Quality Assurance of IMRT Delivery Systems - Siemens

Lynn J. Verhey, Ph.D.
Professor and Vice-Chair
UCSF Dept. of Radiation Oncology
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Siemens Medical Systems, Concord, CA
NOMOS Corporation, Sewickley, PA

Introduction
• IMRT delivery requires special quality assurance due to:
  – Small number of MUs per field
  – Large number of small fields
• Need to investigate several beam properties in detail:
  – Dose linearity
  – Beam flatness and symmetry
• MLC properties to investigate:
  – Leaf leakage for closed pairs and leaf-to-leaf
  – Leaf position accuracy and offset

Introduction (con’t)
• Assumption of inverse-planned IMRT
• Relatively complex plans (e.g., H/N) currently result in 10-20 beam segments per beam direction (CORVUS by NOMOS)
• Properties of Siemens MLC and beam delivery control system, affect the quality assurance methods

Issues of Quality Assurance
• Machine related QA
  Dose linearity
  Field symmetry and flatness
  Leaf position accuracy
  Dose accuracy of each segment
• Patient related QA
  Measure phantom plans
  Check intensity map
  Patient position verification

Inverse Planning Problem
Dose to point i
\[ D_i = x_1 d_1 + \cdots + x_J d_J \]
The dose deposited to the i\textsuperscript{th} point in the body from the j\textsuperscript{th} ray is linearly related to the intensity of that ray

Inverse Treatment Planning
• Prescription requires dose goals for target and normal tissues (possibly 3-point DVHs)
• Planner chooses beams and no. of intensity levels
• Opportunity to place margins between CTV and PTV
• Objective function minimized using penalties based on clinical input
• Output is discrete or continuously varying intensity profiles for each defined beam direction and MLC segments and weights for acceleration of choice
• Many commercial systems now available (CORVUS, Helios, Helax, Pinnacle, CMS, KortRad)
**Conclusions from Nasopharynx Comparison**

- Dose to cord limits GTV dose for 3D plan
- Significantly better cord sparing with IMRT plan than with 3D plan
- Significantly better parotid sparing with IMRT than with 3D plan
- Typically need approximately 120-140 segments over 7-9 directions for good conformality in H/N treatments

**Issues of Quality Assurance**

- Machine related QA
  - Dose linearity
  - Field symmetry and flatness
  - Leaf position accuracy
  - Dose accuracy of each segment
- Patient related QA
  - Measure phantom plans
  - Check intensity map

**Dose Linearity Check**

- Siemens Linacs:
  - Measured a point dose using an ion chamber for an IM square field, consisting of 100, 15x15 cm² segments with 1MU/seg
  - Compressed with this of a standard 15x15 field delivered with 99 MU
- Special effort can be adjusted to achieve better dose linearity

**Siemens MLC Properties**

- Doubly focused, effective arc motion
- 27 leaf pairs projecting to 1 cm, 2 leaf pairs at extremes projecting to 6.5 cm
- Conventional field size 40 x 40 cm
- IMRT field size 28 long x 21 wide determined by overtravel limits of MLC (10 cm) and y-jaw (10 cm)
- Interdigitation of leaves not allowed
- Closure of leaf pair possible
- No velocity control, only step-and-shoot

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Results of Linearity Check

<table>
<thead>
<tr>
<th>Total MU</th>
<th># of Seg</th>
<th>MU/seg</th>
<th>Reading</th>
<th>∆ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>99</td>
<td>99</td>
<td>6 MV</td>
<td>0.4705</td>
<td></td>
</tr>
<tr>
<td>99</td>
<td>1</td>
<td>6 MV</td>
<td>0.4750</td>
<td>1.0</td>
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<tr>
<td>99</td>
<td>99</td>
<td>18 MV</td>
<td>0.4780</td>
<td></td>
</tr>
<tr>
<td>99</td>
<td>1</td>
<td>18 MV</td>
<td>0.4844</td>
<td>1.3</td>
</tr>
</tbody>
</table>

KD-2, Omni, 100 cm SSD, 15x15 cm²

Dose Linearity Check

- Varian Linacs:
  - Measured point doses of special IM field consisting of 190 and 95, 15x15 cm² segments with 0.1 MU/seg, 0.2 MU/seg, and 1 MU/seg, respectively.
  - Programmed with stop and shoot delivery
  - Purposely programmed 2 mm shift between segments to simulate beam on and off
  - Compared with the results of regular 15x15 cm² field with 190 MU and 95 MU respectively.

