VMAT for dummies: Physics, Commissioning, QA and Treatment Planning

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Disclaimer

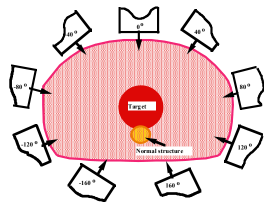
- I hold no financial interest nor have I received research funds, from any of the vendors and products that will be discussed in this presentation

Objectives

- To provide an introduction to intensity modulated arc therapy (IMAT) and volumetric modulated arc therapy (VMAT)
- To discuss some differences between IMAT, VMAT, IMRT and Tomotherapy
- To discuss VMAT commissioning and QA
- To discuss VMAT patient specific QA
- To introduce VMAT capable treatment planning systems

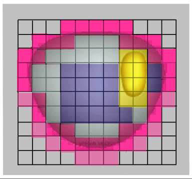
Intensity Modulated Radiation Therapy (IMRT)

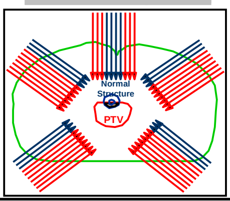
Optimum assignment of non-uniform intensities (i.e.,weights) to tiny subdivisions of multiple beams ("beamlets" or rays) to achieve desired dose distribution or clinical objectives



Inverse Planning

Standard IMRT

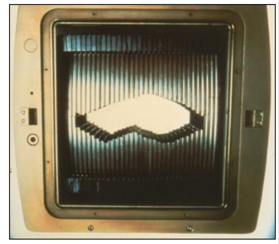




- Divides each treatment field into multiple segments
- Modulates radiation intensity; gives distinct dose to each segment
- Improves precision/accuracy
- Requires inverse treatment planning software to calculate dose distribution
- Allows for dose escalation

Many ways of Delivering IMRT

- Multiple beams from fixed gantry angles, dynamic MLC
  - Step-and-shoot
  - Sliding window
- Rotating beams
  - Slit MLC
    - Serial (NOMOS)
    - Helical (Tomotherapy)



Static - Step and Shoot IMRT

- Uses multiple static MLC segments per field
- Beam off during leaf/gantry/couch motion
- Potentially is slower with long beam on period resulting in increased treatment times
- Complex problems require lots of segments
- It is simpler

Dynamic - Sliding Window IMRT

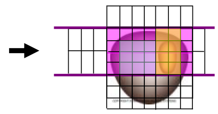
- Uses a dynamic MLC pattern per field
- Beam stays on during leaf/gantry/couch motion
- It is faster thus reducing treatment times
- It is more versatile with higher spatial resolution due to more intensity levels
- It is more complicated and requires more accurate synchronization of leaf positions with beam on time

Rotating Beam IMRT

NOMOS MIMiC (1994)

Multileaf
Intensity
Modulating
Collimator

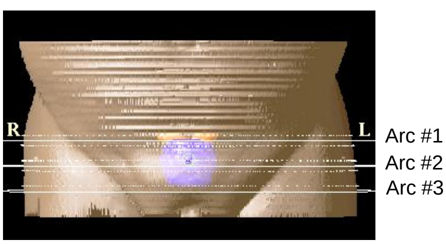
NOMOS MIMIC



Collimator is only 4 cm wide

- Beam shaping by a “MIMiC™” MLC device with 40 leaves
- Maximum field size 4 cm X 20 cm
- Minimum segments size is 1 cm X 1 cm
- Patient must be moved during treatment of larger areas

Prostate IMRT using MIMiC Serial Tomotherapy

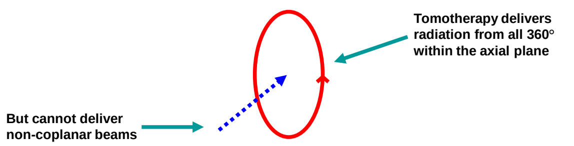


Rotating Beam IMRT

Tomotherapy (2002)

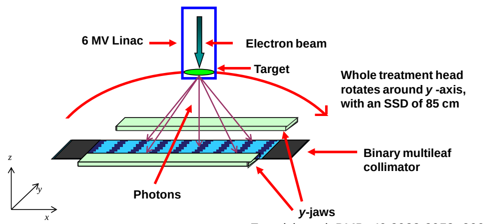
Tomotherapy

- Tomotherapy is rotational IMRT
- It can deliver radiation from all 360° of the axial plane
- Delivery is exclusively coplanar; currently noncoplanar fields cannot be delivered



Tomotherapy

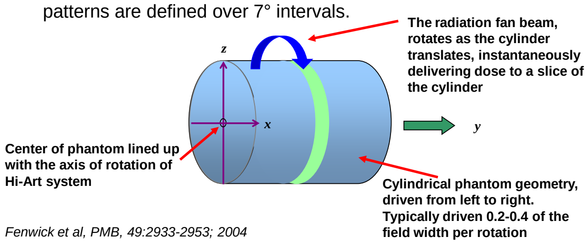
Short 6 MV linac is collimated by jaws and a binary multileaf collimator. The treatment head rotates on a gantry in the XZ plane while a patient is continuously translated through the bore of the machine in the Y direction



Fenwick et al, PMB, 49:2933-2953; 2004

How does Tomotherapy work?

Beam is collimated to a fan beam. The jaw width is held constant (typically 1 or 2.5 cm) for the entire treatment delivery. Laterally the beam is modulated using a binary MLC, which consists of 64 leaves each of width .625 cm for a total possible beam length at isocenter of 40 cm. Individual modulation patterns are defined over 7° intervals.



