Round Table 2 – Dosimetry Challenges Associated with New Technology

Panel members

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Chair

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New Technologies

CT, 4D PET/CT, IGRT, Gating, VMAT, Fluoroscopy….

IMRT, SBRT, SRS and others
Springfield, MO - CoxHealth today announced that it has discovered that 76 patients who had received a very specific type of treatment for brain tumors and other difficult-to-treat conditions using its BrainLAB stereotactic radiation therapy system, were accidentally exposed to radiation in amounts that exceeded the intended, therapeutic dose. The average variation of all the treatments of the 76 patients exceeded the prescribed dose by approximately 50 percent. A variation on the delivered dose of up to 10 percent is not significantly different than the prescribed dose and is considered no more risky than the prescribed treatment.
Dosimetric challenges of new technology

- Reference dosimetry of small and non-standard fields
  - No established protocols exist
- Dosimetry of single small fields
  - Detector problems
Dosimetric challenges of new technology

- Accuracy in IMRT planning and delivery
  - IMRT dose planning and delivery problems

- Imaging dose used with IGRT
  - Should it be combined with treatment dose?
  - Issues associated with additional dose from CBCT
Dosimetric challenges of new technology

- Motion management
  - Is the target motion predictable?
  - Target/OAR definition – 4D?

- Dose delivery to a moving target
  - Is the moving target receiving the prescribed dose?
Dosimetric challenges of new technology

- **Computed Tomography (CT) systems**
  - Are referring physicians and technologists trained?
  - Are dosimetry methods updated for new technology?

- **Radiopharmaceutical therapy (RPT)**
  - How to standardize patient-specific dosimetry (PSD)?
  - Can reference phantom dosimetry be related to PSD?
Computed Tomography (CT) systems

- Eligibility of referring physicians, technologists, and medical physicists
- Updating CT dosimetry methods to accommodate new technology
CT educational challenges

- Referring physicians
  - tend to over-order CT exams (United States)

- Medical physicists
  - Most are not experienced in CT Dosimetry

- CT technologists
  - Unaware of the dose consequences of newer scanners
  - Are too busy to tune exam parameters to patient
  - Have to operate a wide variety of scanners

- All users
  - Nomenclature confusing and counterintuitive
CT dosimetry challenges

- 1972: First clinical CT brain scan
- 1974: First whole-body CT scanner
- 1974: 4th generation CT
- 1989: Helical/Spiral CT
- 1992: Dual Slice CT
- 1994: mA modulation
- 1997: 4 Slice CT
- 2000: 8-40 Slice CT
- 2000: 64 Slice CT
- 2006: Dual Source CT
- 2007: Adaptive Dose Shield
- 2004: Flying Focal Spot
- CT dosimetry challenges
Computed Tomography (CT) systems

- CT Technology has outpaced current CT dosimetry methods
- Rapid advancement in CT capabilities has increased use
- Sophistication of scanners requires more emphasis on training
Reference dosimetry in composite fields

- New technology delivers radiation using combinations of small fields; however, calibration of radiation therapy equipment is currently in terms of static open fields.
- A recent formalism proposes the direct calibration of the unit in so-called plan class specific reference fields (pcsr).
- **Challenge:** Clear criteria for the choice of these new reference fields are as yet to be determined.
PCSR correction factors for dynamic Tomotherapy calibration fields with different homogeneity indices. Chung et al, preferred paper, IDOS, 2010

**Need**

- research in possible parameters affecting the correction factors
- models to predict the correction factors

**Issues to be considered are**

- clinical suitability of the clinical reference calibration setup
- resemblance of the new reference field to true delivery of the given class
- magnitude of the plan class correction factor
- accuracy of the reference dose

\[
\begin{align*}
K_{Q_{pcsr},Q}^{f_{pcsr},f_{ref}}
\end{align*}
\]
Dosimetry of single small fields

- What is a small field?
  - Field size is not large enough to provide CPE at the position of the measurement
  - Collimator obstructs part of the direct source
  - Detector is large

- The criteria for suitable detectors are not clear as the conditions for small field are not independent from each other

- Dosimetric differences can be large
Relative output readings for the 5 mm diameter CyberKnife field (triangles) and relative output readings multiplied with calculated correction factors (circles). (From Palmans, Review, IDOS Meeting, 2010)

**Need:**
- Establish a practical and accurate recipe that allows the accurate measurement of small field reference dose using air-filled ionization chambers
- Establish clear guidelines for assessment of suitability of detectors for reference and relative dosimetry

**Issues to be considered are:**
- Interplay between detector parameters and source parameters
- Effects of beam quality
- Effects of detector properties
Accuracy in IMRT planning and delivery

