Uncertainties in treatment planning

dose computation

Jeffrey V. Siebers

Virginia Commonwealth University
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Conflict of Interest Statement

- Research activities are funded in part by
  - Philips Medical Systems
  - Varian Medical Systems
Why Attend?

- Rank the following in terms of likely impact to patient outcome. **Correct answers in parentheses:**
  - dose calculation accuracy (3)
  - calibration accuracy (4)
  - setup uncertainty (2)
  - uncertainty in contouring the gross tumor volume (1)
Uncertainties in treatment planning dose computation
Objectives

- Address preconceptions about dose calculation accuracy
- Discuss
  - Sources of uncertainty / errors
  - Preventing / reducing dose uncertainty / errors
  - End-to-end benchmark evaluations of dose accuracy
Preconceptions

- If a model based (Superposition/Convolution or Monte Carlo) is used for dose calculation algorithm, I have nothing to worry about.
- My dose calculation accuracy is easily within 1-2%
- Having >95% of points pass gamma means that the field is OK
Inputs to delivered and calculated dose

Accelerator Beam Configuration & Output

Patient Geometry

Delivered Patient Dose

Compare

TPS Commissioning Data

TPS Dose Calculation Algorithm

Calculated Dose
Accuracy

- Goal is to have reported dose equal to the dose received by the patient

- Deviations exist because of
  - Input data imperfections
  - Imperfect modeling
    - Fluence delivery
    - Dose deposition
    - Patient composition
  - Dose algorithm limitations
  - Beam delivery variations
  - Patient changes
Concentration

- MV beams
- Static geometries (no patient changes between time of simulation and time of treatment, no patient setup uncertainties)
- Patient (rather than phantom) dose comparisons
Dose calculation algorithms

- Principles of energy deposition
  - Primary photons interact with material, generating secondary electrons
  - Interaction of secondary electrons, depositing dose, creating scattered photons, and more electrons
- Aim of dose calculation algorithm is to mimic this process – in heterogeneous patient material
Dose Calculation Algorithms

- **Correction based**
  - Reconstitute dose to water
  - Apply correction factors to account for heterogeneities, surface variations, etc.
    - Batho
    - TAR
    - Pencil Beam
    - ...

- **Model based**
  - Directly compute dose to heterogeneous material
    - Monte Carlo
    - Super-position / Convolution
    - ....
Dose Calculation Algorithms

Level of inhomogeneity inclusion:
- none
- primary photons
- scattered photons
- recoil electrons

Dimension of density sampling:
- 0-D: Eff SSD, RTAR, Batho
- 1-D: CBEAM (SLAB), Pencil
- 2-D: IRREG SAR/FFT, dSAR, Δ-Volume
- 3-D: ETAR, 3D FFT, Superposition Convolution

Adapted from TG-85, Tissue Inhomogeneity corrections
Dose Calculation Algorithms

- For a homogeneous flat water phantom, all algorithms should agree
  - Correction-based reconstitute the dose in water
  - Model based source models are tuned to match these conditions
Heterogeneities challenges greatest for high energies and small field sizes

- Water-lung-water phantom

Radiation dis-equilibrium
Adapted from Arnfield, et al, Med Phys, 27(6)
Heterogeneities challenges greatest for high energies and small field sizes

- Water-bone-water phantom

Radiation dis-equilibrium

Adapted from Carrasco, et al, Med Phys, 34(8)
Dose calculation accuracy for patient conditions

- Dependent on commissioning accuracy
- Dependent on accuracy of patient representation (CT-to-electron density)
- Overall results covered under end-to-end tests
Commissioning Data
(sources of deviations)

- The set of data which quantifies delivery output over the range of use conditions
  - used to tune and benchmark dose calculation algorithms
  - usually measured in homogeneous media
- Treatment Planning System specific measurements required
- Systematic errors in the data persist for all treatments
Eclipse TPS
Specific Recommendations

- **TG-53**
  - Commissioning data should be reproducible to <1% of local dose

- **TG-106, IAEA-430, ESTRO Booklet #7**
  - Series of recommendations to reduce measurement errors with goal of <1%

- Even if directly follow recommendations, no guarantee that dose is measured or computed within 1%
Factors affecting commissioning
Detector Selection

- Measurement setup errors
- Measurement modifies quantity being measured
  - Change of build-up and scatter conditions
  - Volume averaging effects / resolution
  - ...

