RapidArc Quality Assurance at Addington Hospital

By

Sekai Shambira
Introduction

RapidArc is a technique that delivers IMRT quality dose distribution in single or more arcs through dMLC, optimisation of arc delivery parameters, variable gantry speed & angle
Introduction cont’d

Such complex treatment requires routine comprehensive QA procedures which must address the reliability & accuracy of these variables.

- **Patient-related QA** - Verification and checking of plan parameters for correctness (like in 3DCRT, IMRT) and
- and **Machine-related QA**
Patient-related QA: Verification

• To verify is to check the truth or accuracy of something (new Oxford international dictionary, 7th Edition)

• In Radiotherapy, it is being used to independently check the dose delivery accuracy

• 3DCRT-IVDs,

• RapidArc/IMRT – Phantoms like Delta4, MatrixX, Mapcheck, …
Phantoms *used for verification at Addington Hospital*

Delta4

MatrixX inserted in the MultiCube phantom
Phantom design

Delta4

MatrixX and Multi Cube

Total no. of chambers: 1020
Resolution: 7.6 mm, interpolated to 1 mm
Fast readout: 20 ms
Active area: 24.3 x 24.3 cm²
Single pixel: Ø = 4.5 x 5 mm², volume 0.07 cm³
Fully integrated in OmniPro-I'mRT software
Verification methodology

- A verification plan is created from the original plan,
- Exported to the Delta4/Omnipro ImRT software,
- Scheduled for treatment,
- The phantom is “treated” and
- The dose is then measured and compared with the imported planned dose
Verification plans *(samples)*

Delta4

MatrixX
Gamma evaluation method

- Used for results analysis (designed for comparison of two different dose distributions, e.g. planned to measured doses).
The calculated dose distribution surface intersects with the ellipsoid representing the acceptance criterion. For each measurement point, the minimum (Gamma index, y) of all \( \Gamma(r_m, r_c) \) for all \( r_c \) is calculated.

\[ \Gamma(r_m, r_c) = \sqrt{\frac{r^2 (r_m, r_c)}{\Delta d_{\text{Acc}}^2} + \frac{\Delta D^2 (r_m, r_c)}{\Delta d_{\text{Acc}}^2}} \]

- \( D_c \): Calculated dose (i.e. planned dose) in position \( r_c \)
- \( D_m \): Measured dose in position \( r_m \)
- \( r = r_m - r_c \)
- \( \Delta D = D_m - D_c \)
- \( \Delta d_{\text{Acc}} \): Acceptable dose difference
- \( \Delta d_{\text{Acc}} \): Acceptable spatial deviation
Verification Results
(sample results for Delta4)

- At Addington, the pass fail criteria adopted is such that the Gamma index calculation uses $\text{DTA}=3\text{ mm}$ and Dose Difference=$3\%$
- A plan passes if $\geq 90\%$ of all the detectors in the phantom have a Gamma Index $\leq 1.0$
Verification Results
(sample for MatrixX)

Results more visual,
Statistical results: valid/invalid Gamma, Gamma digital, DTA, DD, correlation coefficient..

- 95.9% have $\gamma \leq 1.02$
- Corr coeff = 0.9965
Comparison of gamma index (Delta4 & MatrixX) for 10 patients

- Plans that fail: re-planning,
- Possible failure causes: gamma index method (regions of steep dose gradients), overmodulation for certain angles/cases.
- Solution: Compass...
Machine Related QA

- Linac integrity should be maintained in an expected standard for optimal RA delivery.

- Crucial for RA QA (Standard Linac QA procedures):
  - static vs arc dosimetry
  - accuracy in dMLC position,
  - ability to precisely vary dose rate & gantry speed during arc rotation and
  - accurate control of gantry speed

- Effective RA QA requires a recording system that rotates with the gantry (e.g. radiochromic film or an EPID device (used at Addington).
- Varian Dicom files used for RA Machine QA procedures
Methodology & Results:

Test 1. Gantry position/angle verification with display indicators

- 0, 90, 180 and 270° gantry angle,
- Tolerance 0.5°

<table>
<thead>
<tr>
<th>Gantry angle (rotation)</th>
<th>0°</th>
<th>90°</th>
<th>180°</th>
<th>270°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gantry angle (display)</td>
<td>0°</td>
<td>90°</td>
<td>180°</td>
<td>270°</td>
</tr>
<tr>
<td>Difference</td>
<td>0°</td>
<td>0°</td>
<td>0°</td>
<td>0°</td>
</tr>
</tbody>
</table>
Methodology: Test 2. Static Vs Arc Dosimetry

