ARCCHECK: COMPREHENSIVE EVALUATION OF THE DIODE ARRAY PHANTOM - RULES OF THUMB FOR PHANTOM USE FOR QA

By

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Conflicts of Interest:

None, that author is aware of

Disclosures:

This work of conducted with my role as a ‘volunteer medical physicist’ as an independent researcher and collaborator with OSU James CC.

A detailed journal paper in JACMP is accepted for publication in JACMP (Feb-18-2014):

(V.Chaswal, Michael Weldon et. al., “Comprehensive Commissioning and Evaluation of the ArcCheck cylindrical diode array for VMAT patient pre-treatment delivery QA.”)

Why Test?

- New software and hardware upgrades
- Relatively less literature on device's characteristics
- Prior studies* reported:

  => angular and directional dependencies

  => field size dependencies

  => limitation for dosimetry of fixed arcs due to peripheral placement of all the detector diodes (miserable failures of narrow arcs dosimetry, as low as, globaly(3%/3mm)<5%)

"device's capability to catch realistic and clinically relevant dose errors is a subject of future work."

*(Feygelman V et al 2011, Kozalka J et al 2011, Neilson C et al 2013)

Why test?

- To set limits on VMAT patient QA results
- Publish a comprehensive “procedures and testing results” document for the Medical Physics Community to refer.
- To understand the device’s nature before its deployment as a primary QA tool for VMAT at OSU – know its mind!

Testing: Materials

- Linac: TrueBeam™ STx accelerator (Varian Medical Systems, Palo Alto, CA)
- Beam Energy: 6 MV beam with and without flattening filter
- Phantom: ArcCHECK phantom (Console version 1.6)
- Axilliary Software: SNC Patient (version 6.2.3)
- Varian Eclipse treatment planning system (TPS) was used (version 10.0.39)
- Reference dose grids: symmetric 3D dose grid size of 2 mm x 2 mm x 2 mm with angular resolution for both conformal arc and VMAT is set to 4 degree.

Evaluation Testing

- Linac dose rate dependency
- Instantaneous dose rate response of the diode,
- Radiation field size dependency
- Angular dependency
- Couch insertion dependency
- Scatter dose characterization
- Stability and consistency of response
- Symmetry of response
- Dosimetry accuracy for fixed arcs and
- Dosimetry accuracy of VMAT patient plans.

Measurement Geometry

- ArcCHECK phantom set in SAD geometry for all measurements
- Central plug inserted, PMMA density assigned
- Measurements made for 6MV and 6FFF beam

Analysis

Procedures:

- Composite gamma analysis 3%/3mm and 2%/2mm global and local gamma comparisons of TPS reference dose grids with ArcCHECK measured dose grids, using 10% LD threshold

