School of Medical Physics for Radiation Therapy: Dosimetry and Treatment Planning for Basic and Advanced Applications

27-march—7-april 2017

IMRT pre-treatment verification *basic approaches*

Eugenia Moretti

ASUIUD Udine

DISCLAIMER

***

I do not endorse any products, manufacturers, or suppliers.

Nothing in this presentation should be interpreted as implying such endorsement

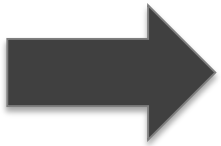
***

Topics

- Scopus
- Experimental methods & strategies (*classical approaches*)
- Gamma metric
- Critical aspects
- Guidelines

For alternative patient-QA solutions

- Not (or not-only) experimental strategies
- Unconventional strategies
- New trends



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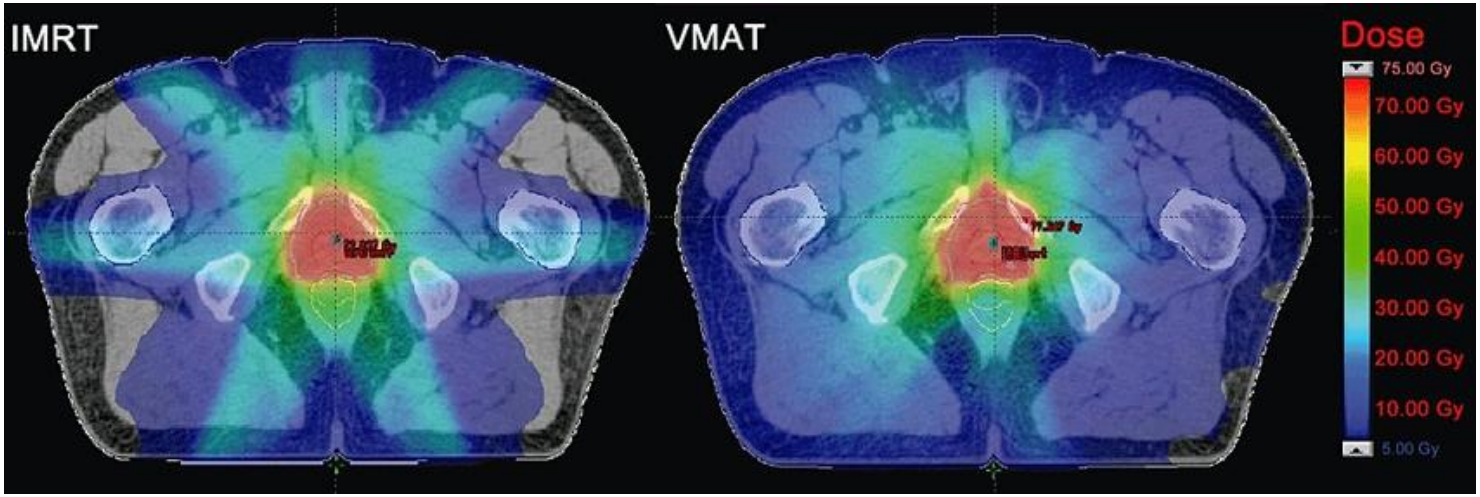
Warning

- IMRT is both static and dynamic IMRT (VMAT)



The concept of Patient-QA(QC) before IMRT

1994

AAPM REPORT NO. 46

COMPREHENSIVE QA FOR RADIATION ONCOLOGY

Patient-specific QA :
Physicist TX plan-review, chart review, IVD

Conventional approach for verifying conformal plans was focused on the TPS commissioning and the dosimetry of some test plans; this could be followed by the independent check of plan MU and in-vivo dosimetry

The concept of Patient-QA(QC) with IMRT

August 2003

Guidance document on delivery, treatment planning, and clinical implementation of IMRT: Report of the IMRT subcommittee of the AAPM radiation therapy committee

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Intensity-modulated radiation therapy (IMRT) represents one of the most significant technical advances in radiation therapy since the advent of the medical linear accelerator. It allows the clinical implementation of highly conformal nonconvex dose distributions. This complex but promising treatment modality is rapidly proliferating in both academic and community practice settings. However, these advances do not come without a risk. IMRT is not just an add-on to the current radiation therapy process; it represents a new paradigm that requires the knowledge of multimodality imaging, setup uncertainties and internal organ motion, tumor control probabilities, normal tissue complication probabilities, three-dimensional (3-D) dose calculation and optimization, and dynamic beam delivery of nonuniform beam intensities. Therefore, the purpose of this report is to guide and assist the clinical medical physicist in developing and implementing a viable and safe IMRT program. The scope of the IMRT program is quite broad, encompassing multileaf-collimator-based IMRT delivery systems, goal-based inverse treatment planning, and clinical implementation of IMRT with patient-specific quality assurance. This report, while not prescribing specific procedures, provides the framework and guidance to allow clinical radiation oncology physicists to make judicious decisions in implementing a safe and efficient IMRT program in their clinics. © *2003 American Association of Physicists in Medicine*. [DOI: 10.1118/1.1591194]

Key words: 3-D conformal radiotherapy, intensity-modulated radiation therapy, inverse planning, plan optimization, quality assurance

TABLE OF CONTENTS

QA of individual treatment plans

1. Independent calculation methods

Patient-specific calculations combined with frequent machine QA represent another approach.

2. Verification measurements

Patient-specific verification measurements test many, but not all the aspects of planning and delivery in a combined fashion.

Patient-QA: the beginning

- Validation of complex systems such as a TPS with an enormous amount of data is a very cumbersome project for which other approaches than point-by-point comparisons should be available. During the introduction of IMRT, the physics community started to perform more extensive verification in 2D (planes) and even in 3D (volumes).

- In an early publication from the group of the Memorial Sloan Kettering Cancer Center in New York a new concept for IMRT verification was introduced
  - Burman C, Chui CS, Kutcher G, Leibel S, Zelefsky M, LoSasso T, Spirou S, Wu Q, Yang J, Stein J, Mohan R, Fuks Z and Ling CC. *Planning, delivery, and quality assurance of intensity-modulated radiotherapy using dynamic multileaf collimator: a strategy for large-scale implementation for the treatment of carcinoma of the prostate.* Int. J. Radiat. Oncol. Biol. Phys. 39, 1997

- MSKCC strategy included (1997):
  - Verification of the planned dose distribution by performing an independent dose calculation
  - Comparison of the planned leaf sequence with that recorded in the MLC log files;
  - Confirmation of the initial and final positions of the MLC for each field by the R&V system
  - Comparison of the dose distribution measured in a flat phantom with that calculated by the TPS for the same experimental conditions;
  - IVD measurements

Memorial Sloan Kettering Cancer Center

The Patient-QA in IMRT: WHY?

- Higher complexity of **planning**, **calculation** and **delivery** compared to 3DCRT

- Calculation critical points: MLC, head scatter, small fields
  - "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." (Med Phys, 30(8))

- Defaillance of Treatment Delivery System

- We can do errors: "..there is evidence that IMRT treatments may not always be as accurate as users believe." (AAPM TG119, Med Phys, 36(11) 2009)

  In 2008, the RADIOLOGICAL PHYSICS CENTER (RPC) reported that of the 250 irradiations of a H&N phantom as a part of an IMRT credentialing process, 71(28%) had failed to meet accuracy criteria of 7% for dose in a low gradient region and/or 4 mm DTA in a high gradient.. This results strongly suggest that some clinics have not been adequately commissioned their planning and delivery systems for IMRT

Patient-specific QA → Accuracy (Safety)

SUPPLEMENTAL MATERIAL

Practical Radiation Oncology (2011)

practical radiation oncology
pro

Safety Considerations for IMRT

Jean M. Moran, Ph.D.,* Melanie Dempsey, M.S.,† Avraham Eisbruch, M.D.,* Benedick A. Fraass, Ph.D.*, James M. Galvin, D.Sc.,‡ Geoffrey S. Ibbott, Ph.D.,§ and Lawrence B. Marks, M.D.#

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End-to-END TEST

4.2.4 Pre-treatment IMRT QA program

The current guidance from ACR and ASTRO for IMRT patient-specific quality assurance recommends verification of the IMRT treatment plan parameters and the use of dosimetric measurements to verify the accuracy of the dose delivery.[26] Due to safety considerations, these tests for acceptability should always be performed prior to the start of the patient's treatment with any given plan.

Machine-QA & Patient-QA

Machine-QA

- To check that the performance of the delivery system does not deviate significantly from their baseline values acquired at the time of acceptance and commissioning.
- These tests machine-specific are performed repeatedly and are performance-oriented.
- AAPM TG142 (2009)

Patient-specific QA

- To ensure the quality of each individual patient treatment.
- The main purpose of these tests is to assure that the intended dose distribution for the specific patient is physically verifiable and that the intensity modulated beams or arcs are technically feasible.

ESTRO PHYSICS BOOKLET No 9 (2008)

In August 2001 the ESQUIRE project, funded by the European Communities, EC, started for a period of two years to boost ESTRO's efforts to improve quality in radiotherapy. The aim of the part of the project called QUASIMODO (QUality ASsurance of Intensity MODulated radiation Oncology) was the safe introduction of advanced technology in radiotherapy first by developing procedures for the QA of treatment planning systems, and second by exploring new methodology for the verification of intensity-modulated radiation therapy, IMRT. From a review of national and international documents discussing QA of treatment planning systems it became clear that there was a need for a minimum number of tests that should not be too cumbersome to perform. This first part of the QUASIMODO project was realised by drafting ESTRO Booklet No. 7 "Quality assurance of treatment planning systems – practical examples for non-IMRT beams".