To verify consistency and stability of beam output for arc beams, dose output measurements are done at isocenter using an ion chamber with build-up cap for:

- Two static fields,
  - Field 1: 180° gantry angle, 72MU
  - Field 2: 180° angle, 900MU

- Two Arc fields,
  - Arc 1: 0-180° arc (half), 72MU
  - Arc 2: 179-181° arc (full), 900MU

% difference between corresponding static and Arc fields is calculated, acceptable tolerance is 2%
Methodology: Tests 3-8

The following tests are done using Varian dicom files:

- **Test 03**: dMLC Dosimetry
- **Test 04**: Picket fence test vs. gantry angle
- **Test 05**: Picket fence test during RapidArc
- **Test 06**: Picket fence test during RapidArc with intentional errors
- **Test 07**: Accurate control of leaf speed during RapidArc
- **Test 08**: Accurate control of Dose rate and gantry speed during RapidArc

Profiles across the acquired images are used for analysis.
Results and discussion:
Test 2. Static Vs Arc Dosimetry
Linac1

<table>
<thead>
<tr>
<th></th>
<th>72MU</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Static/cGy</td>
<td>RA/cGy</td>
<td>Dev from Static,%</td>
<td>Static/Gy</td>
</tr>
<tr>
<td>687.6</td>
<td>682.6</td>
<td>0.73</td>
<td>8.593</td>
</tr>
<tr>
<td>688.5</td>
<td>683.2</td>
<td>0.77</td>
<td>8.599</td>
</tr>
<tr>
<td>686.6</td>
<td>681.5</td>
<td>0.74</td>
<td>8.581</td>
</tr>
<tr>
<td>686.9</td>
<td>680.7</td>
<td>0.90</td>
<td>8.58</td>
</tr>
<tr>
<td>685.4</td>
<td>679.4</td>
<td>0.88</td>
<td>8.564</td>
</tr>
</tbody>
</table>

Dev from Static : 0.80
## Results and discussion:

**Test 2. Static Vs Arc Dosimetry**

**Linac2**

<table>
<thead>
<tr>
<th>Static/cGy</th>
<th>RA/cGy</th>
<th>Dev from Static, %</th>
<th>Static/Gy</th>
<th>RA/Gy</th>
<th>Dev from Static, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>699.3</td>
<td>691.2</td>
<td>1.16</td>
<td>8.779</td>
<td>8.625</td>
<td>1.75</td>
</tr>
<tr>
<td>697.4</td>
<td>691.5</td>
<td>0.85</td>
<td>8.726</td>
<td>8.633</td>
<td>1.07</td>
</tr>
<tr>
<td>698.2</td>
<td>691.6</td>
<td>0.95</td>
<td>8.725</td>
<td>8.635</td>
<td>1.03</td>
</tr>
<tr>
<td>697.9</td>
<td>691.7</td>
<td>0.89</td>
<td>8.724</td>
<td>8.636</td>
<td>1.01</td>
</tr>
<tr>
<td>697.6</td>
<td>692.4</td>
<td>0.75</td>
<td>8.726</td>
<td>8.634</td>
<td>1.05</td>
</tr>
<tr>
<td><strong>0.92</strong></td>
<td></td>
<td></td>
<td><strong>8.726</strong></td>
<td><strong>8.634</strong></td>
<td><strong>1.05</strong></td>
</tr>
</tbody>
</table>

**72MU**

**900MU**
Results: Test 3. dMLC dosimetry

<table>
<thead>
<tr>
<th>Gantry Angle</th>
<th>180</th>
<th>90</th>
<th>0</th>
<th>270</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Deviation from Ref value</td>
<td>0.58</td>
<td>0.21</td>
<td>0.24</td>
<td>0.16</td>
</tr>
</tbody>
</table>

Dose delivery is consistent & stable in dMLC mode at different angles
Results and discussion:
Test 4. Picket fence test vs. gantry angle

- Picket fences for all the gantry angles appear linear, uniform, well aligned & have consistent widths
- The dMLC performance is stable regardless of gantry angle
- The test result is acceptable
Results and discussion:

Test 5: Picket fence during RapidArc

Acceptable dMLC performance in RA mode
Results and discussion:
Test 6: Picket fence test during RapidArc with intentional error