- Detector response
  - ( )
  - ( )
  - ( )
  - ( )
Buildup – alignment errors alters buildup
(hence, electron contamination in source model)
Detector buildup and size

cylindrical chambers, EPOM corrections applied

Affects electron contributions and low energy photon contributions to source model

Depth dose curves match beyond radius of the chamber

Need to subtract off inherent detector buildup

Extrapolation to surface would better estimate surface dose

See: Ververs et al., Med Phys, 36 (4) 1410
Detector resolution
Alters penumbra model

Adapted with permission from Yan et al. Med Phys 35(8)
<table>
<thead>
<tr>
<th>Depth</th>
<th>Measured</th>
<th>Computed</th>
<th>Diff</th>
<th>% Err*</th>
<th>Dist to Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01</td>
<td>21.41</td>
<td>23.69</td>
<td>2.28</td>
<td>2.28%</td>
<td>0.01</td>
</tr>
<tr>
<td>0.21</td>
<td>63.94</td>
<td>53.10</td>
<td>-10.84</td>
<td>-10.86%</td>
<td>-0.05</td>
</tr>
<tr>
<td>0.41</td>
<td>78.78</td>
<td>73.49</td>
<td>-5.29</td>
<td>-5.30%</td>
<td>-0.07</td>
</tr>
<tr>
<td>0.61</td>
<td>87.12</td>
<td>86.01</td>
<td>-1.11</td>
<td>-1.12%</td>
<td>-0.03</td>
</tr>
<tr>
<td>0.81</td>
<td>92.80</td>
<td>93.24</td>
<td>0.44</td>
<td>0.44%</td>
<td>0.02</td>
</tr>
<tr>
<td>1.01</td>
<td>98.25</td>
<td>96.91</td>
<td>-1.34</td>
<td>-1.34%</td>
<td>-0.05</td>
</tr>
<tr>
<td>1.21</td>
<td>99.25</td>
<td>98.93</td>
<td>-0.32</td>
<td>-0.32%</td>
<td>-0.06</td>
</tr>
<tr>
<td>1.41</td>
<td>99.86</td>
<td>98.83</td>
<td>-0.03</td>
<td>-0.03%</td>
<td>-0.01</td>
</tr>
<tr>
<td>1.61</td>
<td>99.70</td>
<td>99.93</td>
<td>0.23</td>
<td>0.23%</td>
<td>---</td>
</tr>
<tr>
<td>1.81</td>
<td>99.20</td>
<td>99.55</td>
<td>0.35</td>
<td>0.35%</td>
<td>---</td>
</tr>
<tr>
<td>2.01</td>
<td>98.60</td>
<td>98.91</td>
<td>0.31</td>
<td>0.31%</td>
<td>---</td>
</tr>
<tr>
<td>2.21</td>
<td>98.10</td>
<td>98.08</td>
<td>-0.02</td>
<td>-0.02%</td>
<td>---</td>
</tr>
<tr>
<td>2.41</td>
<td>97.10</td>
<td>97.25</td>
<td>0.15</td>
<td>0.15%</td>
<td>---</td>
</tr>
<tr>
<td>2.61</td>
<td>96.10</td>
<td>96.37</td>
<td>0.27</td>
<td>0.27%</td>
<td>---</td>
</tr>
<tr>
<td>2.81</td>
<td>95.40</td>
<td>95.52</td>
<td>0.13</td>
<td>0.13%</td>
<td>---</td>
</tr>
<tr>
<td>3.01</td>
<td>94.70</td>
<td>94.62</td>
<td>0.07</td>
<td>0.07%</td>
<td>---</td>
</tr>
</tbody>
</table>

*Pct Err = (Comp - Meas) / Max Depth Dose

Connect at 10 cm
AAPM TG-53 and ESTRO Booklet #7

- Achievable accuracy varies with location
- Stochastic measurement error can impact results
- Use a confidence limit with multiple comparison points exist

\[ = \text{mean deviation} \]

\[ = \text{standard deviation of mean} \]

\[ = \text{multiplicative factor, number of permitted std deviations} \]

\[ = 1.5, \text{one-sided confidence level of 0.067} \]

\[ = 1.96, \text{one-sided confidence level of 0.025, two-sided confidence level of 0.05} \]
Tolerance regions