The second part of the QUASIMODO project was to develop and disseminate more uniform guidelines for validation of IMRT techniques. Fifteen European centres, which just started, or were in the process of setting up IMRT, participated in this project. The experience gained by this multi-centre quality assurance network had to be "translated" into guidelines with respect to verification of IMRT techniques for those institutions having limited experience or starting with IMRT, which resulted in this second ESTRO booklet.

In this booklet we first summarise the various approaches for IMRT verification and the methods of data analysis. After briefly comparing the various techniques for dosimetric verification, quality assurance tests for accelerator and MLC performance are addressed. In separate chapters the use of independent dose calculations and examples of patient-specific QA procedures are then discussed in a comprehensive way. These examples are taken from the various centres that participated in the QUASIMODO project, as well as from some other European centres, and show a large variety of IMRT QA tests performed in daily practice in institutions having already some years of clinical experience with IMRT. The report ends with formulating guidelines concerning type and tolerances of tests to be performed for IMRT verification in relation to the required accuracy, as well as the various strategies for patient-specific IMRT verification. In this chapter also a number of possible pitfalls and potential errors encountered by European centres are described and possible actions suggested to solve these problems. In an appendix a list is given of commercial companies selling QA tools for IMRT verification.

Ben Mijnheer
The Netherlands Cancer Institute-Antoni van Leeuwenhoek Hospital, Amsterdam, The Netherlands

Dietmar Georg
Medical University Vienna-AKH Wien, Austria

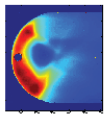
GUIDELINES FOR THE VERIFICATION OF IMRT - *Edited by: Ben Mijnheer and Dietmar Georg*
EUROPEAN SOCIETY FOR THERAPEUTIC RADIOLOGY AND ONCOLOGY

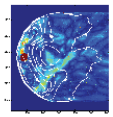
ESTRO

Supported by the EU "Europe against Cancer" Programme Grant Agreements N°SPC.2002480 512.322029

GUIDELINES FOR THE VERIFICATION OF IMRT

Edited by: Ben Mijnheer and Dietmar Georg





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Milan Tomsej
Hans Welleweerd

EUROPEAN GUIDELINES FOR QUALITY ASSURANCE IN RADIOTHERAPY
ESTRO BOOKLET No. 9

ESTRO
European SocieTy for
RADIOTHERAPY
& ONCOLOGY

GUIDELINES FOR THE VERIFICATION OF IMRT

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(Edited by: Mijnheer, Georg)
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ESTRO
Mounierlaan 83/12 – 1200 Brussels (Belgium)

Patient-QA (Estro Booklet)

- The philosophy behind this new approach was that patient-specific verification was required for IMRT and that each plan should be checked prior to delivery

- This was different from the conventional approach where checks are generally performed during the commissioning process of a new TPS or before the implementation of a new technique, using generic or specific geometries in slab or more anthropomorphic phantoms.

IMRT verification: the concet of pyramid according to De Wagter

- 4 different levels of specificity
- Ideally, each time a new or modified IMRT technique is introduced in the clinic, QA starts at the top of the pyramid, i.e. by applying a 3D verification technique of the whole treatment planning and delivery process.
- If unacceptable discrepancies are detected between the 3D dose distribution and the results of the 3D dosimetry verification, the next step is to descend the pyramid to a lower, more specific, level.
- This can be repeated until the error source is revealed.

IMRT verification: the concet of pyramid according to De Wagter

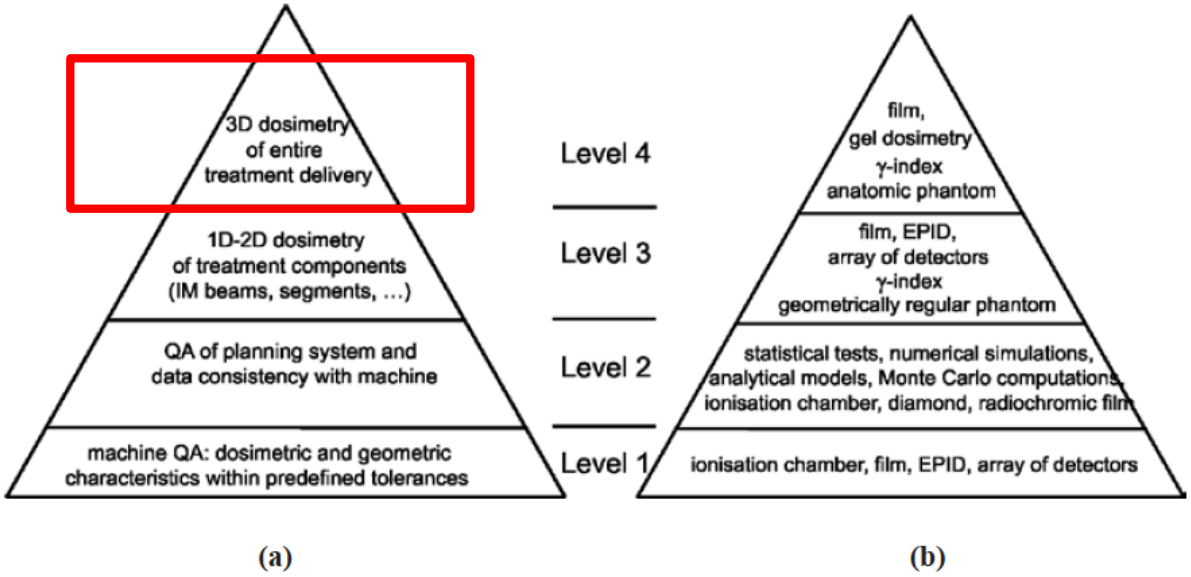

Figure 3.1 (a) Conceptual pyramid that correlates the various levels of dosimetric QA in IMRT. Like the situation for a real pyramid, each level is based on the stability of the underlying levels. The two lower levels can be part of the periodic QA procedures of equipment used for IMRT planning and delivery. For QA of a new clinical IMRT solution, one may start at the top by applying a 3D dosimetric verification of an entire treatment. One descends the pyramid to the lower levels if the 3D dosimetric verification reveals unacceptable discrepancies with treatment planning. (b) Methodology and tools appropriate for each of the levels. (Courtesy Carlos De Wagter, Ghent University Hospital, Ghent, Belgium, and the Institute of Physics).

Patient-QA: the meaning

Once the entire chain of **TPS**, **Data Transfer** and **Treatment delivery** has been commissioned, one needs to ensure that for **a specific patient**

1. appropriate TX plans are made
2. these plans are transferred correctly to the linac
3. the plans are delivered accurately

DATA TRANSFER
(Med Phys, 37(6), 2010])

Catching errors with *in vivo* EPID dosimetry

A. Mans,[a] M. Wendling,[b] L. N. McDermott,[c] J.-J. Sonke, R. Tielenburg, R. Vijlbrief, B. Mijnheer, M. van Herk, and J. C. Stroom
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- IMRT PLAN
  - Rectum ca
  - 5 Gy x 7 fx
  - IMRT S&S
  - 7 fields, 35 segments (10, 18 MV)
- 3D-EPID in-vivo dosimetery
  - Υ_{mean}=2.0;
  - reconstructed @iso: 4.56 Gy vs 4.87 Gy from TPS (underdosage: 6.5%)

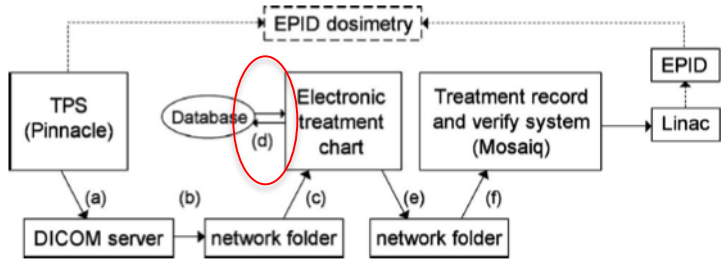
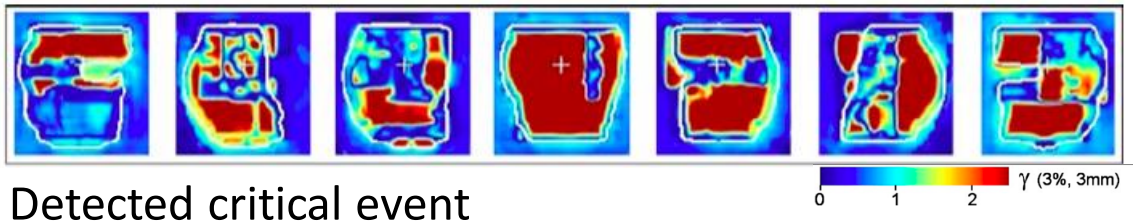


FIG. 1. Schematic overview data flow in our department. Solid lines indicate the route that the treatment plans follow (plan transfer steps are indicated with letters). Dashed lines indicate EPID dosimetry information transfer.



