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TG-218 & Its Implementation into the Clinic

Presented by Jaclyn Carroll, M.S.
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AAPM Spring Clinical Meeting

Disclosure

I have no relevant conflicts of interest to disclose.

I am not a member of AAPM TG-218.

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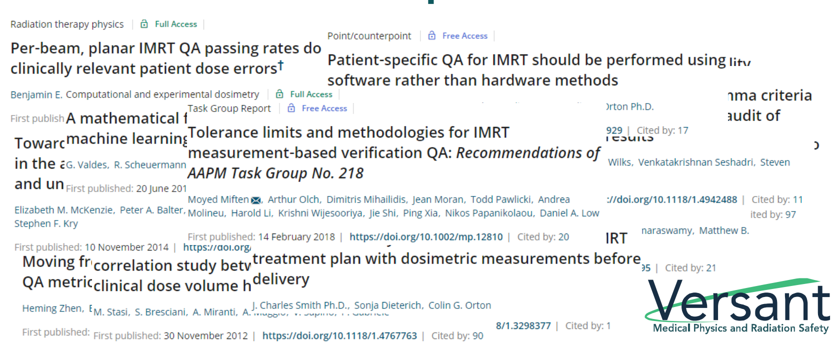
IMRT QA is a hot topic



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Charges of TG-218:

Task Group Report | Free Access
Tolerance limits and methodologies for IMRT measurement-based verification QA: *Recommendations of AAPM Task Group No. 218*
Moyed Miften, Arthur Olch, Dimitris Mihailidis, Jean Moran, Todd Pawlicki, Andrea Molineu, Harold Li, Krishni Wijesooriya, Jie Shi, Ping Xia, Nikos Papanikolaou, Daniel A. Low
First published: 14 February 2018 | https://doi.org/10.1002/mp.12810 | Cited by: 20

- **Review data on IMRT QA dose distribution agreement.**
- **Review & analyze delivery and measurement methods.**
- **Review & compare analysis methods.**
- **Investigate & summarize on-market IMRT QA devices.**

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This talk will cover…

- main points from TG-218.
- recommendations from TG-218.
- our site's experience adopting TG-218 recommendations.

1. *Dose distribution comparisons*
2. *Delivery methods*
3. *Tolerance & action limits*
4. *Courses of action*

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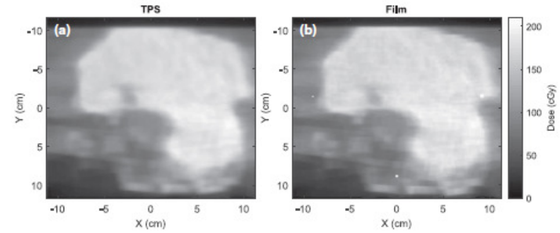
1. Dose Distribution Comparisons

Reference



Evaluated

FIG. 8. Clinical dose distributions from a clinical IMRT plan sent to vendors to test γ calculations. (a) TPS calculated dose distribution (resolution 0.5 mm). (b) Film measurement (resolution 0.5 mm).

How do you compare them?

Image obtained from TG-218, Figure 8.

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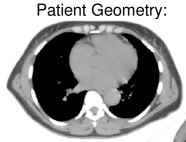
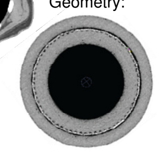
1. Dose Distribution Comparisons

Patient Geometry:



QA Geometry:



Goal

Reference and *Evaluated* dose distributions "agree to within limits that are *clinically relevant*"

Challenges

- Simply, "…the dose deposited in the phantom has a different pattern than the dose deposited in the patient."
- Some methods can be overly sensitive to steep dose gradients, vice versa
- How does a universal tolerance apply to patient anatomy?

