Acceptance Testing, Commissioning, Quality Assurance of VMAT Technology

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***Presenter**

Conflict of Interest

Funding from PA Department of Health through ACR

Funding from NCI/NIH through ACR

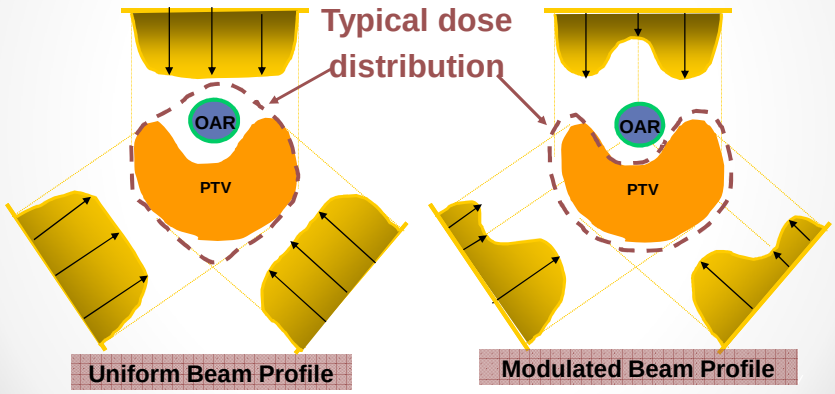
Objectives of Presentation

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 planned, why they are needed, and how to perform these procedures effectively

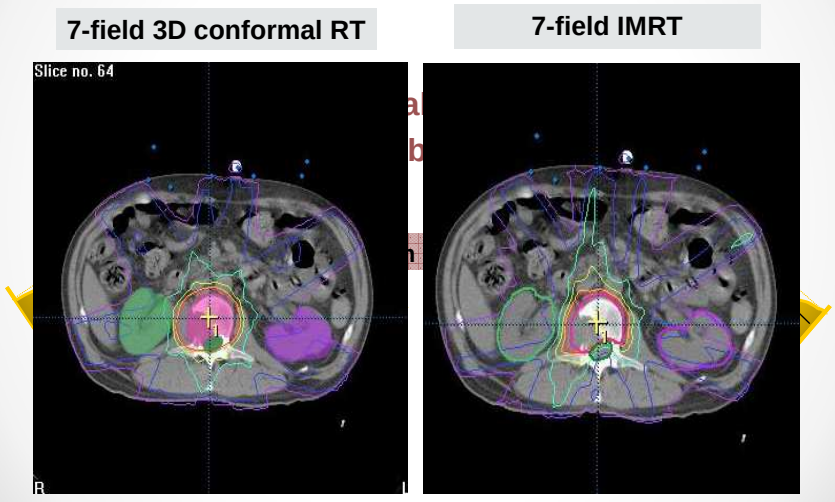
Presentation Outlines

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

3D-CRT Compared to IMRT



The Principle of IMRT: Dose Painting



Principle of IMRT

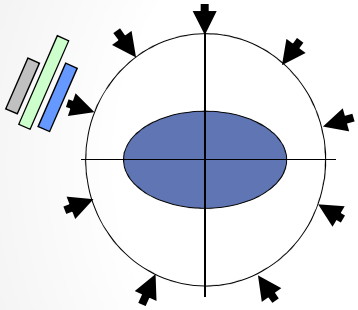
"The DVHs or subsequently derived biological scores depend on the **total number of strata**, which is defined as the product of the number of beams and the intensity levels within each beam. As the number of beams increases, the number of intensity levels required to obtain optimal dose distribution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

Yu, CX: Intensity-modulated arc therapy with dynamic multileaf collimation: an alternative to tomotherapy. Phys. Med. Biol., 40: 1435-49, 1995

What matters is the total number of shape changes!

