Acceptance Testing, Commissioning, Quality Assurance of VMAT Technology

Fang-Fang Yin, Jackie Wu, Ying Xiao*, James Galvin
*Presenter

Conflict of Interest
Funding from PA Department of Health through ACR
Funding from NCI/NIH through ACR
Objectives of Presentation

1. Knowledge of acceptance testing and commissioning: We will discuss what should be done and the steps on how to do acceptance testing and commissioning
2. Methodology of quality assurance: We will discuss what quality assurance procedures, including machine specific and patient specific QAs as well as end-to-end tests should be planned, why they are needed, and how to perform these procedures effectively

Presentation Outlines

- **Fundamentals of VMAT**
  - Acceptance testing/commissioning
  - Quality Assurance
    - Machine specific QA
    - Patient specific QA
- Challenges
3D-CRT Compared to IMRT

Conventional 3-field RT vs. Expected 3-field IMRT

Typical dose distribution

Uniform Beam Profile vs. Modulated Beam Profile

The Principle of IMRT: Dose Painting

7-field 3D conformal RT vs. 7-field IMRT
Principle of IMRT

“The DVHs or subsequently derived biological scores depend on the total number of strata, which is defined as the product of the number of beams and the intensity levels within each beam. As the number of beams increases, the number of intensity levels required to obtain optimal dose distribution should be reduced.”


What matters is the total number of shape changes!

Static and Rotational IMRT

Static Gantry IMRT

Multiple apertures at each angle

VMAT–Rotational IMRT

One aperture at each angle
Fundamentals for VMAT

- **Volumetric-Modulated Arc Therapy (VMAT)**
  - An arc-based approach to IMRT
  - To be delivered on a conventional linear accelerator with conventional MLC
  - During arc beam delivery, the dose rate, the speed of the gantry, and the position of the MLC leaves can be adjusted dynamically

- **RapidArc and SmartArc** are examples of VMAT

Multi-arc to Single arc

One arc or two arcs

- For most of the commercial planning solutions, no more than 2-arcs are needed
- For complex cases, 2-arcs make it easier to connect the apertures thereby offering the optimizer more freedom, leading to significantly improved the dose conformationality

Different IMRTs - Prostate
Different IMRTs – H&N

Why VMAT works?

• Plan quality is determined by the number of independent aperture variations
• Based on 10+ years of experience with IMRT, we have learned that the opportunities in improving plan quality are limited within the constraint of present linac/MLC delivery.
• Clinically acceptable optimal plan does not require much complexity.
Potential Advantages of VMAT

- Is VMAT dose delivery faster?
- Does VMAT produce higher quality plans?
- Does VMAT use fewer monitor units resulting in lower patient total body dose?

VMAT: Faster Delivery?

The comparison of SG-IMRT and VMAT should be undertaken only after the static gantry technique has been fully optimized

- The key to optimizing SG-IMRT is to load all beam parameters before starting dose delivery so that no time is wasted when gantry arrives at its next position
- Some accelerator manufacturers have not optimized their systems in this way
VMAT: Higher Quality Plan?

• Theoretically, VMAT and IMRT are comparable
• Practically, it is extremely difficult to control studies to provide useful results
• *Seven comparison studies performed from late 2009 to late 2010 were examined
• *Some thoughts for plan evaluation:
  o The criteria and methods of comparison should be explicitly stated and justified
  o The probabilities of occurrence of the criteria should be reported
  o Explicit utilities for the criteria should be provided and used to rank the methods


VMAT: How Does Plan Quality Relate to Delivery Time?

Total treatment time and monitor unit efficiency influence the quality of the treatment plan

• Pushing the quality of the treatment plan decreases monitor unit efficiency and increases treatment time for both SG-IMRT and VMAT

• As a result of field size limitations for some MLC designs, the relationship for plan quality, treatment time and monitor unit efficiency is not clear for either approach
VMAT: The Field Size Limitation Problem

MLC field size limitations affect monitor unit efficiency and delivery time for SG-IMRT and VMAT in different ways

- The limited reach of some MLCs can decrease SG-IMRT efficiency by approximately a factor of 2 due to field splitting
- Rotating the MLC by 45 degrees for VMAT can improve monitor unit efficiency
- SG-IMRT and VMAT should be compared for both large and small-field situations

VMAT: Does VMAT Require Fewer Monitor Units?