Image obtained from https://www.sunnuclear.com/solutions/patientqa/arccheck3dvh

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1. Dose Distribution Comparisons

- Dose difference test
- DTA test
- Gamma test

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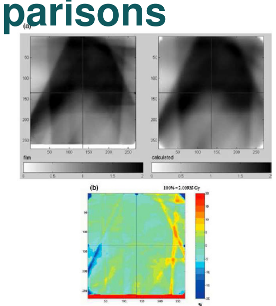
1. Dose Distribution Comparisons

- **Dose difference test**
  - Definition:

    The dose difference test is the most straightforward test to understand and interpret. The dose difference at location $(\vec{r})$ is the numerical difference δ between the evaluated dose $D_e(\vec{r})$ and the reference dose $D_r(\vec{r})$ at that location. Mathematically, the dose difference can be written as

    $$\delta(\vec{r}) = D_e(\vec{r}) - D_r(\vec{r})$$



- **DTA test**
- **Gamma test**

Image obtained from TG-218, Figure 3.

1. Dose Distribution Comparisons

- **Dose difference test**
  - Definition: $\delta(\vec{r}) = D_e(\vec{r}) - D_r(\vec{r})$
  - Faces challenges if dose distribution grid sizes are different
  - Does well in low-dose gradient regions, but not in steep dose gradients
  - Doesn't account for spatial tolerance, but we need to consider it
- **DTA test**
- **Gamma test**

1. Dose Distribution Comparisons

- **Dose difference test**
- **DTA test**
  - Definition: "for a point in the reference distribution, [the DTA is] the closest location in the evaluated dose distribution with the same dose"
    OR: "the closest distance of the evaluated distribution isodose line"
  - Ideal for steep dose gradients, but oversensitive in low-dose gradients
- **Gamma test**

1. Dose Distribution Comparisons

- **Dose difference test**
- **DTA test**
- **Gamma test**
  - Aims to combine aspects of both above tests
  - Definition:

    The displacement between two points, $\vec{r}_r$ and $\vec{r}_e$ in the reference and evaluated distributions, respectively, in the renormalized space was termed γ,

    $$\Gamma(\vec{r}_e, \vec{r}_r) = \sqrt{\frac{r^2(\vec{r}_e, \vec{r}_r)}{\Delta d^2} + \frac{\delta^2(\vec{r}_e, \vec{r}_r)}{\Delta D^2}}. \quad (1)$$

    where $r(\vec{r}_e, \vec{r}_r)$ was the distance between the reference and evaluated points, and $\delta(\vec{r}_e, \vec{r}_r)$ was the dose difference. The minimum displacement was defined as γ

    $$\gamma(\vec{r}_r) = \min\{\Gamma(\vec{r}_e, \vec{r}_r)\}\forall\{\vec{r}_e\} \quad (2)$$

$$\gamma = \min\left(\sqrt{\left(\frac{\Delta D}{\Delta D_t}\right)^2 + \left(\frac{\Delta d}{\Delta d_t}\right)^2}\right)$$

$\Delta D_t =$ Tolerance error for dose, e.g., 3%

$\Delta d_t =$ Tolerance distance-to-agreement, e.g., 3 mm

1. Dose Distribution Comparisons

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1. Dose Distribution Comparisons

- **Dose difference test**
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  - Aims to combine aspects of both above tests
  - Definition: $\gamma = \min\left(\sqrt{\left(\frac{\Delta D}{\Delta D_t}\right)^2 + \left(\frac{\Delta d}{\Delta d_t}\right)^2}\right)$

    if $0 < \gamma < 1$, pass

    if $\gamma > 1$, fail

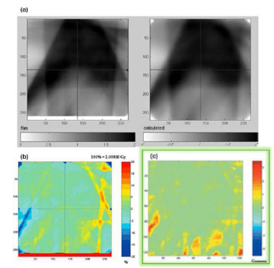

Image obtained from TG-218, Figure 3.

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1. Dose Distribution Comparisons

- **Dose difference test**
- **DTA test**
- **Gamma test**
  - Aims to combine aspects of both above tests
  - Definition: $\gamma = \min\left(\sqrt{\left(\frac{\Delta D}{\Delta D_t}\right)^2 + \left(\frac{\Delta d}{\Delta d_t}\right)^2}\right)$
  - Things to consider:
    - It is universal
    - Spatial resolution
    - Interpretation

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1. Dose Distribution Comparisons

Additional Considerations:

- Dose threshold:
  - Exclude the low-dose (10%) areas from analysis
- Normalization options:
  - Use global normalization versus local normalization
- System performance:
  - Clinical case sent to vendors with varying results- why?