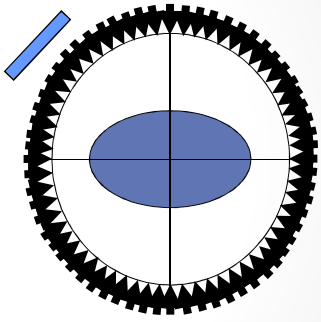
Static and Rotational IMRT

Static Gantry IMRT



Multiple apertures at each angle

VMAT–Rotational IMRT

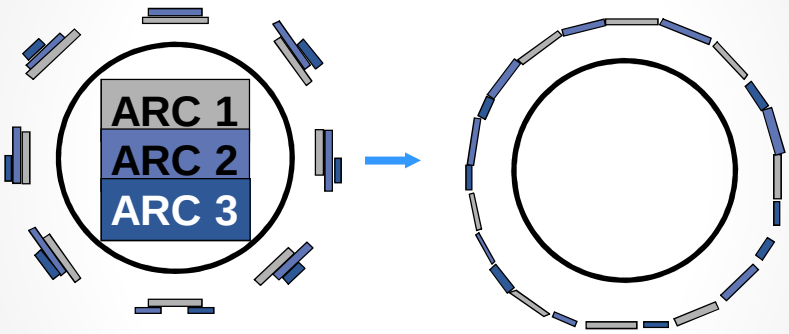


One aperture at each angle

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

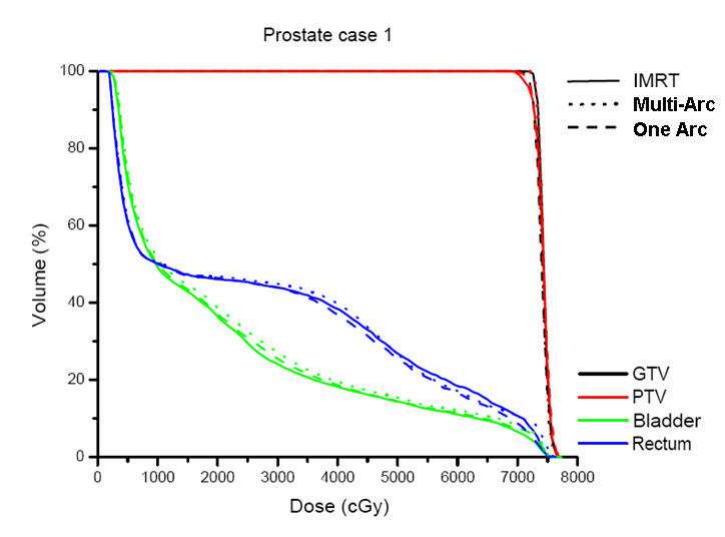


Tang et al, Int. J Rad Onc. Biol Phys, 2007

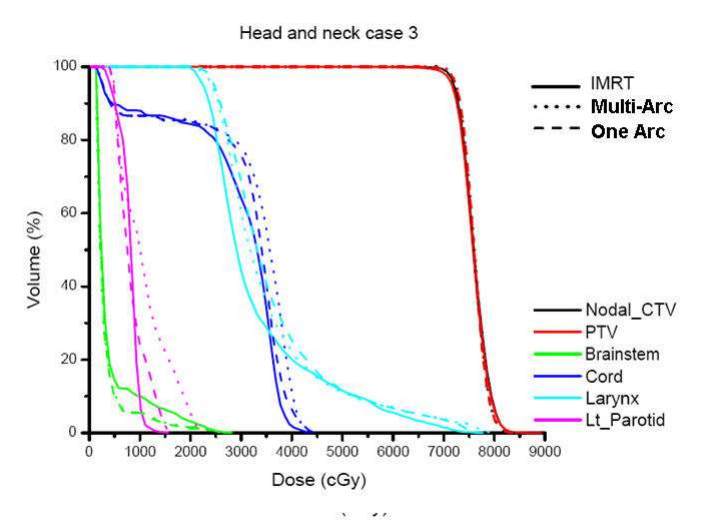
One arc or two arcs

- 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 comformality

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:
  - The criteria and methods of comparison should be explicitly stated and justified
  - The probabilities of occurrence of the criteria should be reported
  - Explicit utilities for the criteria should be provided and used to rank the methods

* Mark H. Phillips and Clay Holdsworth. When is better best? A multi-objective perspective. Med Phys 38, 1635 (2011)

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^{o} 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**

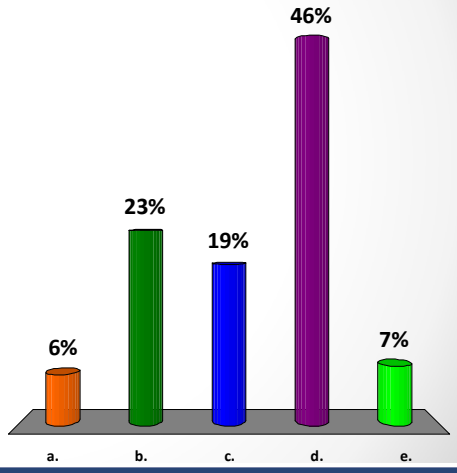
Specials Considerations for VMAT

- **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



SAM Answer 1

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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

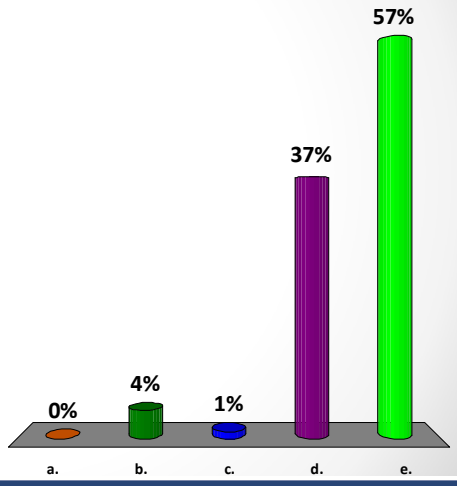
Reference:

Yu, CX: Intensity-modulated arc therapy with dynamic multileaf collimation: an alternative to tomotherapy. Phys. Med. Biol., 40: 1435-49, 1995

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



SAM Answer 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:

G. Tang, M. Earl, S. Luan, S. Naqvi and C.X. Yu, "Converting multiple-arc Intensity-modulated Arc Therapy into a single arc for efficient delivery," Int. J. Rad. Oncol. Biol. Phys 69(3,) Sup, S673 (2007)
Otto K 2008 Volumetric modulated arc therapy: IMRT in a single gantry arc. Med Phys. 35 310-317.