Monitor Unit Efficiency (MUE) is related to MLC leakage and patient total body dose

- Using a relatively large number of small apertures drives MUE
- Pushing plan quality will decrease MUE
- MLCs with a limited reach can require split fields
- Rotating the MLC by 45° can mitigate field size limitations
Current VMAT and QA Options

- Some Existing Planning Systems
  - Eclipse (Varian)
  - ERGO+/Monaco (Elekta)
  - Pinnacle SmartArc (Philips)
  - Prowess (Prowess)

- Some Existing Delivery Systems
  - VMAT/RapidArc (Varian)
  - VMAT (Elekta)

- Some Existing QA Systems
  - Film or film equivalent
  - 2-D ion chamber/diode array (i.e., Matrixx, Octavius, Mapcheck, ...)
  - 3-D diode matrix (Delta 4, ArcChecker, Octavius, Gel/Presage, ...)
  - Some of 3-D devices could be potentially used for 4-D measurement

Specials Considerations for VMAT

- Due to necessary synchronization of both dose rate and gantry motion with MLC movement, it is clear that VMAT involves new and different QA steps relative to conventional IMRT
- This should be reflected in Acceptance Testing (AT), Commissioning (COM), and Routine QA for VMAT
SAM Question 1
For VMAT, the DVHs or subsequently derived biological scores for complicated plans depend on

a. Number of beams
b. Number of intensity levels for each beam
c. Number of arcs
d. Number of intensity levels for each beam (aperture)
e. Exact location of the apertures

Answer: c
Feedback:
More than 2 arcs are needed for a high quality plan for complicated target volume
Reference:
SAM Question 2
For VMAT, the intensity modulation is achieved by all of the following except

- a. Motion of MLC leaves
- b. Variation of dose rate
- c. Variation of gantry rotation speed
- d. Overlapping shape
- e. Moving collimator

Answer: d
Feedback:
The conformal dose painting of VMAT is delivered by varying gantry rotation speed, dose rate, and motion speed of collimators and MLC.

Reference:
Topics in This Presentation

- Fundamentals of VMAT
- **Acceptance testing/commissioning**
- Quality Assurance
  - Machine specific QA
  - Patient specific QA
- Challenges

Acceptance Testing for VMAT

Acceptance testing procedures are typically dictated by equipment manufacturers

- The local physicists can modify manufacturer’s suggested tests or add different tests
- Such changes must be negotiated before a purchase order is signed
- The commissioning tests described in this slide set can be used to modify or add to the manufacturer’s testing
Acceptance Testing Should Include the Following

- Machine readiness
  - Verification of installation against items included in the purchase order (specifications)
  - Inspections of safety and quality of installation and components
- VMAT specific performance testing
  - Testing of functionality of each component and system performance against specifications
- End-to-end testing
  - Dry-runs for a few test cases from simulation to delivery

Commissioning Testing for VMAT

This slide set will concentrate on commissioning and routine QA for VMAT

- The tests described can also be used for the acceptance testing component of QA
Commissioning VMAT Equipment

- There are different ways of performing testing
- There are also different phantom/measurement devices available for VMAT testing
- Different devices may need different ways of operation and measurements. However, the tolerances against baselines should be comparable
- They must provide equivalent information

Testing Tools and Devices for VMAT Commissioning

- Dedicated phantoms
- Electronic portal imager or films
- Dedicated programmed MLC files (could be provided by vendors)
- Software for analysis
- Testing protocol:
  - Parameters
  - Method
  - Tolerance
  - Documentation
  - QA baselines
Commissioning Related to VMAT

1. Mechanical-specific tests*
   a. MLC position test - static gantry
   b. MLC position test - rotating gantry
   c. MLC error detection test during rotation