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2. Delivery Methods

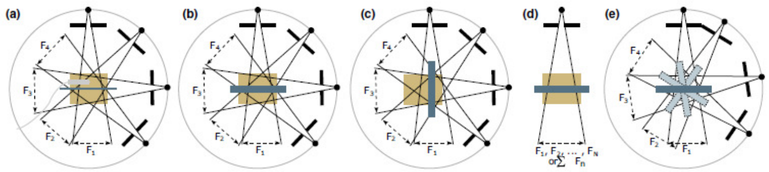

FIG. 6. (a) True composite (TC) delivery on a phantom with an IC placed at a specific depth and a radiographic film at a coronal orientation. (b) TC delivery on a stationary 2D array device placed in the coronal direction on the treatment table. (c) TC delivery on a stationary 2D array device placed in the sagittal direction on the treatment table. (d) Perpendicular field-by-field (PFF) or perpendicular composite (PC) delivery on a stationary 2D array device placed in the coronal direction on the treatment table. (e) PFF or PC delivery on 2D array device mounted on the treatment head.

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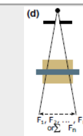
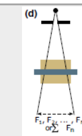
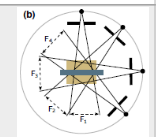
Image obtained from TG-218, Figure 6.

2. Delivery Methods

Method	PC	PFF	TC
Diagram			
Advantages	• single image to analyze	• samples every part of every field • field-by-field analysis may reveal subtle errors	• most closely represents delivery to patient • can validate integrity of patient plan file transfer
Disadvantages	• masks delivery errors • dose distribution is unrelated to that of delivery for patient	• small differences may result in lower passing rates • poor agreement between field-by-field and 3D analysis	• doesn't sample every part of every field • still doesn't account for patient contour or heterogeneities

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Images obtained from TG-218, Figure 6.

3. Tolerance & Action Limits

Definitions

- The **Tolerance Limit** refers to the range within which the IMRT QA process is considered to be unchanging.
- The **Action Limit** sets a minimum level of process performance such that IMRT QA measurements outside the action limits could result in a negative clinical impact for the patient.

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3. Tolerance & Action Limits

What should we use?

- Tolerance Limit: 95%
- Action Limit: 90%

Where do these limits come from?

- Used statistical process control methods to develop
- In agreement with paper by Stambaugh et al.

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3. Tolerance & Action Limits

Flow Chart

Develop your own tolerance and action limits, particularly for special cases (i.e. SRS).

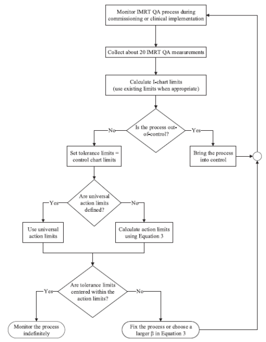

FIG. 9. Flow chart outlines the procedure for setting tolerance and action limits for IMRT QA.

Image obtained from TG-218, Figure 9.

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4. Courses of Action

What happens when your QA fails?

- Check your setup.
- Check for correct file transfer.
- Is anything deviating from normal? Check daily QA. Validate dose calibration with a standard dose (recommended prior to each PSQA).
- Determine where the failed points are. Are they relevant to the plan? Are they clustered in one area?
- Try to isolate the discrepancy, such as by performing a PFF analysis.

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4. Courses of Action

Regarding overall PSQA process:

- Track your results.
  - May reveal trends for specific sites.
  - May indicate room for improvement in other areas of QA process.
    - Stambaugh et al. (Dec. 2018), "*Improvements in treatment planning calculations motivated by tightening IMRT QA tolerances*"
- Move toward structure-by-structure or DVH-based analysis.