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 phamtom/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:**
  - **Ling C, et al "Commissioning and quality assurance of RapidArc radiotherapy delivery system," *Int J Radiat Oncol Biol Phys*. 72, 575-81 (2008)**
  - **Bedford and Warrington, "Commissioning of volumetric modulated arc therapy," *Int J Radiat Oncol Biol Phys*. 73, 537-45 (2009)**
- **General IMRT Guidance Document:**
  - **Ezzell, G. A., J. M. Galvin, et al. "Guidance document on delivery, treatment planning, and clinical implementation of IMRT: report of the IMRT Subcommittee of the AAPM Radiation Therapy Committee." *Med Phys* 30, 2089-115 (2003)**

Published Commissioning References

Ling et al paper

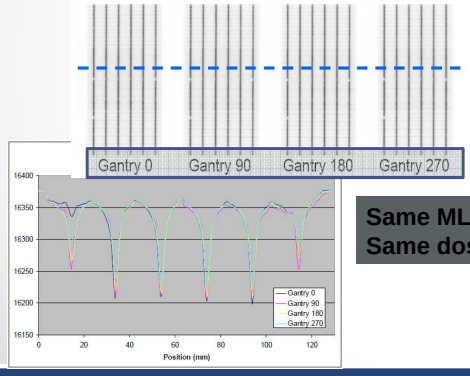
- Varian accelerator was used for testing
- Procedures tend to be specific for this equipment
- Must have good knowledge of the use of Log Files
- Equipment needed is relatively simple

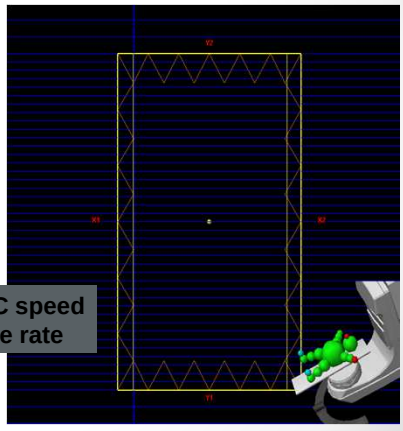
Bedford et al paper

- 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



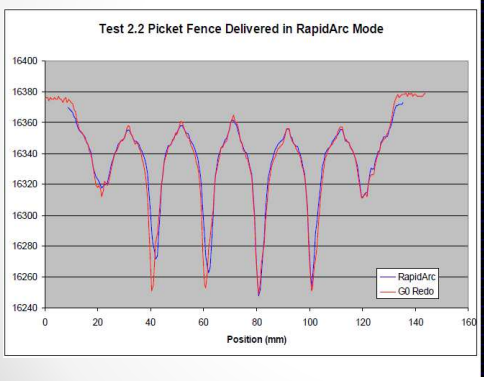


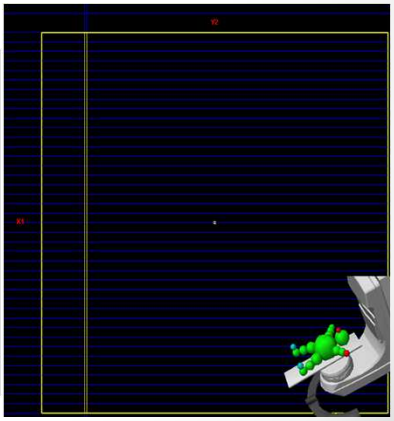
Same MLC speed
Same dose rate

Sample AT 1b: dMLC Position

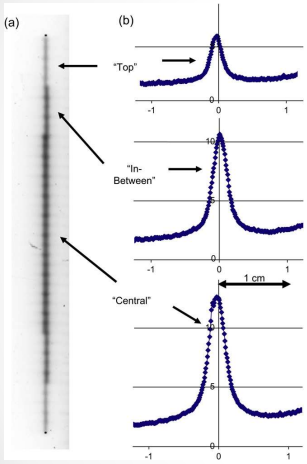
Tests during Rotation

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



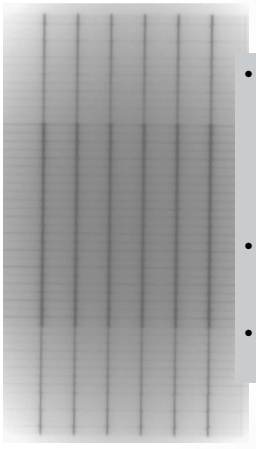


Tests 1a&1b: dMLC Position Accuracy Tests



FWHM
~2.2 mm
~2.6mm
~2.9mm

Film image | Radiation profiles

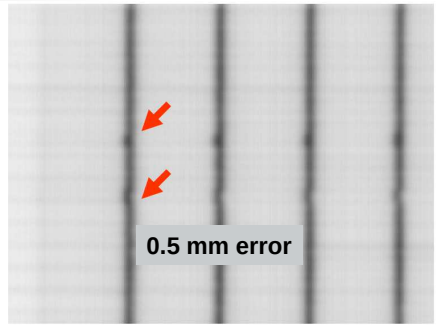


- Film image of 1-mm-wide for two picket fence patterns
- at stationary gantry angle
- in RapidArc mode

