“Commissioning and Quality Assurance of Volumetric Modulated Arc Radiotherapy with RapidArc”

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Overview

1. Introduction

2. Commissioning and QA

   Tests for VMAT

3. Concluding Remarks

1. Introduction

INTENSITY MODULATED RADIATION THERAPY (IMRT)

IMRT delivery

Step & Shoot
- Static Gantry
- Static MLC
- Multiple Fields

Sliding Window
- Static Gantry
- Dynamic MLC
- Multiple Fields

Thomotherapy
- Rotational fan beams
- Slice-by-slice

IMAT
- Dynamic Gantry
- Dynamic MLC
- Multiple Fields

VMAT
- Dynamic Gantry
- Dynamic MLC
- Variable Dose Rate
- Variable Gantry Speed
- Single Field

Reduced treatment time (2min)

1. Introduction

MAJOR QA CONCERNS IN IMRT - MLC

3DCRT

MLC defines dose near the the borders of the critical structures.

- Affects high dose gradient regions
- Variations of leaf speed have no effect on the dose distribution
- No use of closed leaf pairs

DYNAMIC MLC IMRT

Leaves modulate the dose delivered to target volume.

- Dose delivered is sensitive to the gap width defined by each pair

  Average gap error ≤ 0,2 mm for an average dose error < 1%

  (LoSasso et al., 03)
- Leaf speed may influence the dose distribution
- Effect of rounded leaf edge transmission from closed leafs

1. Introduction

VMAT WITH RAPIDARC (Varian Medical Systems)

Both the treatment planning and the linac system incorporate in a single field/arc:

- Dynamic MLC
- Variable dose rate
- Variable gantry speed

- Optimization done using progressive sampling
- Constraints imposed on MLC motion and MU/degree

PLAN

Machine Control Parameters

MLC position as a function of Gantry angle

MLC Controller

Gantry angle as function of cumulative MU

Linac Control System

1. Introduction

PURPOSE

- Clinical implementation of VMAT (from 3DCRT)

2. Commissioning and QA Tests

2.1. Equipment

2.2. Dynamic MLC

2.3. Dose Rate

2.4. Gantry

2.5. RapidArc QA Combined Tests (MLC, Gantry, Dose Rate)

2.6. Treatment Planning System

2.1. EQUIPMENT

LINAC

- LINAC: Clinac DHX (Varian Medical Systems)
- Energy: 6MV

TPS

- TPS: Eclipse (Varian Medical Systems)
- Calculation Algorithm: AAA
- Optimization Algorithm: PRO

2.1. EQUIPMENT

DOSIMETRIC EQUIPMENT

- Ionization chamber: cylindrical 0,125cc (PTW)
- 2D array: seven29 (PTW)
- Film Dosimetry: EBT2 (Standard Imaging) with Epson Scanner 10000XL and RIT 113

PHANTOMS

- CIRS
- Octavius (PTW)
- RW3 Slab phantom (PTW)

2.2. DYNAMIC MLC TESTS

Mechanical

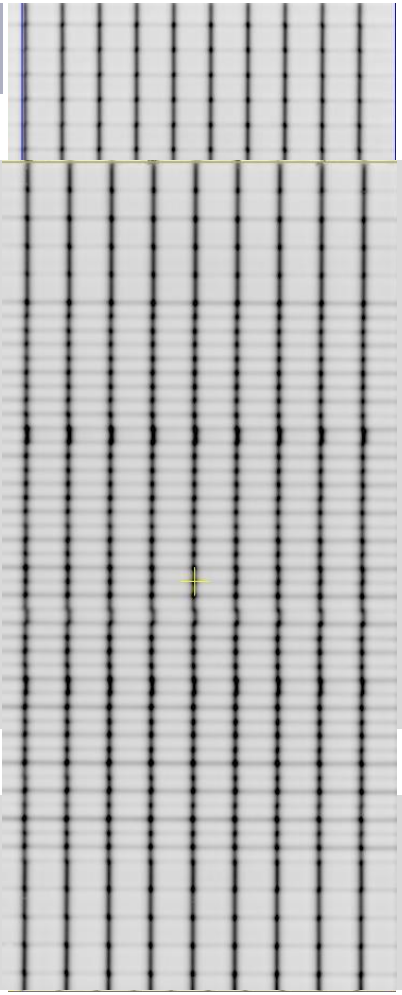
- Leaf positioning/gap width
- Leaf Speed