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Summary

1. **Dose Distribution Comparisons**
   - Use Gamma analysis, 3%/2 mm
2. **Delivery Methods**
   - True Composite (TC) if possible
3. **Tolerance & Action Limits**
   - TL: 95%, AL: 90%
4. **Courses of Action**
   - check setup, evaluate location of failures, file transfer...
   - look for trends in results, keep improving process!

"γ tool should be used as an indicator of problems, not as a single indicator of plan quality." (M. Miften, PPT)

"No single dose comparison tool provides all of the information necessary to quantitatively evaluate or compare dose distributions. Each tool has limitations that need to be understood when conducting evaluations." (TG-120)

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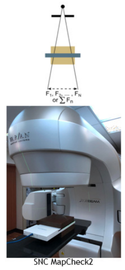
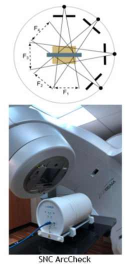
Using TG-218 in the Clinic

- **First, why?**
- **What did we change?**
  - Delivery method
  - Gamma criteria
    3% / 3mm → 3% / 2mm
  - Tolerance & Action Limits
    90% → 95% T.L., 90% A.L.



PC ➔ TC



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Using TG-218 in the Clinic

Methods:

- Delivered 110 patient-specific IMRT/VMAT QA plans (with) →
- Recorded passing rates for 3% / 3mm and 3% / 2mm
- Retrospectively delivered 15 static-beam IMRT QA plans with TC delivery method

Static-beam IMRT QA

VMAT QA

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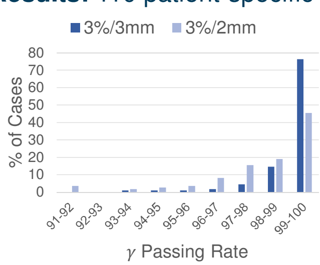
Using TG-218 in the Clinic

Results: 110 patient-specific QA plans using PC delivery



- None were below the 90% AL for 3%/3mm or 3%/2mm
- 8 (7.3%) were below the 95% TL for 3%/2mm
- Average passing rate for
  3%/3mm: 99.2%
  3%/2mm: 98.3%

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Image obtained from M. Miften PPT at http://amos3.aapm.org/abstracts/pdf/124-34859-405535-125518.pdf

Using TG-218 in the Clinic

Results:

Case	Site	PC		TC	
		3%/3mm	3%/2mm	3%/3mm	3%/2mm
1	H&N	99.4	96.6	99.9	99.7
2	H&N	97.9	96.8	94.9	89.9
3	Prostate	98.0	95.2	98.4	97.0
4	H&N	99.6	97.0	100	99.8
5	Prostate	91.6	77.9	98.9	98.3
6	H&N	99.0	97.9	99.3	98.2
7	Pelvis	99.8	98.6	99.7	99.3
8	H&N	99.6	98.7	99.6	99.0
9	Prostate	99.4	99.4	99.5	98.3
10	Lung	99.4	98.8	99.9	99.6
11	H&N	99.7	99.2	99.8	99.7
12	Esophagus	100	99.8	94.3	91.8
13	Vulva	99.0	98.0	99.3	96.7
14	H&N	100	99.5	99.9	99.6
15	Lung	100	100	97.5	96.3

Average passing rates

PC: 98.4% (σ = 1.4%)

TC: 97.6% (σ = 3.0%)

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Using TG-218 in the Clinic

Results:

Case	Site	PC		TC	
		3%/3mm	3%/2mm	3%/3mm	3%/2mm
1	H&N	99.4	96.6	99.9	99.7
2	H&N	97.9	96.8	94.9	89.9
3	Prostate	98.0	95.2	98.4	97.0
4	H&N	99.6	97.0	100	99.8
5	Prostate	91.6	77.9	98.9	98.3
6	H&N	99.0	97.9	99.3	98.2
7	Pelvis	99.8	98.6	99.7	99.3
8	H&N	99.6	98.7	99.6	99.0
9	Prostate	99.4	99.4	99.5	98.3
10	Lung	99.4	98.8	99.9	99.6
11	H&N	99.7	99.2	99.8	99.7
12	Esophagus	100	99.8	94.3	91.8
13	Vulva	99.0	98.0	99.3	96.7
14	H&N	100	99.5	99.9	99.6
15	Lung	100	100	97.5	96.3