2. Dosimetry-specific tests
   Dose profile test at different gantry positions
   a. MLC dosimetry test at different gantry positions
   b. MLC dosimetry test with changing gantry speed and dose rate
   c. MLC dosimetry test with changing leaf speed during rotation

3. Interruption/resumption test

4. End-to-end tests
   a. Data transfer
   b. Patient specific

* The numbers and letters shown on this slide are used to identify the testing procedures on the following slides

Published References Relating to Acceptance Testing and Commissioning

- Commissioning for VMAT follows two early reports:

- General IMRT Guidance Document:
Published Commissioning

References

Ling et al paper
- Varian accelerator was used for testing
- Procedures tend to be specific for this equipment
- Must have good knowledge of the use of Log Files
- Equipment needed is relatively simple

Bedford et al paper
- Elekta accelerator was used for testing
- Procedures tend to be specific for this equipment
- Equipment used is complex and expensive
- Possible to adapt testing to simpler equipment

Sample 1a: dMLC Position

Tests for Static Gantry
- Accuracy of dMLC position vs. gantry position (Ling et al Test 1)
- Tolerance: ± 1 mm
Sample AT 1b: dMLC Position

Tests during Rotation

- Accuracy of dMLC position during arc (Ling et al Test 1)
- Tolerance: ± 1 mm

Tests 1a&1b: dMLC Position Accuracy Tests

- Film image of 1-mm-wide for two picket fence patterns
- at stationary gantry angle
- in RapidArc mode

Sample AT 1c: MLC Error Detection Test

- Ability to accurately detect MLC position error (Ling et al Test 1)
- Criteria: detect sub-millimeter error in position

Field Flatness Test: Dosimetry Test for Gantry Positions

- Field flatness and symmetry of beam profile at all cardinal angles for range of dose rates (LA48 linear array)
- Tolerance: ±3%

<table>
<thead>
<tr>
<th>Orientation</th>
<th>Dose rate (MU/min)</th>
<th>Flatness (%)</th>
<th>Symmetry (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>G-T</td>
<td>37</td>
<td>104.0</td>
<td>101.0</td>
</tr>
<tr>
<td>A-B</td>
<td>600</td>
<td>103.6</td>
<td>100.7</td>
</tr>
<tr>
<td>A-B</td>
<td>75</td>
<td>105.4</td>
<td>103.5</td>
</tr>
<tr>
<td>A-B</td>
<td>37</td>
<td>106.1</td>
<td>104.1</td>
</tr>
</tbody>
</table>

A-B = perpendicular to the axis of gantry rotation;
G-T = parallel to the axis of gantry rotation
* IEC 60976 nomenclature.
Tests 2a: Dosimetry Test for Gantry Positions

Test:
synchronization of leaf travel with dose and gantry rotation

Tolerance:
Compare between-leaf leakage to variation at gaps. Dose variation perpendicular to leaf motion should be similar to parallel scan.

Test 2a: dMLC Dosimetry for Gantry Position

- dMLC dosimetry consistency at different gantry positions (Ling et al Test 2)
- 0.5cm MLC slit sliding over 4 cm range
- Gantry: 0°, 90°, 270°, 180°
- Tolerance: ±2% (over mean value)
Sample Test 2b: dMLC Dose vs Gantry Speed and Doserate

- Accuracy of dose rate and gantry speed control during RapidArc (Ling et al Test 2)
- Tolerance: ± 2%

Sample AT 2b: dMLC Dose vs Gantry Speed and Dose-rate

<table>
<thead>
<tr>
<th>ΔMƯ/Δt (MU/min)</th>
<th>Δθ (degree)</th>
<th>ΔΘ/Δt (degree/s)</th>
<th>Ave Δ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>111</td>
<td>90</td>
<td>5.54</td>
<td>1.1</td>
</tr>
<tr>
<td>222</td>
<td>45</td>
<td>5.54</td>
<td>0.5</td>
</tr>
<tr>
<td>333</td>
<td>30</td>
<td>5.54</td>
<td>0.0</td>
</tr>
<tr>
<td>443</td>
<td>22.5</td>
<td>5.54</td>
<td>0.1</td>
</tr>
<tr>
<td>554</td>
<td>18</td>
<td>5.54</td>
<td>-0.2</td>
</tr>
<tr>
<td>600</td>
<td>15</td>
<td>5.00</td>
<td>-0.5</td>
</tr>
<tr>
<td>600</td>
<td>12.9</td>
<td>4.30</td>
<td>-1.1</td>
</tr>
</tbody>
</table>
Test 2c: dMLC Leaf Speed