Black Box

What you see is NOT what you always get
RPC IMRT phantom family

- 10 prostate phantoms (IMRT)
- 14 thorax phantoms (SBRT/IMRT)
- 31 H&N phantoms (IMRT)
- 8 spine phantoms
incorrect output factors or PDD in TPS
coordinate shift error
inadequacies in beam modeling at leaf ends
not adjusting MU to account for dose differences
measured with ion chamber
inferior heterogeneity correction
2 mm tolerance on MLC leaf position
setup errors
complex IMRT treatment parameters
large QA criteria

Problems detected

Pinnacle – SC

Before

After 0.4 mm
# Accuracy in IMRT planning and delivery

## Phantom Results

Comparison between institution’s plan and delivered dose.

<table>
<thead>
<tr>
<th>Phantom</th>
<th>H&amp;N</th>
<th>Prostate</th>
<th>Spine</th>
<th>Lung</th>
<th>Liver</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irradiations</td>
<td>752</td>
<td>174</td>
<td>19</td>
<td>174</td>
<td>23</td>
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<tr>
<td>Pass</td>
<td>585</td>
<td>143</td>
<td>13</td>
<td>124</td>
<td>12</td>
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<tr>
<td>Pass %</td>
<td>78%</td>
<td>82%</td>
<td>68%</td>
<td>71%</td>
<td>52%</td>
</tr>
<tr>
<td>Criteria</td>
<td>7%/4mm</td>
<td>7%/4mm</td>
<td>5%/3mm</td>
<td>5%/5mm</td>
<td>7%/4mm</td>
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<tr>
<td>Year introduced</td>
<td>2001</td>
<td>2004</td>
<td>2009</td>
<td>2004</td>
<td>2005</td>
</tr>
</tbody>
</table>

Data from Radiological Physics Center, Courtesy: Geoff Ibbott
Solutions for improvement

- Implement the state of art heterogeneity correction algorithm
- Make sure the basic dosimetry data is correct
- MLC QA is paramount
- Reduce the complexity of the IMRT plan
- Consider an independent audit
Imaging Dose with IGRT

- Verification imaging has definite benefits … but … there is a cost …
  - $$$$$
    - Capital cost
    - Commissioning work
  - Time
    - Imaging
    - Repositioning
    - Future: replanning/adaptation
  - Dose
- Tissue dose ~ 3% of prescription
- Bone dose ~ 10% of prescription
- Skin dose ~ 5% of prescription

* Dose to bone ~ 2-3 times dose to tissue.

Downes, Med Phys 36: 4156; 2009

Alaei, Med Phys 37: 244; 2010
Imaging dose with IGRT - challenges

- Dose not uniform/complex
  - Cannot be described by single number
- Incorporate in treatment plan?
  - See Alaei et al, Med Phys 37:244; 2010
  - Unique to each imaging technique
  - Yields added “unwanted” doses to normal tissues
  - What is importance of high doses to bone?
- What about imaging dose measurement techniques?
- Need to optimize imaging procedures to reduce imaging doses
Motion management

- Predictable motion vs uncertainty
  - Predictable motion
    - Adjust margins
    - Can be used in optimization
    - Gating
    - Tracking
  - Uncertainty (Non-predictable)
    - Systematic (e.g., anatomy at planning vs treatment)
    - Robust, probabilistic optimization

Orton, Med Phys 35: 4911; 2008
Motion management - issues

- Target/OAR definition – 4-D?
- Despite use of motion management and advanced RT planning
  - Residual uncertainties remain
    - E.g. shifts in average liver position relative to the vertebral bodies observed as large as 10 mm
    - 7 mm shifts in >10% of RT fractions treated*
- Adaptive protocols evolving
  - Deformable registration
  - Dose accumulation
  - Needs 4-D CT as part of IGRT

* Case, IJROBP 75:302; 2009
Motion management - challenges

- Adaptive therapy is patient, tumor site, equipment and institution specific
- Need actual tumour-related reference to monitor motion
- What should be the limits for on-line image-guided setup correction?
- How will these vary when imaging is directed by soft tissue contours, implanted markers or other surrogates?
- How reproducible is the clinic’s management of breathing motion by gating or other strategies?
- What is the appropriate PTV after introduction of a new IMRT/IGRT/motion management method?
- What is the “real” accumulated dose to each tissue voxel?
Determination of the dose delivered to a moving target

- Begins with detailed imaging (4D CT)
- Various motion control mechanisms
  - ABC, gating, abdom. comp., none
- Accurate dose calculation algorithm in lungs
  - Dose blurring/under-dosing PTV
- Good QA of technique prior to patient treatments
Imaging issues