- Central axis $\delta_1$
- Inner $\delta_3$
- Penumbra $\delta_2$
- Outer $\delta_4$
- Build up $\delta_2$
- Norm point $\delta_0$

$\delta_{50-50}$

$\delta_{90-50}$
Tolerance regions

Adapted from Venselaar 2001, ESTRO, Booklet #7, and TG 53

- AAPM and ESTRO list these as example tolerances
- Looser or tighter criteria may be required depending on clinical test

<table>
<thead>
<tr>
<th>Region</th>
<th>Simple Homogeneous Media (Minimal Beam Modifiers)</th>
<th>One Complexity Heterogeneous Media (Wedges, Asymmetric Field, Complex Field Shape)</th>
<th>Multiple Complexities: A Combination of More than One Complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \delta_0 )</td>
<td>Normalization point</td>
<td>0.5%</td>
<td>1%</td>
</tr>
<tr>
<td>( \delta_1 )</td>
<td>Central axis depth dose</td>
<td>2%</td>
<td>3%</td>
</tr>
<tr>
<td>( \delta_2 )</td>
<td>Build-up &amp; Penumbra</td>
<td>10% or 2 mm</td>
<td>15% or 3 mm</td>
</tr>
<tr>
<td>( \delta_3 )</td>
<td>Inner high dose, low dose gradient</td>
<td>3%</td>
<td>3%</td>
</tr>
<tr>
<td>( \delta_4 )</td>
<td>Outer low dose, low gradient, normalized to central axis or inner region dose at same depth</td>
<td>3%</td>
<td>4%</td>
</tr>
<tr>
<td>RW(_{50})</td>
<td>Radiological width</td>
<td>2 mm (&lt;20 cm) or 1% (&gt;20 cm)</td>
<td></td>
</tr>
<tr>
<td>( \delta_{50-90} )</td>
<td>Penumbra width</td>
<td>2 mm</td>
<td>3 mm</td>
</tr>
</tbody>
</table>
Depth Dose Tolerances

Entrance region has both % dose difference and DTA tolerances.

Confidence limits recommended for % dose tolerances.

Entrance region requires use of DTA criteria.

Limiting maximum typically done (provides better fit).
Lateral Profile Tolerances

Penumbra region has both % dose difference and DTA tolerances

Confidence limits recommended for % dose tolerances

Limiting maximum difference typical (provides better fit)
Clinical depth dose examples
6 MV, multiple field sizes

<table>
<thead>
<tr>
<th>Build-up region (0–2 cm)</th>
<th>Field size</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5x5 cm²</td>
</tr>
<tr>
<td>Average deviation (%)</td>
<td>0.4</td>
</tr>
<tr>
<td>Standard deviation (%)</td>
<td>9</td>
</tr>
<tr>
<td>Confidence limit (%)</td>
<td>17</td>
</tr>
<tr>
<td>Dose Tolerance (%)</td>
<td>10</td>
</tr>
<tr>
<td>Max DTA (mm)</td>
<td>1.6</td>
</tr>
<tr>
<td>DTA Tolerance (mm)</td>
<td>2</td>
</tr>
<tr>
<td>Status</td>
<td>Passed</td>
</tr>
</tbody>
</table>

*Failure due to not accounting for inherent detector buildup and volume effect

K=1.96 for confidence limit
Commissioning Notes

- Commissioning must cover full range of clinical conditions
  - Beam Modifiers
  - SSDs
- Different beam/source models can be used to match differing conditions
- Failure to match measurements is not necessarily a failure of the dose calculation algorithm, but likely a failure to adequately tune the beam/source model
IMRT Commissioning Challenges

- Small fields, radiation dis-equilibrium
- Small field output factors
  - Volume averaging effects
- MLC penumbra modeling
  - (partial transmission through rounded leaf tip)
  - Detector blurring effects
- MLC radiation leakage
  - Tighter tolerances required since beam delivery is superposition of multiple fields
AAPM Rpt 82: IMRT Guidance Document
benchmark test cases

- 2-3% agreement expected in low gradient regions

End-to-end pseudo-clinical configurations

- Simple slab phantoms
- Sample test results provided for 9 institutions
TG-119 performance

Table 5–3. Dosimetric accuracy performance on the TG-119 test cases for the high dose point measured in the PTV with an ionization chamber. Values given are $100\times[\text{(measured dose)} - \text{(plan dose)}/\text{(prescription dose)}]$ and are averaged over the nine institutions that performed the tests.

