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IMRT and VMAT Patient Specific QA Using 2D and "3D" Detector Arrays

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Outline

- Why IMRT/VMAT QA
- AAPM TG218 UPDATE
 - Tolerance Limits and Methodologies for IMRT Verification QA
- Common sources of error
- The ideal dosimeter
- Patient specific QA devices available
- IMRT QA evaluation considerations
- In the era of 3D...

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IMRT/VMAT QA, Why?

- Higher complexity of planning, calculation and delivery compared to 3DCRT
- "...there is evidence that IMRT treatments may not always be as accurate as practitioners believe." (AAPM TG 119)
- "IMRT doses are calculated by dividing beams into smaller sections, called *beamlets*, that have varying intensities. Because the dimensions of the beamlets may be too small to establish electronic equilibrium within them, calculations based on corrections to broad-beam data will not suffice." (Medical Physics, Vol. 30, No. 8, pp. 2089–2115)

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IMRT/VMAT QA, Why?

We need to know if the plan delivered is an accurate representation (dosimetricaly) of the calculated plan

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The (common) IMRT QA process

- IMRT/VMAT patient plan is approved.
- Plan parameters are copied to a phantom (Verification Plan)
- Plan is recalculated on the phantom geometry.
 - Beams can remain as planed for the verification plan (composite verification plan)
 - Beams can be arranged to remove gantry, collimator and table angle. (field-by-field verification)
- Calculated dose for a known plane location is exported.

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The (common) IMRT QA process

- The phantom is setup
- Delivery of the plan
- Acquisition of the dose at the specified plane
- Comparison of the calculated and measured planar doses.
- Evaluation/Decision

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The ideal dosimeter should:

- Be accurate
- Be precise
- Show a linear response to dose
- Have minimal variation with radiation quality
- Have minimal variation with absolute dose
- Have minimal variation with dose rate
- Have minimal directional dependence
- Have a high spatial resolution

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Detectors

- Vented parallel plate ionization chambers
- Diodes
- Liquid ionization chambers

Angular dependence

- Almost all detector arrays experience angular dependence.
- Solutions
 - Use inclinometer and internal angular dependence corrections
 - Manufacture phantoms that account for the problem
 - Irradiate only perpendicular to the detector



Shimohigashi et al. JACMP, VOLUME 13, NUMBER5, 2012

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Absolute Dose

- Vented IC
 - Can be calibrated and measure absolute dose
- Diodes
 - Need cross calibration
- Liquid Filled IC
 - Need cross calibration



Energy Dependence

- Diodes experience energy dependence
- Solution
 - Use of separate calibration files
- Ionization chambers have minimal energy dependence

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Failed IMRT/VMAT QA

- Device Setup errors/phantom setup errors
- Exported planar dose of the wrong plane or orientation (sagital instead of coronal)
- If TPS does not export using Patient name planar doses can be mixed
- Exclusion of the couch can introduce errors.
- Detector was not warmed up
- Detector was used with a different machine user factor
- Detector was not calibrated correctly

Failed IMRT/VMAT QA

- Wrong calibration curve was used (film/diodes)
- Detector does not have up to date calibration
- Incorrect tolerance criteria
- Connectivity issues
- Dose gradients too steep for detector resolution

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Failed IMRT/VMAT QA

- Re-measure
- Re-export
- Re-evaluate
- Re-Setup

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- Re-measure
- Re-evaluate





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Characteristics						
	V	40000		a de		
	Sun Nuclear	PTW		IBA		
	MapCheck2	1500	1000SRS	MatrixX		
Detector type	Diode	Vented IC	PP-liquid filled	Vented IC		
Resolution(mm)	7.07	10	2.5/5	7.62		
# of Detectors	1527	1475	977	1020		
Max field size	26x32	27x27	11x11	24.4x24.4		
Weight kg (detector/phantom)	7.1 (21)	5.4 (24/29)	5.4 (24/29)	10 (19.8)		

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Characteristics

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	Sun Nuclear	PTW	Scandidos
	ArcCheck	OCTAVIUS 4D	Delta ⁴
Detector type	Diode	Vented IC/PP Liquid filled	Diode
Resolution(mm)	10	10/2.5-5	5/10
# of Detectors	1386	729/977	1069
Max field size	27	24 / 11	20
Weight kg (detector/phantom)	16	5.4 / 29	24



Patient specific QA

	ArcCheck	OCTAVIUS 4D	Delta ⁴	MapCheck	PTW 1500	OCTAVIUS1000 SRS	MatriXX
Field by Field*	8	8	8	\$	8	\$	8
Composite (static gantry)	6	\$	\$	6	2	5	6
"True" Composite*	6	8	8	89	59	\$ 9	\$?
VMAT	6	\$	\$	94	00	00	00

 ${\mathbin{\mathring{\diamond}}}\,{\mathbin{\P}}$ with a dedicated phantom

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From Approved Plan to Verification Plan

At the TPS...