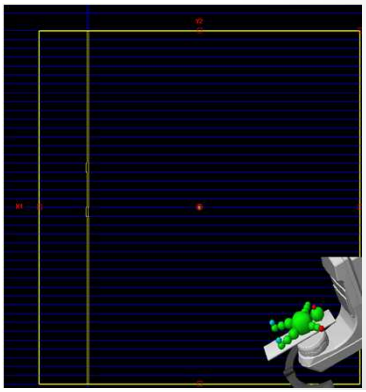
Ling C, et al Red J 2009

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

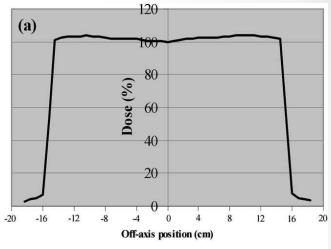


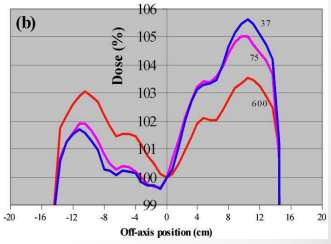
Picket Fence with Errors



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%





Orientation		Dose rate (MU/min)	Flatness (%)*	Symmetry (%)*
G-T	In-plane	37	104.0	101.0
A-B		600	103.6	100.7
A-B	Cross-plane	75	105.4	103.5
A-B		37	106.1	104.1

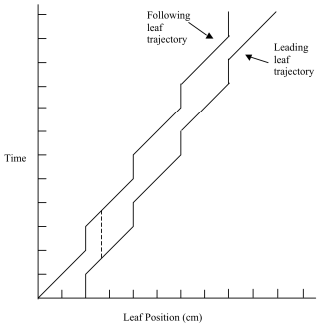
A-B = perpendicular to the axis of gantry rotation;
G-T = parallel to the axis of gantry rotation
* IEC 60976 nomenclature.

Bedford et al Red J 2009

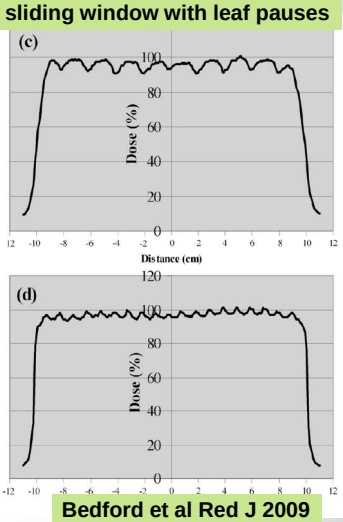
Tests 2a: Dosimetry Test for Gantry Positions

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.



sliding window with leaf pauses



Bedford et al Red J 2009

Test 2a: dMLC Dosimetry for Gantry Position

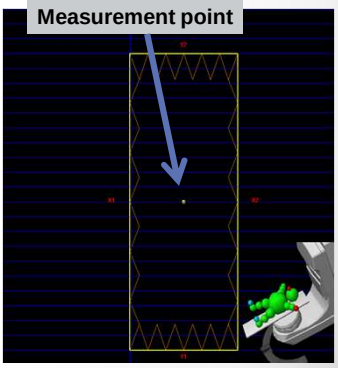
- dMLC dosimetry consistency at different gantry positions (Ling et al Test 2)
- 0.5cm MLC slit sliding over 4 cm range
- Gantry: 0°, 90°, 270°, 180°
- Tolerance: ± 2% (over mean value)

Gantry	Difference (%)
180	1.39
90	-1.83
0	0.80
270	-0.36
min-max error	3.222
max/mean	1.014
min/mean	0.982

Collimator =0

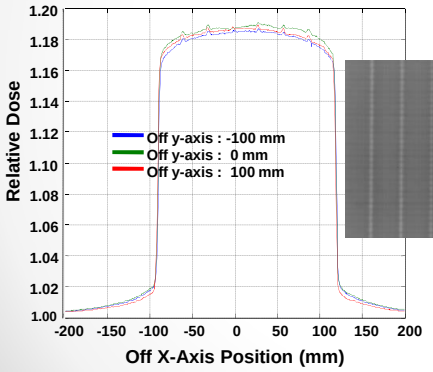
Gantry	Difference (%)
180	0.33
90	-0.08
0	-0.09
270	-0.15
min-max error	0.475
max/mean	1.003
min/mean	0.998