Dosimetric

- Gap stability
- Dosimetric leaf gap

2.2. DYNAMIC MLC TESTS (LoSasso *et al*, 98, 01, 03)

LEAF POSITIONING/GAP WIDTH



FENCE TESTS

Setup: Film and EPID at isocenter

- Picket Fence, Garden Fence
- Match lines of 1 mm gap
- G=0°/90°/270°
- Introduction of different positionning errors.

Analysis: Visual (0.5 mm)

RIT Software (Position, FWHM , Transmission)

2.2. DYNAMIC MLC TESTS (LoSasso *et al*, 98, 01, 03)

LEAF POSITIONING/GAP WIDTH

SWEEPING GAP:

Setup: 2D array in Octavius at isocenter

- 5 mm sliding window beam creating a uniform dynamic field of 12x27 cm
- Dose normalization to static field
- Center and off-axis (2cm) measurements
- G=0º/90º/270º

Analysis: 2% tolerance (Van Esch et al., 02)

RESULTS (comparing to G=0º)			
Average	**X=0.0 cm**	**X=2.0 cm**	**X=-2.0 cm**
G=90º	0,2%	0,2%	-0,1%
G=270º	1,2%	1,1%	-0,8%

2.2. DYNAMIC MLC TESTS

LEAF SPEED

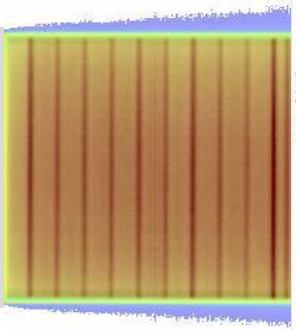
Setup: EPID at isocenter

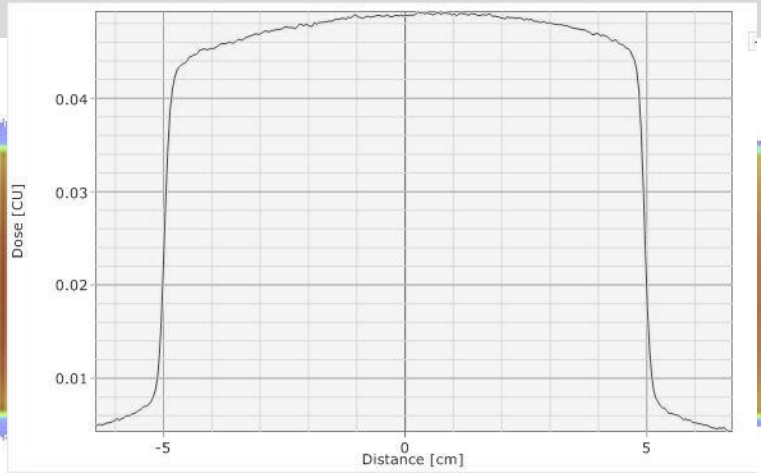
- dMLC plan (sweeping gap 1cm) with all the leaves moving at constant speed.
- Three plans: low (0,4cm/s), medium (1,2cm/s) and high (2.4cm/s) speed.
- Field dimensions of 10x40 cm (C=90º) and 10x30 cm (C=0º).
- G=0º/90º/270º

Analysis: Visual

Profile Uniformity

Dynalog File Viewer





2.2. DYNAMIC MLC TESTS (LoSasso *et al*, 98, 01, 03)

DOSIMETRIC LEAF GAP

Setup: Ionization chamber at isocenter with solid water phantom

• 6 different dMLC fields with fixed leaf gap widths (0.5; 1.0; 2,0; 5,0; 10.0; 20.0 mm) sweeping at constant velocity