Results of Linearity Check

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</thead>
<tbody>
<tr>
<td>19</td>
<td>1</td>
<td>19</td>
<td>0.0934</td>
<td></td>
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<tr>
<td>19</td>
<td>190</td>
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<td>38</td>
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<td>38</td>
<td>0.1866</td>
<td></td>
</tr>
<tr>
<td>38</td>
<td>190</td>
<td>0.2</td>
<td>0.1864</td>
<td>0.04</td>
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<tr>
<td>95</td>
<td>1</td>
<td>95</td>
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<tr>
<td>95</td>
<td>190</td>
<td>0.5</td>
<td>0.4655</td>
<td>0.08</td>
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</table>

CL_2300, 6MV, 1.5 cm depth, 100 cm SSD, 15x15 cm²

Field Symmetry and Flatness Check

- Field symmetry and flatness are tuned through a feedback loop from the internal ion chambers.
- Small MU delivered to each segment may affect the field symmetry and flatness.
- Conventional profile measurement can not be used because of insufficient MUs.
- The ion chamber is placed at following symmetry points (+5, +5), (+5, -5), (-5, +5), and (-5, -5) in a 15 x 15 cm² field delivered in IMRT fashion.

Results of Symmetry and Flatness

<table>
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<tbody>
<tr>
<td>(0,0)</td>
<td>19</td>
<td>19</td>
<td>0.0905</td>
<td>0.0</td>
</tr>
<tr>
<td>(0,0)</td>
<td>99</td>
<td>99</td>
<td>0.4780</td>
<td>0.0</td>
</tr>
<tr>
<td>(-5, 5)</td>
<td>99</td>
<td>1</td>
<td>0.4844</td>
<td>1.34</td>
</tr>
<tr>
<td>(5, 5)</td>
<td>99</td>
<td>1</td>
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CL_2300, 18MV, 3.2 cm depth, 100 cm SSD, 15x15 cm²

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<td>(0,0)</td>
<td>19</td>
<td>19</td>
<td>0.0904</td>
<td>0.1</td>
</tr>
<tr>
<td>(5, 5)</td>
<td>19</td>
<td>1</td>
<td>0.0912</td>
<td>0.8</td>
</tr>
<tr>
<td>(5, -5)</td>
<td>19</td>
<td>0.1</td>
<td>0.0912</td>
<td>0.8</td>
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CL_2300, 6MV, 1.5 cm depth, 100 cm SSD, 15x15 cm²

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<td>19</td>
<td>19</td>
<td>0.0924</td>
<td>0.0</td>
</tr>
<tr>
<td>(5, 5)</td>
<td>19</td>
<td>0.1</td>
<td>0.0933</td>
<td>0.1</td>
</tr>
<tr>
<td>(5, -5)</td>
<td>19</td>
<td>0.1</td>
<td>0.0920</td>
<td>1.52</td>
</tr>
</tbody>
</table>

CL_2300, 18MV, 3.2 cm depth, 100 cm SSD, 15x15 cm²
MLC Leaf Position Check and Field Penumbra

- MLC leaf position accuracy and field penumbra become more important in IMRT treatment, because it can affect dose through the entire field as the multiple segments abutting together, not just on the edge of the field as in conventional delivery.
- Leaf position accuracy for Siemens and Varian Linacs meets their specifications.

Leakage after calibration Leakage without calibration

Siemens MLC

Intensity pattern showing need for calibration

Multileaf Collimator Designs

- Each manufacturer has a different design for their MLC:
  - Location, leaf width, and leaf end design
  - Single focused or double focused
  - Restrictions on motion (path, over-travel, interleaf)
  - Field size
- These factors have an impact on dose delivery and must be considered in treatment planning.

Rounded Leaf End vs Penumbra

Elekta MLC System

Varian MLC System
Leaf Motion Constraints

- Interleaf motion (Varian)
- No Interleaf motion (Siemens)
- Minimum gap (Elekta)

MLC Field Size for IMRT

<table>
<thead>
<tr>
<th>Linac</th>
<th>IMRT Field Size</th>
<th>Nominal Field Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Varian</td>
<td>29 x 26 (40) cm²</td>
<td>40 x 26 (40) cm²</td>
</tr>
<tr>
<td></td>
<td>(2 x 14.5 cm)</td>
<td></td>
</tr>
<tr>
<td>Siemens</td>
<td>21 x 20 (27) cm²</td>
<td>40 x 27 (40) cm²</td>
</tr>
<tr>
<td>Elekta</td>
<td>25 x 25 cm²</td>
<td>40 x 40 cm²</td>
</tr>
</tbody>
</table>

Siemens SMLC-IMRT Delivery System

- Automatic field sequencing system (Primeview/SIMTEC)
  - For both conventional and IMRT delivery
  - Automatically deliver all gantry angles including segments in each IM field
  - Supports step and shoot SMLC delivery
  - ~ 5 - 6 sec. RV overhead per segment
  - Treat 100 - 120 segments in 20 minutes
  - Only integer MU can be specified per segment
  - Supports network RTP