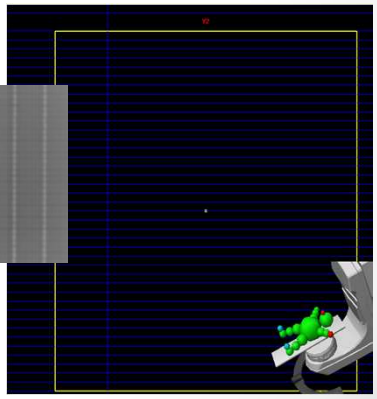
Collimator =90



Sample Test 2b: dMLC Dose vs Gantry Speed and Doserate

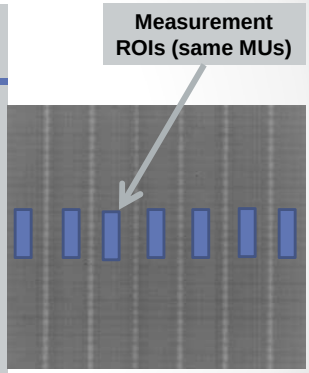
- Accuracy of dose rate and gantry speed control during RapidArc (Ling et al Test 2)
- Tolerance: + 2%





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

ΔMU/Δt (MU/min)	Δθ (degree)	Δθ/Δt (degree/s)	Ave Δ (%)
111	90	5.54	1.1
222	45	5.54	0.5
333	30	5.54	0.0
443	22.5	5.54	0.1
554	18	5.54	-0.2
600	15	5.00	-0.5
600	12.9	4.30	-1.1

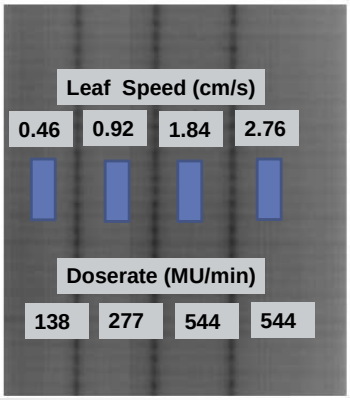


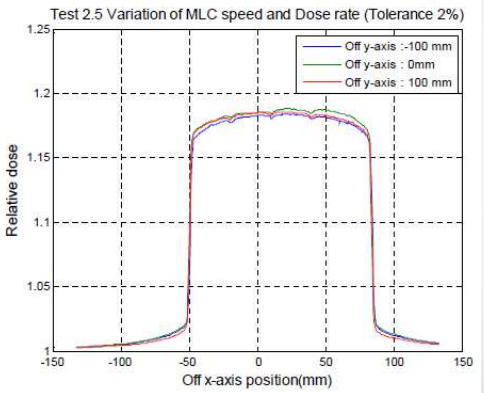
Duke University

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)



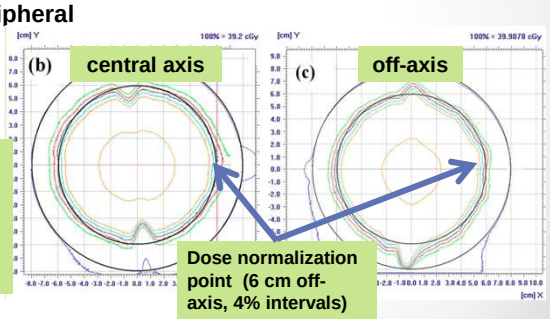


Sample 2a&2c: Dosimetry Test

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



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**

Gantry angle (°)	Collimator angle (°)	Motion	Measured calculated dose	Measured static dose
0	0	X1→X2*	1.12	0.985
0	0	X2→X1	1.12	0.984
270	0	X1→X2	1.12	0.983
270	0	X2→X1	1.11	0.972
270	90	X1→X2	1.12	0.982
270	90	X2→X1	1.13	0.987

An aperture moving at uniform speed

Gantry angle (°)	Collimator angle (°)	Motion	Measured calculated dose	Measured static dose
0	0	X1→X2*	1.20	0.984
0	0	X2→X1	1.20	0.985
270	0	X1→X2	1.19	0.976
270	0	X2→X1	1.19	0.978
270	90	X1→X2	1.19	0.978
270	90	X2→X1	1.19	0.980

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

- **G.M. Mancuso, J.D. Fontenot, J.P. Gibbons, B.C. Parker, "Comparison of action levels for patient-specific quality assurance of intensity modulated radiation therapy and volumetric modulated arc therapy treatments," Med. Phys. 39, 4378-4385 (2012).**
- **G. A. Ezzell, J. W. Burmeister, N. Dogan, T. J. LoSasso, J. G. Mechalakos, D. Mihailidis, A. Molineu, J. R. Palta, C. R. Ramsey, B. J. Salter, J. Shi, P. Xia, N. J. Yue, and Y. Xiao, "IMRT Commissioning: Multiple Institution Planning and Dosimetry Comparisons, a Report from AAPM Task Group 119," Med.Phys. 36, 5359-5373 (2009).**