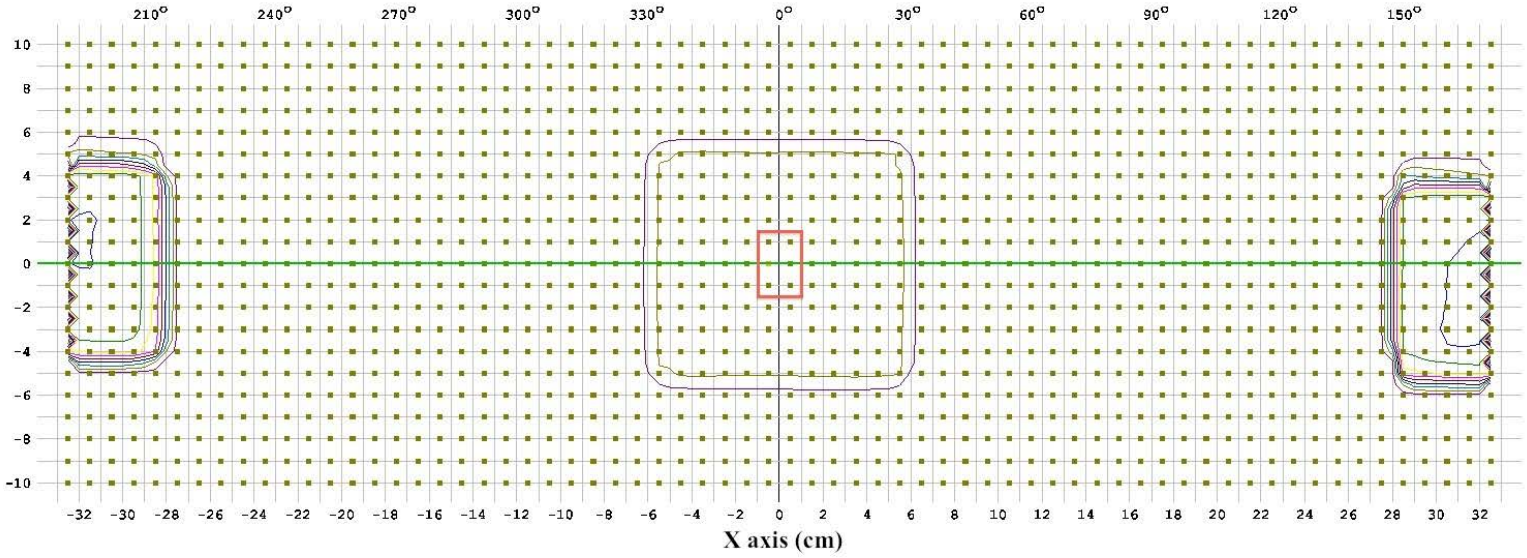
- Diode by Diode absolute dose comparison by looking at ‘same co-ordinate diode(s)’ in the TPS and SNC Patient SW:
    - average dose from 6 central diodes
    - LHS diode versus RHS diode versus TPS
    - diodes at off-axis distances etc

I. Linac dose rate dependency: set-up

- 10x10 cm^2 field size, 100 cm SAD geometry
- 50 MU for 6X and 100 MU for 6F
- 6X dose rates tested (MU/min): 20, 40, 200, 400, 600
- 6F dose rates tested (MU/min): 600, 800, 1000, 1200, 1400

I. Linac dose rate dependency: Analysis

Comparison of measured dose with reference dose using average dose from 6 central diodes



I. LINAC DOSE RATE DEPENDENCY: RESULTS

- The dose output measured by ArcCHECK diodes is stable (within 1%) over the whole range of dose rates (20–600 MU/min for 6X and 600–1400MU/min for 6F beam).

Rule(s) of Thumb (RoT) for QA:

ArcCHECK shows No significant linac dose-rate based dependency.