- Detected critical event
  - 27 of 35 segments (control points) were corrupted
- Diagnosis
  - Transfer (d): ETC → ETC Database
  - "Lost delayed-write data" (Windows XP, event ID50): cluster of errors → in ETC WS network-transfer log-files were found
  - Leaves&jaws were stored in separate tables: probably, one record containing leaves posotions was lost, causing asynchrony among leaves and jaws positions

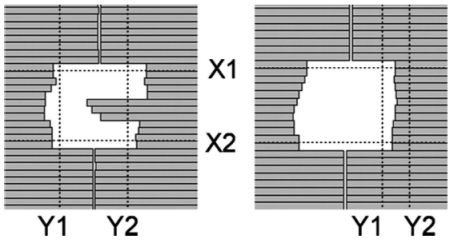


FIG. 3. Two examples of corrupted segments (control points) from a step-and-shoot IMRT plan. Due to a network transfer error, leaf positions of the next segment were used, while jaw positions were correct. MLC leaves are displayed in gray and jaw positions are indicated with dashed lines.

Patient-QA: the current paradigma

- Plan is approved

- Plan parameters are copied to a phantom (Verification Plan or hybrid plan)
- Plan is recalculated on the phantom geometry

  - **Field-by-field verification**: beams can be arranged to remove gantry, collimator and table angle
  - **Composite verification plan**: Beams can remain as planned for the verification plan (this is most common with VMAT)

- Calculated dose for a known plane location is exported and matched

Pre-treatment patient-QA: failed results

- Device Setup errors/phantom setup errors
- Exported planar dose of the wrong plane orientation
- Exported the “wrong plan”
- Delivered the “wrong plan”
- Exclusion of the couch could introduce error
- Detector was not warmed up
- Detector was used with a different machine user factor
- Detector was not calibrated correctly
- Wrong calibration curve was used (film/diodes)
- Detector does not have up to date calibration
- Dose gradients too steep for detector resolution

Failed results → actions

- Re-measure
- Re-export
- Re-setup
- Re-evaluate
- Deeper investigation (De Wagter pyramid approach)
- Try to employ another device
- Try to predict the dose to patient, explain the estimate (with uncertainty) the clinical consequences and discuss with RO
- At the end…..re-plan

The dosimeter

In the evaluation of the match *calculated vs measure*, to find the eventual errors in the chain TPS-TDS, we must know and check our measurement system → **1st step: characterization of the dosimeter and evaluation of its sensitivity to setup and dosimetric errors**

In general the **ideal dosimeter** *should*

1. be accurate
2. be precise
3. show a linear response to dose
4. have minimal variation with radiation quality
5. have minimal variation with absolute dose
6. have minimal variation with dose rate
7. have minimal directional dependence
8. have a high spatial resolution

The ideal dosimeter for intensity modulated radiation therapy (IMRT): What is required?

C De Wagter
Department of Radiotherapy, Ghent University Hospital, Belgium

① The ideal dosimetry method should allow absolute dose determination (dose in Gy rather than in %) without the use of (re)normalization procedures to convert relative to absolute dose.

② The full 3D measured dose distribution has to be “available” after IMRT treatment delivery to the dosimeter. (…). The 3D dosimeter should supply enough volumetric data to support an iterative process between level 4 and the lower levels (Pyramid concept).

③ The ideal dosimeter is free of perturbation and its response is independent of orientation of irradiation. These requirements are ideally met if the dosimeter itself acts as a tissue equivalent phantom or a part of it.

The ideal dosimeter for intensity modulated radiation therapy (IMRT): What is required?

C De Wagter
Department of Radiotherapy, Ghent University Hospital, Belgium

④ The dosimetric precision and accuracy should be rigorously specified at various dose levels.

⑤ The dosimeter response should have a sufficiently large dynamic range and be insensitive to photon energy spectrum and dose rate. By nature of IMRT, stray dose becomes important. Stray dose is deposited at low dose rate by photons of deviating energy spectrum. In complete-treatment or composite IMRT dose distributions, dose-rate effects in the detector might have higher impact than expected at first sight.

⑥ The dosimeter should allow dose measurements close to the surface or interfaces and controlling the tissue equivalence of the phantom in order to measure dose near and – ultimately – in high hand low-density regions (high spatial resolution)

The dosimeter

(...) Ideally the actual dose delivery, in **3D**, of patient treatments should be verified after performing a comprehensive acceptance testing and commissioning programme of the various phases of the planning and delivery process of IMRT. At this moment in vivo dose verification of IMRT is only employed in a few institutions* and pre-treatment verification of IMRT delivery, applying a large variety of phantom-detector combinations, is more often employed clinically (…)

GUIDELINES FOR THE VERIFICATION OF IMRT

Markus Alber
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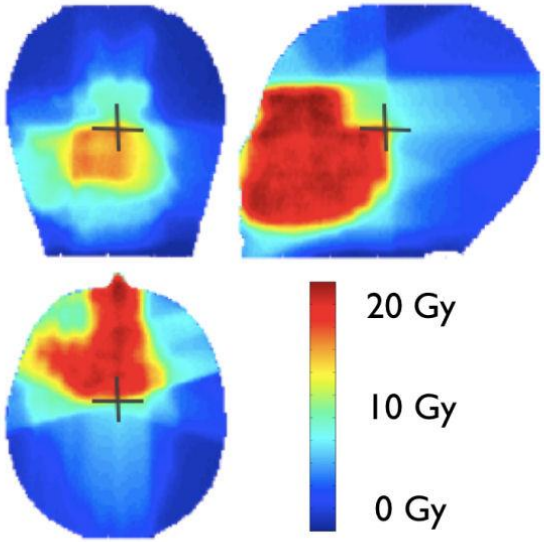
**Today, this is not longer true:*

IVD is still a complex matter but new modalities were studied.

→ *Adamson's lectures*

Ideal (3D) dosimeter: Gel



Courtesy of De Deene et al.

- Gel dosimeters are manufactured from radiation sensitive chemicals that, upon irradiation with ionising radiation, undergo a fundamental change in their properties as a function of the absorbed radiation dose.
- Fricke gel and polymer gel
- Readout system: >MRI, optical CT, x-ray CT, US, vibrational spectroscopy

Several “dosimeters”

- **High dosimetric accuracy evaluation**
  - Ionization chambers for individual point measurements
  - Different devices are commercially available consisting of a phantom with **multiple diodes/ICs (2D/3D matrix)** for dose distribution at multiple points
- **High-resolution evaluation**
  - Films
  - EPID
- **It is not easy to obtain a system that combines high dosimetric accuracy with a high spatial resolution**

Ionizations Chambers

- Cylindrical ICs are used for point-dose measurements because of their stability, linear response to absorbed dose, small directional dependence, beam quality response independence, and traceability to a primary calibration standard

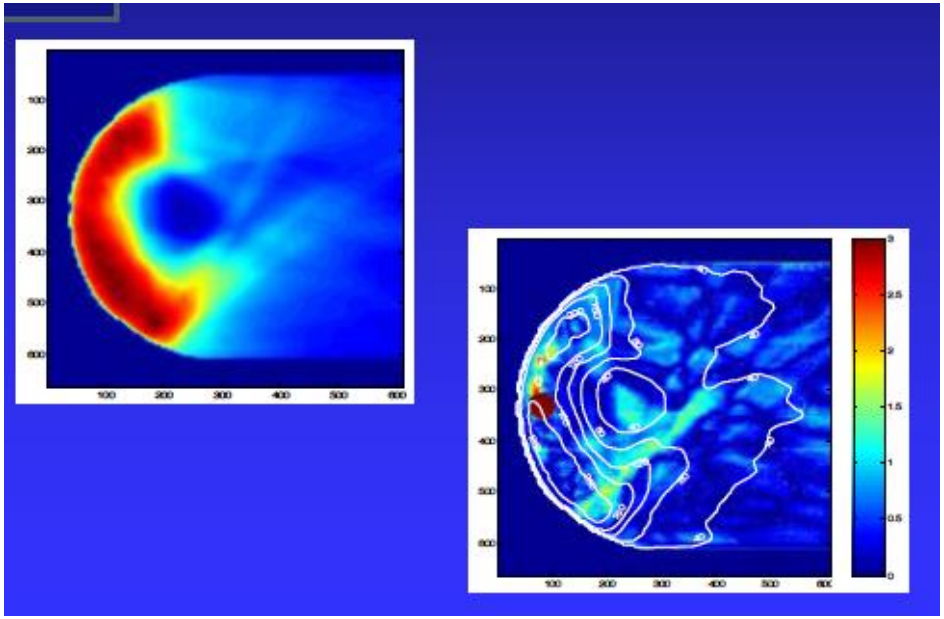
- All ICs exhibit some volume averaging due to their size. Therefore, care should be taken that Ics are only used in relatively homogeneous dose regions

- Measurements at field edges may lead to larger deviations because of the absence of charged particle equilibrium

- Large number of slit-like apertures in VMAT plans increase the likelihood of measuring at field edges, even if the composite dose distribution is homogeneous

Radiochromic films

Radiochromic films are commonly used as **reference dosimetry systems**, which means that they can measure absolute dose as other dosimeters (IC for example) as long as there is an established conversion of the film response (absorbance) to dose deposited within reference medium (usually water) that caused measured change in absorbance



Radiochromic films

- They change its color upon irradiation without the need for chemical development
- Dose deposited within a sensitive layer of the film produces polymerization of the active component, the degree of which depends on the amount of energy deposited
- Response of the film to radiation is commonly expressed in terms of optical density change, which can be easily measured by any photometric device (*Linear CCD-based flatbed document scanners as the most convenient and most commonly used optical densitometers*)
- They can be easily extended from 2D to 3D dosimetry by embedding the sheets between water equivalent plastics or even in-homogenous human like phantoms

Radiochromic films

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Review Paper

Reference radiochromic film dosimetry: Review of technical aspects

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ABSTRACT

For decades, film was used as a powerful two-dimensional (2D) dosimetry tool for radiotherapy treatment verification and quality assurance. Unlike the old silver-halide based radiographic films, radiochromic films change its color upon irradiation without the need for chemical development. Radiation dose deposited within a sensitive layer of the radiochromic film initiates polymerization of the active component, the degree of which depends on the amount of energy deposited. Response of the film to radiation is commonly expressed in terms of optical density change, which can be easily measured by any photometric device. However, a number of factors may have an impact on the signal detected by the measuring device. This review summarizes technical aspects associated with the establishment of reference radiochromic film dosimetry and its subsequent use for either clinical or research applications.

