IMRT Treatment Plan Validation & Independent MU Calculation

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Outline
1. Machine and MLC specific QA.
2. Patient Specific QA.
   (a) Geometric.
   (b) Dosimetric.

Patient Specific QA
1. Geometric verification
   a. Isocenter setup.
   b. portal verification ➔ Field aperture.
2. Dosimetric verification
   a. Point dose (MU) check
      — multiple points are HIGHLY recommended.
   b. Fluence map check
      — extremely important!

Isocenter Verification

IMRT Portal Verification

DISCLOSURE

The IMRT plan validation software described in this talk is being commercialized by Prodigm Inc. (Chico, California). The company has licensed the software from the presenter’s group.
**Patient Specific QA**

1. **Geometric verification**
   - a. Isocenter setup.
   - b. Portal verification → Field aperture.

2. **Dosimetric verification**
   - a. Point dose (MU) check
     ---multiple points are HIGHLY recommended.
   - b. Fluence map check
     ---extremely important!

**IMRT pre-treatment QA**

- Verification of 3D dose distribution

  or

- Verification of point doses +
- Verification of fluence maps/leaf-sequence files

**Dose/MU verification**

**Alternative: Independent Dose/MU Calculation**

1. Independent MU verification is done using hand-calculation in conventional Rx.
2. A similar independent MU check procedure is needed for IMRT—ion chamber or independent cal.
3. A computerized MU calculation has to be used due to the intrinsic complexity of the problem.
Cumulative IMRT Dose:
Sum the contributions from all segments.

\[
D = \sum_{i} \text{MU}_i \cdot D_i = \text{MU} \sum_{i} f_i \cdot D_i \\
f_i = \text{MU}_i / \text{MU}
\]

Point Dose Calculation in IMRT

1. Open field.
2. Wedged field.
3. IMRT.
4. General approach: sum contributions from all beamlets.

How to calculate the dynamic modulation factor \( C_m \)?

\[
D = \text{MU} \sum_{\alpha} \delta_{\alpha} C_m d^0_m \\
C_m = \sum_{\alpha} [\beta_{\alpha} + \alpha(1 - \delta_{\alpha})] f_i \\
\delta_{\alpha} = \begin{cases} 
1 & \text{if } m \in A_i \\
0 & \text{if } m \notin A_i 
\end{cases}
\]

\( C_m \) can be calculated using the information contained in MLC leaf sequence file.

MU Verification in IMRT

\[
D = \text{MU} \sum_{i} f_i d_i \\
f_i = \text{MU}_i / \text{MU} \\
d_k = \sum_{m \in A_i} d^0_m + \sum_{m \in A_k} d^1_m \\
d'_\alpha = \alpha d^0_\alpha \\
\alpha \cdots \text{transmission}
\]

Calculation of beamlet calculation.
1. Beamlet kernel from convolution, Monte Carlo, …
2. Clarkson calculation.

Primary Dose

\[
d^\prime = C' \cdot (C \cdot \text{MU})' = X'_A, Y'_A
\]

Contributions from “scatter beamlets”
Summary of dose verification for a prostate case

<table>
<thead>
<tr>
<th>Gantry angle</th>
<th>TPS calculation</th>
<th>Primary dose</th>
<th>Scatter dose</th>
<th>Beam dose</th>
<th>Ion chamber measurement</th>
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<td>30</td>
<td>45.4</td>
<td>44.9</td>
<td>3.6</td>
<td>45.0</td>
<td>43.8</td>
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<td>3.3</td>
<td>32.5</td>
<td>33.3</td>
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<tr>
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<td>33.7</td>
<td>30.4</td>
<td>3.3</td>
<td>32.5</td>
<td>33.3</td>
</tr>
<tr>
<td>Total dose</td>
<td>253.6</td>
<td>231.7</td>
<td>17.5</td>
<td>249.2</td>
<td>249.6</td>
</tr>
</tbody>
</table>

Results of Calculation

Difference between independent calculation and TPS

Results of Chamber Measurements

Comparison of results of dose verification

Calculation of Head Scatter

Head scatter calculation — three-source model:
- A primary photon source for the primary photons from the target.
- A planar annulus extra-focal photon source for the scattered photons from the primary collimator.
- A planar disk extra-focal photon source for the scattered photons from the flattening filter.