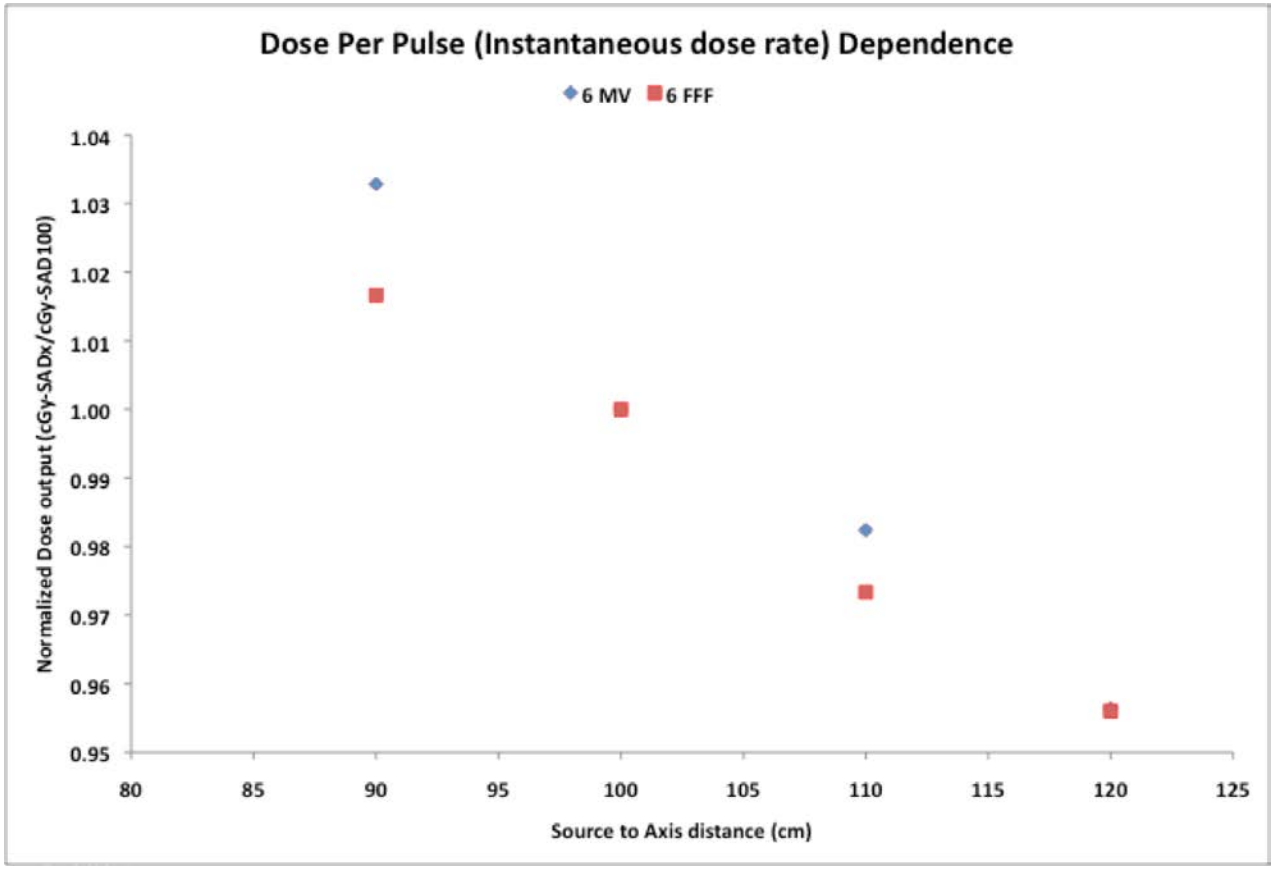
=> Dose output stays stable for different dose-rates

II. Instantaneous dose rate response of the diode

- 10x10 cm^2 field size, on a varying SAD geometry (90, 100, 110, and 120 cm), 100MU for both 6X and 6F energies

- Analysis: comparison of measured dose with reference dose using average dose from 6 central diodes

II. Instantaneous dose rate response: Result



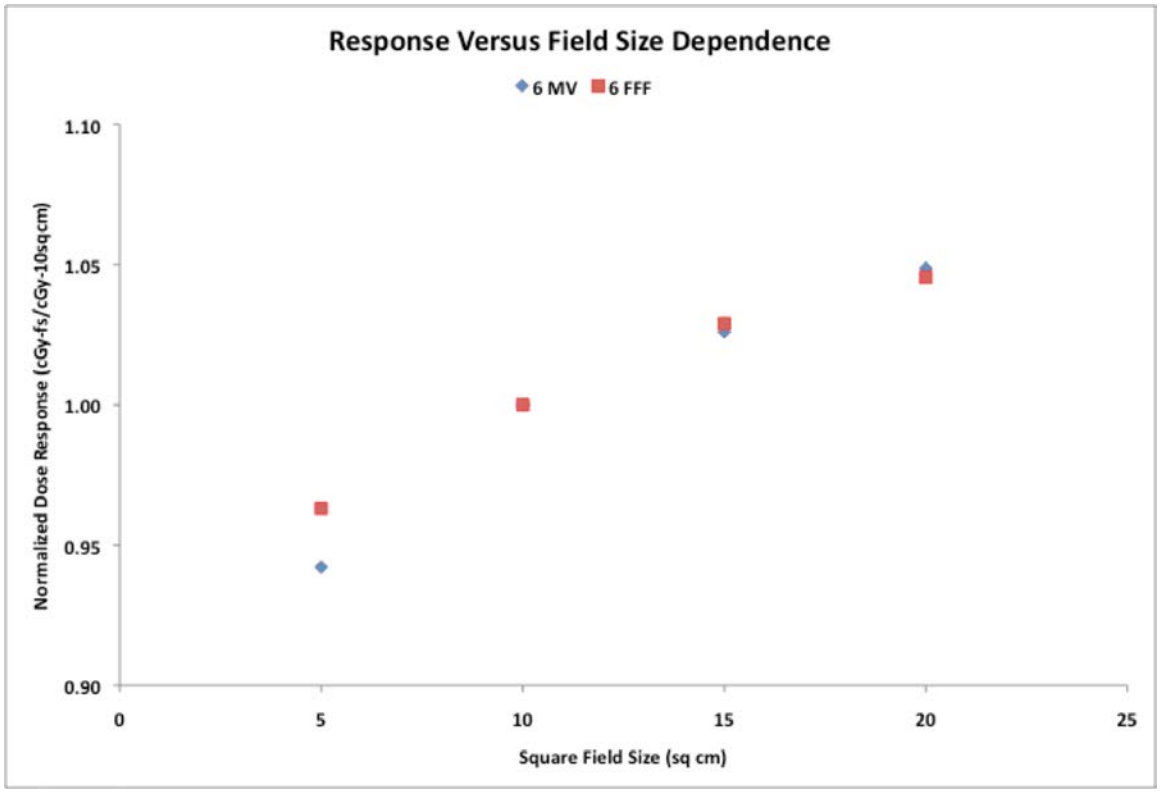
RoT:

- Diodes over-respond (under-estimate dose) when ArcCHECK closer to the radiation source, by nearly 0.3%/cm on an average
- Diodes Under-respond (over-estimate dose) when farther by nearly 0.15%/cm

III. Radiation field size dependency

- 100 cm SAD geometry and 100 MU delivery for four static field sizes (5x5, 10x10, 15x15 and 20x20 cm^2)
- Analysis: comparison of measured dose with reference dose using average dose from 6 central diodes

III. Radiation field size dependency: Results



RoT:

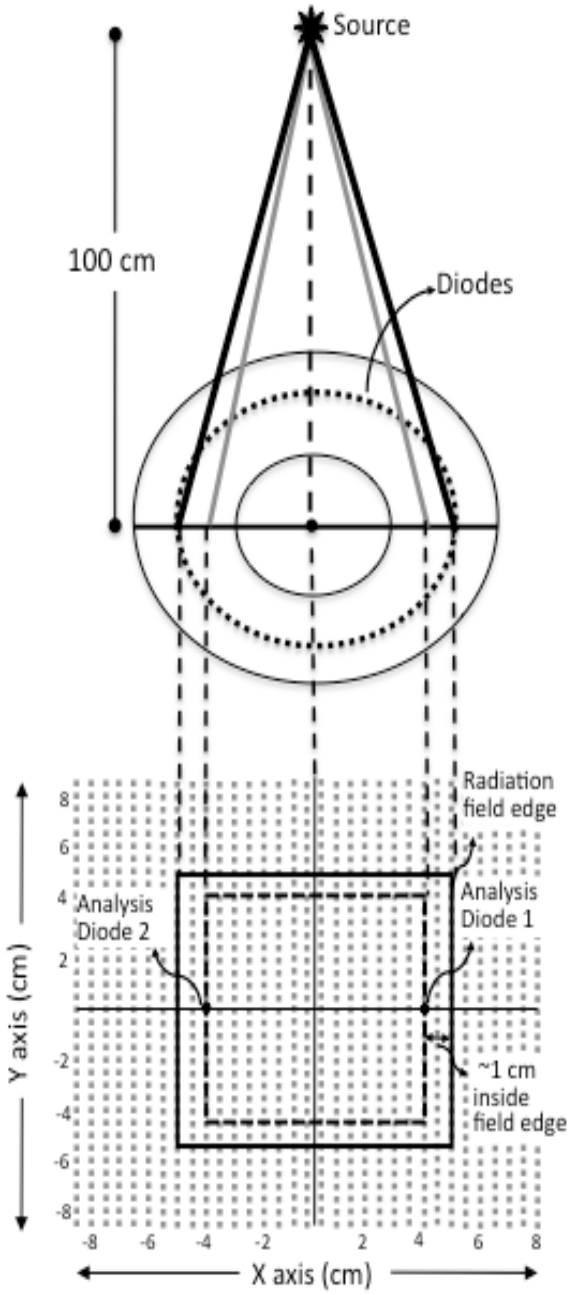
No significant field size based dependence.