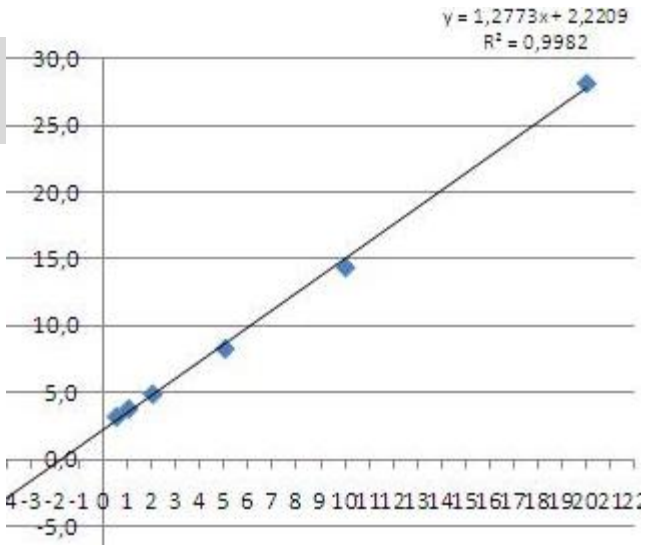
• Total field size of 10x10 cm.

Analysis: Extrapolation to zero dose gives the DLG

Literature:

- 1.9 mm (Sivakumar, S.S. et al., 08)
- 1.8 mm (LoSasso, 03)
- 1.5 mm (Bhardwaj et al., 07)

RESULTS	
DLG	1.7 mm



2.3. DOSE RATE TESTS

- Linearity
- Stability
- Simmetry and Hommogeneity

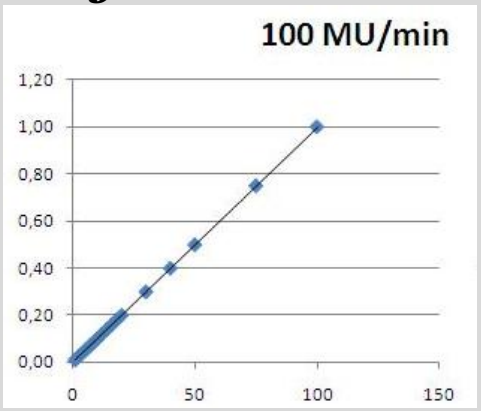
2.3. DOSE RATE TESTS

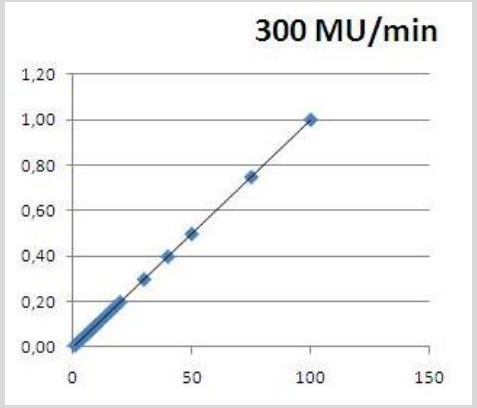
LINEARITY

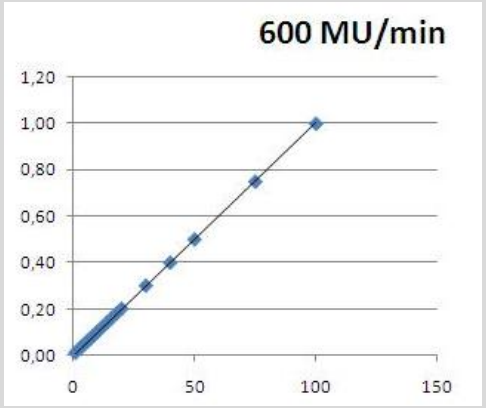
Setup: Ionization chamber at isocenter in solid water phantom

- Irradiation of fields with the same size and increasing MU
- Dose Normalization to Reference Field of 100 MU
- 100 MU/min, 300MU/min and 600 MU/min.