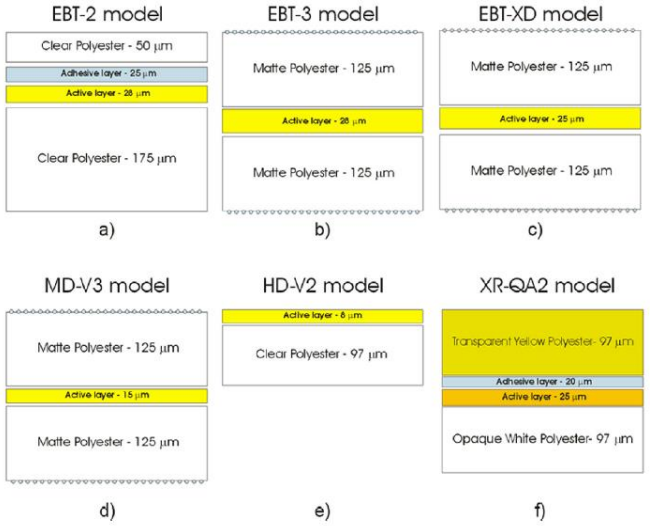


Figure 1. Diagram of the Gafchromic™ film structure/dimensions: (a) EBT2 (b) EBT3 (c) EBT-XD, (d) MD-V3, e) HD-V2, and (f) XR-QA2 film model.

Table 1
Available Gafchromic™ film models for radiation therapy and diagnostic radiology dose measurements with useful dose ranges and chemical compositions of sensitive layers.

Film model	Dose Range	Sensitive layer elemental composition by atomic%										Z_{eff}
		H	Li	C	N	O	Na	Al	S	Cl	Bi	
HD-V2	10–100 Gy	58.2	0.6	27.7	0.4	11.7	0.5	0.3	0.1	0.6		7.63
MD-V3	1–100 Gy	58.2	0.6	27.7	0.4	11.7	0.5	0.3	0.1	0.6		7.63
EBT-XD	0.04–40 Gy	57.0	0.6	28.5	0.4	11.7	0.1	1.5	0.1	0.1		7.46
EBT2	0.01–30 Gy	56.5	0.6	27.4	0.3	13.3	0.1	1.6	0.1	0.1		7.46
EBT3	0.01–30 Gy	56.5	0.6	27.4	0.3	13.3	0.1	1.6	0.1	0.1		7.46
XR-QA2	0.1–20 cGy	56.2	1.0	27.6	1.6	11.7				0.1	1.7	55.2

Arrays

- Different types of **detector arrays of diodes or Cis** are available:

  2D consisting of arrays

  “3D”consisting of biplanar arrays or cylindrical arrays or 2D-array that rotates synchronously with gantry in VMAT

- Shortcoming: low spatial resolution
  - Exceptions are arrays utilizing micro liquid-ICs which may have a resolution of 2.5 mm

- When performing gamma index analysis, depending on the algorithm used to calculate the gamma-values, low spatial resolution may lead to under-sampling

Arrays&VMAT

- Gantry angle dependence is observed for static planar 2-D arrays whereas this is not significant for bi-planar arrays
- To obtain an accurate measurement using static planar arrays, the use of correction factors is advised
- Another solution is to rotate the detector plane in conjunction with the gantry, so that it is always perpendicular to the beam axis
- This can for example be done by rotating the phantom synchronously with the gantry (using an inclinometer) or by using a dedicated holder with which the dosimetry system is mounted directly on the gantry

2D→3D dosimeter

- A number of detector array systems offer the possibility of a 3D dose reconstruction in the phantom, based on the 2D measurements.
- Different methods are available to calculate a 3D dose reconstruction from 2D data.
- It is important that the reconstruction method and its limitations are well understood to interpret the results correctly.
- Some methods use input from the TPS in certain steps of the dose reconstruction to compute the dose. As a result, some errors in the TPS will therefore not be detected using this verification procedure

2D-arrays

Characteristics




	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)

3D-arrays

Delta⁴ Phantom+

THE WIRELESS PHANTOM

Use Real Tumor Motion

The Scandidos HexaMotion 6D motion platform accurately replicates the actual tumor motion. The QA is based on how the real tumor is moving. The motion patterns both for the tumor and the patient can be imported from your motion management system and the same movement cycle is then exactly executed with the Delta⁴ phanto
The phantom is positioned fast and wit
sub-millimeter accuracy.

DELTA^{4DVH} ANATOMY

Analyze the dose delivered in the patient anatomy

With the Delta^{4DVH} Anatomy software option you can verify and analyze the dose that has been delivered to the patient anatomy. Based on the measurements in the isocentric target region and dose calculation of the dose in the patient anatomy you now have a truly independent verification of the delivered dose.

- Delivered dose directly in the patient anatomy
- Independent from the TPS and the delivery system
- Use initial CT or fraction Cone-beam CT data

Delta⁴

Technical specification

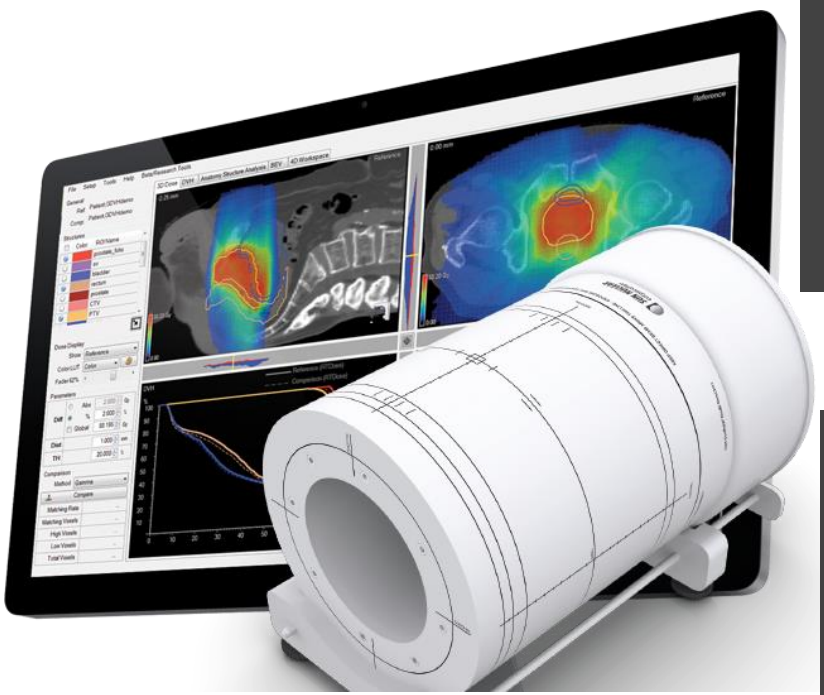
Cylinder phantom	
Material	PMMA; optional Plastic Water DT®
Diameter	22 cm
Length	40 cm
Ion chamber insert in cylinder	Inserts for common cylindrical ion chambers available
Detectors	
Type	p-Si
Total number	1069
Layout	Distributed on coronal and sagittal plane
Max field size	20 x 38 cm² (with merger of two consecutive measurements, otherwise 20 x 20 cm²)
Distance between detectors	
Central area (6 x 6cm²)	5 mm (or 2.5mm in longitudinal direction with merger of two consecutive measurements)
Outer area	10 mm
Size (radial x axial)	1 x 0.05 mm³ = 0,00004 cm³
Detector stability (6MV beam)	Better than 0.1% per kGy, typically 0.04%/kGy
Size and weight	
Total length	71 cm
Total weight	27kg
Compatibility	
Modalities	Photon beams, with and without flattening filter
Treatment Plan import	Any Treatment Planning system that can export DICOM RT Plan and RT Dose, Structure
ss Communication	
Wireless data communication protocol	Wi-Fi 802.11 n
operational capacity	>4 hours
	Rechargeable Li-ion battery – Power supply for charging included

ScandiDos

Archeck™

- 1386 SunPoint® Diode Detectors (0.019 mm3)
- Consistent Beams Eye View (BEV) for all gantry angles measuring entrance and exit dose
- Real-time electrometer measures every pulse, as well as composite and sub-arcs
- Interior cavity allows wide range of detector and inhomogeneity inserts

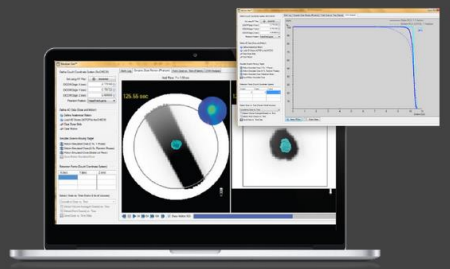
SUN NUCLEAR corporation



Respiratory MotionSim™

Simulate the dosimetric impact of target motion with proven accuracy.

