Clinical Implementation of Volumetric Modulated Arc Therapy

UT M.D. Anderson Cancer Center

Ramaswamy Sadagopan, Rebecca M. Howell, Weiliang Du and Peter Balter
Definition

- Intensity Modulated Arc therapy where the following three parameters are modulated simultaneously:
  - Gantry rotation
  - Dose rate
  - Leaf speed.
Overview

- Advantages of Modulated Arc Therapy
- Configuring the Accelerator / R & V system
- Treatment Planning System commissioning
- Patient specific QA (film and ion-chamber)
- RPC phantom and partial treatments verifications
- Routine QA (output @ dose rates, DMLC QA, linearity check at several dose rates, constancy check)
Advantages of modulated arc treatment - Varian Demo Plan

**IMRT Treatment plan**
- 1147 MU & 5.5 min
- 3D dose max = 108.8%

**RapidArc Plan**
- 804 MU & 1.5 min
- 3D dose max = 114.7%

[Link to Varian Demo Plan](http://www.varian.com/us/oncology/treatments/treatment_techniques/rapidarc/comparsion.html)
Advantages of modulated arc treatment

- Speed of delivery (MLC travel optimized, ref)
- Less MU, less secondary dose to normal tissue and hence low probability for secondary cancer (Aperture based optimization, ref)
- Potential for improved optimization due to increased number of beam directions
- Less wear on MLC
Configuring the Accelerator

Prerequisites:

- On-Board Imager kV Imaging System (OBI) with OBI Advanced Imaging Software
- Millennium 120 MLC or High Definition MLC (HDMLC) with dynamic MLC option
- ARIA Oncology Information System v8.5 or later, or RapidArc-compatible, 4DITC-compatible 3rd party information system
- Eclipse Treatment Planning with RapidArc treatment planning software license.
- 4D-ITC
Configuring the Accelerator

- Need clutch less system for gantry rotation, dual read outs for gantry angle (CBCT include these) and a stronger chain for the drive.
- 4DTC software version 8 (Enable the rapid arc treatment on the console under Treatment Administration software)
- Clinac software v7.8
- Enable the Dynalog files if needed.
Configuring Accelerator contd

- Clinac software v7.8

The software described in this Customer Release Note is compatible with the following system components:

- MLC 6.8 and above
- 4DITC 8.0 and above
## New Features and Enhancements

<table>
<thead>
<tr>
<th>Application</th>
<th>New Main Features</th>
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</table>
| **RapidArc Treatment Delivery** | - C-Series 7.8 supports the RapidArc treatment delivery capability when used with the Millennium MLC and the 4D Integrated Treatment Console, “4DITC”.  
- C-Series 7.8 now supports the upload of individual control points within the treatment plan for a gantry arc from 4DITC. This new treatment type is called “RapidArc X”.  
- Up to 180 individual control points (dose relative to gantry position) are allowed. The result of this individual control point weighting is variable MU per degree and variable gantry speed.  
- The minimum MU per degree on any given control point can be as low as 0.1. Dose-less segments are also allowed.  
- The maximum MU per degree is 20 for standard photon energies and 60 for the 6MV SRS beam.  
- DPSN interlock response has been changed to support RapidArc dynamic delivery.  
- The Clinac Dynalogs are expanded to record RapidArc deliveries. Plan vs. actual values for dose and gantry position are recorded by the Dynalog. Standard deviation calculations are included. |

| RV Status codes              | Two additional status codes are now available.  
- 602: Upper and/or lower collimator axis out of range.  
- 605: Internal error while validating plan. |

| Software Upgrade Capability  | An upgrade to Version 7.8 software can be performed for previous C-Series Version 7 releases. |
Configuring R & V system

