging the right selection of staff for the DAC is vitally important to its success.
- Close cooperation between stakeholders (SSDL, RT centers) and professions (MPEs, MPs, Oncologists, technologists) is essential.
- The RT centers should recognize the DA benefits.
- The RT centers should understand and the consequences of the observed discrepancies and how they affect the treatment of patients, as well as the necessity and timeframes of corrective and perspective actions.

THANK YOU