Volumetric Modulated Arc Therapy - Clinical Implementation

Daliang Cao, PhD, DABR

Swedish Cancer Institute, Seattle, WA

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Outline

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

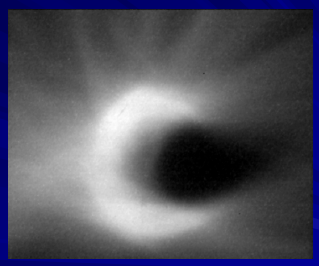
History of VMAT

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

C X Yu 1995 *Phys. Med. Biol.* **40** 1435-1449 doi:10.1088/0031-9155/40/9/004

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

IMAT

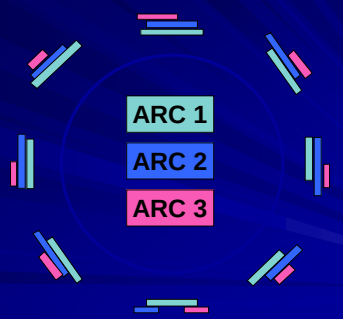


- 1995- Initial paper described the delivery technique and demonstrated feasibility.

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



From Cedric Yu

Benefit of Rotational IMRT

Number of Beam Directions	Objective Function Value	Standard Deviation In The Target Dose	Minimum Dose Covering 90% of the Target (1.0 = Max)	Mean Dose To the Region At Risk	Total Integral Dose
3	0.665	0.124	0.747	0.488	2533
5	0.318	0.090	0.814	0.215	2564
7	0.242	0.064	0.867	0.206	2597
9	0.222	0.064	0.855	0.192	2599
11	0.202	0.058	0.879	0.186	2570
15	0.187	0.053	0.908	0.180	2542
21	0.176	0.049	0.912	0.171	2543
33	0.151	0.038	0.933	0.155	2544

Improvement found by increasing the number of beam angles

Independent of the number of beam angles

D.M. Shepard, et al, *Medical Physics*, 26 pp. 1212 (1999); T.R. Mackie, et al, *Intensity Modulated Radiation Therapy – The State of the Art*, pp. 247 (2003)

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 tools 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.

Courtesy of Varian Medical

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 announces Elekta Infinity – a new System for Faster, more precise Treatment of Cancer Tumors

Stockholm, Sweden, October 29, 2007

Elekta, a global leader in radiation oncology and non-invasive neurosurgery solutions, announced Elekta Infinity™, the definitive new digital linear accelerator optimized for delivering Volumetric Intensity Modulated Arc Therapy® (VMAT), a very fast Intensity Modulated Radiation Therapy (IMRT) treatment delivered in single or multiple arcs, at the 49th Annual Meeting of The American Society for Therapeutic Radiology and Oncology (ASTRO). The meeting is being held October 28-November 1, at the Los Angeles Convention Center.

In the Elekta booth, Jay Hoey, Executive Vice President Product Creation at Elekta and CEO of IMPAC Medical Systems, announced the new Elekta Infinity, which more precisely targets tumors and protects surrounding healthy tissue, while drastically reducing radiation therapy treatment times.

The foundations of infinite possibility

ELEKTA

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.

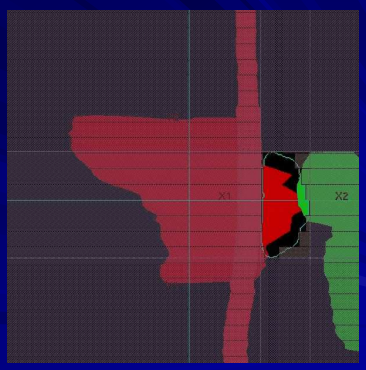
VMAT Treatment Planning

Commercial Planning Systems

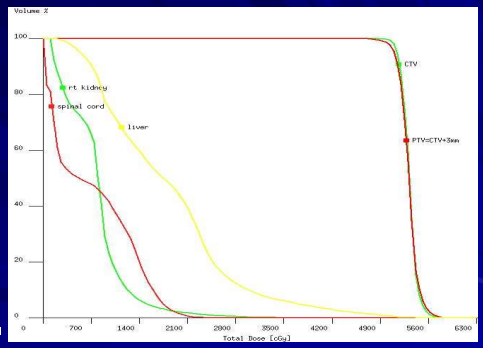
- Elekta Ergo++®
- Elekta Monaco® VMAT
- Philips SmartArc®
- Eclipse RapidArc®
- Prowess® & Nucletron MasterPlan® (Work In Progress)