- Mosaiq v1.6001 or up
TPS Commissioning

- Eclipse V8.6 Commissioning (ready for clinical use)
  - Model photon beam (AAA, PBC, DVO, PRO)
  - Validation of Photon Models (5 depths 1.5 to 20 cm, FS 3 to 20 cm², agreement 1% in general)
  - HU vs Electron density calibration table
  - Dicom export/import setup
  - Machine and DMLC Setup
  - QA plan setup
  - IMRT QA verification
TPS Commissioning

- **RPC phantom verification**
- Dynalog files evaluation
- Dynamic MLC QA (necessary for “sliding window” IMRT)
- Constancy verification of RapidArc plan using monthly QA Setup
- Treatment planning strategies

Pinnacle in Progress
### MLC Configuration Properties

#### General
- **ID**: Millennium_120
- **Manufacturer**: Varian Medical Systems
- **Model**: Millennium 120
- **Serial No.**: 4381
- **Rotation**: 0.0 deg

#### Leaf
- **Minimum Dose Dynamic Leaf Gap**: 0.0500 cm
- **Minimum Arc Dynamic Leaf Gap**: 0.0500 cm
- **Minimum Static Leaf Gap**: 0.0500 cm
- **Maximum Leaf Speed**: 2.50 cm/s
- **Dose Dynamic Leaf Tolerance**: 0.200 cm
- **Arc Dynamic Leaf Tolerance**: 0.500 cm

- **Arc Enabled**: Yes
- **Dose Enabled**: Yes

**Details**
TPS Commissioning

![Dosimetric Data Table]

- **Machine**: Varian 2110
- **Energy**: 6X

<table>
<thead>
<tr>
<th>Material</th>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>MLC</td>
<td>Transmission Factor</td>
<td>0.015000</td>
</tr>
<tr>
<td>MLC</td>
<td>Dosimetric Leaf Gap [cm]</td>
<td>0.200000</td>
</tr>
<tr>
<td>BL1</td>
<td>Transmission Factor</td>
<td>0.030000</td>
</tr>
<tr>
<td>Block Tray</td>
<td>Transmission Factor</td>
<td>0.970000</td>
</tr>
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</table>
Recommended SmartArc Physics Parameters

The following should be used as guidelines for machine configuration. If specific recommendations conflict with information provided by your manufacturer, then the values should be adjusted accordingly.

1 Varian linear accelerators
   1.1 Physics: Gantry Tab
      1.1.1 Arc rotation direction
         Specify CW and CCW if you will be using
   1.2 Physics: Delivery Tab
      1.2.1 Maximum gantry rotation speed (deg./
         If you are using ARIA for your record an
         or the value that is configured in Aria. It
         used in ARIA. If you are using Mosaiq, e
      1.2.2 Maximum jaw speed (cm/sec)
         This parameter is not used.
      1.2.3 Maximum MLC leaf speed (cm/sec)
         Enter the correct maximum leaf speed, T
         The value must not exceed the one ent
      1.2.4 Dynamic Arc (Yes/No)

Varian Volumetric Modulated Arc Therapy (VVMAT) description
document for vendors of Radiotherapy Treatment Planning Systems

Description Document
June 2009
Pinnacle Machine Commissioning

This is a test machine!!!
Patient Specific QA
Film and Ion Chamber QA

- Film and Ion Chamber QA analogous to MDA IMRT QA procedure:
  - Create verification plan in Eclipse for OmniPro phantom.
  - Deliver dose to phantom.
  - Compare measured and calculated ion chamber dose and film dose.

![Diagram showing film placement and isocenter at Z=2.0 cm]

Bars away from beams
Patient Specific QA Ion Chamber/Film Results

- Absolute dose agreed within 1%.

- > 99% of film pixels had gamma ≤ 1.0 (3% and 3mm).