Fenwick et al, PMB, 49:2933-2953; 2004

Binary MLC Technology

	MIMIC	Tomotherapy
# of Leaves/slice	20	64
Leaf Width	~ 1 cm	0.625 cm
Max Field Width	20 cm	40 cm
Slice Length	~ 1 or 2 cm	0.5 to 5 cm
# of slices per arc	2	1
Table index accuracy	~ 0.5 mm	0.25 mm
Leaf Thickness	6 cm tungsten +1 cm of st steel	10 cm tungsten
Primary Collimator Thickness	Accelerator dependent	22 cm tungsten

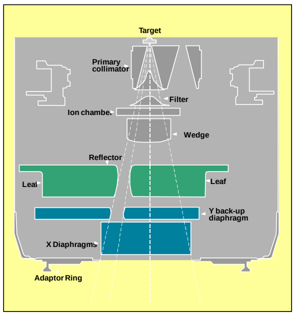
Standard MLC IMRT vs. Tomotherapy (Spiral or Slice-by-Slice)

- Tomotherapy
  - Custom designed dedicated device for IMRT
  - Equivalent to a very large number of beams
  - CT imaging during treatment
- Standard MLC
  - Dose distributions achievable with Tomotherapy can also be achieved with DMLC
  - Non-coplanar beams
  - Higher energies
  - Imaging with cone-beam CT or with "CT-Linac"
  - Utility factor (dose received by the patient / number of MUs)
  - Wide scale availability

Varian MLC

- MLC dynamic motion
- Field size: 40 cm x 40 cm
- Up to 120 leaves
- No patient movement required
- Static or dynamic MLC which speeds treatment and improves patient comfort

Elekta MLC



- Real-time beams-eye optical verification
- Field size: 40 cm x 40 cm
- 32.5 cm leaf travel
- Back-up diaphragms to minimize transmitted radiation
- Smaller leaf movement and opposing leaves do not touch

MLC QA Recommendations (TG 50)

Table 3. Multileaf Collimation Quality Assurance*

Frequency	Test	Tolerance
Patient Specific	Check of MLC-generated field vs. simulator film (or DRR) before each field is treated	2 mm
	Double check of MLC field by therapists for each fraction	Expected field
	On-line imaging verification for patient on each fraction	Physician discretion
	Port film approval before second fraction	Physician discretion
Quarterly	Setting vs. light field vs. radiation field for two designated patterns	1 mm
	Testing of network system	Expected fields over network
	Check of interlocks	All must be operational
Annually	Setting vs. light vs. radiation field for patterns over range of gantry and collimator angles	1 mm
	Water scan of set patterns	50% radiation edge within 1 mm
	Film scans to evaluate interleaf leakage and abutted leaf transmission	Interleaf leakage <3%, abutted leakage <25%
	Review of procedures and in-service with therapists	All operators must fully understand operation and procedures

*This table is reproduced in part from Klein, Low, and Purdy (1996).

Boyer et al, Med Phys Pub, 1-54; 2001

MLC QA Recommendations (TG 142)

TABLE V. Multileaf collimation (with differentiation of IMRT vs non-IMRT machines).

Procedure	Tolerance
Weekly (IMRT machines)	
Qualitative test (i.e., matched segments, aka "picket fence")	Visual inspection for discernable deviations such as an increase in interleaf transmission
Monthly	
Setting vs radiation field for two patterns (non-IMRT)	2 mm
Backup diaphragm settings (Elekta only)	2 mm
Travel speed (IMRT)	Loss of leaf speed >0.5 cm/s
Leaf position accuracy (IMRT)	1 mm for leaf positions of an IMRT field for four cardinal gantry angles. (*Picket fence* test may be used, test depends on clinical planning-segment size)
Annually	
MLC transmission (average of leaf and interleaf transmission), all energies	±0.5% from baseline
Leaf position repeatability	±1.0 mm
MLC spoke shot	≤1.0 mm radius
Coincidence of light field and x-ray field (all energies)	±2.0 mm
Segmental IMRT (step and shoot) test	<0.35 cm max. error RMS, 95% of error counts <0.35 cm
Moving window IMRT (four cardinal gantry angles)	<0.35 cm max. error RMS, 95% of error counts <0.35 cm

Klein et al, Med Phys, 36:4197-4212; 2001

QA recommendations

Table 5. Suggested procedures for initial and regular volumetric modulated arc therapy quality assurance

Frequency	Test	Tolerance (*i.e.*, action level)
Initially	Flatness/symmetry at range of dose rates with gantry rotation	±3% on symmetry
	Sliding window leaf test at gantry angle 0°	<Interleaf leakage (*i.e.*, approximately 5%)
	Slide and shoot leaf test at gantry angles 0°, 90°, 180°, and 270°	<Interleaf leakage (*i.e.*, approx. 5%
	Asynchronous leaf test	< interleaf leakage, i.e. approximately 5%)
	Sliding window dose test	<4%
	Acceleration/deceleration test	<1 mm position error on edges of gradient
	Collimator position test at gantry angles 0°, 90°, 180°, and 270°	<Interleaf leakage (*i.e.*, approximately 5%)
	Rotation test at 160, 640, and 1280 MU	±10% local dose at periphery
Monthly	Flatness/symmetry at 600 MU/min and 37 MU/min at 1 gantry angle*	±3%
	Rotation test at 640 MU	±10% local dose at periphery
	Slide and shoot leaf test at gantry angle 0°*	<Interleaf leakage (*i.e.*, approximately 5%)
Annually	Beam interruption and termination	Functional and <10% local dose at periphery on rotation test

These tests are in addition to those recommended by the American Association of Physicists in Medicine Task Group 40 report on quality assurance (4) (although some of the tests overlap with normal quality assurance, in which case the test is indicated with an asterisk).