Tests during Rotation

Combinations of leaf speed/dose-rate to give equal dose to four strips in a RapidArc (Ling et al Test 3)

Leaf Speed (cm/s)
- 0.46
- 0.92
- 1.84
- 2.76

Doserate (MU/min)
- 138
- 277
- 544
- 544

Sample 2a&2c: Dosimetry Test for dMLC Synchronization

- Test of synchronization of gantry position, leaf position, and dose rate
- Film and cylindrical phantom
- Central axis: static 16x1 cm (no MLC motion)
- Off-axis: dynamic 16x1 cm field (8cm from center)
- Tolerance: Uniformity of peripheral dose mostly within ±4% of local control point dose

MU | G speed | doserate
---|---------|---------
160 | 6°/s    | 150 MU/min
640 | 3°/s    | 300 MU/min
1280| 1.5°/s  | 600 MU/min

Dose normalization point (6 cm off-axis, 4% intervals)

Bedford et al Red J. 2009
Alternative 2b&2c: dMLC

Dosimetry for Gantry Position

- A sliding window (2x20cm dynamic slit) at different gantry angles to test effect of gravity on MLC movement (leaf speed/aperture width)
- Test with both uniform and variable leaf speed
- Tolerance: ±1% intensity change relative to gantry zero
- Tolerance: ±3% compared measured to calculated doses

<table>
<thead>
<tr>
<th>Gantry angle (°)</th>
<th>Collimator angle (°)</th>
<th>Motion</th>
<th>Measured calculated dose</th>
<th>Measured static dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>X1→X2*</td>
<td>1.12</td>
<td>0.985</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>X2→X1</td>
<td>1.12</td>
<td>0.984</td>
</tr>
<tr>
<td>270</td>
<td>0</td>
<td>X1→X2</td>
<td>1.12</td>
<td>0.983</td>
</tr>
<tr>
<td>270</td>
<td>90</td>
<td>X1→X2</td>
<td>1.12</td>
<td>0.982</td>
</tr>
<tr>
<td>270</td>
<td>90</td>
<td>X2→X1</td>
<td>1.13</td>
<td>0.987</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Gantry angle (°)</th>
<th>Collimator angle (°)</th>
<th>Motion</th>
<th>Measured calculated dose</th>
<th>Measured static dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>X1→X2*</td>
<td>1.20</td>
<td>0.984</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>X2→X1</td>
<td>1.20</td>
<td>0.985</td>
</tr>
<tr>
<td>270</td>
<td>0</td>
<td>X1→X2</td>
<td>1.19</td>
<td>0.976</td>
</tr>
<tr>
<td>270</td>
<td>90</td>
<td>X1→X2</td>
<td>1.19</td>
<td>0.978</td>
</tr>
<tr>
<td>270</td>
<td>90</td>
<td>X2→X1</td>
<td>1.19</td>
<td>0.980</td>
</tr>
</tbody>
</table>

An aperture moving at uniform speed
An aperture moving at variable speed

Bedford et al Red J 2009

Sample 3: Treatment

 Interruption/Resumption Test

- Use benchmark end-to-end test that includes measurement of dose distribution and absolute dose at a point
- Interrupt beam in middle of delivery and continue treatment to completion
- Tolerance: 98% of points in agreement to 2% and 2 mm compare with reference uninterrupted delivery
Sample 4: End-to-End Tests