Analysis:







2.3. DOSE RATE TESTS (Yang *et al*, 04)

STABILITY

Setup: Ionization chamber at isocenter in solid water phantom

- Irradiation of different combination of (number of fields, MU) with the same total dose - from 1 field with 100 MU up to 100 fields with 1 MU.
- 100 UM/min, 300UM/min and 600 MU/min.
- Dose normalization to Reference Field of 100 MU
- Dose normalization to Reference Dose Rate of 300 MU/min

Analysis: 2% Tolerance

2.3. DOSE RATE TESTS (Yang *et al*, 04)

STABILITY

RESULTS Dose Normalization to Ref Field				
UM/FIELD	**# FIELDS**	**100 MU/min**	**300 MU/min**	**600 MU/min**
100	**1**	0.0 %	0.0 %	0.0 %
20	**5**	-0.1 %	-0.1 %	-0.2 %
10	**10**	-0.2 %	-0.3 %	-0.5 %
5	**20**	-0.4 %	-0.6 %	-1.1 %
4	**25**	-0.4 %	-0.7 %	-1.3 %
2	**50**	-1.1 %	-1.4 %	-2.2 %
1	**100**	-2.2%	-2.8 %	-5.4 %

RESULTS Dose Normalization to Ref Dose Rate			
UM/FIELD	**# FIELDS**	**100 MU/min**	**600 MU/min**
100	**1**	0.0 %	-0.1 %
20	**5**	0.1 %	-0.2 %
10	**10**	0.1 %	-0.3 %
5	**20**	0.2 %	-0.6 %
4	**25**	0.3 %	-0.7 %
2	**50**	0.3 %	-1.0 %
1	**100**	0.7%	-2.6 %

2.3. DOSE RATE TESTS

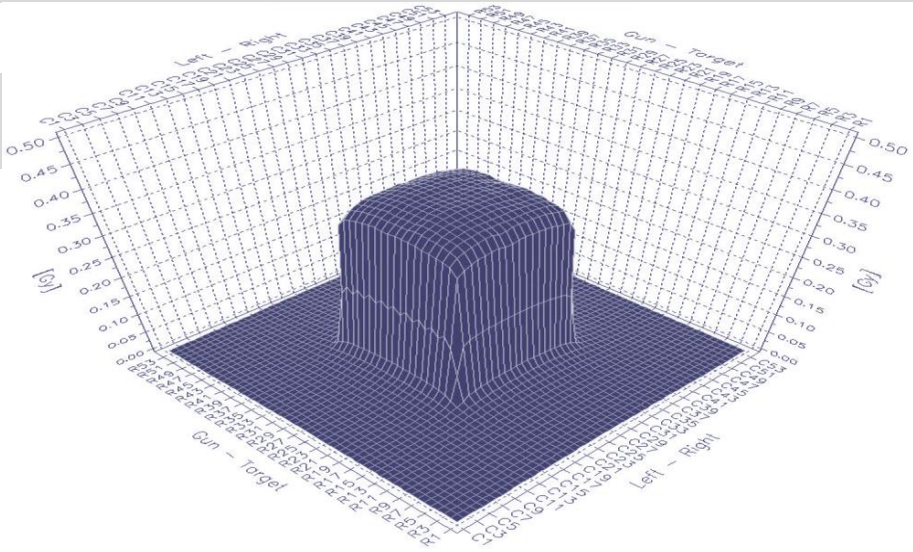
SIMMETRY AND HOMOGENEITY

Setup: 2D array with Octavius phantom

- Irradiation of fields of different sizes (5x5 cm, 10x10cm, 20x20 cm) and increasing MU.
- 100 MU/min, 300MU/min and 600 MU/min.