Elekta Ergo++
Anatomy based semi-inverse planning

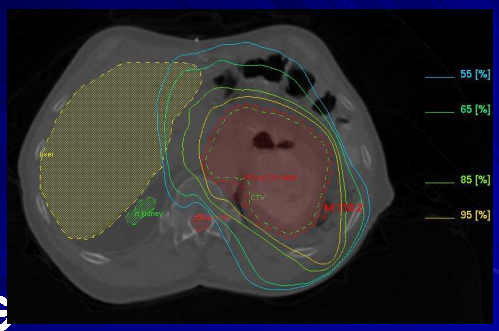
- The shape of each segment within a VMAT arc is determined by the Beam's Eye View (BEV) of targets and adjacent critical structures.
- After aperture shape is determined, the weight of each segment is optimized to achieve a desirable dose distribution.



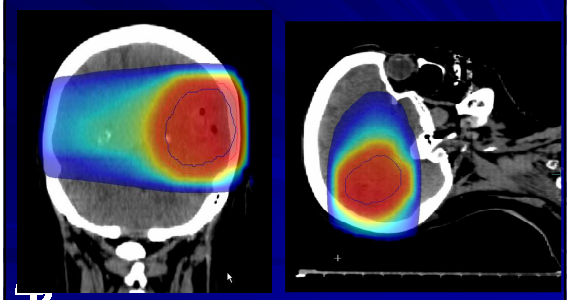
Ergo++ - Pancreas - Case 1



Ergo++ - Pancreas - Case 1



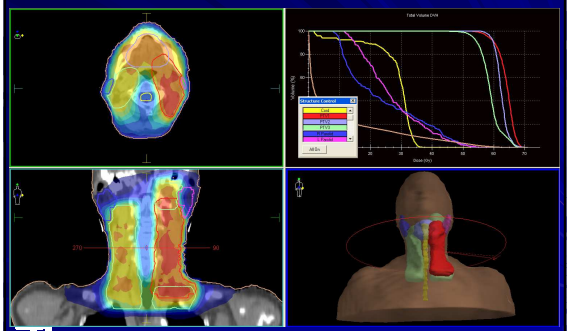
Ergo++ - GBM



Elekta Monaco

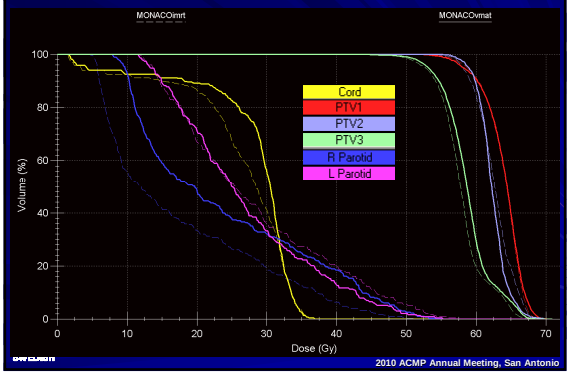
- Monaco is an IMRT planning system originally developed at the University of Tubingen.
- VMAT planning is a work in progress.
- An arc sequencer was used to convert the optimized fluence maps into a single VMAT arc.
- Dose calculation uses Monte-Carlo dose engine.

Elekta Monaco

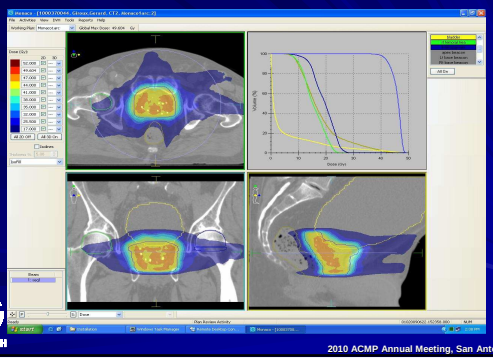


PTV1 (60 Gy), PTV2 (57 Gy), and PTV3 (54 Gy).