Axial  Coronal  Saggittal

Axial  Coronal  Saggittal
Phantoms

Thorax-Lung Phantom

Tie-Rod for Top Tray

Top/Bottom Trays

Screw-Drive/Motor
Solutions

- Ensure imaging system is appropriate to capture all motion correctly
- Restrict motion as much as possible
- Test dose calculation algorithm
- Perform QA measurements prior to patient treatments
Nuclear medicine therapy

"Radionuclide Therapy"*
- humans

...and Dosimetry

*("radioiodine therapy" OR "radionuclide therapy" OR "isotope therapy" OR "radioimmunotherapy" OR "radiolabeled antibody therapy" OR "radioimmunoconjugate therapy") AND ("dosimetry" OR "absorbed dose"); limit = humans
In the treatment of loco-regional or metastatic disease, no recommendation can be made about the superiority of one method of radioiodine administration over another (empiric high dose versus blood or body dosimetry).
Recommends neither for nor against. The panel concludes that the evidence is insufficient to recommend for or against providing the service or intervention because evidence is lacking that the service or intervention improves health outcomes, the evidence is of poor quality, or the evidence is conflicting. As a result, the balance of benefits and harms cannot be determined.

Cooper DS, et al. Thyroid ‘09
Dosimetry requirements in nuclear medicine therapy

- **1970’s**
  - Thyroid CA therapy

- **2010’s**
  - Radioimmunotherapy
  - Radiopptide therapy
  - MIBG
  - ⁹⁰Y-spheres
  - Bone agents
  - Alpha-emitters

Reference Phantom Dosimetry (RPD)

Energy absorbed per unit mass:

\[
\tilde{\alpha}_s \times \Delta x \phi_{t-s} / M_t
\]

\(D_t = \tilde{\alpha}_{s1} \cdot S(t\leftarrow s1) + \tilde{\alpha}_{s2} \cdot S(t\leftarrow s2) + \ldots\)

Patient-Specific Dosimetry (PSD)

CT

SPECT/PET

Eff. Half-life

• Non Uniform Density in Lungs
• Non Uniform Activity Distribution

• Non Uniform Clearance

Tumor

Mean Dose = 57.7 Gy
Mean BED = 58.5 Gy
EUD = 25.0 Gy

Lung

Mean Dose = 9.5 Gy
Mean BED = 9.8 Gy
EUD = 8.3 Gy
New radiopharmaceuticals: dose-escalation studies (Phase 1)

**Tracer Study**
- Activity Data
  - SPECT or PET
- Anatomy Data
  - CT (or MRI)
- For each patient

**PSD**
- Calculate AD
- Determine AA for AD level 1, 2, etc

**Escalation Study**
- AA level 1, 2, etc
- Assess Tox at each AA level
- Identify AA level for Limiting Tox (AADLT)

**Patient 1**
- AD = AD_{DLT}
- AD < AD_{DLT}

**Patient 2**
- AD < AD_{DLT}

**Time and Activity**
- Time: 1, 2, 3, 4
- Activity: 1, 2, 3, 4
Patient-specific dosimetry-based treatment planning

Tracer Study imaging
- Activity Data
  - SPECT or PET
  - Anatomy Data
  - CT (or MRI)

PSD
- AD
- BED
- EUD
- AA for AD$_{DLT}$
- AA for tumor kill

Treat
- To normal organ tolerance
- To tumor kill

Other input
- RadioBio Params
- Normal Organ Tolerance (BED)
- from x-beam
- from Phase I study
- M2M model

Other input
- Normal Organ Tolerance (BED)
- from x-beam
- from Phase I study
- M2M model
Technology is largely dictated by manufacturers even if there is a lack of standardization in dosimetric procedures.

Physicists are under tremendous pressure to implement new technologies......working long hours... even without adequate knowledge (i.e. imaging for IGRT).

This leads to significant probability for clinical errors and a very heavy responsibility on clinical medical physicists to avoid these...

Overall experience to a level commensurate with the technical complexity of the new modalities is required.
Questions to the audience

- Should the implementation of new technologies be based on a thorough evaluation of the expected benefits rather than being driven by the technology itself? (or in other words should new technologies be **not** implemented **UNLESS** there has been a thorough evaluation?)
  - With the rapid evolution of new technologies, what steps should be in place to ensure that patients are treated or diagnosed safely and accurately?
- How do you balance this with the demand from the physicians and management to implement new technologies right away?
Questions to the audience

- Should an imaging physicist be part of the radiotherapy physicist team?
  - Is ad-hoc imaging training of a RT physicist enough?