Analysis: 3% Tolerance

RESULTS
Variation of ± 0.5% relative to 50 MU Field



2.4. GANTRY TESTS

DOSE STABILITY

Setup: Ionization chamber at isocenter with buildup cap

- Dose comparison between G=0º and 360º Arc rotation
- 9 Field dimensions: from 5x5 cm up to 40x40 cm.

Analysis: 1% Tolerance

RESULTS
≤ 0.5%

2.5. RAPIDARC QA COMBINED TESTS

- Picket Fence
- Gantry speed vs Dose Rate vs Output
- MLC Speed vs Output

2.5. RAPIDARC QA COMBINED TESTS

(Ling *et al*, 08)

GANTRY SPEED VS DOSE RATE VS OUTPUT

Setup: EPID at isocenter

- 7 static MLC fields of 20x1.8 cm irradiated with the same dose but different combinations of dose rate(111-600 MU/min) and gantry speed (5.5-4.3°/s).
- Normalization to a static open field.

Analysis:

RESULTS (Central Profile)								
Band	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**MEAN**
Deviation	1.9 %	0.7 %	0.6 %	-0.4%	-1.0 %	-0.8 %	-1.0 %	0.9 %

Literature:

- Mean 0.7 % (Ling et al., 08)

2.5. RAPIDARC QA COMBINED TESTS

(Ling *et al*, 08)

MLC SPEED VS OUTPUT

Setup: EPID at isocenter

- 4 bands of dynamic MLC fields combined different leaf speeds (0.46-2.76 cm/s) with different dose rates to achieve the same dose.
- Normalization to a static open field.

Analysis:

RESULTS (Central Profile)					
Band	**B1**	**B2**	**B3**	**B4**	**MEAN**
Deviation	0.1 %	-0.2 %	0.3 %	-0.2%	0.2 %

Literature:

- Mean 0.4 % (Ling et al., 08)

2.6. TPS TESTS

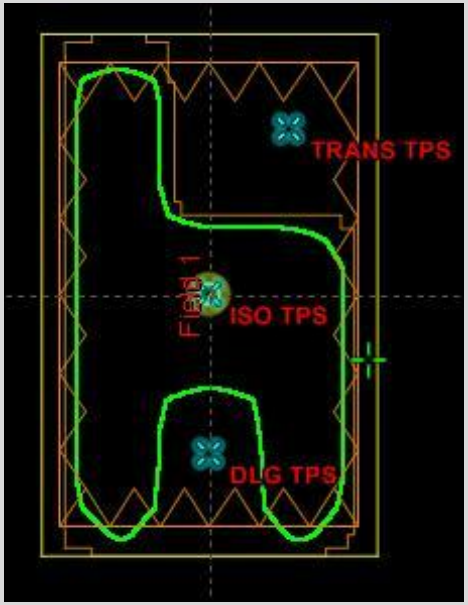
- MLC parameter optimization
- QA RapidArc Test Plans
- Clinical RapidArc Test Plans

2.6. TPS TESTS (Van Esch *et al*, 02)

MLC PARAMETER OPTIMIZATION

Setup: Ionization chamber in water phantom

- Chair-like fluence was created and irradiated
- Measurements at depths: 5 cm, 10 cm and 20 cm
- Measurements at: Homogeneous dose, Transmission and DLG zones
- Comparison of calculated versus measured dose for optimization of MLC transmission and DLG parameters in TPS.