Bedford et al, IJROBP, 73:537-545; 2009

Intensity Modulated Arc Therapy (IMAT)

- IMAT is an arced based approach to IMRT that can be delivered by a conventional linac with MLC
- During each arc, the dose rate, gantry speed and MLC leaf positions can be dynamically changed during rotational beam delivery
- IMAT typically requires multiple superimposing arcs to achieve desired dose distribution
- The degree of intensity modulation is related to the number of beam segments per arc and the number of arcs

Intensity Modulated Arc Therapy (IMAT)

- Intensity modulated arc therapy (IMAT) proposed in 1995 by Yu
- Clinical implementation at the U Maryland in 2002
- Commercialization in 2008
  - Varian: Rapidarc
  - Elekta: VMAT

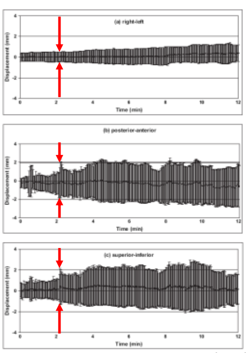
Volumetric Modulated Arc Therapy (VMAT)

- Term VMAT was introduced in 2007 to describe rotational IMRT delivered in a single arc
- VMAT differs from existing techniques such as helical IMRT (tomotherapy) or IMAT
- Helical IMRT treatments apply dose in thick overlapping slices that take more time to deliver
- IMAT, which uses several concentric arcs to deliver a conformal dose distribution, potentially takes much longer to deliver than a treatment using VMAT, which delivers dose to the whole volume rather than slice by slice

The Value of Faster Treatments

- Significant motion can be observed during individual fractions on some patients
- Faster treatments will reduce the effects of intra-fractional motion
- Likelihood of organ displacement typically increases with the time elapsed after initial patient alignment
- Patients will benefit from faster treatments (Eg. prostate patients with bladder control issues)
- Increased patient throughput due to shorter treatment times

The Value of Faster Treatments – Prostate



Right - Left

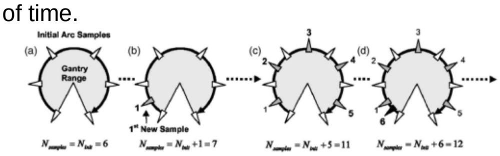
Post - Ant

Sup - Inf

Li et al, IJROBP, 71:801-812; 2008

VMAT - Single Arc IMRT

The optimization strategy is to start with a few angular positions creating MLC patterns to meet constraints, then progressively add more angular positions/ MLC patterns between the existing positions to create an intensity modulated dose distribution that can be delivered in a short period of time.



Otto, Med Phys, 35:310-317; 2008

VMAT – Optimization Constraints

- Maximum MLC displacement constraint for Varian MLC
  - At max speed the gantry rotates through a 360 deg arc in 60 s

$$\left(\frac{d\theta}{dt}\right)_{max} = 6\,\frac{deg}{sec}$$

  - Max leaf speed of MLC leaves is 3 cm/s

$$\left(\frac{dx}{dt}\right)_{max} = 3\,\frac{cm}{sec}$$

- By constraining VMAT delivery to a maximum leaf displacement of 0.5 cm/deg of gantry rotation, the maximum total time for MLC motion over a 360 deg arc is 60 s, which matches the 60s gantry rotation period

$$\left(\frac{dx}{d\theta}\right)_{max} = \frac{\left(\frac{dx}{dt}\right)_{max}}{\left(\frac{d\theta}{dt}\right)_{max}} = 0.5\,\frac{cm}{deg}$$

Otto, Med Phys, 35:310-317; 2008

VMAT – Optimization Constraints

- Maximum MU weight is also constrained throughout the optimization to ensure that the maximum dose rate is rarely exceeded

$$\left(\frac{dMU}{d\theta}\right)_{max} = \frac{\left(\frac{dMU}{dt}\right)_{max}}{\left(\frac{d\theta}{dt}\right)_{max}}$$

$$\left(\frac{dMU}{dt}\right)_{max} \uparrow \Rightarrow \left(\frac{d\theta}{dt}\right)_{max} \downarrow$$

Otto, Med Phys, 35:310-317; 2008

Varian Rapidarc

- Rapidarc optimization uses a progressive direct aperture optimization (Otto et al)
- The RapidArc planning algorithm carefully exploits many of the characteristics of Varian's modern linear accelerators and multileaf collimators, including:
  - Beam stability
  - Leaf interdigitation
  - Varian's dynamic "sliding window" beam shaping
  - Varian's "gridded gun," which makes it possible to vary the dose rate as a function of the gantry angle

Rapidarc Operation

- The treatment is controlled by:
  - **Clinac controller** and
  - **MLC Controller**
- Clinac controller is responsible for maintaining the relationship between MU versus Gantry position
- MLC controller is responsible for maintaining the MLC versus Gantry position relationship

Rapidarc Operation

- The relationship is provided by the segmental treatment table (STT) created by 4DiTC
- Two separate STT files, one forwarded to the Clinac and another to the MLC controllers
- Each STT file contains control points that relate dose versus gantry angle and leaf position versus gantry angle
- Between each control point, the gantry speed, the dose rate, and the MLC leaf speed are constant
- MLC leaves are allowed to travel in both directions, in and out.

Rapidarc Operation

Control Points are used to define RapidArc delivery:

- Based on 177 control points for a complete 360 degrees arc
- Each control point has information on:
  - MLC shape (aperture)
  - number of MU's
  - maximum dose rate
  - maximum gantry speed

Rapidarc Operation

- RapidArc dose delivery technique requires the synchronization of the dynamic MLC, dose rate, and gantry speed to deliver a specific dose to a point in space.
  - Dose rate and gantry speed variation must be in synchrony with the movement of the MLC
- Gantry speed must slow down so that the MLC leaves can catch up to the specified leaf positions.
  - Maximum treatment time depends on complexity of the treatment plan

Rapidarc Operation

- Gantry must slow down to deliver field with large number of MU's or the dose rate can be increased
- The treatment time is determined by
  - physical limitations of the dose delivery
  - treatment plan complexity

Rapidarc Delivery Limits

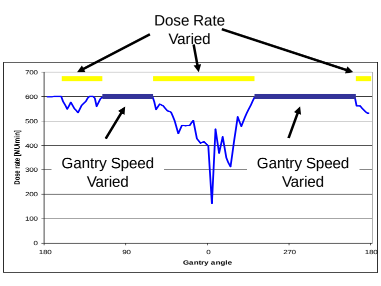
Treatment time is also constraints by linac delivery limitations:

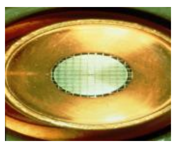
- Variable gantry speed: 0.5 – 5.6 deg/sec
- Variable dose rate: 0 – 600 MU/min
- Variable dose per deg: 0.2- 20 MU/deg
- Variable MLC speed: 0 – 2.5 cm/s

Commissioning and Quality Assurance

- Develop a set of commissioning measurements that will check proper operation of RapidArc components
  - Dose Rate
  - Leaf Position
  - Leaf Speed
  - Gantry Speed

Rapidarc Dose Rate Modulation





Control coincident timing of microwave pulse and electron gun pulse to vary dose rate. Goes from zero to maximum dose rate in 10 ms. Or decreases from 600 MU/min in increments of 1.67 MU/min.

Ling et al, IJORBP, 72:575-581, 2008

Commissioning and QA Tests

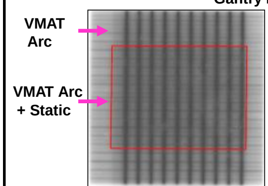
- DMLC position accuracy during VMAT (Picket Fence Test)
- Dose Rate and Gantry Speed variability during VMAT
- MLC speed accuracy during VMAT
- Gap-width Tests at highest MLC speed, against Gravity
- Dynalog file Analysis
- Annual, Monthly and Daily QA testing and analysis
- End to end testing

Picket Fence Test

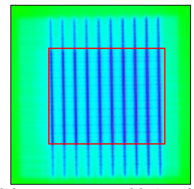
- This test verifies the position of leaves in dynamic mode
- Expose a large part of film to a picket fence pattern under dynamic mode
- On the same film expose a static picket fence pattern only in the central region of the film

Picket Fence Test

Gantry Mount Film Holder

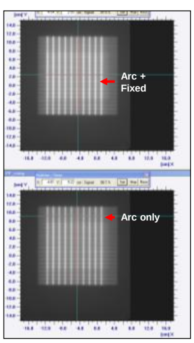


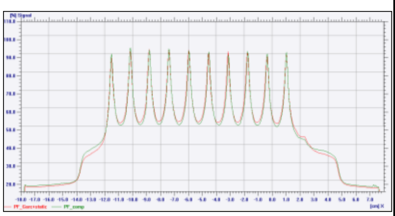
Picket Fence Test with Film



Picket Fence test with CR Plate

Picket Fence Test





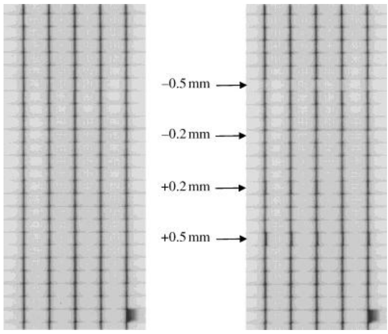
Du et al, MDACC

Picket Fence Test

PF Index	Distance (mm)	Angular Difference (degree)
1	0.57	-0.09
2	0.48	-0.16
3	0.47	-0.19
4	0.27	-0.14
5	0.26	-0.14
6	-0.04	-0.08
7	0.17	-0.06
8	0.44	-0.08
9	0.52	-0.06
10	0.54	-0.06

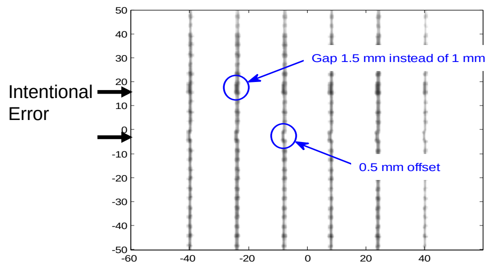
VMAT and static gantry picket fence test: Distance < 1mm, Angle < 1°

Picket Fence Test with Simulated Error



J ICRU, 10:61-82; 2010

Picket Fence Test with Simulated Error



Popple et al, U Alabama

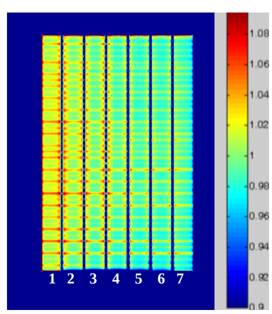
Dose Rate Gantry Speed (DRGS) Test

Tests the dose delivery accuracy under different combinations of dose rate and gantry speed

Segment No.	Gantry start angle (deg)	Covered angle (deg)	Dose rate (MU/min)	Gantry speed (deg/s)
1	179.0	102.5	105	4.8
2	76.5	51.2	210	4.8
3	25.3	37.5	314	4.8
4	347.8	30.7	417	4.8
5	317.1	26.5	524	4.8
6	290.6	24.6	592	4.8
7	266.0	23.2	600	4.4

Jorgensen et al, Med Phys 38:1425-1434, 2011

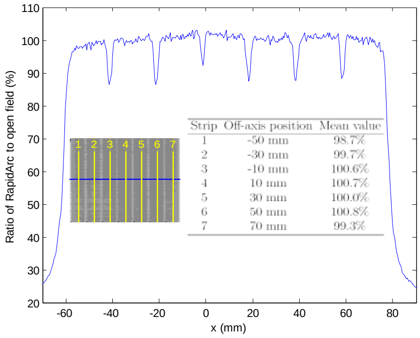
Dose Rate Gantry Speed (DRGS)



Strip #	Dose Ratio: arc/static
1	1.018
2	1.009
3	1.001
4	0.994
5	0.991
6	0.991
7	0.990

Du et al, MDACC

Dose Rate Gantry Speed (DRGS)