Dosimetric Verification Procedures at UCSF

- In the beginning, dosimetric verification was performed prior to each patient's first treatment using solid water phantom with ion chambers and film (Results - The measured point doses near the maximum were all within 5% of predicted doses)
- Now designing system for q/a checks using cylindrical plastic phantom with multiple holes for MOSFET dosimetry. Will move to this method in the future.
Dosimetric Verification - Results

- Observations independent of delivery system
  - High dose regions of plan (typically >85% max) were generally within 2% of calculated
  - Lower dose regions (typically planned for 30-50% of max) were 10-15% higher than planned
  - In general, higher complexity (more intensity levels and segments) gave higher discrepancies

Dosimetric Verification - Interpretation

- Dose discrepancies approximately the same for plans delivered with Siemens and Varian accelerators - i.e., independent of dose delivery system
- Probable cause is dose calculation algorithm within planning system which does not deal well with small fields and leaf transmission and scatter - soon Monte Carlo can answer question
- Dose errors due to DMLC control delays probably not clinically significant though more research needed

What have we learned so far with our IMRT experience?

- There is no perfect system - limitations of planning system, IMRT delivery system and dose verification must be considered
- Clinical needs drive us to complex IMRT plans (many fields and segments) therefore, delivery speed is important
- Dose accuracy not as good for high complexity due to large numbers of small fields and small dose per segment
- IMRT field length and field width requirements can limit use

Current Limitations with use of IMRT for Precision H/N Radiotherapy

- Patient immobilization and target localization
- 3D dose verification
- Treatment parameter verification
- Control of optimization process
- Efficient registration of biological imaging to fix planning CT
- Accelerator control system efficiency
- MLC leaf positioning accuracy
- Dose calculation accuracy
- Dose delivery technology

Patient immobilization and target localization

- Dose gradients for IMRT are large in all directions so immobilization and target localization even more important than for 3DCRT
- Work in progress includes:
  - Advanced imaging, use of portal images and automated search routines to locate targets
  - Stage correction for daily imaging of patient, setup
  - Coach motions activated to repatriate correctly on a daily basis using feedback
  - CT in treatment room (or on gantry) to verify plan before treatment
  - Motion prevention such as gated therapy for lung and thorax tumors

Lateral Head & Neck 6 MV images acquired with Am-Si Flat Panel

- 2 MU Localization image
- Verification Image
Automated Radioopaque Marker Detection

Target Alignment

ISOLOC calculates target location and necessary moves to bring the target to the isocenter. The preference is used to distinguish the moves.

3-D Dose Verification

- Can only do single point or plane (film) dose verification at this time
- In the future:
  - Bang Gels read out by MR
  - Instrumented phantoms with multiple fixed points using diodes or very small ion chamber or MOSFET (This is UCSF choice)
  - Portal imaging to image transmitted dose and programs to back-project information to patient
  - MV-CT using treatment beam

Treatment parameter verification

- Difficult to verify set of MLC position information for IMRT treatments
- In the future:
  - Use portal imagers to image intensity pattern and to verify MLC positions "on the fly"
  - Special programs to verify MU calculation per beam segment

Intensity Pattern Verification for IMRT Delivery

Individual beam segments

Reconstructed intensity map

Dose calculation accuracy

- Currently, inverse planning programs have very simple dose calculation algorithms due to requirements of speed
- In the future:
  - Multiple calculation algorithms will be available to check plan during optimization process
  - Monte Carlo-dose calculation program will become readily available to evaluate the optimized plan
  - Speed of Monte Carlo will become so fast that it can be done during the optimization process (CORVUS will incorporate Peregrine Monte Carlo dose algorithms in the near future)

Workload - IMRT vs. 3DCRT

- Comparisons recently made of physics effort and treatment times for IMRT vs. 3DCRT for complex treatment plans
- Physics times were on average a factor of 2-3 higher than for 3DCRT (8 hours vs. 3 hours)
- IMRT treatment times somewhat longer on average than for 3DCRT (20 - 45 vs. <15 min)
- Physician time somewhat greater for IMRT, mostly due to target contouring time (not documented)

UCSF Experience with IMRT - Conclusions to date

- Routine Monte Carlo calculations of expected dose distributions will be available in very near future with Peregrine and other programs
- Portal imager will soon be able to provide rapid, high contrast images to help verify patient and target position automatically
- Linac manufacturers working hard to make IMRT faster and dose delivery more accurate
- IMRT still not simple enough to be used in all clinics, but we are on the right track