2.6. TPS TESTS (Van Esch *et al*, 02)

MLC PARAMENTER OPTIMIZATION

Analysis: 3% Tolerance

RESULTS			
DEPTH	**ZONE**	**INITIAL**	**FINAL**
5 cm	ISO	-0.8 %	-0.4 %
	TRANS	-10.2 %	0.8 %
	DLG	-7.6 %	-0.6 %
10 cm	ISO	-0.6 %	-0.3 %
	TRANS	-9.7 %	-0.7 %
	DLG	-5.3 %	-0.5 %
20 cm	ISO	-0.8 %	-0.6 %
	TRANS	-2.8 %	-1.8 %
	DLG	-1.2 %	1.6 %

RESULTS		
PARAMETER	**INITIAL**	**FINAL**
TRANS	1,9 %	1,57 %
DLG	1,7 mm	1,4 mm

Literature:

- DLG: 1.9-2.6 mm (Van Esch et al.,02)
- TRANS: 1.5-1.8 % (Van Esch et al.,02)

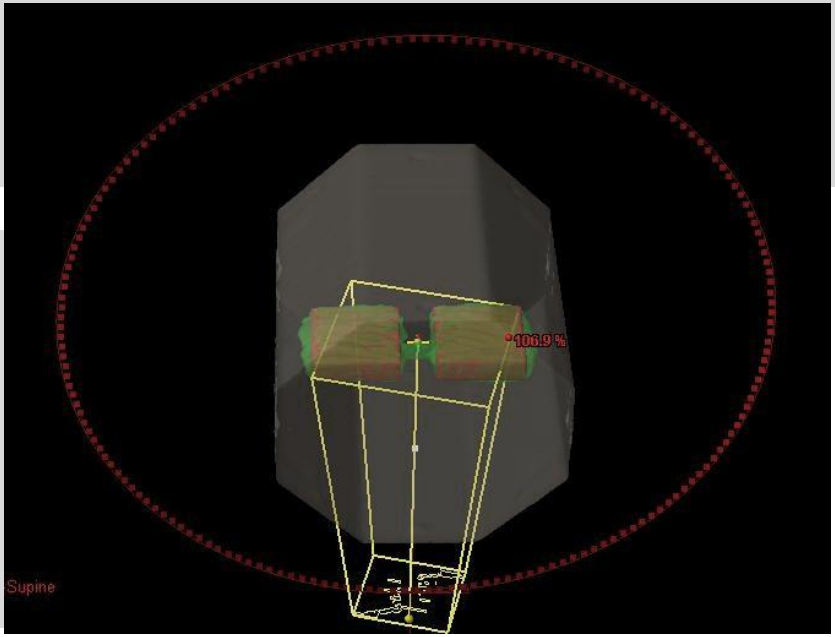
2.6. TPS TESTS (Van Esch *et al*, 02)

QA RAPIDARC TEST PLANS

ACCURACY OF DOSE CALCULATION FOR DIFFERENT VOLUMES

Setup: 2D array with Octavius

- 2 adjacent target volumes.
- Plan 1 – targets with the same dose
- Plan 2 – targets with different doses



Analysis: Gamma analysis (3%, 3mm)

RESULTS		
PLAN	**% γ < 1**	**Mean γ**
1	99.7 %	0.40
2	99.7 %	0.37

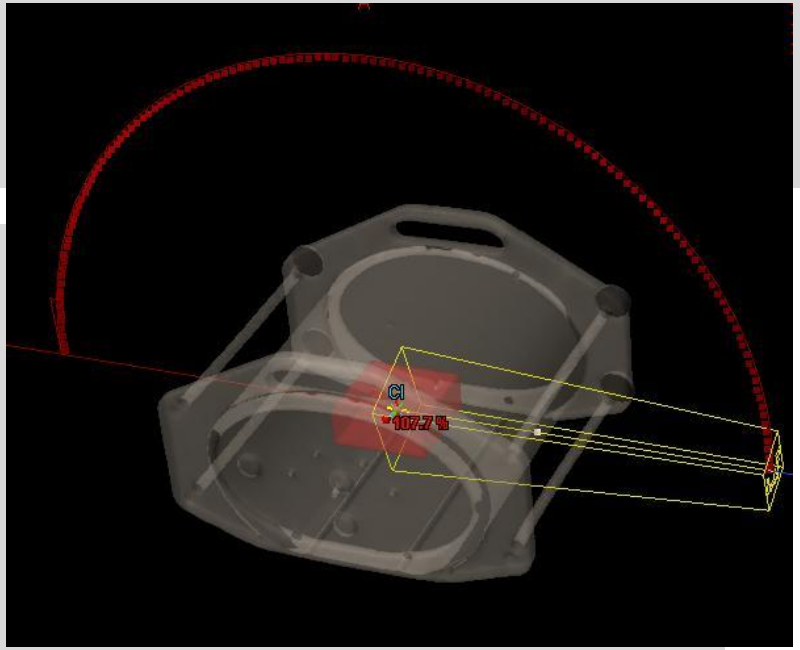
2.6. TPS TESTS (Van Esch *et al*, 02)

