Volumetric Modulated Arc Therapy
- Clinical Implementation

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Outline

- Basics of VMAT and its recent development
- VMAT treatment planning
- VMAT commissioning and QA

History of VMAT

Intensity-modulated arc therapy with dynamic multileaf collimation: an alternative to tomotherapy

VMAT, formally known as Intensity Modulated Arc Therapy (IMAT), was first brought up by Dr. Cedric Yu in 1995.

IMAT

1995: Initial paper described the delivery technique and demonstrated feasibility.

Basics of IMAT

- IMAT is a rotational IMRT that can delivered using conventional linear accelerators with conventional MLC.
- Radiation is on while gantry is rotating with MLC leaves moving continuously.
- Intensity modulation is created by overlapping arcs.
IMAT Delivery

ARC 1
ARC 2
ARC 3

From Cedric Yu

IMAT: 1995-2007

- Over this time, the IMAT delivery technique largely withered on the vine.
- Linac manufacturers did not have control systems capable of delivering IMAT.
- No treatment planning system offered a robust inverse planning tool for IMAT.

IMAT: 2008-2010

- Elekta and Varian introduced control systems that are capable of delivering IMAT.
- Key innovation is that the dose rate, gantry speed, and MLC leaf positions can be changed dynamically during rotational beam delivery.
- The term VMAT has been adopted.
- The first robust commercial VMAT planning solutions were introduced.

Varian – The Single Arc Approach

- Varian’s initial RapidArc solution focused exclusively on single arc treatments.
- “RapidArc” requires a Varian linac, OBI, EPID, and Eclipse treatment planning.
- Single arc delivery times are typically 2 minutes or less.
Elekta introduces Elekta Infinity – a new system for faster, more precise treatment of cancer tumors

Elekta VMAT – Key Features

- One can simultaneously vary: gantry position, gantry speed, leaves of the multi-leaf collimator (MLC), back-up diaphragm, and dose rate
- Single or multiple arc delivery
- Coplanar or non-coplanar delivery
- Collimator rotation

Siemens – Cone Beam Therapy (CBT)

- Siemens has a VMAT delivery solution under development.
- Their approach is based on delivering bursts of radiation symmetrically about a series of discrete beam angles during gantry rotation.
- The beam is turned on and off during the gantry rotation with dose rates up to 32 MU/sec.

VMAT Treatment Planning

Commercial Planning Systems

- Elekta Ergo++®
- Elekta Monaco® VMAT
- Philips SmartArc®
- Eclipse RapidArc®
- Prowess® & Nucletron MasterPlan® (Work In Progress)

Elekta Ergo++
Anatomy based semi-inverse planning

- The shape of each segment within a VMAT arc is determined by the Beam’s Eye View (BEV) of targets and adjacent critical structures.
- After aperture shape is determined, the weight of each segment is optimized to achieve a desirable dose distribution.
**Elekta Monaco**

- Monaco is an IMRT planning system originally developed at the University of Tubingen.
- VMAT planning is a work in progress.
- An arc sequencer was used to convert the optimized fluence maps into a single VMAT arc.
- Dose calculation uses Monte-Carlo dose engine.

**Elekta Monaco**

- PTV1 (60 Gy), PTV2 (57 Gy), and PTV3 (54 Gy).
**Philips SmartArc**

- SmartArc is an extension of the current DMPO functionality in Pinnacle.
- Designed to work with both Varian and Elekta.
- FDA 510(k) clearance was received in April 09
- Currently available clinically in Pinnacle® 9.0

**Prostate Example**

- 1 arc, 180 cGy/fraction
- 480 monitor units, 1.75 minutes

**H & N Example**

- 2 arcs, 512 monitor units
- 4 min, 7 sec, delivery time

**SmartArc**

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**Prostate Example**

- 1 arc, 180 cGy/fraction
- 480 monitor units, 1.75 minutes
Comparison of different inverse planning approaches

A Pancreas Case

Anatomy-based  
Fluence-based  
Aperture-based

A Pancreas Case

Thick Solid lines: Anatomy-based  
Thin Solid lines: Fluence-based  
Dashed lines: Aperture-based

A H&N Case

Which Planning System to Choose?

The anatomy-based Inverse planning is easy to plan and is capable of generating conformal dose distributions for simple cases. However, it may fail to provide a solution for more complex cases.

Both fluence-based and aperture-based inverse planning approaches can achieve comparable plan qualities for most of the clinical cases.