- TPS calculated verification plan on phantom
- Extraction of planar dose at the level of the detector
- Delivery of the plan to the phantom
- Comparison of measurement vs. calculated planar doses





<image>





Scandidos Delta⁴















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CTRC experience - Field by Field analysis

CTRC experience - Composite plan analysis





CTRC experience – RA Comparison 2D planar dose, 3%-3mm,10% threshold

Dationt #	SITE	FILM		PTW	Scandidos
Patient #				Seven29	Δ4
1	Brain	91.7	99.8	94.5	98.8
2	Brain	99.3	99.2	98.9	99.8
3	H&N	94.4	98.8	95.8	99
4	Liver	100	100	99.8	99.8
5	Lung	99.6	95.7	98.7	99.2
6	Lung	99.9	97.9	99.9	98.1
7	Prostate	94.9	98.3	96.0	97.2
8	Prostate	98.8	97.9	97.9	98.1
9	Prostate	94.2	96.2	96.8	98.1
10	Prostate	94.0	97.5	96.2	98.4
11	Prostate	98.4	98.4	97.8	96.5
12	Prostate	99.1	95.1	98.4	97.9
13	Prostate	92.9	96.7	99.4	97.4
14	Prostate	99.2	98.9	99.8	98.9
15	Spine	96.8	96.2	98.7	99.3
	Average	96.9	97.8	97.9	98.4

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How to pass IMRT QA

Considerations for IMRT QA evaluation

Uncertainties - From AAPM TG218

- "There are many sources of uncertainty in IMRT planning and delivery."
- In terms of treatment planning, the uncertainties include:
 - MLC leaf end modeling (MLC systems),
 - MLC tongue and groove effect,
 - leaf/collimator transmission,
 - collimators/MLC penumbra modeling,
 - compensator systems (scattering, beam hardening, alignment),
 - output factors for small field sizes,
 - head backscatter,
 - dose calculation grid size,
 - off-axis profiles and
 - heterogeneity corrections.

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Uncertainties - From AAPM TG218

- Spatial and dosimetric uncertainties of the delivery systems also have effects on IMRT dose distribution delivery accuracy.
- These uncertainties include:
 - MLC leaf position errors (random and systematic),
 - MLC leaf speed acceleration/deceleration,
 - Gantry rotational stability,
 - Table motion stability, and
 - Beam stability (flatness, symmetry, output, dose rate, segments with low MUs).

Uncertainties - From AAPM TG218

- Another source of uncertainty among clinics using measurement-based patient-specific IMRT QA programs are the measurement and analysis tools used to interpret the QA results.
- These software tools have several parameters that must be chosen to perform the analysis and the results can vary significantly depending on those choices.
- <u>One example is the selection of whether to use</u> <u>global or local dose normalization to compare</u> <u>measured and calculated dose distributions</u>.



- Global normalization should be used.
 - Local normalization is more stringent than global normalization for routine IMRT QA. It can be used during the IMRT commissioning process and for troubleshooting IMRT QA.
- The dose threshold should be selected to exclude low dose areas that have no or little clinical relevance

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From AAPM TG218-recommendations

- IMRT QA, tolerance limits, and action limits
 - Perpendicular field-by-field (PFF)
 - Perpendicular composite (PC)
 - True Composite (TC)
 - <u>This method most closely simulates the</u> <u>treatment delivery to the patient.</u>

- IMRT QA measurements should be performed using the TC delivery method
- IMRT QA measurements should be performed using the PFF delivery method if the QA device is not suitable for TC measurements.
- IMRT QA measurements <u>SHOULD NOT</u> be performed using the PC delivery method which is prone to masking delivery errors.
- Analysis of IMRT QA measurements and the corresponding treatment plan should be performed in absolute dose mode
- A dose calibration measurement compared against a standard dose should be performed before each measurement session to factor the variation of the detector response and accelerator output into the IMRT QA measurement.

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From AAPM TG218-recommendations

- Tolerance limits: the γ passing rate should be ≥ 95%, with 3%/2mm and a 10% dose threshold.
- Action limits: the γ passing rate should be ≥ 90%, with 3%/2mm and a 10% dose threshold.
- Tighter criteria should be used, such as 2%/1mm or 1%/1mm to detect subtle regional errors
- A dose threshold below 10% should be considered if the critical structure dose tolerance is less than 10% of the prescription dose (e.g. IMRT re-irradiation cases) or the low dose region is clinically relevant.

- For IMRT QA performed with an IC and film, tolerance and action limits for the ion chamber measurement should be within ≤ 2% and ≤ 3%, respectively, and the film γ passing rate limits should be assessed as specified above.
- The IMRT treatment process should be monitored and thoroughly investigated if the γ passing rate is systematically lower than the tolerance limits and higher than the action limits.

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From AAPM TG218-recommendations

- For any case with γ passing rate less than 100%,
 - the γ distribution should be carefully reviewed rather than relying ONLY on distilled statistical evaluations,
 - review of γ results should include other relevant γ values (maximum, mean, minimum, median), as well as a histogram analysis.
 - an analysis of the maximum γ value and the percentage of points that exceed a γ value of 1.5 should be performed.

- <u>γ statistics should be reviewed on a structure by structure</u> <u>basis if the user software allows for it</u> (vendors should include this feature in their future software development).
- Track γ passing rates across patients (vendors should support a tracking feature in their future software development).
- Whenever referring to a γ passing rate, <u>always</u> specify the dose difference (global or local) and DTA criteria and the dose threshold. Without these parameters, the passing rate is meaningless.
- Software tools that can provide a measure of the agreement between measured and calculated DVHs of patient structures are preferred over analysis in phantoms.



3D γ index 3%, 3mm, Max dose, 10% threshold





 $3D\,\gamma$ index 3%, 3mm, Local dose, 10% threshold









2D γ index 2%, 2mm, Max dose, 10% threshold





Summary

- Electronic 2D detector arrays suffer from limited spatial resolution and angular dependence
- Provide fast and efficient methods of patient specific QA
- No direct correlation between γ index and plan quality
- 3D dose computation solutions are currently available and provide more information for plan evaluation.