QA RAPIDARC TEST PLANS

ACCURACY OF DOSE CALCULATION WITH HETEROGENEITIES

Setup: Ionization chamber with CIRS phantom (air insert)

- Single target with homogeneous dose.
- Target Sizes: 5x5 cm; 5x10 cm; 5x20 cm.
- Arc: 90º to 270º to exclude couch.



Analysis: 3% Tolerance

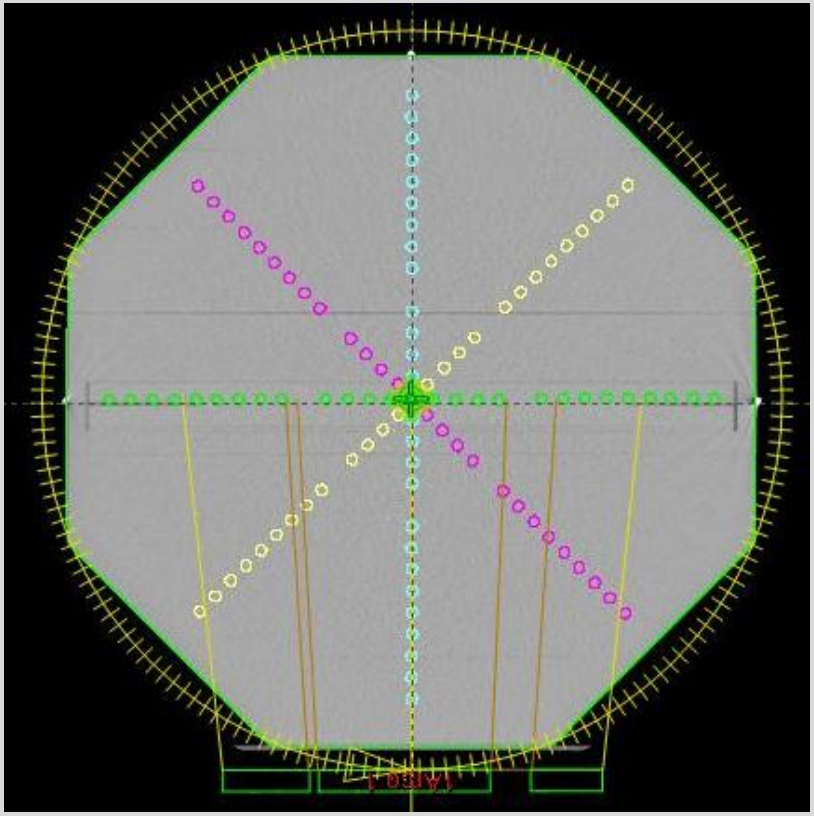
RESULTS			
PLAN	**5x5**	**5x10**	**5x20**
Dose Difference	2.2 %	2.1 %	2.2 %

2.6. TPS TESTS

CLINICAL RAPIDARC TEST PLANS

Setup: 2D array, ionization chamber and EBT2 film with Octavius

- Single arcs exported from hypothetical patient plans onto phantoms.
- Ion chamber (low dose gradients) and 2D array used for **absolute dosimetry**.
- Film used for **relative dosimetry**.