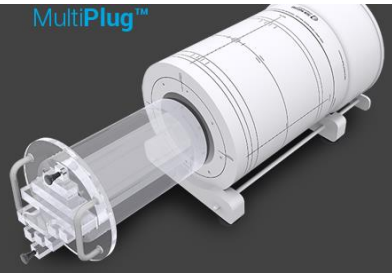
- Evaluate motion impacts on 3D Dose and DVH
- Determine if motion management is necessary, and add to QA motion management plans
- Use existing QA measurements and avoid bulky mechanical motion phantoms



Dose and DVH QA

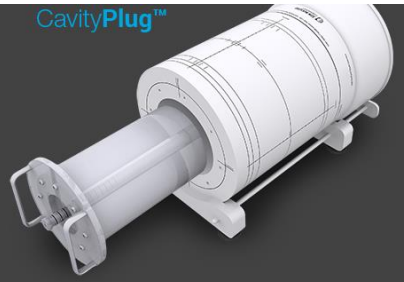
Full 3D Dose reconstruction for target and OAR DVH QA with 3DVH® software

MultiPlug™

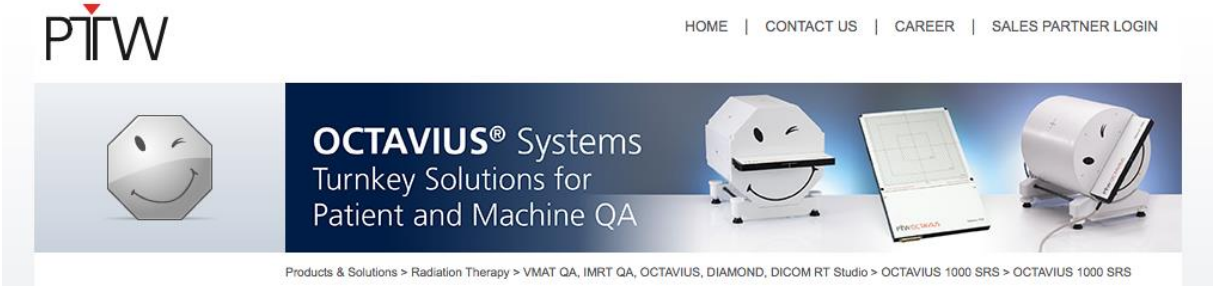


- Hounsfield Unit (HU) conversion testing
- Tissue equivalent inserts:
  - Muscle, Bone, Lung, Adipose, Titanium
- Dose in up to 25 locations
- Film cassette insert
- Bezel angle indicator for rotation within cavity
- Precision milled detector holder included
  - Solid insert included to achieve solid cavity

CavityPlug™

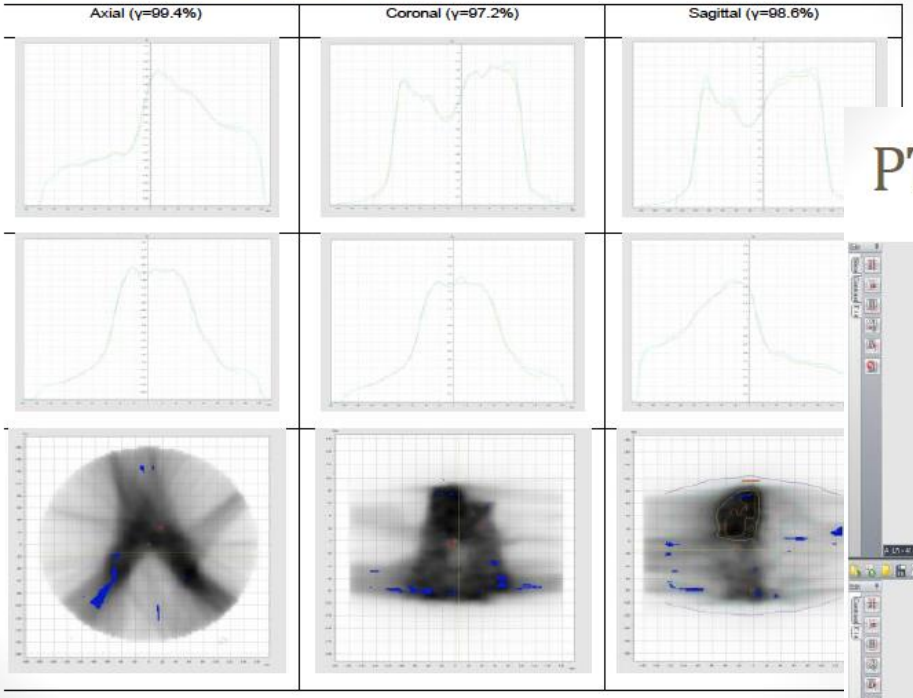


- Precision fitted to ArcCHECK cavity
- Measure dose in cavity center
- Precision milled detector holder included
  - Solid insert included to achieve solid cavity

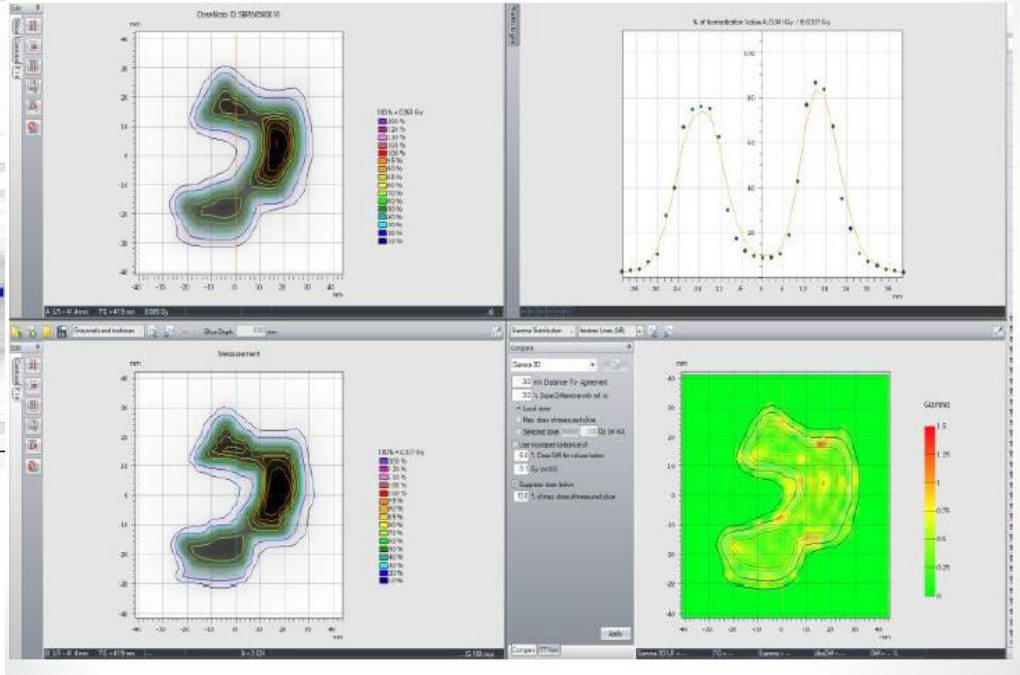


OCTAVIUS®

PTW Octavius 4D



PTW Octavius 1000SRS



Definitions used in patient-specific QA

- A low gradient region is a region in which the dose varies less than 20% per cm, compared to the local dose value
- A spatial resolution of 2 mm or better is considered ‘high-resolution”
- The **reference dose** is the dose prescribed to the relevant target volume (PTV)
- If elective target volumes are present with substantially different dose levels, the prescribed dose to these regions should be used as reference dose for those volumes. It might be necessary to run the gamma analysis multiple times with different reference doses

Gamma-analysis (Low et al., Med. Phys, 1998)

A technique for the quantitative evaluation of dose distributions

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(Received 9 June 1997; accepted for publication 2 March 1998)

The commissioning of a three-dimensional treatment planning system requires comparisons of measured and calculated dose distributions. Techniques have been developed to facilitate quantitative comparisons, including superimposed isodoses, dose-difference, and distance-to-agreement (DTA) distributions. The criterion for acceptable calculation performance is generally defined as a tolerance of the dose and DTA in regions of low and high dose gradients, respectively. The dose difference and DTA distributions complement each other in their useful regions. A composite distribution has recently been developed that presents the dose difference in regions that fail both dose-difference and DTA comparison criteria. Although the composite distribution identifies locations where the calculation fails the preselected criteria, no numerical quality measure is provided for display or analysis. A technique is developed to unify dose distribution comparisons using the acceptance criteria. The measure of acceptability is the multidimensional distance between the measurement and calculation points in both the dose and the physical distance, scaled as a fraction of the acceptance criteria. In a space composed of dose and spatial coordinates, the acceptance criteria form an ellipsoid surface, the major axis scales of which are determined by individual acceptance criteria and the center of which is located at the measurement point in question. When the calculated dose distribution surface passes through the ellipsoid, the calculation passes the acceptance test for the measurement point. The minimum radial distance between the measurement point and the calculation points (expressed as a surface in the dose–distance space) is termed the γ index. Regions where $\gamma > 1$ correspond to locations where the calculation does not meet the acceptance criteria. The determination of γ throughout the measured dose distribution provides a presentation that quantitatively indicates the calculation accuracy. Examples of a 6 MV beam penumbra are used to illustrate the γ index. © *1998 American Association of Physicists in Medicine.* [S0094-2405(98)01905-1]

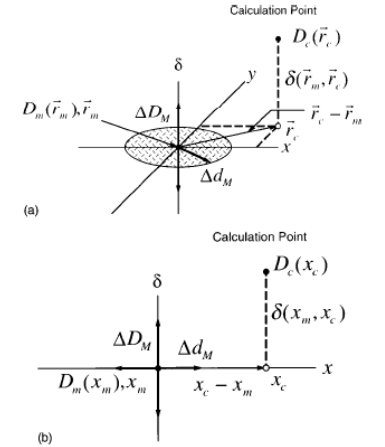

FIG. 1. Geometric representation of dose distribution evaluation criteria for the dose-difference and distance-to-agreement tests. (a) Two-dimensional representation. (b) One-dimensional representation.