-3σ (case 2)

-2σ (case 12)

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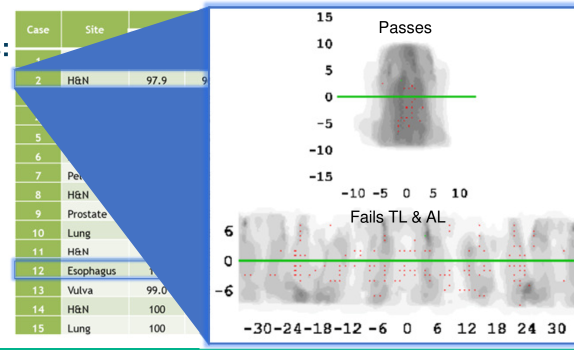
Using TG-218 in the Clinic

Results:



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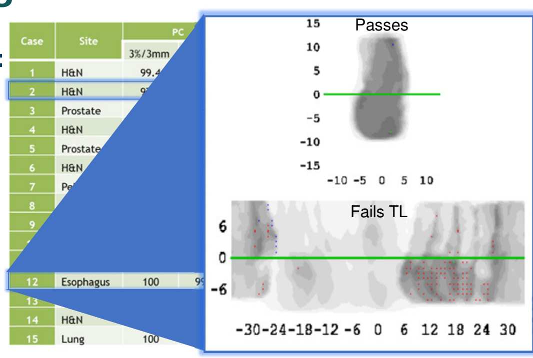

Using TG-218 in the Clinic

Conclusions

What's the effect on our clinical workflow?

Change	Average gamma passing rate	
	Old	New
Gamma criteria (3%/3mm → 3%/2mm) (110 patient plans, PC method)	99.2	98.3
Delivery method (PC → TC) (15 select plans, 3%/2mm criteria)	98.4	97.6

Where are we now?

- Adopted new gamma criteria, delivery method & practice limits, looking to begin using DVH-based analysis program

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Thank you!

Brian Hasson, Ph.D.
Charlie Geraghty, M.S.
Texin Li, Ph.D.
Lee Myers, Ph.D.
Sandy Konerth, M.S.

References

- **TG-218**

Miften M, Olch A, Mihailidis D, Moran J, Pawlicki T, Molineu A, et al., "Tolerance limits and methodologies for IMRT measurement-based verification QA: recommendations of AAPM task group no. 218." Med Phys. 2018; 45(4):e53–e83.

- **TG-120**

D. A. Low, J. M. Moran, J. F. Dempsey, L. Dong, and M. Oldham, "Dosimetry tools and techniques for IMRT," Med. Phys. 2011; 38, 1313–1338.

- **TG-218 PowerPoint slide set**

Miften, M. TG-218: How to Handle Pretreatment Measurement IMRT Verification QA [PowerPoint Slides]. Retrieved from http://amos3.aapm.org/abstracts/pdf/124-34859-405535-125518.pdf

Question 1

The TG-218 report provides comprehensive recommendations for a department's patient-specific IMRT/VMAT QA program. Select the best summary of recommendations for the following aspects: delivery method, gamma analysis criteria, low-dose threshold, universal tolerance limit, universal action limit.

a. Perpendicular Composite, 3%/2mm, 10%, 98%, 90%
b. True Composite, 3%/2mm, 10%, 95%, 90%
c. Perpendicular Field-by-Field, 3%/3mm, 10%, 90%, 80%
d. True Composite, 3%/3mm, 10%, 95%, 90%

Question 2

When a patient-specific IMRT/VMAT QA fails a given universal tolerance limit, what are the steps that a physicist should take?

a. Ensure correct setup of measurement device.
b. Ensure correct file transfer of plan from TPS to R&V system.
c. Check the machine's daily QA results for output, flatness and symmetry.
d. Deliver a standard field to verify the calibration of the measurement device.
e. All of the above.