<table>
<thead>
<tr>
<th>Test</th>
<th>Location</th>
<th>Mean (% )</th>
<th>Standard deviation (%)</th>
<th>Maximum (%)</th>
<th>Minimum (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multitarget</td>
<td>Isocenter</td>
<td>0.1</td>
<td>1.7</td>
<td>3.0</td>
<td>-2.0</td>
</tr>
<tr>
<td>Prostate</td>
<td>Isocenter</td>
<td>-0.1</td>
<td>1.6</td>
<td>2.2</td>
<td>-2.6</td>
</tr>
<tr>
<td>Head and neck</td>
<td>Isocenter</td>
<td>-1.0</td>
<td>1.3</td>
<td>1.1</td>
<td>-3.6</td>
</tr>
<tr>
<td>CShape (easier)</td>
<td>2.5 cm anterior to isocenter</td>
<td>-0.1</td>
<td>2.8</td>
<td>3.8</td>
<td>-5.9</td>
</tr>
<tr>
<td>CShape (harder)</td>
<td>2.5 cm anterior to isocenter</td>
<td>-0.1</td>
<td>3.6</td>
<td>5.4</td>
<td>-6.1</td>
</tr>
<tr>
<td>Overall combined</td>
<td></td>
<td>-0.002</td>
<td>2.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Confidence limit (k = 1.96)</td>
<td></td>
<td></td>
<td>4.5%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Adapted from AAPM Report No. 119 (Ezzell et al. 2009) with permission.)

Users expected to perform tests and get “similar” performance

Average = 2.2% dose uncertainty for homogeneous test cases
Commissioning accuracy

- Commissioning is critical

- Accurate commissioning will save significant time in the long run since it will reduce the overall time on per-patient QA (will get better per-patient agreement rates)
Other influential factors

http://www.smart-kit.com/s2178/100-most-influential-persons-ranked/
Based on Michael Hart’s “The 100: a ranking of the most influential persons in history”
CT HU calibration variations

- IAEA study
  - 6 institutions measurements with same phantom
  - ~8% variation in HU observed for bone-like materials
    (Relative Electron Density = 1.5)
Relative electron density (RED) tolerance

- Tolerance to maintain dose error of less than
  - 2% for photons
  - 2 mm for electrons

- @6 MV, ~10% RED variation required for 5 cm thick heterogeneity

- Typical HU to RED errors contribute <2% to dose error

Adapted from Kilby and Sage, Physics in Medicine and Biology, 47 (9)
Relative electron density tolerance
Effects on patient dose

Table 5–4. Changes in dose per monitor unit (MU) values that would result from increasing the relative electron density by 3% for water and soft tissues, 5% for lung, and 8% for bone. Beam energies are listed.

<table>
<thead>
<tr>
<th>Treatment Site</th>
<th>Δ dose/MU (%)</th>
<th>Mean dose (%)</th>
<th>Max dose (%)</th>
<th>Min dose (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prostate (16 MV)</td>
<td>−1.7</td>
<td>−1.6</td>
<td>−1.4</td>
<td>−1.6</td>
</tr>
<tr>
<td>Breast (6 MV)</td>
<td>−0.8</td>
<td>−0.6</td>
<td>−0.8</td>
<td>−0.8</td>
</tr>
<tr>
<td>Lung (6 MV)</td>
<td>−1.3</td>
<td>−1.3</td>
<td>−1.3</td>
<td>−1.6</td>
</tr>
<tr>
<td>Brain (6 MV)</td>
<td>−1.0</td>
<td>−1.0</td>
<td>−0.8</td>
<td>−1.1</td>
</tr>
</tbody>
</table>


HU to RED calibration contributes < 2% to dosimetric uncertainty
Fields with high dose gradients require fine dose matrix spacing to avoid interpolation errors in gradient regions:

- ≤2.5 mm spacing sufficient to prevent dose errors greater than 1% (Dempsey et al, 2005)
- Shifting dose matrix origin by ½ of voxel size results in dose deviations for large voxels
  - Absolute dose matrix location matters
- 2 mm spacing yields 1.8% dose uncertainty (Chung et al, 2006)

