Moving from a simple Type A independent dose calculation to a Type B or Type C based independent dose calculation

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Background
**ICRU Report 24:** “Dosimetry systems must be capable of delivering dose to an accuracy of 5%”
This guidance is echoed in subsequent reports

**AAPM TG-40:** Recommended independent check (of MU calculation) within 48 hours
“This review should occur prior to treatment; where this is not possible (e.g., emergency treatment), then it should be done before the third fraction or before 10% of the dose has been delivered, whichever occurs first”

**AAPM IMRT Subcommittee Report:** “Direct measurements will be necessary until independent dose calculation methods are developed and validated.”

**AAPM TG-114:** Recommendations on independent calc software commissioning, & calc details, timing, & tolerances

**AAPM TG-71:** Codified a formalism for hand calculations

Some details provided in 2017 AAPM presentation

Dose Calculation Algorithm Classification

- **Type A**: Models that do not consider the changes in electron transport
- **Type B**: Models that in an approximate way consider changes in lateral electron transport
- **Type C**: Algorithms in which the physics generating the dose absorption process is accounted for

Choice of 2\textsuperscript{nd} Calculation Algorithm

**Type A (simple hand calc)**

**Advantage:** effects of scatter, missing tissue, and tissue heterogeneity are separated and can be independently assessed

**Disadvantage:** Simple calc is limited for complex calculations involving small fields and/or heterogeneity corrections.

**Type B or C (sophisticated calc)**

**Advantages:**
- Improved dosimetric accuracy especially in the presence of scatter disequilibrium and tissue heterogeneities
- Ability to assess dosimetric uncertainties on the patient DVH

**Disadvantage:** Black box… (difficulty to assess sources of uncertainties)

TG-219 recommendation to transition from single point comparisons to a system that computes dose distribution throughout the high dose volume

AAPM 2017 Presentation: TG219: IT’S USE, STRENGTHS AND WEAKNESSES
Why Transition to a Type B or C Independent Dose Calc Algorithm?
Appropriate Geometry for Simple (Type A) Calc

- Points within 2 cm of a field edge may experience disequilibrium effects arising from lack of lateral scatter.
- Points should be located, if possible, in soft tissue and positioned at least 1.0 cm downstream and 1.0 cm lateral to heterogeneous tissue interfaces to avoid large disequilibrium effects.

TG-114 recommended action levels

TABLE III. Guidelines for action levels for disagreement between verification and primary calculations with heterogeneity corrections.

<table>
<thead>
<tr>
<th>Primary calculation geometry</th>
<th>Similar calculation algorithms</th>
<th>Different calculation algorithms</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Same patient geometry (%)</td>
<td>Approx. patient geometry (%)</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>

TG-219 may provide updated action levels for IMRT 2\textsuperscript{nd} calculations.

Type A Calc. Accuracy for Complicated Cases

Increasing incidence of cases for which scatter equilibrium, inhomogeneity, etc. for which a type A calculation is inadequate

Use of SBRT over time

Independent recalculation outperforms traditional measurement-based IMRT QA methods in detecting unacceptable plans

**Purpose:** To evaluate the performance of an independent recalculation and compare it against current measurement-based patient specific intensity-modulated radiation therapy (IMRT) quality assurance (QA) in predicting unacceptable phantom results as measured by the Imaging and Radiation Oncology Core (IROC).

**Methods:** When institutions irradiate the IROC head and neck IMRT phantom, they are also asked to submit their internal IMRT QA results. Separately from this, IROC has previously created reference beam models on the Mobius3D platform to independently recalculate phantom results based on the institution’s DICOM plan data. The ability of the institutions’ IMRT QA to predict the IROC phantom result was compared against the independent recalculation for 339 phantom results collected since 2012. This was done to determine the ability of these systems to detect failing phantom results (i.e., large errors) as well as poor phantom results (i.e., modest errors). Sensitivity and specificity were evaluated using common clinical thresholds, and receiver operator characteristic (ROC) curves were used to compare across different thresholds.

**Results:** Overall, based on common clinical criteria, the independent recalculation was 12 times more sensitive at detecting unacceptable (failing) IROC phantom results than clinical measurement-based IMRT QA. The recalculation was superior, in head-to-head comparison, to the EPID, ArcCheck, and MapCheck devices. The superiority of the recalculation vs these array-based measurements persisted under ROC analysis as the recalculation curve had a greater area under it and was always above that for these measurement devices. For detecting modest errors (poor phantom results rather than failing phantom results), neither the recalculation nor measurement-based IMRT QA performed well.