Elektra Monaco



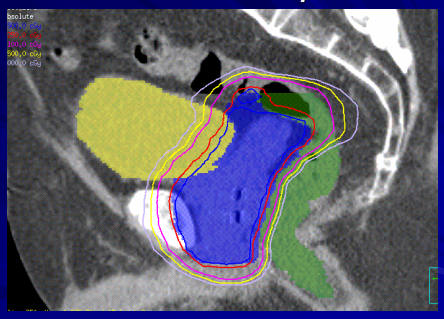
Elektra Monaco



Philips SmartArc

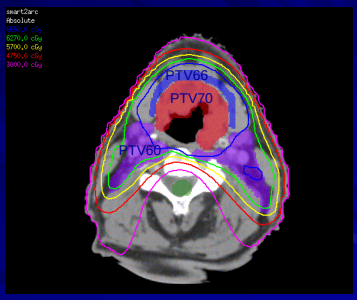
- *SmartArc is an extension of the current DMPO functionality in Pinnacle.*
- *Designed to work with both Varian and Elekta.*
- *FDA 510(k) clearance was received in April 09*
- *Currently available clinically in Pinnacle^3 9.0*

Prostate Example



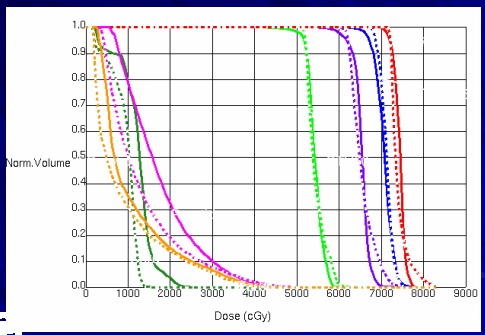
- 1 arc, 180 cGy/fraction
- 480 monitor units, 1.75 minutes

H&N Example



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

H&N Example



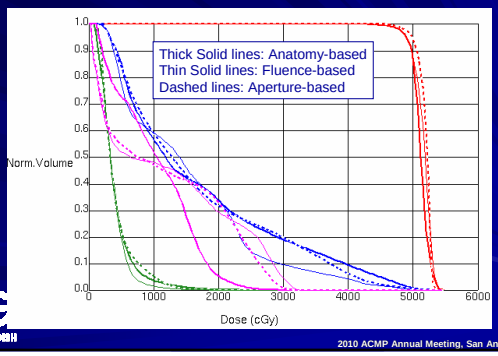
Solid = SmartArc Dashed = Tomotherapy

Comparison of different inverse planning approaches

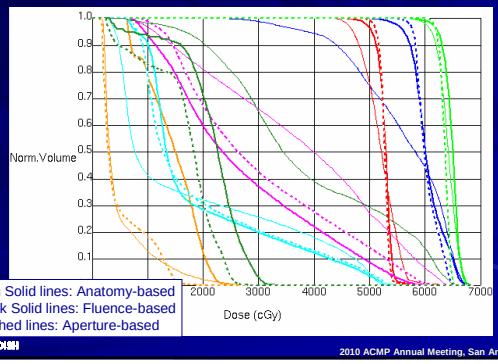
A Pancreas Case

Anatomy-based | Fluence-based | Aperture-based

A Pancreas Case



A H&N Case

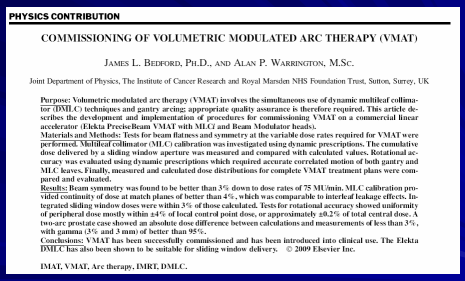


Which Planning System to Choose?

- 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



PHYSICS CONTRIBUTION

COMMISSIONING OF VOLUMETRIC MODULATED ARC THERAPY (VMAT)

James L. Bedford, Ph.D., and Alan P. Warrington, M.Sc.