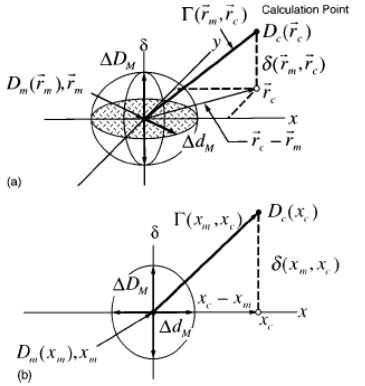

FIG. 2. Geometric representation of dose distribution evaluation criteria using the combined ellipsoidal dose-difference and distance-to-agreement tests. (a) Two-dimensional representation. (b) One-dimensional representation.

Gamma-formalism (1)

The γ is calculated based on finding the minimum Euclidean distance for each reference point, see Fig. 1 in conjunction with the following description. For each reference point in the dose distribution, calculate against each point in the evaluated distribution:

1. the distance between reference to evaluated point: $\Delta r(\mathbf{r}_R, \mathbf{r}_E)$
2. the dose difference between the reference and evaluated point: $\Delta r(\mathbf{r}_R, \mathbf{r}_E)$

Where $\mathbf{r}_R$ is the reference point, $\mathbf{r}_E$ is the evaluated point. The dose difference is calculated using Eq. (1):

$$\Delta D(r_R r_E) = D_E(r_E) - D_R(r_R) \quad (1)$$

where $D_E(r_E)$ is the dose at a point in the evaluated dose distribution, r_E, and $D_R(r_R)$ is reference point dose.

Then for each point in the evaluated distribution, calculate the γ using Eq. (2):

$$\Gamma(\mathbf{r_R}, \mathbf{r_E}) = \sqrt{\frac{\Delta r^2(\mathbf{r}_R, \mathbf{r}_E)}{\delta r^2} + \frac{\Delta D^2(\mathbf{r}_R, \mathbf{r}_E)}{\delta D^2}} \quad (2)$$

where δr is the distance difference criterion and δD is the dose difference criterion.

The γ is then taken as the minimum value calculated over all evaluated points as shown in Eq. (3):

$$\gamma(\mathbf{r}_R) = min\{\Gamma(\mathbf{r_R}, \mathbf{r}_E)\}\forall\{\mathbf{r_E}\} \quad (3)$$

The δr and δD criteria form an ellipsoid around the reference point as shown in Fig. 1. If an evaluated point is located within this then the reference point will pass since γ will be <1.

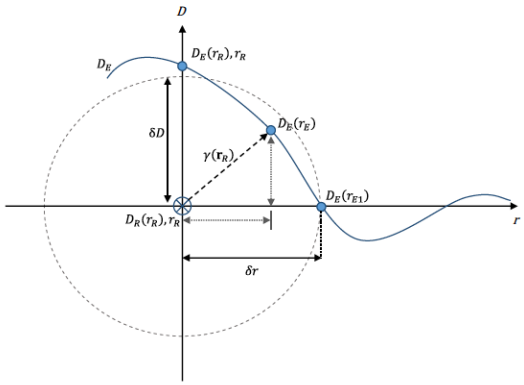

Fig. 1. Schematic representation of the gamma index method in 1D. Adapted from Low et al. (1998). The y-axis is Dose, *D*, and the x-axis is distance, *r*. The cross is the reference point and the blue line represents the evaluated dose distribution with the solid circles being discrete points along the line. The δr and δD criteria create an acceptance ellipse around the reference point. In this schematic and using Eq. (2), point $D_E(r_R), r_R$ would have $\Gamma > 1$, $D_E(r_E)$ would be $\Gamma < 1$, and $D_E(r_{E1})$ would be $\Gamma = 1$, $D_E(r_E)$ would be $\Gamma < 1$ (since it is inside the acceptance ellipse). Therefore the result of Eq. (3) would be $\gamma < 1$ for the reference point.

γ-ndex is a tool that combines dose and distance criteria in a single, quantitative test. The doses and spatial coordinates are first renormalized by user-selected dose & distance agreement criteria.

□-function is the minimum distance between two dose distributions, but in an unusual space. The distance includes not only space, but dose as well.

Gamma-formalism (2)

- It is standard to report the passing criteria in the format δD(%)/δr(mm).
- The most common passing criteria used is 3%/3 mm which was originally recommended in the work by Low et al.
- The tool was originally developed to compare measured water tank beam data against a treatment planning system algorithm.
- The criteria of 3%/3 mm were used due to the limitations of TPS algorithms at the time, where particularly penumbra modelling was a source of uncertainty.
- Because the gamma takes into account dose-diff and distance diff it was well-suited to the modulated fields in IMRT, however the criteria of 3%/3 mm has persisted.

Gamma-index: practical considerations

- For a 2D and 3D evaluation all measured points with a dose below 10%-20% of the reference dose should be discarded to avoid false positives due to low signal-to-noise in the low dose area.

- The choice of the actual cut-off value is at the discretion of the user, in part based on the treatment site, the equipment used and the choice between a 2D and 3D gamma evaluation.

Gamma-index: practical considerations

Global vs local

Typically the γ calculations are categorised into two different types; local and global. The contrast between the two types is the way the dose difference is calculated. For a local γ, Eq. (1) gives the definition for a local dose difference. For global gamma, Eq. (1) has to be modified to become Eq. (4):

$$\Delta D(r_R, r_E) = \frac{D_E(r_E) - D_R(r_R)}{D_{norm}} \quad (4)$$

where D_{norm} is a normalisation dose value which can be defined as any value; for example, as the maximum dose within the reference dose distribution or a point selected in a high dose low gradient region. The two types of γ have advantages and disadvantages.

The two types of γ have advantages and disadvantages

- The local γ will tend to highlight failures in high dose gradient regions and in low dose regions, whereas the global γ will tend to mask these errors but show the errors within the higher dose regions.
- The choice of the γ calculation will depend on the needs of the test.
- Many data in literature based on global calculation (AAPM array data included)

Gamma-index: practical considerations

- To achieve a DTA of 3 mm or better, it is recommended to perform the dose computation with a resolution of 3 mm or better.
  - The slice thickness of the imaging dataset used for dose computation should be considered to meet this criterion.
- For the γ-evaluation, it may be necessary to normalise the measured dose distribution to the computed one and register them.
- All equipment used should be calibrated properly and their limitations in terms of dosimetric and spatial accuracy/precision should be known and taken into consideration.
- The γ-evaluation tool should be considered with care and should not be used as the only evaluation criterion

Gamma-evaluation: review

IC3DDose: The 6th International Conference on 3D Radiation Dosimetry IOP Publishing
Journal of Physics: Conference Series **250** (2010) 012071 doi:10.1088/1742-6596/250/1/012071

Gamma Dose Distribution Evaluation Tool

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Abstract. Quantitative comparisons of dose distributions are an integral component of a medical physicist's responsibility of assuring high quality radiation therapy dose delivery. While overlays and other displays of multiple dose distributions are useful for such evaluations, quantitative evaluations require a mathematical comparison. The dose-difference is the most straightforward method for comparing two dose distributions, but it can show large differences in steep dose gradient regions, even for relatively small misalignments. A tool, termed γ,was developed to take both dose and spatial difference into account. It does this automatically, evaluating distributions for dose difference and spatial discrepancies in regions of shallow and steep dose gradients, respectively. The tool has been used extensively in commercial dose measurement and evaluation software. This chapter describes the tool, some alternative techniques, and limitations of the tool.

Gamma-index: computational aspects

Physica Medica 36 (2017) 1–11

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Review paper

Challenges in calculation of the gamma index in radiotherapy – Towards good practice

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ABSTRACT

The gamma index (γ) is one of the most commonly used metrics for the verification of complex modulated radiotherapy. The mathematical definition of the γ is computationally expensive and various techniques have been reported to speed up the calculation either by mathematically refining the γ or employing various computational techniques. These techniques can cause variation in output with different software implementations. The γ has traditionally been used to compare a 2D measured plane against a 2D or 3D dose distribution. Recently, software algorithm and hardware improvements have led to the possibility of using measured 2D data from commercial detector arrays to reconstruct a 3D-dose distribution and perform a volumetric comparison against the treatment planning system (TPS). A limitation in this approach is that commercial detector arrays have so far been limited by their spatial resolution which may affect the accuracy of the reconstructed 3D volume and subsequently the γ calculation. Additionally, 3D versus 3D γ comparison adds a layer of complication in the calculation of the γ given the increase in the number of calculation points and the result cannot be as easily interpreted in the same way as 2D comparison. This review summarises and highlights the computational challenges of the γ calculation and sheds light on some of these issues by means of a bespoke MATLAB software to demonstrate the impact of interpolation, γ search distance, resolution and 2D and 3D calculations. Finally, a recommendation is made on the minimum information that should be reported when publishing γ results.