2 mm resolution required for < 2% dosimetric uncertainty
Accelerator output variations

Although not dose calculation accuracy, accelerator output variations contribute to overall dosimetric accuracy.
Error detection and mitigation strategies
# Monitor Unit Verification Calculations

**TG-114, non-IMRT action level guidelines**

<table>
<thead>
<tr>
<th>Homogeneous Geometries</th>
<th>Similar Calculation Algorithms</th>
<th>Different Calculation Algorithms</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Same</td>
<td>Approximate</td>
</tr>
<tr>
<td>Primary calculation geometry</td>
<td>2</td>
<td>2.5</td>
</tr>
<tr>
<td>Minimal field shaping</td>
<td>2.5</td>
<td>3</td>
</tr>
<tr>
<td>Substantial field shaping and/or contour change</td>
<td>2</td>
<td>2.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Heterogeneous Geometries</th>
<th>Similar Calculation Algorithms</th>
<th>Different Calculation Algorithms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary calculation geometry</td>
<td>Same</td>
<td>Approximate</td>
</tr>
<tr>
<td>Large field</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Wedged fields, off-axis</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Small field and/or low density heterogeneity</td>
<td>3</td>
<td>3.5</td>
</tr>
</tbody>
</table>

(Adapted from AAPM Report No. 114 (Stern et al. 2011) with permission.)
Monitor Unit Verification Calculations

Based on ESTRO Booklet #10, "Independent dose calculation concepts and models"

Stated accuracy of ±3% on central axis, ±5% off axis when > 2 cm from dose gradient

Free program

Can be used with 3D-CRT, IMRT and electrons
Transfer plan to R&V system

Extract plan from R&V, recompute with MC

<3% DVH difference?

Yes

Print and sign DVHs and dose differences

Notify planning team

Include in chart

No

Differences acceptable?

Yes

Differences acceptable?

No

Compare MC and TPS with in-phantom measurements

Adjust MUs to best match with measurements

Obtain acceptable IMRT plan

Independent dose calculation
Measurement-based IMRT Patient-Specific Quality Assurance

- **Guidelines**
  - ESTRO Booklet 9, Guidelines for the Verification of IMRT (Alber 2008)
  - AAPM TG-119: Guidance document on delivery, treatment planning, and clinical implementation of IMRT (Ezzell et al 2003)
  - No uniform consensus measurement recommendation

- **Typical methods**
  - Ion chamber measurement in low dose gradient region
  - 2D planar fluence validation
  - Composite in-phantom dose delivery validation
  - 3D-DVH tools

- **Processes validated**
  - Information transfer from TPS to accelerator
  - Ability of linac to deliver the treatment
  - Accuracy of the dose calculation process
If SD in dose measurement is 2.5%, and a 5% action level is used, expect action required for ~5% of cases

Appropriate action is investigation
Gamma Evaluations

- Typically based on fraction of points with $\gamma < 1$, with cut-off ranges of >90%-95% of points with 3%, 3 mm criteria
- Action levels are based on achieved passing levels rather than correlative analysis with clinical effect
- Kruse 2010 and Nelms et al. 2011 show gamma passing rates are not correlated with clinically significant dose errors
  - Many additional examples at 2011 AAPM meeting
- In example above, 100% of points have $\gamma < 1$ if radius of 0% dose region is $\leq 3$ mm
- Must look at more than just %points with $\gamma < 1$
End-to-end test cases

The Far Side
Commissioning of Radiotherapy Treatment Planning Systems: Testing for Typical External Beam Treatment Techniques

Report of the Coordinated Research Project (CRP) on Development of Procedures for Quality Assurance of Dosimetry Calculations in Radiotherapy

IAEA-TECDOC-1583

January 2006
IAEA TECDOC 1583

- Scan phantom for CT calibration
- 8 test cases defined
- Plan pseudo-treatments
- Measure doses with ionization chamber
- Compare with respect to tolerances