Treatment Planning Results

		TG-119		This work	
Parameter	Plan goal (cGy)	Mean (cGy)	Std dev (cGy)	IMRT (cGy)	VMAT (cGy)
		Multitarget			
Central target D_{99}	>5000	4955	162	4857	5132
Central target D_{10}	<5300	5455	173	5475	5532
Superior target D_{99}	>2500	2516	85	2543	2648
Superior target D_{10}	<3500	3412	304	3266	3410
Inferior target D_{99}	>1250	1407	185	1277	1255
Inferior target D_{10}	<2500	2418	272	2541	2398
		Prostate			
Prostate D_{95}	>7560	7566	21	7609	7560
Prostate D_5	<8300	8143	156	7784	7813
Rectum D_{30}	<7000	6536	297	6846	6830
Rectum D_{10}	<7500	7303	150	7464	7473
Bladder D_{30}	<7000	4394	878	4868	4627
Bladder D_{10}	<7500	6269	815	6930	6941
		Head and neck			
PTV D_{90}	>5000	5028	58	5203	5147
PTV D_{99}	>4650	4704	52	4763	4755
PTV D_{20}	<5500	5299	93	5385	5439
Cord maximum	<4000	3741	250	3940	3951
Left parotid D_{50}	<2000	1798	184	1875	1850
Right parotid D_{50}	<2000	1798	184	1833	1910
		C-shape			
PTV D_{95}	>5000	5010	17	5001	5007
PTV D_{10}	<5500	5440	52	5330	5463
Core D_{10}	<2500	2200	314	2489	2163

Point Measurements

	IMRT		VMAT	
Location	TPS dose (cGy)	% diff	TPS dose (cGy)	% diff
		Multitarget		
Central target	214.7	−0.40 ± 0.06	218.4	0.31 ± 0.05
Superior target	119.6	−0.55 ± 0.19	108.1	−0.03 ± 0.05
Inferior target	65.4	−2.82 ± 0.10	56.0	−1.15 ± 0.05
		Prostate		
PTV	184.0	−0.75 ± 0.06	185.4	−0.60 ± 0.07
Rectum	137.4	−1.66 ± 0.13	146.8	−1.53 ± 0.07
Bladder	136.4	1.34 ± 0.20	134.4	−2.78 ± 0.20
		Head and neck		
PTV	212.8	−2.85 ± 0.00	206.5	−4.24 ± 0.06
Spinal cord	126.9	−1.42 ± 0.30	135.8	−4.20 ± 0.19
		C-shape		
Central core	54.9	−0.87 ± 0.07	48.1	−2.04 ± 0.06
Outer target	208.4	1.82 ± 0.06	207.5	−2.76 ± 0.15
Average	...	−0.82 ± 0.48	...	−1.89 ± 0.50
|Average|	...	1.45 ± 0.27	...	1.96 ± 0.48

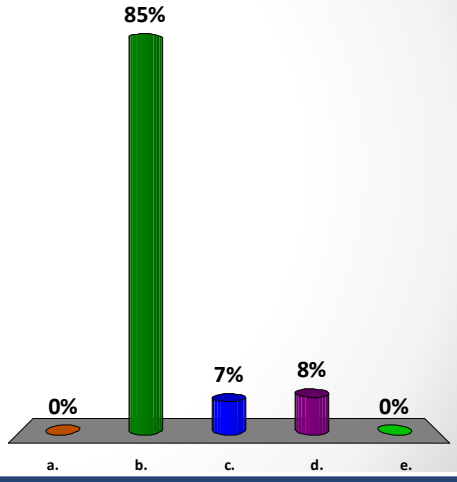
Film Measurements

	% points with $\gamma_{3\%,3\text{ mm}} < 1$		% points with $\gamma_{2\%,2\text{ mm}} < 1$	
Film plane	IMRT	VMAT	IMRT	VMAT
		Multitarget		
Coronal	99.2 ± 0.3	99.0 ± 0.1	98.2 ± 0.4	97.1 ± 0.1
Sagittal	98.7 ± 0.3	99.0 ± 0.2	98.0 ± 0.2	97.5 ± 0.3
		Prostate		
Coronal	100 ± 0.0	100 ± 0.0	99.4 ± 0.2	99.8 ± 0.1
Sagittal	98.9 ± 0.2	100 ± 0.0	98.5 ± 0.4	100 ± 0.0
		Head and neck		
Coronal	99.1 ± 0.1	97.7 ± 0.2	96.0 ± 0.3	93.8 ± 0.1
Sagittal	96.5 ± 0.3	98.3 ± 0.1	93.9 ± 0.2	95.8 ± 0.1
		C-shape		
Coronal	99.3 ± 0.2	99.9 ± 0.0	98.2 ± 0.5	99.2 ± 0.1
Sagittal	99.3 ± 0.2	98.6 ± 0.5	98.2 ± 0.4	96.4 ± 0.7
Average	98.9 ± 0.4	99.1 ± 0.3	97.6 ± 0.6	97.5 ± 0.8

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:

G. A. Ezzell, J. W. Burmeister, N. Dogan, T. J. LoSasso, J. G. Mechalakos, D. Mihailidis, A. Molineu, J. R. Palta, C. R. Ramsey, B. J. Salter, J. Shi, P. Xia, N. J. Yue, and Y. Xiao, "IMRT Commissioning: Multiple Institution Planning and Dosimetry Comparisons, a Report from AAPM Task Group 119," Med.Phys. 36, 5359-5373 (2009).