Popple et al, U Alabama

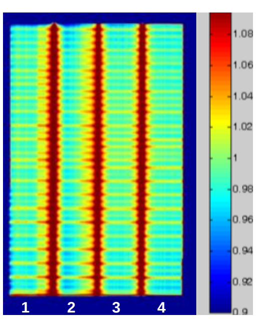
Dose Rate MLC Speed (DRMS) Test

Tests the dose rate control under MLC leaf movement of varying speed

Segment No.	Gantry start angle (deg)	Covered angle (deg)	Dose rate (MU/min)	MLC leaf speed (cm/s)	Gantry speed (deg/s)
1	170	18	480	1.6	4.8
2	152	12	600	2.4	4.0
3	140	32	240	0.8	4.8
4	108	76	120	0.4	4.8

Jorgensen et al, Med Phys 38:1425-1434, 2011

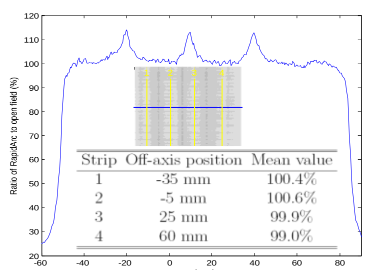
Dose Rate MLC Speed (DRMS)



Strip #	Dose Ratio: arc/static	Std Dev
1	0.999	0.018
2	0.998	0.021
3	0.998	0.017
4	0.993	0.016

Du et al, MDACC

Dose Rate MLC Speed (DRMS)

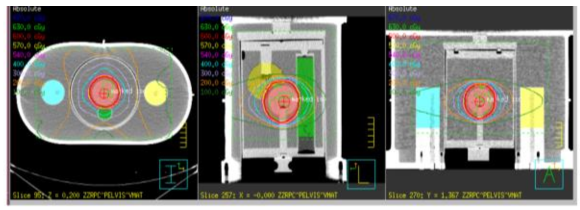


Popple et al, U Alabama

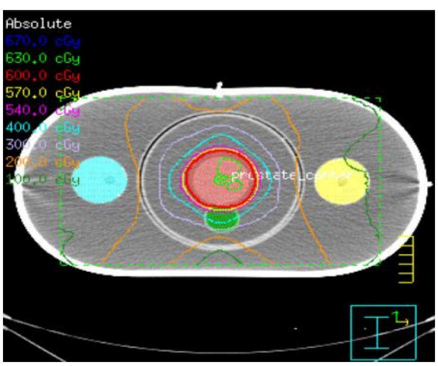
End to End Testing RPC Phantom

- Anthropomorphic pelvic phantom incorporating a cylindrical imaging insert with prostate, rectum and bladder
- Imaging insert replaced with dosimetric insert containing TLD in prostate center and two sheets of GAFChromic film to provide dose distribution in coronal and sagittal planes
- Left and right femoral head each with TLD
- Phantom was irradiated with VMAT to 6 Gy

End to End Testing RPC Phantom



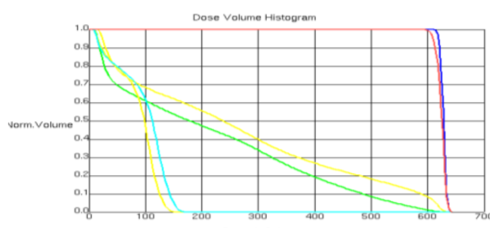
RPC Phantom



Rx = 6 Gy
 # arc = 4;

MU Total = 1074

RPC Phantom



PTV – Red; Prosate – Dark Blue; Rectum – Green; Bladder – Yellow; Fem Heads – Light Blue and Light Yellow

Normal Organs	No more than 15% volume receives dose that exceeds	No more than 25% volume receives dose that exceeds	No more than 35% volume receives dose that exceeds	No more than 50% volume receives dose that exceeds
Bladder	6.7 Gy	6.3 Gy	6.0 Gy	5.7 Gy
Rectum	6.3 Gy	6.0 Gy	5.7 Gy	5.0 Gy

RPC TLD & Film Results

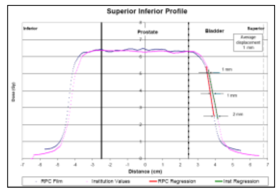
Location	RPC vs. Inst.	Criteria	Acceptable
Center Prostate (Left)	1.03	0.93 – 1.07	Yes
Center Prostate (Right)	1.01	0.93 – 1.07	Yes
Bladder	1 mm	≤ 4 mm	Yes
Rectum	2 mm	≤ 4 mm	Yes

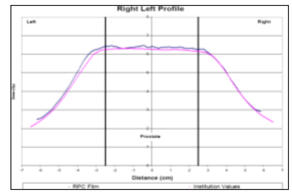
Location	Institution Dose (cGy)	TLD Dose (cGy)	Measured/Institution
Center Prostate (Left)	626	644	1.03
Center Prostate (Right)	626	635	1.01

Location	Institution Dose (cGy)	TLD Dose (cGy)	Acceptability (cGy)*
Femoral Head (Left)	117	120	75 - 164
Femoral Head (Right)	144	149	104 - 194

**RPC tolerance 7% quoted as percentage of prescribed dose*

Film profile through center of prostate





- Displacement between the measured dose gradient and institution's calculated dose gradient has been determined in the region near bladder and rectum.
- Displacements measured at three levels and averaged.
- MDACC results = 2mm. RPC tolerance < 4 mm.

Interrupted Treatments

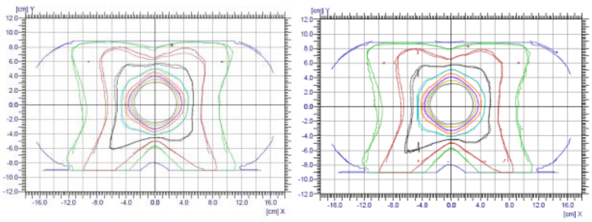
- If an interlock is asserted during treatment, follow normal procedures to clear interlock
- If able to clear interlock, treatment will resume from point where interlock asserted.
- Interlock will not affect the accuracy of dose delivered to the patient.
- Tested by inserting interlock during treatment of QA phantom and then resuming treatment.
- Film and ion chamber data were analyzed.