Test Case 7
### Table 1
Description of clinical test cases

<table>
<thead>
<tr>
<th>Description of test cases</th>
<th>Test case No.</th>
<th>Reference point</th>
<th>Measurement point/field</th>
<th>Agreement criteria (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single field: SSD = 100 cm, field size 10 × 10 cm², gantry 0°, coll. 0° Points 1, 3, 5 and 10 on central axis, point 9 outside the field.</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td><strong>Tangential field</strong>, oblique incidence and lack of scattering: SAD set-up at point 1, field size 15 × 10 cm², gantry 90°, coll. 90°, wedge 45°.</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Significant blocking of the field corners: SSD = 100 cm, field size 14 × 14 cm² blocked to a 10 × 10 cm², gantry 0°, coll. 45°</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Four-field box: SAD set-up at point 5; Field1: field size 15 × 10 cm², gantry 0°, coll. 0°; Field2: field size 15 × 8 cm², gantry 90°, coll. 0°; Field3: field size 15 × 10 cm², gantry 180°, coll. 0°; Field4: field size 15 × 8 cm², gantry 270°, coll. 0°.</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Customised blocking of cylinder Ø 10 cm: SAD set-up at point 2, gantry 0°, coll. 0°.</td>
<td>5</td>
<td>2</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Oblique incidence with irregular L-shaped field (blocking off the centre of the field): SAD set-up at point 5, field size 20 × 10 cm² (blocked to 12 × 6 cm²), gantry 45°, coll. 0°.</td>
<td>6</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Plan with asymmetrically wedged fields: SAD set-up at point 3; Field1: field size 10 × 12 cm², gantry 0°, coll. 0°; Field2: field size 10 × 6 cm² asymmetrical (half beam), gantry 90°, coll. 90°; physical wedge 30°; Field3: field size 10 × 6 cm² asymmetrical (half beam), gantry 270°, coll. 270°; soft wedge 30°.</td>
<td>7</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Plan with non-coplanar field: SAD set-up at point 5; Field 1: field size 4 × 4 cm², gantry 30°, coll. 0°, couch 270°; Field 2: field size 4 × 16 cm², gantry 90°, coll. 330° couch 0°; Field 3: field size 4 × 16 cm², gantry 270°, coll. 30°, couch 0°.</td>
<td>8</td>
<td>5</td>
<td>5</td>
<td>3</td>
</tr>
</tbody>
</table>
If assume errors are normally distributed, then can use this data to determine dose uncertainty

Assume 2-tailed error

Average agreement criteria ~3.5%

Example

Model-based w lateral transport, HE X-ray, 5% out of tolerance corresponds with ~2σ, therefore σ = ~1.8%,

Typical best agreement at lower energy

More complex algorithms are better

Adapted from Gershkevitsh, et al, Radiotherapy and Oncology, 89 (2009) 338
9 institution study
- Common phantom, common CT scan
- In-house treatment plan and delivery
- Ionization chamber + film measurements
- Undeveloped films and computed doses sent to processing center for analysis

Adapted from Bohsung, et al, Radiotherapy and Oncology, 76 (3) 2005
Too few data points to provide trends
User-specific differences likely due to planning, commissioning, and delivery differences

PTV 1.4+/-1.6% Average

Adapted from Gillis, et al, Radiotherapy and Oncology, 76 (3) 2005
Radiological Physics Center

Mission Statement
The mission of the Radiological Physics Center is to assure NCI and the Cooperative Groups that institutions participating in clinical trials deliver prescribed radiation doses that are clinically comparable and consistent.

We do this by assessing the institutions radiotherapy programs, helping the institutions implement remedial actions, assisting the study groups in developing protocols and QA procedures, and informing the community of our findings.

http://rpc.mdanderson.org/rpc/
RPC Beam Output Check Data

- Percent of institutions and percent of beams with more than 1 RPC TLD dose measurement > 5% different from institution reported dose
- Average beam failure rate ~5%
  (consistent with $\sigma=2.5\%$ if assume normally distributed errors)
- Average institution failure rate ~17%
- Std dev of all output checks is ~1.8%

Data provided by David Followill, Ph.D., RPC
RPC Lung Phantom for SBRT Credentialing

3 cm diameter PTV

RPC Lung Phantom, RTOG Protocol L-0236
Stereotactic Body Radiation Therapy

Guidelines for Planning and Irradiating the RPC Lung Phantom.
Revised April 2004

Credentialing for this protocol requires four steps: (1) submission of the Facility Questionnaire with supporting documentation to the Image Guided Therapy Center (ITC, http://itc.wustl.edu), (2) a successful dry run test, (3) completion of the phantom treatment experiment and (4) submission of the treatment plan for the first patient treated at the site on this protocol prior to delivering any protocol treatment. The purpose of steps (2) and (3) is to confirm that the dose distribution planned by each institution can be delivered by that institution, and treatment plans can be correctly submitted to the ITC. The RTOG is requesting that each institution keep the phantom for no more than 2 weeks. During this two-week period, the institution will image, plan, and irradiate the phantom and return it to the Radiological Physics Center (RPC). Thank you for your cooperation with this constraint.