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
  - Machine specific QA
  - 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**

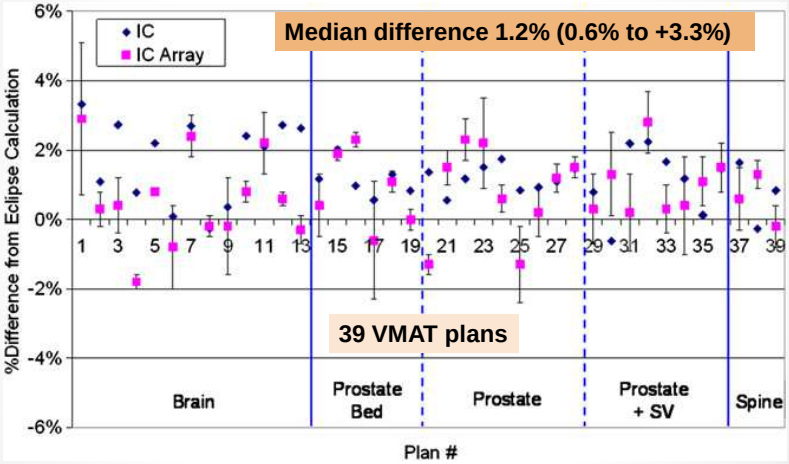
Patient Specific QA- Method

- 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

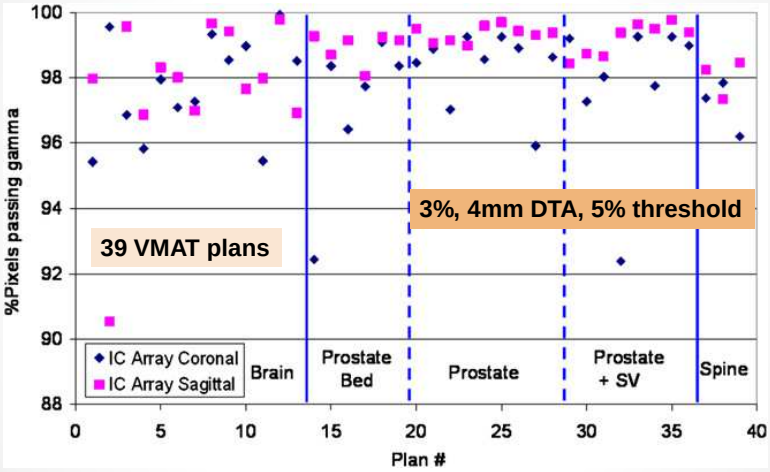
- Phantom (hardware)
  - Solid water
  - Special phantom
- Data analysis (software)
  - Multiple planes (axial, coronal, sagittal)
  - Profiles
  - Points
  - Gamma analysis
  - Tolerances: from commissioning results
- Collision check
  - Before patient on the couch
  - When patient on the couch

Ion Chamber vs. Eclipse



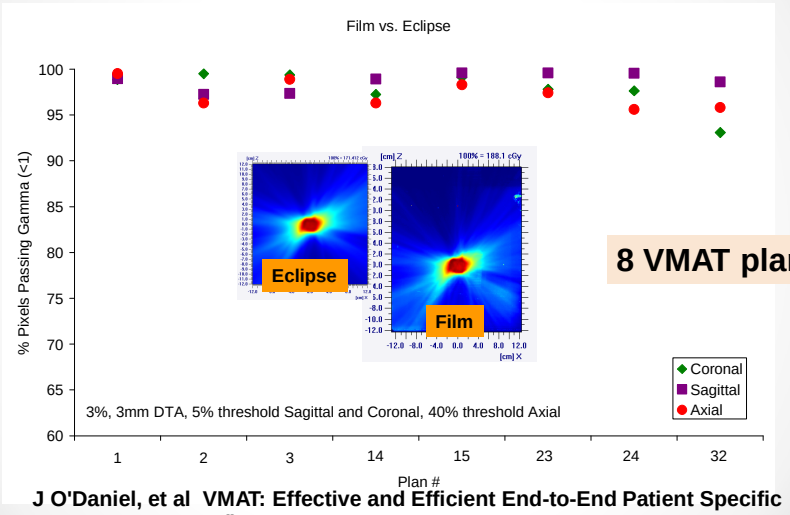
J O'Daniel, et al VMAT: Effective and Efficient End-to-End Patient Specific Quality Assurance." Intl. J. Radiat Oncol Phys Biol 82:1567-1574 (2012).