2.6. TPS TESTS

CLINICAL RAPIDARC TEST PLANS

Analysis: Gamma analysis (3%, 3mm, 20% threshold)

3% for absolute dosimetry with ion chamber

RESULTS					
PLAN	**I.C.**	**FILM**		**2D ARRAY**	
		% γ < 1	**Mean γ**	**% γ < 1**	**Mean γ**
1	-0.9 %	97.6 %	0.41	95.4 %	0.41
2	-0,1 %	99.3 %	0.35	97.4 %	0.38
3	1.8 %	99.7 %	0.34	100.0 %	0.34
4	0.1 %	99.4 %	0.33	96.6 %	0.41
5	-1.0 %	98.2 %	0.42	96.6 %	0.45
6	1.7 %	99.9 %	0.38	99.3 %	0.34
AVERAGE	0.3 %	99.0 %	0.37	97.6 %	0.39

Literature: ≤ 3% ≥ 95%/90% ≥ 95%

3. Concluding Remarks

MAIN QA TESTS

Daily:

- Continuous Stripes
- MLC Speed
- RA QA Combined tests

Monthly:

- Sweeping gap

Patient:

- Ion chamber
- 2D array
- Film

MAIN QA CHALLENGES

MLC:

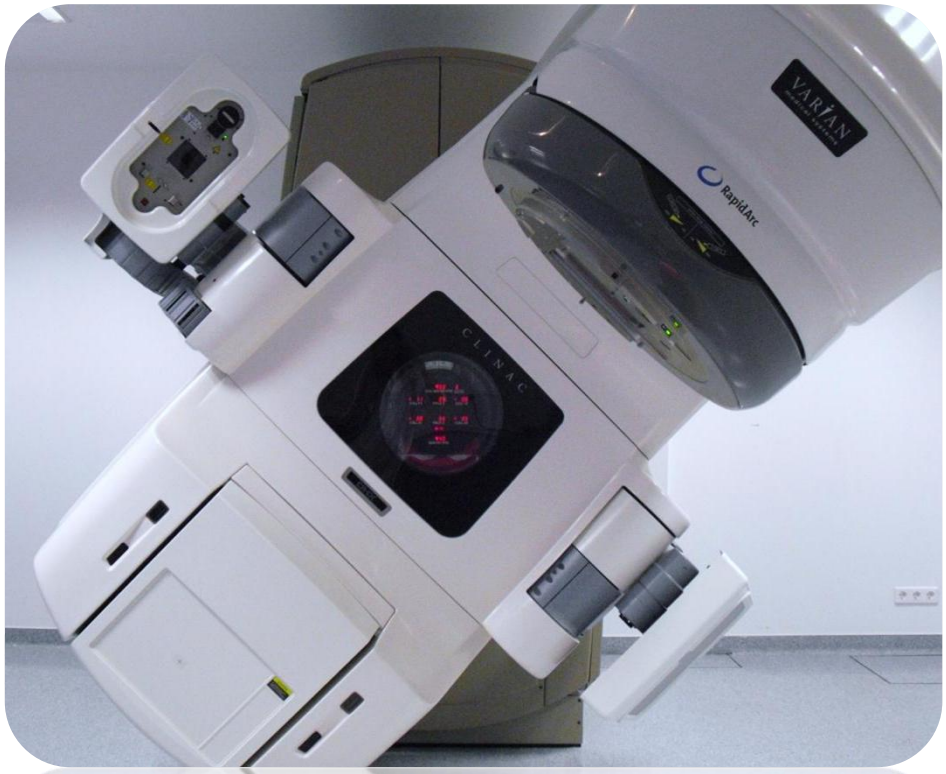
- Time consuming when done quantitatively to every leaf
- More studies needed with dynalog file viewer analysis

Gantry Speed:

- No standard tests to evaluate gantry speed (apart from Ling *et al.*,08)

3. Concluding Remarks

VMAT was implemented successfully in clinical practice.



Thank you