Measurements match TPS within 1%

	$\gamma(3\%/3mm) \leq 1$		$\gamma(2\%/2mm) \leq 1$	
	global	local	global	local
6X	99.88%	92.13%	98.13%	84.15%
6F	98.90%	88.85%	97.43%	85.65%

Beam angle dependency

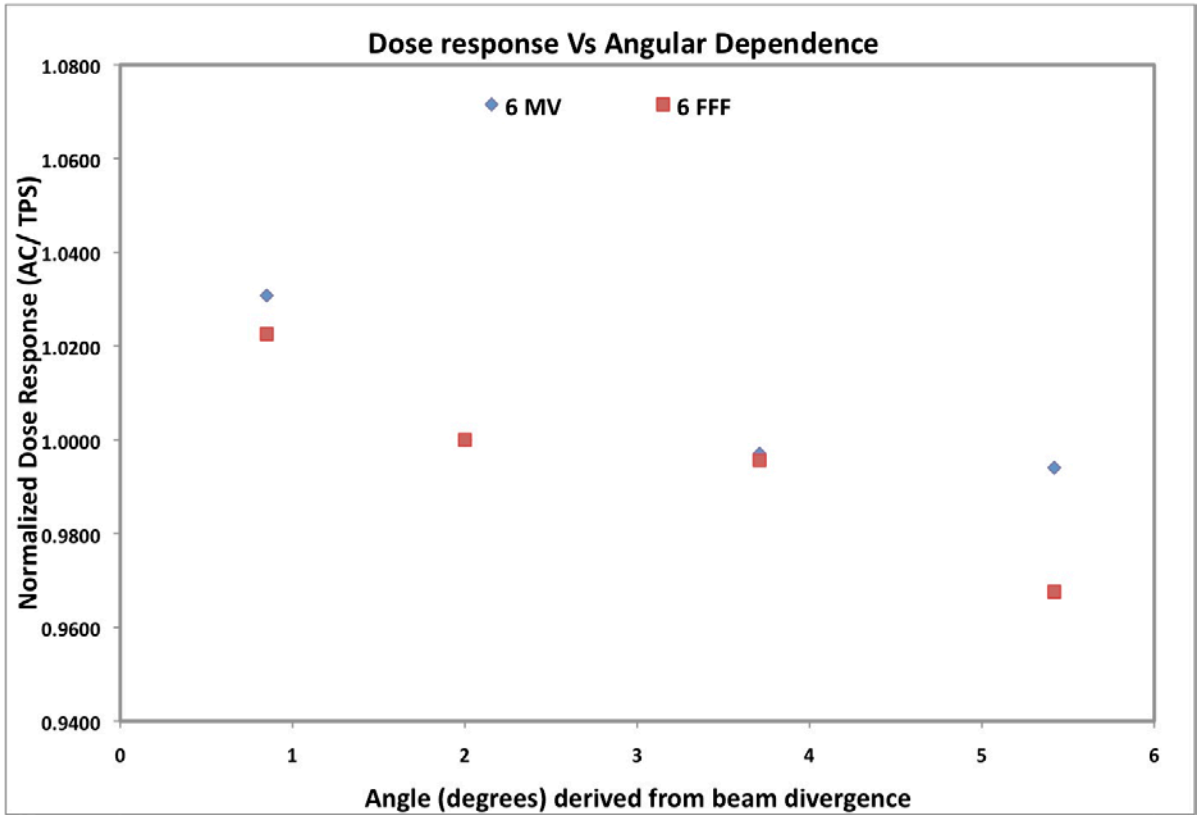
- Dose data derived from FS data using beam's divergence angle
- Considers angles ranging between 0.86° to nearly 6°
- These angles comprise the full range of the clinically significant BEV-diode based geometry



Beam angle dependency: Analysis

Data analysis using diode by diode based comparison.