The central question: when the plan is “ok”?

- **Agreement Index: which GPR%?**

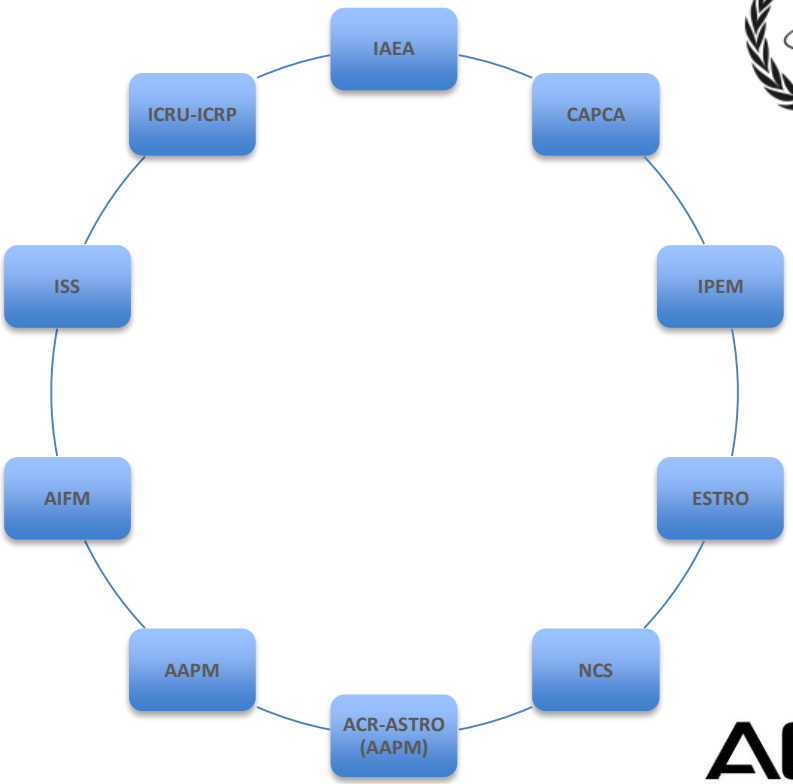
  - Gamma passing rate (points with γ≤1 where γ is calculated usually with 3 mm-3%)

    85% **90%** **95%** ????

- **The choice depends on**

  - IMRT equipment and delivery modality
  - Modulation Complexity Score→ Plan quality
  - Verification type (field by field or composite plan)
  - Normalization procedure for dose diff%
  - Size of the measurements samples
  - Cutoff
  - QA policy of RO department

Guidelines



ESTRO
European Society for RADIOTHERAPY & ONCOLOGY

Nederlandse Commissie voor Stralingsdosimetrie

ISTITUTO SUPERIORE DI SANITÀ

Aifm
Associazione Italiana di Fisica Medica

ICRP

IPEM

CAPCA

pro
www.practicalradonc.org

ACR
AMERICAN COLLEGE OF RADIOLOGY

ACR
RADIOLOGY
ASTRO

AAPM TG119 (Med Phys 36(11) – 2009)

IMRT commissioning: Multiple institution planning and dosimetry comparisons, a report from AAPM Task Group 119

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Main focus is to evaluate the overall performance of an MRT system and to determine reasonable confidence limits (CLs) for assessing the adequacy of the dosimetric commissioning.

The TG119 developed a specific set of tests for IMRT commissioning considered representative of the most common clinic sites.

The tests present a range of optimization problems requiring simple to complex modulation patterns, so they providing system checks of different types and different levels of complexity

TG119 adopts the concept of CL

- TG119 has quantified the “degree of agreement that should be expected” using the concept of “CONFIDENCE LIMIT” as proposed by some authors (Venselaar et al, Palta et al.).
- If the difference between the measured then the predicted is within a reasonable confidence limit, the the result can be considered acceptable

- The TG119 has established CONFIDENCE LIMITS for different types of measurements, by combining data from the participating centers
- Each of the centers that have participated to the study has passed the previous RPC IMRT intercomparison test using the RPC’ H&N dosimetry phantom (resulting “Ok center”)

TG119 - Confidence limits CLs

- The CL is based on
  - *the average difference between measured and expected values for a number of measurements of similar situations (SYSTEMATIC DIFFERENCE)*

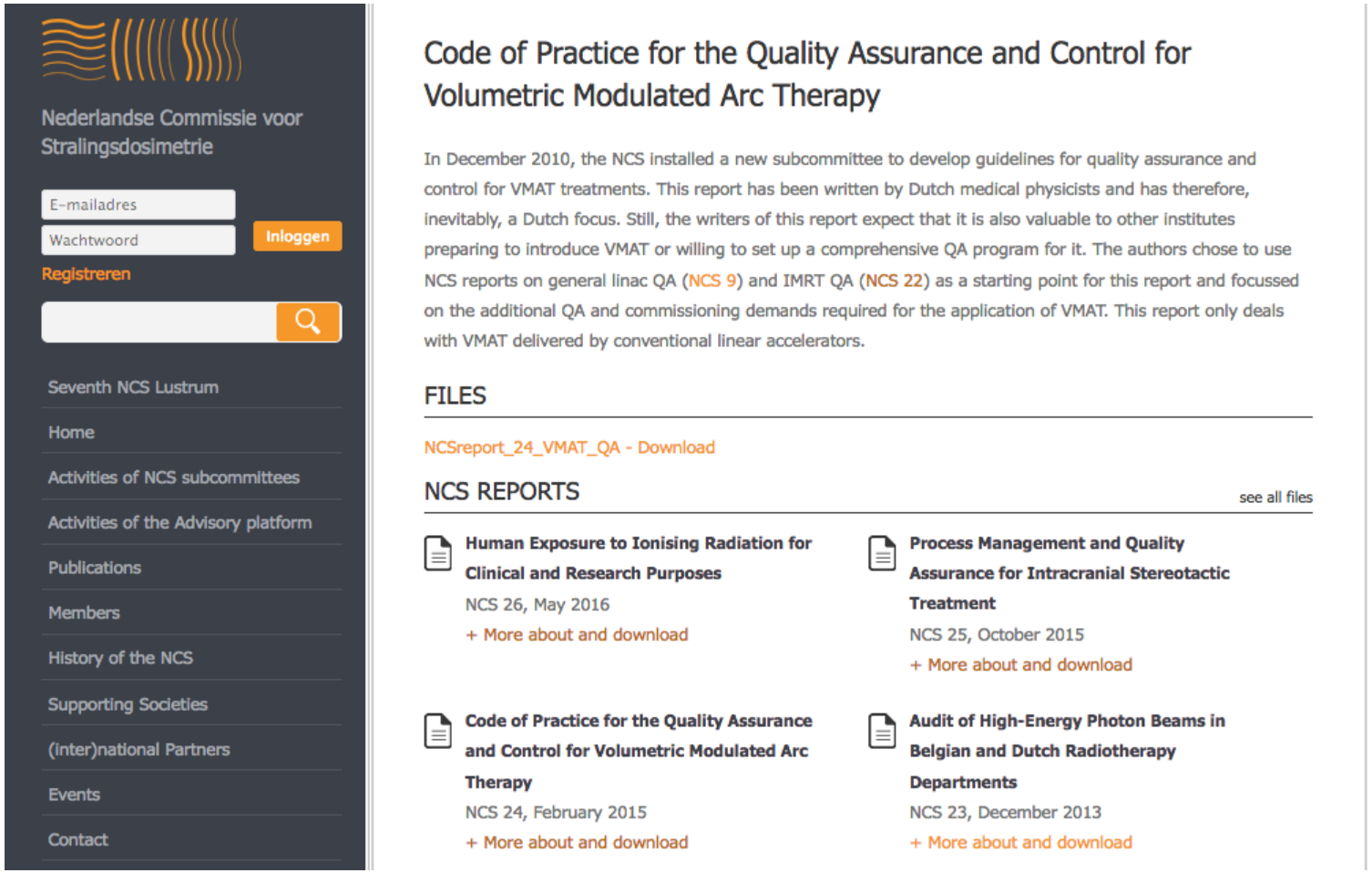
  summed with
  - the standard deviation of the differences multiplied by some factor (RANDOM DIFFERENCE)
- In the formula proposed by Palta (2003), CL is the sum of the absolute value of the average difference and the standard deviation of the differences multiplied by a factor of 1.96

$$CL = |\text{mean deviation}| + 1.96\ SD$$

- Note that CL is dominated by the SD term with its factior of about 2

- This is based on the statistics of a normal distribution: it is expected that 95% of the measured points will fall within the confidence limit.
- TG119 adopted the Palta formalism

Netherlands Guidelines



Netherlands Commission on Radiation Dosimetry

Netherlands Guidelines

Code of Practice for the Quality Assurance and Control for Intensity Modulated Radiotherapy

NEDERLANDSE COMMISSIE VOOR STRALINGSDOSIMETRIE

Report 22 of the Netherlands Commission on Radiation Dosimetry
June 2013

April 2013

Netherlands Commission on Radiation Dosimetry
Subcommittee "IMRT QA",
June 2013

Code of Practice for the Quality Assurance and Control for Volumetric Modulated Arc Therapy