### Absolute Dosimetry Results - Ion Chamber Data

<table>
<thead>
<tr>
<th>Field (MV)</th>
<th>Couch</th>
<th>Coll</th>
<th>Gantry</th>
<th>MU</th>
<th>Ion Chamber Readings (nC)</th>
<th>Dose (cGy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6</td>
<td>0</td>
<td>45</td>
<td>792</td>
<td>3.796</td>
<td>330.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Total Measured</td>
<td>330.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Calculated Dose</td>
<td>328.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>% diff</td>
<td>0.9%</td>
</tr>
</tbody>
</table>

The ratio of the measured to calculated dose is between 0.95 and 1.05, monitor units do not need adjustment.

### Relative Dosimetry Results - Film Data

- a. Eclipse Dose Plane
- b. Measured Film Dose
- c. Film Gamma
- d. Isodose Overlay

Total number of pixels: 78400
Deviation: 0.15
- Pixels in Ranges:
  - 0.00 to 0.75: 78253 (99.81%)
  - 0.75 to 0.87: 147 (0.19%)
If an interlock is asserted during treatment, follow normal procedures to clear interlock.
- If able to clear interlock, treatment will resume from point where interlock asserted.

Interlock will not affect the accuracy of dose delivered to the patient.
- Tested by inserting interlock during treatment of QA phantom and then resuming treatment.
- Film and ion chamber data were analyzed.
  - Absolute measured dose agreed with plan dose within 1%.
  - The film analysis: >99% of the pixels had a gamma ≤ 1
Dose delivered to the isocenter is still accurate, even if beam is interrupted multiple times as in gated delivery.

- Tested by turning beam off repeatedly 15 times during delivery to the QA phantom and comparing ion chamber reading obtained from uninterrupted delivery. Results are within 0.2%.
Partial Treatments

- If interlock can not be cleared and have true partial treatment, the partially treated plan can be reconstructed in Eclipse to assess the dosimetric impact.

- QA was performed on the “partially” delivered plan.
  
  Results were comparable to full treatment delivery.

In this example, the treatment was stopped after delivery of 400 MU. Gantry end angle is 0.0. The Gantry end angle can be compared to stop angle during treatment delivery.

Eclipse calculation for one fraction partial arc 0 to 400 MU.
Monthly QA - Constancy Verification of RapidArc Delivery

1. Created verification plan of prostate plan using CT data set of the monthly QA phantom.

2. Determined dose to ion chamber (from Eclipse DVH).

3. Delivered RA plan to phantom, measure dose, and compare measured and calculated doses.

This will be measured on monthly basis as routine QA.
As part of commissioning, we delivered treatment 3X, and reviewed dynalog files.

- Maximum leaf position deviation for all 3 runs was in the range of 1mm to < 1.5 mm.
  - The maximum deviation occurred for less than 3% of the leaf positions for all 3 deliveries.
  - Negligible dosimetric effect.

- Recommend dynalog file analysis 3X during a patient’s course of treatment.
### Linearity Check and Calibration

- Monitor chamber linearity need to be verified at all available dose rates. (annual)
- Output calibration need to be verified at all available dose rates. (monthly)

<table>
<thead>
<tr>
<th>MU</th>
<th>Ratio normalized to 200 MU @ 400 MU/min</th>
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<tbody>
<tr>
<td></td>
<td>100 MU/min</td>
</tr>
<tr>
<td>5</td>
<td>1.011</td>
</tr>
<tr>
<td>10</td>
<td>1.008</td>
</tr>
<tr>
<td>25</td>
<td>1.005</td>
</tr>
<tr>
<td>50</td>
<td>1.004</td>
</tr>
<tr>
<td>100</td>
<td>1.003</td>
</tr>
<tr>
<td>200</td>
<td>1.003</td>
</tr>
<tr>
<td>400</td>
<td>1.004</td>
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DMLC QA – picket fence test

Arc+fixed

Arc only
DMLC QA – gantry speed & dose rate
RapidArc Prostate Treatment Planning Tips
MDA IMRT Treatment Plan
8 Beam Technique
M.D. Anderson IMRT Treatment Plan

- In addition to DVH constraints, plan should minimize high isodose lines that bisect the rectum.