- Dosimetry and positioning verification from simulation to delivery for phantoms
- End-to-end test for benchmark cases (for example, test cases from AAPM Task Group 119)
- Perform patient-specific QA measurements prior to the start of treatment and for any plan change
- Tolerance: 95% of points in agreement to 4% and 4 mm. Other tolerances may be accepted if there is a reasonable justification

Commissioning (COM)

- Validate that VMAT is capable of delivering radiation beams as good as IMRT could
- Understand the limits of planning optimization, gantry rotation, beam blocking, couch rotation, and leaf speed, collimator settings
- Develop treatment process and guidelines
Sample VMAT COM: Using Benchmark Data

Compare IMRT vs VMAT with TG 119 Test Set

- Treatment Planning System – Pinnacle
- Measurement Phantom - (“cheese phantom,” TomoTherapy)
- Delivery System - Elekta Infinity System


<table>
<thead>
<tr>
<th>Parameter</th>
<th>Plan (cGy)</th>
<th>TG-119</th>
<th>This work</th>
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<tbody>
<tr>
<td>Central target D90</td>
<td>&gt;5000</td>
<td>4955</td>
<td>162</td>
</tr>
<tr>
<td>Central target D10</td>
<td>&lt;5300</td>
<td>5455</td>
<td>173</td>
</tr>
<tr>
<td>Superior target D90</td>
<td>&lt;2500</td>
<td>2516</td>
<td>85</td>
</tr>
<tr>
<td>Superior target D23</td>
<td>&lt;2500</td>
<td>3412</td>
<td>304</td>
</tr>
<tr>
<td>Inferior target D90</td>
<td>&gt;1250</td>
<td>1407</td>
<td>185</td>
</tr>
<tr>
<td>Inferior target D10</td>
<td>&lt;2500</td>
<td>2418</td>
<td>272</td>
</tr>
<tr>
<td>Prostate D90</td>
<td>&gt;7500</td>
<td>7566</td>
<td>21</td>
</tr>
<tr>
<td>Prostate D2</td>
<td>&lt;8300</td>
<td>8143</td>
<td>156</td>
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<tr>
<td>Rectum D90</td>
<td>&lt;7000</td>
<td>6536</td>
<td>297</td>
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<tr>
<td>Rectum D10</td>
<td>&lt;7500</td>
<td>7303</td>
<td>150</td>
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<tr>
<td>Bladder D90</td>
<td>&lt;7000</td>
<td>4394</td>
<td>878</td>
</tr>
<tr>
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<td>&lt;7500</td>
<td>6269</td>
<td>815</td>
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<tr>
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<td>&gt;5000</td>
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<td>58</td>
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<tr>
<td>PTV D20</td>
<td>&gt;4650</td>
<td>4704</td>
<td>32</td>
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<tr>
<td>PTV D23</td>
<td>&lt;5500</td>
<td>5399</td>
<td>93</td>
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<tr>
<td>Cord maximum</td>
<td>&lt;4000</td>
<td>3741</td>
<td>250</td>
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<tr>
<td>Left parotid D90</td>
<td>&lt;=2000</td>
<td>1798</td>
<td>184</td>
</tr>
<tr>
<td>Right parotid D90</td>
<td>&lt;=2000</td>
<td>1798</td>
<td>184</td>
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<tr>
<td>PTV D50</td>
<td>&gt;5000</td>
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<td>17</td>
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<tr>
<td>PTV D20</td>
<td>&lt;5500</td>
<td>5440</td>
<td>52</td>
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<tr>
<td>Core D10</td>
<td>&lt;2500</td>
<td>2200</td>
<td>314</td>
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### Point Measurements