Ion Chamber Array vs. Eclipse



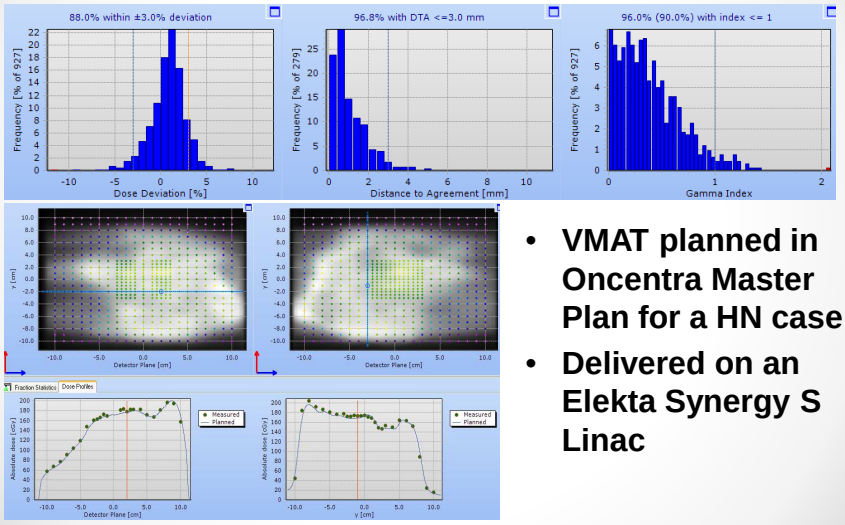
J O'Daniel, et al VMAT: Effective and Efficient End-to-End Patient Specific Quality Assurance." Intl. J. Radiat Oncol Phys Biol 82:1567-1574 (2012).

Film vs. Eclipse



J O'Daniel, et al VMAT: Effective and Efficient End-to-End Patient Specific Quality Assurance." Intl. J. Radiat Oncol Phys Biol 82:1567-1574 (2012).

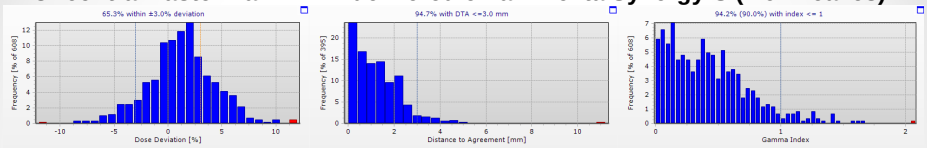
Sample 3D Patient Specific QA with 3D Dosimeter (Delta4)



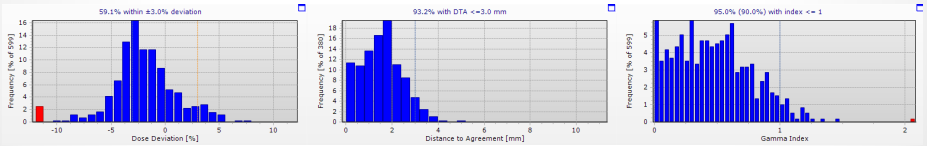
- **VMAT planned in Oncentra Master Plan for a HN case**
- **Delivered on an Elekta Synergy S Linac**

Sample 3D Patient Specific QA for TG119 C-Shape (Delta4)

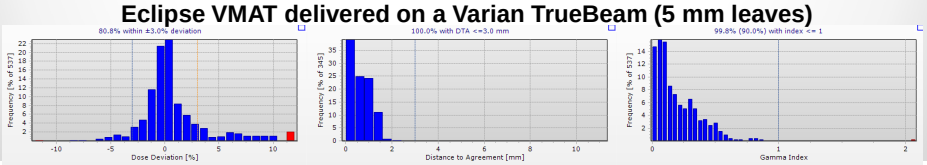
Oncentra MasterPlan VMAT delivered on an Elekta Synergy S (1 cm leaves)



Oncentra MasterPlan VMAT delivered on an Elekta Synergy S (4 mm leaves)



Eclipse VMAT delivered on a Varian TrueBeam (5 mm leaves)



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

J O'Daniel, et al VMAT: Effective and Efficient End-to-End Patient Specific Quality Assurance." Intl. J. Radiat Oncol Phys Biol 82:1567-1574 (2012).

Effective vs. Efficient

Method	Preparation	Delivery	Analysis
Ion chamber: first	15	15	5
Film: first	15	20	20
Ion chamber array: first	15	15	5
Ion chamber: additional	15	7	5
Film: additional	15	10	10
Ion chamber array: additional	15	7	5
IC + 2 film + 2 ICA	75	67	45
IC + 2 ICA	45	37	15
IC + ICA	30	30	10

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

J O'Daniel, et al Intl. J. Radiat Oncol Phys Biol 82:1567-1574 (2012)

Topics in This Presentation

- Fundamentals for VMAT
- Acceptance testing/commissioning
- Quality Assurance
  - Machine specific QA
  - 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