- The 30 Gy line should be conformal and not cover the posterior wall of the rectum and at minimum at least 45 Gy should always split the rectum.
### MDA DVH Criteria for 76 Gy in 38 Fx

<table>
<thead>
<tr>
<th>Structure</th>
<th>V1 (%)</th>
<th>Condition</th>
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<tbody>
<tr>
<td>CTV</td>
<td>V100</td>
<td>≥ 76</td>
</tr>
<tr>
<td>PTV</td>
<td>V98%</td>
<td>≥ 76</td>
</tr>
<tr>
<td>Rectum</td>
<td>V60%</td>
<td>≤ 40</td>
</tr>
<tr>
<td>Rectum</td>
<td>V50%</td>
<td>≤ 45</td>
</tr>
<tr>
<td>Rectum</td>
<td>V40%</td>
<td>≤ 60</td>
</tr>
<tr>
<td>Rectum</td>
<td>V20%</td>
<td>≤ 70</td>
</tr>
<tr>
<td>Rectum</td>
<td>V15%</td>
<td>≤ 76</td>
</tr>
<tr>
<td>Rectum</td>
<td>V5%</td>
<td>≤ 78-80</td>
</tr>
<tr>
<td>Bladder</td>
<td>V20%</td>
<td>≤ 70</td>
</tr>
<tr>
<td>Femoral Heads</td>
<td>V50%</td>
<td>≤ 45</td>
</tr>
<tr>
<td>Femoral Heads</td>
<td>V10%</td>
<td>≤ 50</td>
</tr>
</tbody>
</table>
Rapid arc planning tips - prostate

- 360° (45 CA) rotation was not good even with NT objectives and avoidance structures
- Switched to 210 -150 (300 arc)
- Increased the number of avoidance structures in the posterior
- Increased to two arcs CW and CCW of 210-150
- Reduce dose to top and bottom most PTV slices by 5%.
Developing a “Comparable” RA Treatment 4\textsuperscript{th} Attempt

- 300° arc (collimator 45°), typical constraints for bladder, rectum, and femoral heads + \textbf{NT objectives and avoidance structures}.

want to improve the dose fall-off posteriorly.
Avoidance Structures 1 and 2

Avoidance Rings: very similar to rings used by GU service for IMRT treatment planning.

Ring 1: 1 cm expansion of PTV (remove PTV + 1 mm).
Ring 2: 3 cm expansion of PTV, (remove PTV +1 mm and ring 1).
Avoidance Structures:
- Overlap of rectum and ring 1.
- Overlap of rectum and ring 2.
Avoidance Structures 5 and 6

Expansions of Ring1+Rectum:

Posterior Avoidance 1 (small)
- 1.5 cm laterally
- 5 cm posteriorly

Posterior Avoidance 2 (large)
- 4.5 cm laterally
- 5 cm posteriorly
Best Results
Recall our first attempt plan:

And now our “best” result plan:
Planning PTVs

- In general, RA plans tend to be “hot” on the superior and inferior slices.
- Create Planning PTVs to cool down superior/inferior slices and maintain dose to rest of PTV.

**Treatment Planning PTVs**
- Planning PTV1 = Only the sup/inf slices of PTV
- Planning PTV2 = PTV – Planning PTV1

**Dose Criteria for Planning PTVs**
- 5% less dose to planning PTV 1

**Evaluation Criteria for Treatment Plan**
- Evaluate DVH for “original” PTV
Best Results

Fall-off distance between 70Gy and 40Gy isodose lines is 0.5cm.
### Acknowledgements

- Andrew Lee, M.D., Reviewed numerous treatment plans and helped develop the planning strategy.
- Physics Assistants:
  - Scott LaNeave, Jared Ohrt, and Luke Whittlesey, provided assistance with demonstration and training regarding the current IMRT QA protocol and OmniPro software.
- Jennifer Johnson, assisted with the Diamond calculation test.
Key references:


THANK YOU

Questions?