This phantom has been designed and constructed by the RPC. The RPC phantom contains an imaging and dosimetric insert. The insert, which is part of the left lung, contains a centrally located GTV (3 cm x 5 cm). There are three orthogonal sheets of radiochromic film passing through the center of the target and two TLD capsules within 0.5 cm of the center of the target. The phantom also contains normal structures: the right lung, the heart, with one TLD capsule in its center; and the spinal cord, with one TLD in its center.

If you have any questions, please contact the appropriate person:
- RPC: Paula Alvarez (713) 745-8980 paulavarez@mdanderson.org
- MD Anderson: Mike Gillin (713) 563-2507 mgillin@mdanderson.org
- ITC: Bill Straube (314) 362-9762 bstraube@itc.wustl.edu
- ITC: Jim Purdy (314) 362-2639 purdy@itc.wustl.edu

**DOSIMETRY INFORMATION TO BE SUBMITTED:**

The following information is to be submitted to the RPC (include in the phantom shipping box):

- Original hard-copy isodose distributions without applying correction for tissue heterogeneity in the sagittal, axial, and coronal planes through the center of the target volume. Please ensure that each plane fills an entire page and that a scale is printed on the page.
- Original hard-copy isodose distributions applying correction for tissue heterogeneity in the sagittal, axial, and coronal planes through the center of the target volume. Please ensure that each plane fills an entire page and that a scale is printed on the page. Be sure to apply on each field the number of monitor units obtained from the plan generated without correction for tissue heterogeneity.
- A completed RPC Lung Phantom Institution Information form.

The following information is to be submitted to the ITC (see protocol for additional submissions):

- The digital treatment planning data, with and without applying correction for tissue heterogeneity, in the RTOG Data Exchange format using either FTP or tape (see the ITC web site for details).
- Original hard copy isodose distributions without applying correction for tissue heterogeneity in the sagittal, axial, and coronal plane through the center of the target (identical to those sent to the RPC).
- A copy of the completed RPC Lung Phantom-Institution Information form that was sent to the RPC.
- Send the hard copy data (isodoses and forms) to: Bill Straube, M.S., Image Guided Therapy Center, Washington University, 4511 Forest Park Ave., Suite 200, St Louis, MO 63108.
Deviation by algorithm

- 0.4% MC
- 2.7% Tomo
- 3.1% Pinnacle
- 4.2% AAA
- 4.4% XiO
- 5.2% PB
- 3.4% Average

Data provided by David Followill, Ph.D., RPC
UK PARSSPORT

- Head and Neck 3DCRT and IMRT comparison credentialing
- Tests field patterns
- Sample patient fields

Fig. 1. Examples of the (a) IMRT and (b) conventional plans used for the audit. Primary and elective nodal PTVs, parotid glands, and the spinal cord are shown. For the IMRT plan the patient has an extended neck and the conventional plan is for a patient with a straight neck.
IMRT is NOT inherently less accurate than 3DCRT
Commissioning is essential
3% tolerance suggested for target doses
Summary

- Commissioning is critical
  - Measurement data accuracy
  - Proper interpretation (deconvolution)
  - Source modeling
- Model based dose calculations are superior (provided accurately commissioned)
- HU conversions result in $\sigma<2\%$
- 2 mm dose grid resolution for $\sigma<2\%$
- End-to-end tests are crucial and required to assess your own clinical accuracy
  - 2%-5% accuracy observed in end-to-end tests
  - No single accuracy number can be provided that you can use in your clinic
  - You must make your own measurements
Thanks

AAPM HQ Staff
- Karen MacFarland
- Betsy Phelps
- ...

2011 AAPM Summer School
Uncertainties in External Beam Radiation Therapy
immediately following the Joint AAPM/COMP Meeting
August 4 - 9, 2011 • Simon Fraser University • Burnaby, BC