Interrupted Treatments

- Dose delivered to the isocenter is still accurate, even if beam is interrupted multiple times as in gated delivery.
- Tested by turning beam off repeatedly15 times during delivery to the QA phantom and comparing ion chamber reading obtained from uninterrupted delivery. Results within 0.1% from each other.
- Dynalog files can be analyzed for continued QA during the course of the treatment.

Interrupted Treatments

Uninterrupted Treatment | **Interrupted Treatment**



<4% of pixels have $\Gamma > 1$

Interrupted Treatments

Uninterrupted Treatment

Measurements In the following tables, Dose is the product of the reading and the above dose factor.

Field	Energy (MV)	Couch	Coll	Gantry	MU	Ion Chamber Readings (nC)	Ion Chamber Dose (cGy)
AA	6	0	15	210	140	0.965	86.9
BB	6	0	345	150	141	0.951	85.6
CC	6	0	15	210	140	0.950	85.5
DD	6	0	345	150	141	0.958	86.2
						Total Measured	344.2
						Calculated Dose	343.0
						% diff*	0.3%

% Diff = 0.3%

Interrupted Treatment

Measurements In the following tables, Dose is the product of the reading and the above dose factor.

Field	Energy (MV)	Couch	Coll	Gantry	MU	Ion Chamber Readings (nC)	Ion Chamber Dose (cGy)
AA	6	0	15	210	140	0.946	85.5
BB	6	0	345	150	141	0.955	86.3
CC	6	0	15	210	140	0.949	85.7
DD	6	0	345	150	141	0.960	86.7
						Total Measured	344.3
						Calculated Dose	343.0
						% diff*	0.4%

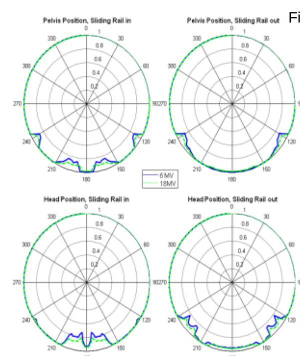
% Diff = 0.4%

Couch Rails Attenuation

Li et al, JACMP; 2011

Couch Rails Attenuation

Field Size: 5 cm x 5 cm



Li et al, JACMP; 2011

Couch Rails Attenuation
Anal Cancer Case

Couch Rails In

Measurements In the following tables, Dose is the product of the reading and the above dose factor.

Field	Energy (MV)	Couch	Coll	Gantry	MU	Ion Chamber Readings (nC)	Ion Chamber Dose (cGy)
A1	6	0	30	182	463	1.747	157.9
B1	6	0	330	178	381	0.669	60.4
						Total Measured	218.3
						Calculated Dose	216.5
						% diff*	0.8%

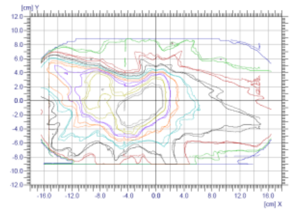
Couch Rails Out

Measurements In the following tables, Dose is the product of the reading and the above dose factor.

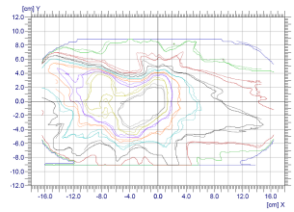
Field	Energy (MV)	Couch	Coll	Gantry	MU	Ion Chamber Readings (nC)	Ion Chamber Dose (cGy)
A1	6	0	30	182	463	1.773	159.6
B1	6	0	330	178	381	0.662	59.6
						Total Measured	219.2
						Calculated Dose	216.5
						% diff*	1.2%

Couch Rails Attenuation
Anal Cancer Case

Couch Rails In



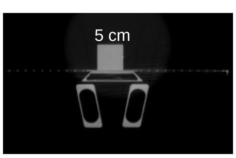
Couch Rails Out

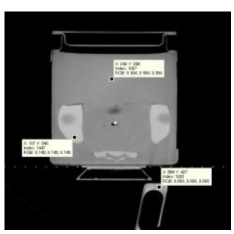


Γ within 1% of each other

Couch Rail Attenuation

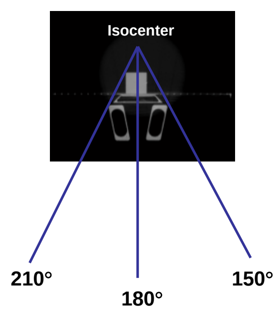
- Gantry start/stop angles???





CT number of couch rails = ~200 HU

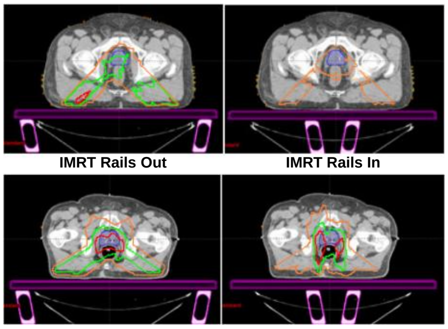
Couch Rail Attenuation



For a typical prostate patient, a 30 degree gantry swing from 180 is needed to avoid beam central axis passing through the edge of couch rails

Du et al, MDACC

Dose loss due to couch and rails



VMAT Rails Out | VMAT Rails In

Orange: 1Gy; Green: 2 Gy; Red: 3Gy

Pulliam et al, PMB, 56:7435-7447; 2011

Dose loss due to couch and rails

Treatment modality and target	Mean dose loss (relative to clinical scenario)		
	Rails-out	Rails-in	Imaging couch top only
IMRT			
CTV	4.2%	2.0%	2.0%
PTV	4.1%	1.9%	1.9%
RapidArc			
CTV	3.2%	2.9%	2.0%
PTV	3.2%	3.1%	2.1%