**Conclusions:** A simple recalculation outperformed current measurement-based IMRT QA methods at detecting unacceptable plans. These findings highlight the value of an independent recalculation, and raise further questions about the current standard of measurement-based IMRT QA. © 2019 American Association of Physicists in Medicine [https://doi.org/10.1002/mp.13638]
Commercial software with Type B or C independent dose calculations

• Dose calculation details:
  – Algorithms:
    • Collapsed Cone Convolution Superposition
    • Monte Carlo
  – Volumetric dose calculation
  – Beam model:
    • Standardized per linac model
    • Customized / tuned to individual linac

• Analysis details:
  – DVH based comparisons
    • Comparison to dose limits & constraints
    • Comparison to value(s) from TPS
  – Gamma analysis

• Ancillary Options
  – Treatment delivery simulation, plan detail checks, etc.
  – Log file analysis (pre-treatment or daily monitoring)
  – Incorporation of EPID / Pre-Treatment QA into model
  – Incorporation of daily CBCT for dosimetric analysis
Independence of 2\textsuperscript{nd} Calculation

- **Independence** = using a different methodology and/or different program than that used for the primary calculation.
- Independence cannot be obtained using same program as primary calculation. Even if TPS has more than one calculation model implemented, use of a separate program is strongly recommended because many of the potentially errant parameters would be common to both calculation models.
- When beam and patient models are similar, the algorithmic implementations should be different.
- Files containing beam data and parameters should be separate and independent.

Commissioning

• From TG-114 (2011)
  – Performance of **independent calc should be compared to measurements** (not just to the TPS), and compared, if possible, with the results of other established calculation systems of known accuracy
  – Commissioning tests should include **clinically relevant geometries** that verify the accuracy of shaped field calculations and calculations in heterogeneous media
  – Commissioning should establish the accuracy of system in different clinical situations, and this should be used to **establish action levels**

• From TG-219 (2017 AAPM Presentation)
  – Commissioning of the secondary dose/MU software should be performed based on the recommendations of AAPM report 53 and MPPG 5A. Ongoing QA for the secondary dose/MU software should be carried out annually and anytime a TPS or secondary dose/MU software upgrade occurs, consistent with MPPG 5A. The software validation and benchmarking should be done following the recommendations of AAPM Task Group 119

Commissioning Examples From Literature

Commissioning results of an automated treatment planning verification system

Christopher L. Nelson, Bryan E. Mason, Ronald C. Robinson, Kelly D. Kisling, Steven M. Kirsner

- Customized the independent calc model
  - Extracted beam data from standardized model
    - field sizes 1x1cm$^2$ to 40x40cm$^2$
    - PDDs
    - Profiles (in field, penumbra, tail)
  - Compared to TPS beam data when customizing beam model
    - Inputs:
      - PDD values at three depths, & three field sizes
      - output factors for six different field sizes
      - off-axis ratios for a 40x40cm$^2$ at six locations

- Dose comparison for 40 clinical treatment plans
  - Solid water phantom
  - CC04 Ion chamber (% difference)
  - Kodak EDR2 film (3% / 3mm Gamma)

Commissioning and clinical implementation of the first commercial independent Monte Carlo 3D dose calculation to replace CyberKnife M6™ patient-specific QA measurements

Maaike T. W. Milder1  |  Markus Alber2,3  |  Matthias Söhn3  |  Mischa S. Hoogeman4

- Beam Model Validation
  - Comparison of calculated values with measurement for PDDs, Output factors, Off axis ratios

- Independent dose calculation of clinical plans
  - Retrospectively re-calculated 84 clinical treatment plans
  - Range of treatment sites (n=5) & PTV sizes (30-300cc).
  - 3D Gamma Index Comparison (2%, 1mm, global, 10% cutoff)

- Establishing action levels
  - Action criteria set using control charts for Gamma Index agreement, as described in the paper & in TG-218
Our experience

- Monte Carlo Independent Dose Calculation Software (SciMoCa)
- Data for beam modeling
  - PDDs
  - Profiles
  - Output factor tables
  - Leaf gap -> need method, & detector for Monte Carlo modeling
- Acceptance & software functionality
- Commissioning:
  - Comparison with measurement data in water
    - Point dose spot checks (profiles & PDDs for geometry not included in beam modeling data)
    - Profiles & Penumbra
    - Output factors
    - Static MLC fields
  - Heterogeneity & HU to Density Calculation
    - HU calibration verification
    - Density override function
    - Heterogeneity correction verification
  - Comparison with measurements in clinical plans
    - Ion chamber measurements
  - Comparison with TPS for clinical plans
    - Multiple treatment sites & geometries
  - Workflow & action criteria
    - DVH analysis
    - Dose to water or dose to medium?
    - Handling of body contour, couch structures
    - immobilization device, bolus, etc.
- SRS specific commissioning
## Spot Check Ion chamber Measurements