Joint Department of Physics, The Institute of Cancer Research and Royal Marsden NHS Foundation Trust, Sutton, Surrey, UK

Purpose: Volumetric modulated arc therapy (VMAT) involves the simultaneous use of dynamic multileaf collimator (DMLC) techniques and gantry arcing; appropriate quality assurance is therefore required. This article describes the development and implementation of procedures for commissioning VMAT on a commercial linear accelerator (Elekta Precise Beam VMAT with MLCf and Beam Modulator heads).
Materials and Methods: Tests for beam flatness and symmetry at the variable dose rates required for VMAT were performed. Multileaf collimator (MLC) calibration was investigated using dynamic prescriptions. The cumulative dose delivered by a sliding window aperture was measured and compared with calculated values. Rotational accuracy was evaluated using dynamic prescriptions which required accurate correlated motion of both gantry and MLC leaves. Finally, measured and calculated dose distributions for complete VMAT treatment plans were compared and evaluated.
Results: Beam symmetry was found to be better than 3% down to dose rates of 75 MU/min. MLC calibration provided continuity of dose at match planes of better than 4%, which was comparable to interleaf leakage effects. Integrated sliding window doses were within 3% of those calculated. Tests for rotational accuracy showed uniformity of peripheral dose mostly within ±4% of local central point dose, or approximately ±0.2% of total central dose. A two-arc prostate case showed an absolute dose difference between calculations and measurements of less than 3%, with gamma (3% and 3 mm) of better than 95%.
Conclusions: VMAT has been successfully commissioned and has been introduced into clinical use. The Elekta DMLC has also been shown to be suitable for sliding window delivery. © 2009 Elsevier Inc.

IMAT, VMAT, Arc therapy, IMRT, DMLC.

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

VMAT Commissioning tests

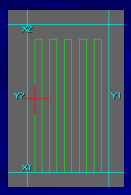
- Beam flatness and symmetry
- MLC leaf calibration
- Sliding window dose
- Rotational accuracy
- Beam interruption and termination

VMAT Machine Specific QA

The three major variables during VMAT delivery

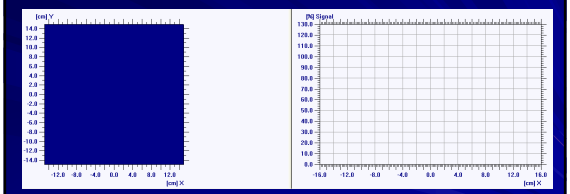
- MLC leaf position
- Gantry angle
- Dose rate

A special VMAT plan with specific MLC leaf motion patterns and dose rate variations was developed to check all three major variables



- Gantry continue rotates while the MLC leaves are moving.
- Dose rate also varies while gantry is rotating.
- The plan was measured using a MatriXX 2D ion chamber inserted in a MULTICube phantom.
- The data were recorded in movie mode with 0.1 second sampling time.

The VMAT plan for machine QA

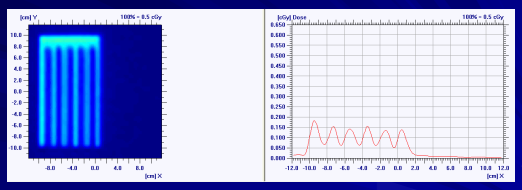


The theoretical dose distribution calculated using convolution/superposition dose engine in Pinnacle. The calculation was done with 1° gantry spacing.

How to check the variables

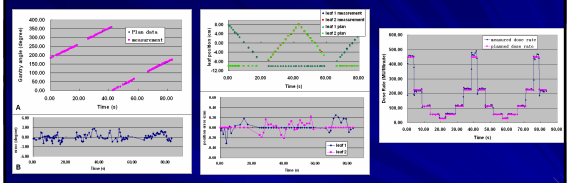
- MLC leaf motion: The projection position of the tip for each MLC leaf on the MatriXX device can be used to determine the MLC leaf motion accuracy.
- Gantry angle: The projection width of the 1cm gap between MLC leaves on the MatriXX device can be used to determine the gantry angle.
- Dose rate: The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

The measurement result



The measurement was interpolated into 1mm 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 1.1mm with a maximum error of 3.1mm 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

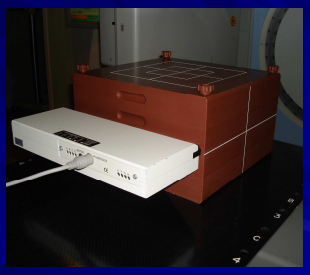
VMAT plan QA methods

- 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

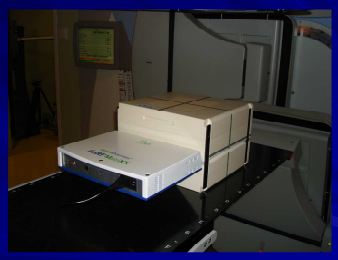
- A stack of solid water phantom with a total thickness of 15cm.
- A 0.6cc farmer chamber was inserted at the depth of 10cm.
- A film was sandwiched 1cm above the ion chamber.