Pulliam et al, PMB, 56:7435-7447; 2011

Couch Rail Recommendation

- Dosimetric effect of rails:
  - Composite difference should be small: 0 – 3%
  - Small difference detected in QA (small dataset)
  - Pinnacle: Currently couch not modeled
  - Avoid if possible
- Recommendation:
  - Use ± 30° angle avoidance if possible
  - If difficult to get a good plan, use full arc. Attenuation: 0~3%

Collision Concerns

- Therapists should test for gantry clearance before exiting the linac vault
- Risk of collision increases with:
  - Treatment isocenter is lateral to patient midline;
  - Treatment isocenter is anterior;
  - Large immobilization device used;
  - Couch is rotated
  - Frog-legged position

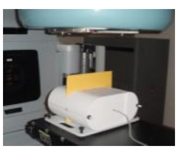
Patient Specific QA

- In VMAT, the gantry is rotating, the dose rate is varying and the MLC leaves are moving
- The dynamic nature of the delivery must be accounted for in the QA
- Simple fluence maps verification may not be sufficient
- The measurement of a composite dose in a phantom is preferred

Patient Specific QA

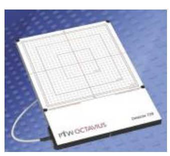
- Treatment planning system (TPS) VMAT calculated plan for a patient is verified using a phantom
- A verification or hybrid plan is generated in the TPS
- The plan is delivered to the phantom
- The measured and calculated absolute dose and dose distributions are compared

Patient Specific QA devices

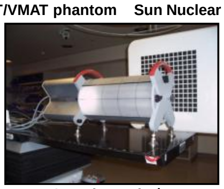


IBA IMRT/VMAT phantom

Sun Nuclear ArcCheck



PTW Octavius



Scandos Delta[4]

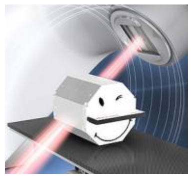
IBA Matrixx Evolution

PTW Octavius

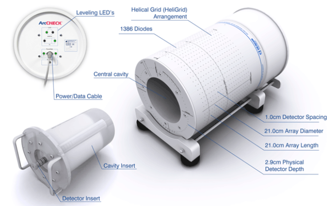
- Ion chamber array with 729 (27x27) cubic ion chambers
- Vented plane-parallel ion chambers are 5 mm x 5 mm x 5 mm in size, and the center-to-center spacing is 10 mm.
- Electronics separated minimizing radiation damage
- The array is 22 mm flat and 3.2 kg light.
- The surrounding material is acrylic (PMMA).
- Array can be moved 5 mm to close the gaps between chambers. By shifting the array 3 times the whole area is covered. The number of measuring points can be increased to 2916.
- The array can be used in a flat phantom or in the octagonal phantom OCTAVIUS.
- Can be used with gantry mount.

PTW Octavius II

- Octagon phantom made from polystyrene (density 1.04 g/cc)
- Octagon diameter 32 cm, length 32 cm
- Weight 24 Kg
- Verisoft software for patient plan verification



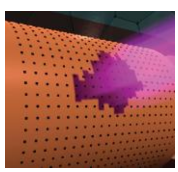
Sun Nuclear ArcCHECK



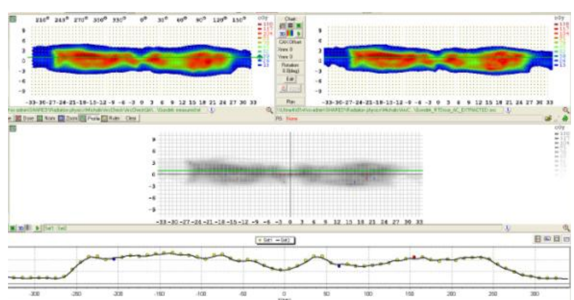
Detector type:	SunPoint Diode Detectors	Detector volume (cm³):	0.000019
Detector quantity:	1386	Detector stability:	0.5%/kGy at 6MV
Detector spacing (cm):	1.0	Dose rate dependence:	± 1%, 75 - 250cm SSD
Array diameter (cm):	21.0	Update frequency (ms):	50
Array length (cm):	21.0	Radiation measured:	• Electrons, 6 MeV to 25 MeV • Photons, Co-60 to 25 MV
Cavity diameter (cm):	15.0	PC Hardware:	2 CPU Core, 1.6 GHz CPU Speed, 2 GB RAM
Inherent buildup (g/cm²):	3.2	Number of connection cables:	Single power/data cable
Inherent backscatter (g/cm²):	3.2	Dimensions (cm²) / Weight (kg):	27.0 x 43.0 / 16.0
Detector physical depth (cm):	2.9	Operating system:	Windows 2000, XP 32-bit, or Vista 32-bit
Array geometry (cm):	Helical Grid (HeliGrid) 1cm offset	Minimum Requirements:	2 GB RAM, 1 available USB port, Dual-core processor, 50 MB hard disk space, 4 MB VGA video card (1024 x 768), 16-bit color depth
Phantom Material:	PMMA (Acrylic)	Recommended Requirements:	16 MB video RAM, OpenGL harware accelerated video card
Active detector area (mm²):	0.64		

Sun Nuclear ArcCHECK

- 1386 diode detectors arranged in cylindrical geometry
- Measure entrance and exit dose
- Center cavity accommodates inserts
- Result is a composite dose for entire delivery