<table>
<thead>
<tr>
<th>Linac</th>
<th>Energy</th>
<th>n</th>
<th>Ion Chamber vs. Independent calc (Monte Carlo)</th>
<th>Ion Chamber vs. primary TPS (AAA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TB</td>
<td>6X</td>
<td>40</td>
<td>-0.07% ± 0.54% [-1.29%, 1.18%]</td>
<td>-0.28% ± 0.39% [-1.54%, 0.53%]</td>
</tr>
<tr>
<td>STX</td>
<td>6X</td>
<td>40</td>
<td>0.04% ± 0.59% [-0.98%, 1.52%]</td>
<td>-0.21% ± 0.32% [-1.13%, 0.45%]</td>
</tr>
<tr>
<td>TB</td>
<td>6XFFF</td>
<td>40</td>
<td>-0.52% ± 0.60% [-1.79%, 0.98%]</td>
<td>0.33% ± 0.40% [-0.67%, 1.27%]</td>
</tr>
<tr>
<td>STX</td>
<td>6XFFF</td>
<td>40</td>
<td>-0.55% ± 0.66% [-1.72%, 1.04%]</td>
<td>0.17% ± 0.36% [-0.67%, 0.99%]</td>
</tr>
<tr>
<td>TB</td>
<td>10X</td>
<td>40</td>
<td>-0.43% ± 0.88% [-1.99%, 2.26%]</td>
<td>0.08% ± 0.30% [-0.72%, 1.06%]</td>
</tr>
<tr>
<td>STX</td>
<td>10X</td>
<td>40</td>
<td>-0.49% ± 0.58% [-1.54%, 0.92%]</td>
<td>0.13% ± 0.22% [-0.38%, 0.54%]</td>
</tr>
<tr>
<td>TB</td>
<td>10XFFF</td>
<td>40</td>
<td>-1.03% ± 0.73% [-2.76%, 0.83%]</td>
<td>0.19% ± 1.29% [-0.91%, 8.14%]</td>
</tr>
<tr>
<td>STX</td>
<td>10XFFF</td>
<td>40</td>
<td>-0.85% ± 0.84% [-2.18%, 1.71%]</td>
<td>-0.09% ± 0.21% [-0.58%, 0.40%]</td>
</tr>
<tr>
<td>TB</td>
<td>15X</td>
<td>40</td>
<td>-0.47% ± 0.71% [-2.04%, 0.94%]</td>
<td>-0.04% ± 0.30% [-0.65%, 0.99%]</td>
</tr>
<tr>
<td>STX</td>
<td>15X</td>
<td>40</td>
<td>-0.45% ± 0.48% [-1.43%, 0.67%]</td>
<td>0.19% ± 0.49% [-0.38%, 2.42%]</td>
</tr>
</tbody>
</table>
Agreement of AAA (primary TPS) and Monte Carlo (independent calc) with ion chamber point dose measurement for clinical IMRT and VMAT plans

<table>
<thead>
<tr>
<th>MLC field size (mm)</th>
<th>IMRT (various sites)</th>
<th>VMAT (various sites)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AAA</td>
<td>Monte Carlo</td>
</tr>
<tr>
<td>6X</td>
<td>2.9%</td>
<td>3.9%</td>
</tr>
<tr>
<td>6XFFF</td>
<td>3.9%</td>
<td>3.0%</td>
</tr>
<tr>
<td>10X</td>
<td>-0.7%</td>
<td>1.2%</td>
</tr>
<tr>
<td>10XFFF</td>
<td>-0.1%</td>
<td>-0.7%</td>
</tr>
<tr>
<td>15X</td>
<td>1.5%</td>
<td>1.1%</td>
</tr>
</tbody>
</table>
Dose to Medium vs. Dose to Water

Primary TPS:
• AAA-> Dose to water
• AXB-> Dose to medium

Independent calc algorithm:
• Monte Carlo-> dose to medium

*our current procedure is for the independent calc to always match the TPS
Dose Agreement Criteria Options

• TG-219:
  – Plan acceptability should be based on the composite plan.
  – Single beam agreement should be used to help further the understanding of the plan quality

• Analysis options:
  – DVH based comparisons
    • Organ specific dose limits & constraints
    • Organ specific comparison to value(s) from TPS
  – Gamma analysis
Comparison criteria: organ specific dose limits & constraints

• Advantages:
  – Adds an automated layer into the check
  – Ability to verify important dose constraints on a 2nd algorithm

• Disadvantages:
  – Lots to configure upfront
  – Challenging for situations where a single criteria per organ is not applicable (multiple physicians with specific constraints, varying treatment regimes, etc.)
  – Ancillary to the focus of the independent dose calculation algorithm (checks appropriateness of organ doses, rather than accuracy of dose calculation)
Comparison criteria: Organ specific comparison to value(s) from TPS

- We use mean PTV dose within ±5%
  - Could also add other constraints for PTV (D$_{95}$%, D$_{99}$%, D$_{1}$%, etc.)
  - Could also add similar OAR constraints

- Advantages:
  - Corollary of traditional 2$^{nd}$ calculation point dose comparison vs. volume dose comparison
  - PTV constraints focused on high dose volume

- Disadvantages:
  - Does not inherently verify whether the organ dose is appropriate
Comparison Criteria: 3D Gamma Index

- We use 3% / 1mm, global, 15% threshold 85-90% action level
- Advantages:
  - Analysis is comprehensive (uses full dose matrix)
- Disadvantages:
  - Does not account for spatial clinical relevance (PTVs / OAR)
  - Can mask errors when improper comparative measures are used, or if the volume of dose discrepancy is small
Independent Calc. for Lung SBRT

- type A vs. AAA
- TPS vs. Monte Carlo

- w/ het.
- no het.

% dose difference

AAA
AXB
Independent Calc for Multi-Target SRS

- Pre-treatment QA: Difficult / tedious to verify all PTVs
- Independent Monte Carlo calc is comprehensive & thus serves as an excellent complement to pre-treatment QA
Thank you!