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<tr>
<th>Location</th>
<th>IMRT</th>
<th>VMAT</th>
<th>% diff</th>
<th>% diff</th>
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<tbody>
<tr>
<td></td>
<td>TPS dose (cGy)</td>
<td>% diff</td>
<td>TPS dose (cGy)</td>
<td>% diff</td>
</tr>
<tr>
<td></td>
<td>Multitarget</td>
<td>Prostate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Central target</td>
<td>214.7</td>
<td>184.0</td>
<td>-0.40 ± 0.06</td>
<td>218.4</td>
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<tr>
<td>Superior target</td>
<td>119.6</td>
<td>137.4</td>
<td>-0.55 ± 0.19</td>
<td>108.1</td>
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<tr>
<td>Inferior target</td>
<td>65.4</td>
<td>136.4</td>
<td>-2.82 ± 0.10</td>
<td>56.0</td>
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<tr>
<td>PTV</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rectum</td>
<td></td>
<td></td>
<td>-0.75 ± 0.06</td>
<td>185.4</td>
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<tr>
<td>Bladder</td>
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<td></td>
<td>-1.66 ± 0.13</td>
<td>146.8</td>
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<tr>
<td>PTV</td>
<td></td>
<td></td>
<td>-2.85 ± 0.00</td>
<td>206.5</td>
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<td>Spinal cord</td>
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<td></td>
<td>-1.42 ± 0.30</td>
<td>135.8</td>
</tr>
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<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>C-shape</td>
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<tr>
<td>Central core</td>
<td>54.9</td>
<td>45.9</td>
<td>0.87 ± 0.07</td>
<td>48.1</td>
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<tr>
<td>Outer target</td>
<td>208.4</td>
<td>207.5</td>
<td>1.82 ± 0.06</td>
<td>207.5</td>
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<tr>
<td>Average</td>
<td></td>
<td></td>
<td>-0.82 ± 0.48</td>
<td>...</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td>1.45 ± 0.37</td>
<td>...</td>
</tr>
</tbody>
</table>

### Film Measurements

<table>
<thead>
<tr>
<th>Film plane</th>
<th>% points with $y^{&gt;3.3,\text{mm}} &lt; 1$</th>
<th>% points with $y^{&gt;2.2,\text{mm}} &lt; 1$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IMRT</td>
<td>VMAT</td>
</tr>
<tr>
<td>Coronal</td>
<td>99.2 ± 0.3</td>
<td>Multitarget</td>
</tr>
<tr>
<td>Sagittal</td>
<td>98.7 ± 0.3</td>
<td>Prostate</td>
</tr>
<tr>
<td>Coronal</td>
<td>100 ± 0.0</td>
<td>100 ± 0.0</td>
</tr>
<tr>
<td>Sagittal</td>
<td>98.9 ± 0.2</td>
<td>100 ± 0.0</td>
</tr>
<tr>
<td>Coronal</td>
<td>99.1 ± 0.1</td>
<td>97.7 ± 0.2</td>
</tr>
<tr>
<td>Sagittal</td>
<td>96.5 ± 0.3</td>
<td>98.3 ± 0.1</td>
</tr>
<tr>
<td>Coronal</td>
<td>99.3 ± 0.2</td>
<td>99.9 ± 0.0</td>
</tr>
<tr>
<td>Sagittal</td>
<td>99.3 ± 0.2</td>
<td>98.6 ± 0.5</td>
</tr>
<tr>
<td>Average</td>
<td>98.9 ± 0.4</td>
<td>99.1 ± 0.3</td>
</tr>
</tbody>
</table>
SAM Question 3

For ion chamber measurements, a reasonable confidence limit that should be adopted for VMAT QA should be

a. 1%
b. 3%
c. 5%
d. 4%
e. 7%

SAM Answer 3

1. For ion chamber measurements, a reasonable confidence limit that should be adopted for VMAT QA should be

a) 1%
b) 3%
c) 5%
d) 4%
e) 7%

Answer: b

Feedback:
Confidence limit for VMAT is calculated from the local measurements with average and standard deviation.