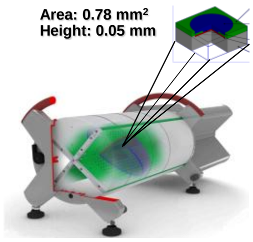


Sun Nuclear ArcCHECK

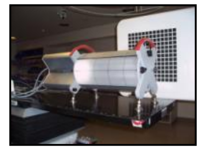


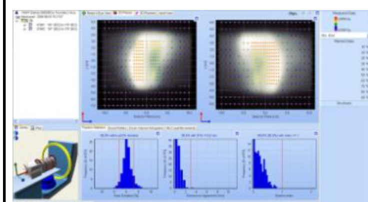
Scandidos Delta4

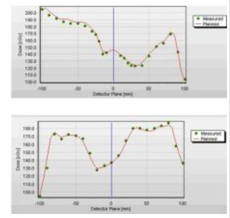
- A cylinder-shaped plastic phantom with 2 imbedded orthogonal crossing detector planes
- 1069 diode detectors
- 5 mm spacing in center and 10 mm spacing at periphery
- Dose is recorded in 2 planes and a 3D dose is reconstructed for comparison with the QA plan



Scandidos Delta4 QA





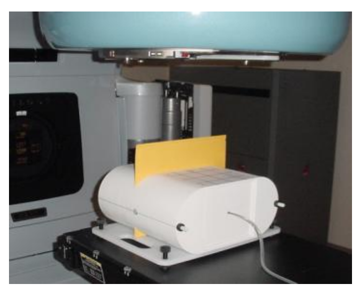


IBA Matrixx

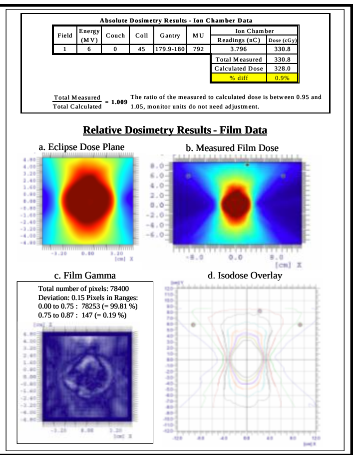
- 2D array of 1020 air vented pixel ion chambers.
- Active area 24.4x24.4 cm^2
- Pixel distance 7.62 center to center
- The cumulative dose is measured using the MatriXX placed in the MULTICube phantom.
- 2D dose distribution can be measured for coronal and sagittal planes.

IBA IMRT/VMAT phantom

Scanditronix-Wellhofer
IMRT QA Phantom
Omnipro Software
CC04 Chamber
EDR Film



Patient-Specific QA Ion Chamber/Film Results



- Absolute dose agreed within 1%.
- > 99% of film pixels had gamma ≤ 1.0 (3% and 3mm).

In VMAT, which of the following linac parameters are allowed to dynamically vary during treatment delivery:

0%	1. Dose Rate.
0%	2. Gantry Speed.
0%	3. MLC Leaf Positions.
0%	4. All of the above.
0%	5. None of the above.

10

Answer

- In VMAT, the dose rate, gantry speed and MLC leaf positions are allowed to dynamically vary during treatment delivery.

Reference:

"Volumetric modulated arc therapy: IMRT in a single arc", Med Phys. 35, 310 (2008).

Rotating gantry IMRT constitute all of the following except:

0%	1. Serial Tomotherapy.
0%	2. Helical Tomotherapy.
0%	3. Intensity Modulated Arc Therapy.
0%	4. Volumetric Modulated Arc Therapy.
0%	5. Step-and-shoot IMRT.

10

Answer

- Serial Tomotherapy, Helical Tomotherapy, Intensity Modulated Arc Therapy and Volumetric Modulated Arc Therapy are all forms of rotating gantry IMRT. Step-and-shoot IMRT is delivered with a fixed gantry.

Reference:

"Intensity-modulated arc therapy: principles, technologies and clinical implementation", Phys Med Biol. 56, R32 (2011).

Which of the following tests are recommended by the AAPM TG-142 report for MLC Annual QA?

0%	1. MLC transmission.
0%	2. Leaf Position Repeatibility.
0%	3. Moving window IMRT test.
0%	4. Segmental (step and shoot) IMRT test.
0%	5. All of the above.

10

Answer

- AAPM TG-142 "Quality Assurance of Medical Accelerators report" recommends that MLC transmission, leaf position repeatibility, moving window IMRT test, segmental IMRT and other tests be performed on an annual basis.

Reference:

"Task group 142 report: Quality assurance of medical accelerators", Med Phys. 36, 4202 (2009)

Which of the following tests are essential during the commissioning of Rapidarc?

0%	1. Accuracy of DMCL position.
0%	2. Ability to vary dose-rate & gantry speed.
0%	3. Ability to accurately vary MLC leaf speed.
0%	4. End to end testing.
0%	5. All of the above.

10

Answer

- During the commissioning of Rapidarc the accuracy of DMLC position, ability to vary dose rate and gantry speed, ability to accurately vary MLC leaf speed and end to end testing are all essential tests.

Reference:

"Commissioning and Quality Assurance of Rapidarc radiotherapy delivery system" Int J Radiat Oncol Biol Phys. 72, 577 (2008).

All of the following devices could be used for VMAT patient specific QA except for:

0%	1. Phantom Laboratory Catphan phantom.
0%	2. Phantom with film and ionization chamber.
0%	3. IBA Matrixx.
0%	4. Sun Nuclear ArcCheck.
0%	5. Scandidos Delta^4.

10

Answer

- All the devices could be used for VMAT patient specific QA except for the Catphan which is an imaging phantom.

References:

"Volumetric modulated arc therapy: effective and efficient end to end patient specific quality assurance", Int J Radiat Oncol Biol Phys. In press (2011).

"Commissioning of volumetric moduated arc therapy (VMAT)", Int J Radiat Biol Phys. 73, 542 (2009).

In Rapidarc treatment delivery average prescription dose loss to target structures from couch attenuation is approximately:

0%	1. 1%
0%	2. 3%
0%	3. 5%
0%	4. 10%
0%	5. 20%

10

Answer

- In Rapidarc treatment delivery average prescription dose loss to target structures from couch attenuation is approximately 3%.

Reference:

“The clinical impact of the couch top and rails on IMRT and arc therapy”, Phys Med Biol. 56, 7442 (2011).