Test sensitivity acceptable …
Results and discussion:

Test 7: Accurate control of leaf speed during RapidArc

Deviation from ref value (%)

-1.22
-0.31
1.14
0.51

Dose output is consistent despite the use of different combinations of MLC speed & dose rate
Results and discussion:

Test 8: Accurate control of dose rate & gantry speed during RA

Deviation from ref value (%)

1.12
0.26
-0.41
-0.52
-0.61
-0.39

machine can vary DR & GS during RA to achieve specified values
Appendix A: RA monthly QA worksheet sample (Addington Hospital)

<table>
<thead>
<tr>
<th>Test (1.4)</th>
<th>Gantry angle calibration</th>
<th>Test (1.5)</th>
<th>Pickoff fence test at Gantry angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gantry Angle</td>
<td>Measured Angle</td>
<td>Difference</td>
<td>Gantry Angle</td>
</tr>
<tr>
<td>$0.5^\circ$</td>
<td>0</td>
<td>0</td>
<td>0.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Test (1.2)</th>
<th>Inter-leaf separation calibration</th>
<th>Test (1.3)</th>
<th>Arc Dosimetry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Verify inter-leaf separation for gantry and MLC rotation using leaded Collimator Phantom</td>
<td>Inter-leaf separation within 1mm (Y/N)</td>
<td>Fixed field chamber with buildup cap at the leaded Collimator</td>
<td></td>
</tr>
<tr>
<td>$1\text{mm}$</td>
<td>$Y$</td>
<td>$Y$</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Test (1.4)</th>
<th>dMLC Dosimetry</th>
<th>Test (1.5)</th>
<th>Pickoff fence test at Gantry angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gantry Angle</td>
<td>Measured reading (Cl. Nc. etc)</td>
<td>Difference from the mean (%)</td>
<td>Gantry Angle</td>
</tr>
<tr>
<td>$2%$</td>
<td>0.100</td>
<td>0.010</td>
<td>0.010</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Test (1.6)</th>
<th>Pinhole exposure test during RapidArc</th>
<th>Test (1.7)</th>
<th>Pinhole exposure test during RapidArc with deliberate errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gantry Angle</td>
<td>Junctional slice from gantry position (Y/N)</td>
<td>Junctional slice from gantry position (Y/N)</td>
<td>Junctional slice from gantry position (Y/N)</td>
</tr>
<tr>
<td>$1\text{mm}$</td>
<td>$Y$</td>
<td>$Y$</td>
<td>$Y$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Test (1.8)</th>
<th>Pinhole exposure test during RapidArc with deliberate errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gantry Angle</td>
<td>Junctional slice from gantry position (Y/N)</td>
</tr>
<tr>
<td>$2\text{mm}$</td>
<td>$Y$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Test (1.9)</th>
<th>Accurate control of gantry angle during RapidArc delivery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exposion (mm)</td>
<td>Exposure (Cl)</td>
</tr>
<tr>
<td>$3%$</td>
<td>0.400</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Test (1.10)</th>
<th>Accurate control of gantry speed during RapidArc delivery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exposion (mm)</td>
<td>Exposure (Cl)</td>
</tr>
<tr>
<td>$2%$</td>
<td>0.200</td>
</tr>
</tbody>
</table>
Conclusion

• A perfectly-looking plan, with perfect DVH and all does not guarantee the administration of the intended dose. Verify!

• The picket fence test has been successfully adopted for use in RA at Addington Hospital together with the standard Linac tests

• A comprehensive RapidArc QA system is a prerequisite for the accurate delivery of optimal treatment and its successful implementation is vital
THANK YOU
Appendix B: Comparison between 3D CRT & RapidArc
Acknowledgements

- Fellow members of the Addington Hospital Radiation Oncology Medical Physics team:
  Graeme Lazarus and Thuso Ramaloko
References

• Report from the feasibility testing of MatriXX device for RapidArc QA; Bocanek, J. 2008.
• Commissioning and QA of RapidArc delivery system, Ling et al, 2008
• QA of OMRT and RapidArc: An Overview; Fog, L.S. 2011
• Dosimetry validation of Volumetric Modulation Arc Therapy by using MatrixX in MultiCube Phantom, Yeh, C. 2008
• Varian RapidArc Manuals
• Epiqa Rapid Arc Commissioning Tests
• Delta4 and MatrixxX, OmniPro iMRT User Manuals