Beam angle dependency: Results



RoT:

- New correction factors for angular dependence work;
- Within 0.86° to 6° beam incidence, the difference from TPS is ~ 3%

Couch insertion dependency

Measurements using a 10x10 cm^2 arc delivery compared with the dose calculated in the TPS with and without the couch insertion

Result: γ(3%/3mm) increased from 89.5% to 100%, and γ(2%/2mm) increased from 73.1% to 95.5%, when couch was inserted

RoT:

Always perform dose calculations in the TPS with the couch ROI contoured.

Scatter dose characterization

- Diodes over-respond to low energy photons
- measured for varying amount of scatter derived from irradiations of field sizes of 5x5, 10x10, 15x15 and 20x20 cm^2 field sizes
- at distances varying between 1 cm to 8 cm from the field's edge
- both axial and transverse directions.

Table 4: Out of field scatter response of ArcCHECK diodes compared with TPS calculated scatter for 6X beam.

Out of field distance (cm)	Axial scatter measurements			Transverse scatter measurements		
	Diode (cGy)	TPS (cGy)	% diff	Diode (cGy)	TPS (cGy)	% diff
6 MV, 5x5 cm^2						
1	1.99	1.42	40.1	2.23	1.47	51.7
2	1.60	1.16	37.9	1.42	0.81	75.3
4	0.69	0.51	35.3	0.69	0.43	60.5
6 MV, 10x10 cm^2						
1	4.28	3.58	19.6	3.48	2.55	36.5
2	3.07	2.46	24.8	2.51	1.95	28.7
4	2.00	1.69	18.3	1.46	1.20	21.7
8	1.31	1.10	19.1	-	-	-
6 MV, 15x15 cm^2						
1	7.06	6.25	13.0	3.86	3.84	0.5
2	5.47	4.55	20.2	2.62	2.60	0.8
5	3.60	3.30	9.1	-	-	-
8	3.04	2.94	3.4	-	-	-

6MV SCATTER CHARACTERIZATION

RoT:

- Always an over response as compared to the TPS

- as high as 13% to 40%, at 1 cm from field edge

-Eclipse under-estimates Out of field doses

-Scatter doses may differ from TPS, but may not be drastically different from actual doses

-Be vary of conclusions you make!

Table 5: Out of field scatter response of ArcCHECK diodes compared with TPS calculated scatter for 6F beam.

Out of field distance (cm)	Axial scatter measurements			Transverse scatter measurements		
	diode (cGy)	TPS (cGy)	% diff	Diode (cGy)	TPS (cGy)	% diff
6 FFF 5x5 cm^2						
1	3.72	2.63	41.4	3.22	3.08	4.5
2	2.43	1.63	49.1	1.92	1.53	25.5
4	1.41	0.92	53.3	1.11	0.59	88.1
10	0.68	0.41	65.8	-	-	-
6 FFF, 10x10 cm^2						
1	7.45	5.71	30.5	5.25	3.18	65.1
2	5.46	3.89	50.4	3.65	2.18	67.4
4	3.65	2.68	36.2	2.16	1.16	86.2
8	2.48	1.81	37.0	-	-	-
6 FFF, 15x15 cm^2						
1	11.37	9.22	23.3	6.04	3.53	71.1
2	7.67	7.84	-2.2	3.93	2.14	83.6
5	5.94	4.80	23.8	-	-	-
8	5.11	4.36	17.2	-	-	-

6FFF SCATTER CHARACTERIZATION

RoT:

- Always an over response as compared to the TPS

- as high as 23% to 40%, at 1 cm from field edge

-Eclipse under-estimates Out of field doses

-Scatter doses may differ from TPS, but may not be drastically different from actual doses

-Be vary of conclusions you make!