VMAT Commissioning and QA
Elekta VMAT Commissioning

**VMAT Commissioning tests**
- Beam flatness and symmetry
- MLC leaf calibration
- Sliding window dose
- Rotational accuracy
- Beam interruption and termination

**VMAT Machine Specific QA**
The three major variables during VMAT delivery
- MLC leaf position
- Gantry angle
- Dose rate

**The VMAT plan for machine QA**
The theoretical dose distribution calculated using convolution/superposition dose engines in Pinnacle. The calculation was done with 1° gantry spacing.

**How to check the variables**
- MLC leaf motion: The projection position of the tip for each MLC leaf on the MatrixXX device can be used to determine the MLC leaf motion accuracy.
- Gantry angle: The projection width of the 1cm gap between MLC leaves on the MatrixXX device can be used to determine the gantry angle.
- Dose rate: The absolute dose measured in the open area from each 0.1s sample can be used to determine the actual dose rate.

*J.L. Bedford and A.P. Warrington, Commissioning of Volumetric Modulated Arc Therapy (VMAT). IROBP 73 (2) pp. 537-545 (2009)*
The measurement result

The measurement was interpolated into 1 mm dose grid using cubic spline interpolation method. The sample time is 0.1 second.

QA Results

- The standard deviation of the gantry angle error is 1.0° with a maximum error of 2.6°.
- The standard deviation of the leaf position error is 1.1 mm with a maximum error of 3.1 mm in this case.
- The mean error of the dose rate is 2.7 MU/minutes or 3.2% in relative mode.

VMAT patient specific QA

VMAT plan QA methods

- Film & ion chamber.
- 2D diode array (Mapcheck in MapPhan phantom)
- 2D ion chamber array (MatriXX in MULTIcube phantom)
- Other 2D/3D diode system (Delta4 & ArcCheck)

Film & Ion Chamber

- A stack of solid water phantom with a total thickness of 15 cm.
- A 0.6 cc Farmer chamber was inserted at the depth of 10 cm.
- A film was sandwiched 1 cm above the ion chamber.

2D Diode Array

- A Mapcheck device inserted into a MapPhan solid water phantom
**2D ion Chamber Array**

- An IBA Matrix® 3D ion-chamber array inserted in a M. TICube phantom.

**Scandidos Delta®**

- A cylinder-shaped plastic phantom with 2 imbedded orthogonal crossing detector planes.
- 1069 diode detectors
- Dose is recorded in 2 planes and a 3D dose is reconstructed for comparison with the QA plan.

**Arc Check – Sun Nuclear**

- 1386 diode detectors arranged in cylindrical geometry
- Measures entrance and exit dose
- The QA can be done in composite or per control point

**A Head-&-Neck Case**

- A three-arc head & neck case with 498 MU to deliver 200 cGy per fraction
- The delivery time for this case is 5.6 minutes

**Film & Ion Chamber QA result**

- With 2% and 2mm criteria, the gamma analysis passing rate is 96.5%
- Dose threshold in gamma analysis is 10%

**MapCheck in MapPhan QA result**

- With 2% and 2mm criteria, the gamma analysis passing rate is 96.5%
- Dose threshold in gamma analysis is 10%
Dose Rate Dependency

- The variation of dose response with the dose rate can reach up to 2.5% for MapCheck diode.

Angular dose response of MapCheck diode

- Significant variation of the dose response can be found when the incidence beam angle is parallel to the detector plane.
- Each diode in MapCheck may have different angular dose response curve.

MatriXX QA results

- With 2% and 3% dose criteria, the passing rate is 96.2% for this central dose.
- No dose threshold was applied in gamma analysis. Note the passing rate reduces to 97.1% if a 10% threshold is applied.

ArcCheck QA result

- Gamma analysis passing rate is 95.2% for this case.

Summary

- VMAT has been introduced into daily clinic. As a rotational approach to IMRT, VMAT can provide highly conformal dose distributions with excellent delivery efficiency.
- Various commercial planning systems are available for VMAT planning. For relatively simple cases, all systems can provide high plan quality. However, the anatomy-based semi-inverse planning algorithm may fail to provide a clinical acceptable plan for more complicated head & neck cases.
- The gantry angle, MLC leaf position, and dose rate are three major variables during VMAT delivery that need to be checked as part of machine specific QA. Various systems can be used for VMAT patient-specific QA provided that users know the limits of each system.