Three-source model

The primary photons directly from the target:
- (about 90% total photons)

The scattered photons:
- (about 10%)
- (about 6%)
- (about 3%)

Others:
- About 1%
Results

1. 10x10cm Field

<table>
<thead>
<tr>
<th></th>
<th>Desired</th>
<th>No correct</th>
<th>Correct for Transmission only</th>
<th>Correct for Head Scatter only</th>
<th>Correct for both effects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>30.0</td>
<td>30.0</td>
<td>30.0</td>
<td>30.0</td>
<td>30.0</td>
</tr>
</tbody>
</table>

The data of symmetric rectangular fields for the 6MV (within 0.3%)---------Y. Yang, L. Xing et al., Med. Phys. 29, 2024-33, 2002.

The measured absolute dose profiles at depth 5cm

The importance of head scatter contribution

With and without head scatter (Varian MLC)

~2% for small field IMRT
~4% for large field IMRT

Steps of independent MU calculation for intensity modulated field

1. Read in MLC file.
2. Calculate dynamic modulation factors.
3. Input SSD.
4. Head scatter and modulation factor calculation.
5. Clarkson summation weighted by the beamlet dynamic modulation factors.
6. Compare with the dose from TPS.

The method works for different MLCs—52-, 80-, 120-leaf MLCs, MIMiC, with different beamlet sizes.
Point dose verification is not enough for IMRT.

Planar dose distribution must be verified to validate an IMRT treatment plan!

We propose to verify:

- Point dose verification
- Fluence map verification

Point dose + fluence map check is the solution!

Computer verification of fluence maps

1. Point dose verification is not enough for IMRT.
2. Planar dose distribution or fluence maps need to be verified.
3. Film/PID/BIS for fluence verification is time-consuming. Furthermore, it may have problem in verifying dynamic delivery.
Verification of leaf-sequence files for IMRT

Fluence calculation
1. Sum the contributions from all segments.

\[ F_k = \sum_{m \in A_k} F^0_m + \sum_{m \notin A_k} F^r_m \]

\[ d'_m = \alpha \cdot d''_m \quad \alpha \cdot \text{transmission} \]

\[ C_n = \sum_k \left[ \delta_{m,A_k} + \alpha (1 - \delta_{m,A_k}) f_k \right] \]

\[ \delta_{m,A_k} = \begin{cases} 1 & \text{if } m \in A_k \\ 0 & \text{if } m \notin A_k \end{cases} \]

Calculation of fluence.
1. Average MLC transmission model.
2. Other fluence models (one-source, two-source, etc.).
Quantitative comparison of two fluence maps

1. Maximum difference in pixel values—local quantity.

2. Correlation coefficient—global quantity.

\[ r = \frac{\sum_{n} (F_n - \bar{F})(R_n - \bar{R})}{\sqrt{\sum_{n} (F_n - \bar{F})^2} \sqrt{\sum_{n} (R_n - \bar{R})^2}} \]

Comparison of independent calculation & TPS calculation

Case Number | Max. discrepancy in the pixel value |
--- | --- |
1 | -0.4 |
2 | -0.3 |
3 | -0.2 |
4 | -0.1 |
5 | 0 |
6 | 0.1 |
7 | 0.2 |
8 | 0.3 |
9 | 0.4 |
10 | 0.5 |

Max. discrepancy in the pixel value

After the planning: QA

RTP exchange file | Intensity maps | ACQSIM plan file

QA program
- checks leaf sequence against the intensity map (for every field)
- checks point doses

VARIS
Summary

• IMRT QA: Routine MLC QA + Patient Specific QA.
• Patient Specific QA: multiple point doses + fluence maps.
• Point dose check is not enough—do not forget intensity maps.
• Head scatter need to be considered.
• Integrated software for IMRT QA has been developed.

GO WITH COMPUTER!