Stability and consistency of response

- A continuing procedure
- Measurements acquired using static 10x10 cm^2 fields at four cardinal angles

- Two-fold benefit:

  a) dosimetric set-up accuracy testing and

  b) device constancy measurements

Result: global-γ(3%/3mm) = 100% over 4 months of measurements! ☺

Symmetry of response

- Classic phantom flip test
- Irradiations using wide open arcs are used
- Two wide field arcs of field sizes 10x25 cm^2 and 25x25 cm^2, each spanning 358°, are used in the detector flip test, 400 MU/arc are delivered while phantom in SAD set-up

Symmetry of response: Result

Arcs	γ(3%/3mm) ≤ 1		γ(2%/2mm) ≤ 1	
	global	local	global	local
10x25 arc	99.9%	99.9%	98.3%	98.1%
10x25 arc flip	99.8%	99.8%	97.6%	97.5%
25x25 arc	99.8%	99.6%	95.6%	95.0%
25x25 arc flip	99.6%	99.4%	94.5%	94.0%
Average	99.8%	99.7%	96.5%	96.2%
Std Dev	0.13	0.22	1.76	1.96

RoT:

- Highly axially-symmetric response over long axis
- On a busy evening when you set the phantom the wrong side in, don't pull your hair! Not worth it.

DOSIMETRY ACCURACY FOR FIXED NARROW ARCS

Arcs	6MV γ(3%/3mm) ≤ 1		6MV γ(2%/2mm) ≤ 1		6 FFF γ(3%/3mm) ≤ 1		6 FFF γ(2%/2mm) ≤ 1	
	global	local	global	local	global	local	global	local
Narrow width arcs								
2x10	75.0%	-	59.2%	-	89.9%	-	69.9%	-
3x10	87.9%	-	52.5%	-	96.1%	-	68.1%	-
5x5	96.1%	80.3%	75.0%	66.4%	99.9%	90.0%	88.2%	80.0%

RoT:

- Narrow arcs have limited dosimetry accuracy, more chances of a failed or just pass plan
- One dimension< 5 cm is a narrow arc

Dosimetry accuracy: wide open arcs

Arcs	6 MV γ(3%/3mm) ≤ 1		6 MV γ(2%/2mm) ≤ 1		6 FFF γ(3%/3mm) ≤ 1		6 FFF γ(2%/2mm) ≤ 1	
	global	local	global	local	global	local	global	local
5x10	99.9%	77.2%	76.5%	63.9%	99.3%	84.3%	77.8%	74.8%
10x10	100%	81.7%	95.5%	75.5%	100.0%	99.9%	85.1%	84%
10x25	99.9%	99.9%	98.3%	98.1%	100.0%	99.9%	98.1%	97.0%
5x25	99.9%	99.9%	94.1%	93.6%	91.6%	88.5%	67.0%	63.6%
25x25	99.8%	99.6%	95.6%	95.0%	98.6%	95.9%	80.7%	74.0%
Average	99.9%	95.3%	95.9%	90.6%	99.5%	98.6%	88%	85.5%
Std Dev	0	0.09	0.02	0.10	0.01	0.03	0.09	0.16

RoT:

High dosimetry accuracy demonstrated by both local and global gamma passing rates at 3/3 and 2/2 levels

Dosimetry accuracy: VMAT patient plans

Plan	6 MV		6 FFF	
	γ(3%/3mm)	γ(2%/2mm)	γ(3%/3mm)	γ(2%/2mm)
Brain (4 Arcs)	96.1%	91.0%	98.3%	93.3%
RTOG0933 (2 Arcs)	99.9%	97.4%	99.9%	98.3%
Scalp (3 Arcs)	98.5%	92.0%	99.4%	97.2%
RPC-HN (2 Arcs)	94.7%	86.3%	99.0%	95.7%
RPC-Spine (4 partial Arcs)	91.1%	76.6%	97.9%	91.6%
Average	96.1%	88.7%	98.9%	95.2%
Std Dev	3.4	7.8	0.8	2.8

- All Plans a clinical pass
- RoT: 6FFF has greater passing rates than 6 MV
- Why RPC-spine and HN case low at 2%/2mm?

Thank You!!