Reference:
Quality Assurance (QA)

• The QA program for the VMAT is similar to conventional IMRT in principle but with different measurements due to its dynamic nature during VMAT delivery

• The QA program is to validate the functionality and performance of the accepted features

• The QA program includes
  o Machine specific QA
  o Patient specific QA

Machine Specific QA

• Accuracy of the MLC leaf positions during VMAT delivery

• Ability of the system to accurately vary the dose rate and gantry speed during VMAT delivery

• Ability of the system to accurately vary the MLC leaf speed during VMAT delivery

• Tolerances: Baselines from commissioning
Machine Specific QA

• Daily - TG-142 plus VMAT specifics
  o Rotational delivery of dose to phantom (optional)

• Monthly: TG-142 plus VMAT specifics
  a. End-to-end test for a patient-specific QA

• Annually – TG 142 plus VMAT specifics
  a. MLC leaf positioning accuracy during rotation
  b. MLC dosimetry test with changing gantry speed and dose rate
  c. MLC dosimetry test with changing leaf speed during rotation
  d. Interruption/resumption test

• Criteria: baselines from commissioning

Patient Specific QA- Method

• Hybrid QA technique
  o Plan to phantom
  o Dose measurement to phantom
  o Performed prior to treatment

• Rotational nature
  o Not limited to a single plane

• Instruments
  o Ion chamber
  o 2/3-D array/matrix (ion chamber, diodes, portal dosimeter, film,...)
Patient Specific QA - Method

• Phantom (hardware)
  o Solid water
  o Special phantom

• Data analysis (software)
  o Multiple planes (axial, coronal, sagittal)
  o Profiles
  o Points
  o Gamma analysis
  o Tolerances: from commissioning results

• Collision check
  o Before patient on the couch
  o When patient on the couch

---

Ion Chamber vs. Eclipse

Median difference 1.2% (0.6% to +3.3%)

Ion Chamber Array vs. Eclipse

39 VMAT plans

Film vs. Eclipse

8 VMAT plans

• VMAT planned in Oncentra Master Plan for a HN case
• Delivered on an Elekta Synergy S Linac
Effective vs. Efficient

- Stage 1: Intensive QA
  - Ion chamber, film in 3 planes, ion chamber array in 2 planes, 3D polymer gel dosimetry

- Stage 2: Rigorous QA
  - Ion chamber, ion chamber array in 2 planes

- Stage 3: Effective and Efficient QA
  - Ion chamber, ion chamber array in 1 plane
  - Ion chamber array only


### Effective vs. Efficient

<table>
<thead>
<tr>
<th>Method</th>
<th>Preparation</th>
<th>Delivery</th>
<th>Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ion chamber: first</td>
<td>15</td>
<td>15</td>
<td>5</td>
</tr>
<tr>
<td>Film: first</td>
<td>15</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Ion chamber array: first</td>
<td>15</td>
<td>15</td>
<td>5</td>
</tr>
<tr>
<td>Ion chamber: additional</td>
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<td>7</td>
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<tr>
<td>Film: additional</td>
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<tr>
<td>Ion chamber array: additional</td>
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<td>7</td>
<td>5</td>
</tr>
<tr>
<td>IC + 2 film + 2 ICA</td>
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<td>67</td>
<td>45</td>
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<tr>
<td>IC + 2 ICA</td>
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<tr>
<td>IC + ICA</td>
<td>30</td>
<td>30</td>
<td>10</td>
</tr>
</tbody>
</table>

Approximate time required (minutes) for a well trained QA operator to complete ion chamber, film, and ion chamber array QA

Topics in This Presentation

• Fundamentals for VMAT
• Acceptance testing/commissioning
• Quality Assurance
  o Machine specific QA
  o Patient specific QA

• Challenges

Challenges of VMAT: QA

QA time is longer for physicist:
• Integrated QA devices
  – New 3D dosimeter for absolute dose measurement
• Real-time dose monitoring
• Selectively use of the technology
Challenges of VMAT: Motion

Organ and patient motion could cause unexpected dose deviations:

- Simultaneous imaging and delivery
- Real-time 4D imaging for target verification
- Interplay effect
- Breath-hold technique

Conclusion

- VMAT is one format of rotational IMRT for dose painting
- Implementation of VMAT requires careful planning, testing, and verifications
- Thoroughly testing and commissioning are necessary prior to patient treatment
- QA is critical, always compare with static field IMRT plan in the early phase
- VMAT should be judged by its accuracy, safety, efficiency, applicability, integration, and adaptation
Thank you for your attention