2D Diode Array



- A MapCheck device inserted into a MapPhan solid water phantom

2D ion Chamber Array



- An IBA Matrixx® 2D ion-chamber array inserted in a MULTICube phantom.

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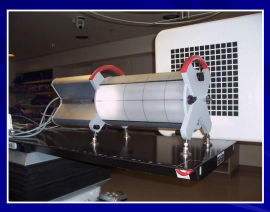
Scandidos Delta[4]

- 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.



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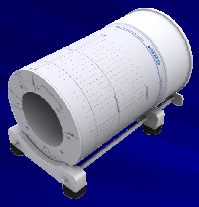
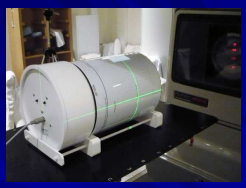
Arc Check – Sun Nuclear





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

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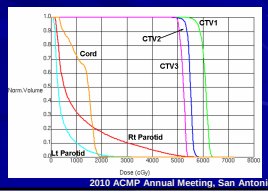
A Head-&-Neck Case

- 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



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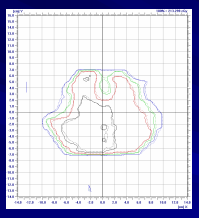
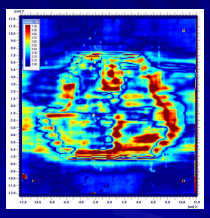
Film & Ion Chamber QA result



measurement



plan

- The Gamma analysis passing rate in this case is 96.4%
- The measured ion chamber dose was 0.2% more than the planned one

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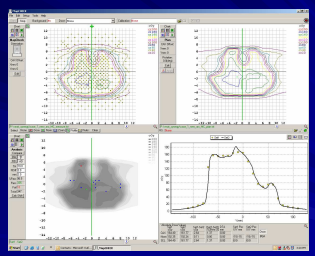
MapCheck in MapPhan QA result



- With 3% and 3mm criteria, the gamma analysis passing rate is 96.5%
- Dose threshold in gamma analysis is 10%

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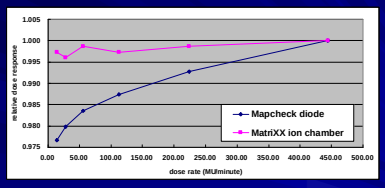
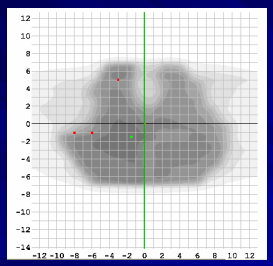
Dose Rate Dependency



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

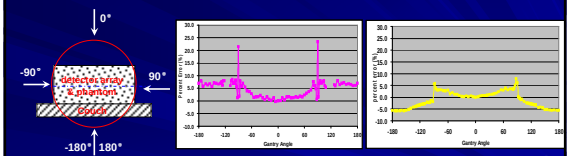
Calibrate MapCheck with medium dose rate



Dose calibration was performed at 224 MU/Min

- Gamma passing rate increased to 98.8%

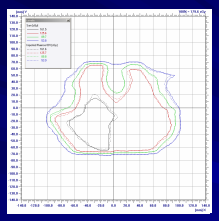
Angular dose response of MapCheck diode



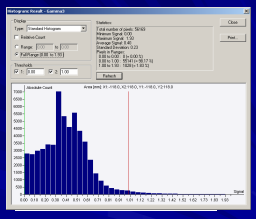
phantom setup | MapCheck Diode | MatriXX ion chamber

- 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



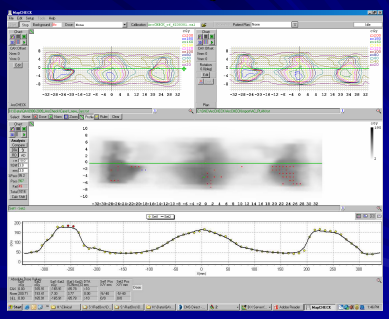
measurement



plan

- With 3% and 3mm criteria, the passing rate is 98.2% for this coronal slice
- 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 relative 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.