NEDERLANDSE COMMISSIE VOOR STRALINGSDOSIMETRIE

Report 24 of the Netherlands Commission on Radiation Dosimetry
February 2015

February 2015

Netherlands Commission on Radiation Dosimetry
Subcommittee VMAT QA
February 2015

Canada guidelines

CPQR
Canadian Partnership for Quality Radiotherapy
PCQR
Partenariat canadien pour la qualité en radiothérapie

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TECHNICAL QUALITY CONTROL | RELEASE: THE TQC SUITE

Technical Quality Control Guidelines

Making sure the technology works


Trillium Health Partners

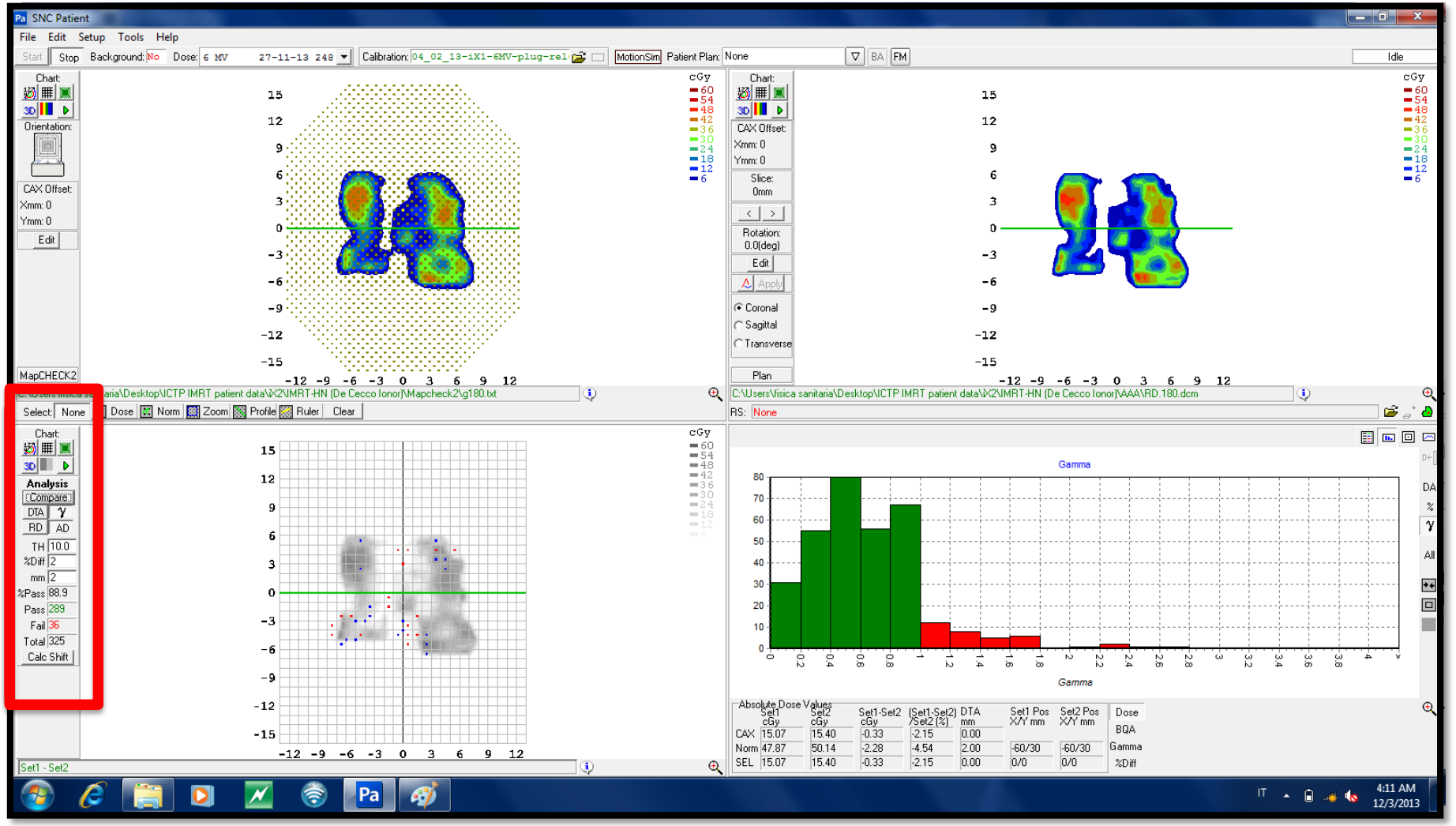
Technical quality control (TQC) guidelines are intended to provide direction for assuring optim performance of radiation treatment equipment programs across the country, an essential requirement of high quality and safe patient ca While technical drivers from international organizations like the American Association of Physicists in Medicine (AAPM) exist, they may applicable across the spectrum of practice environments like Canada, are not regularly up and have not been properly validated. In 2010 CPQR, together with the Quality Assurance Radiation Safety Advisory Committee (QARSAC) of COMP undertook an extensive review

Equipment Specific TQC Guidelines

(Dosimetric, geometric and mechanical properties of the equipment)

- Accelerator integrated cone beam systems for verification imaging (Expert reviewer: Jean-Pierre Bissonnette)
- Brachytherapy remote afterloaders (Expert reviewer: Normand Freniere)
- Conventional radiotherapy simulators (Expert reviewer: Marie-Joelle Bertrand)
- Computed tomography simulators (Expert reviewer: Philippe Despres)
- CyberKnife (Expert reviewers: Eric VanderVoort, Horacio Patrocinio, Tom Chow, Emilie Soisson, Dominic Nadeau)
- Data management systems (Expert reviewer: Natalie Pomerleau-Dalcourt)
- GammaKnife (Expert reviewers: Anita Berndt, Mathieu Guillot, Monique vanProoijen)
- Kilovoltage radiotherapy machine (Expert reviewer: Christophe Furstoss)
- Low dose rate permanent seed brachytherapy (Expert reviewer: Luc Beaulieu)
- Major dosimetry equipment (Expert reviewer: Gerard Lagmago Kamta)
- Medical linear accelerators and multi-leaf collimators (Expert reviewers: Charles Kirkby, Esmaeel Ghasroddashti, Crystal Plume Angers, Erin Barnett, Grace Zeng)
- Patient-specific dosimetric measurements for modulated therapies (Expert reviewer: Andrea McNiven)

gamma index varies with criteria settings



More stringent criteria: 2%-2mm

Real-world examples of sensitivity failures of the 3%/3mm pass rate metric and published action levels when used in IMRT/VMAT system commissioning

B Nelms[1], G Jarry[2], M Chan[3], C Hampton[4], Y Watanabe[5] and V Feygelman[6]
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Abstract. In IMRT/VMAT system commissioning (as with any system), quality is improved by striving for tight tolerances of stringent metrics of accuracy. For 5 cases, passing rates for 3%/3mm gamma analysis v
more stringent/sensitive cri
applied, and in each case sig
3%/3mm passing rates. In
examples of observed "false
the 3%/3mm gamma passing
the IMRT/VMAT delivery cl

- Different errors in the MLC leaf position for VMAT were correlated to DVH values
- Planar (2D-Array) and bi-planar (Delta4) arrays were used
- **A stricter γ (2%/2mm) criterion is necessary in order to detect MLC positional errors**
- Even a γ index rate > 90% does not guarantee the absence of significant clinical dose deviations

Heilemann G, Med. Phys. 2013

Re-Thinking about QA

POINT/COUNTERPOINT

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QA procedures in radiation therapy are outdated and negatively impact the reduction of errors

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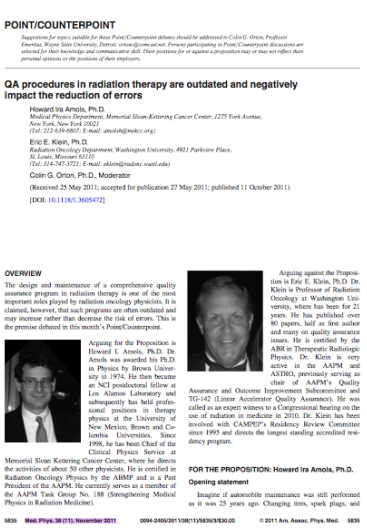
Colin G. Orton, Ph.D., Moderator



POINT/COUNTERPOINT

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QA procedures in radiation therapy are outdated and negatively impact the reduction of errors

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(Received 25 May 2011; accepted for publication 27 May 2011; published 11 October 2011)

[DOI: 10.1118/1.3605472]

OVERVIEW

The design and maintenance of a comprehensive quality assurance program in radiation therapy is one of the most important roles played by radiation oncology physicists. It is claimed, however, that such programs are often outdated and may increase rather than decrease the risk of errors. This is the premise debated in this month's Point/Counterpoint.

Arguing for the Proposition is Howard I. Amols, Ph.D. Dr. Amols was awarded his Ph.D. in Physics by Brown University in 1974. He then became an NCI postdoctoral fellow at Los Alamos Laboratory and subsequently has held professional positions in therapy physics at the University of New Mexico, Brown and Columbia Universities. Since 1998, he has been Chief of the Clinical Physics Service at Memorial Sloan Kettering Cancer Center, where he directs the activities of about 50 other physicists. He is certified in Radiation Oncology Physics by the ABMP and is a Past President of the AAPM. He currently serves as a member of the AAPM Task Group No. 188 (Strengthening Medical Physics in Radiation Medicine).

Arguing against the Proposition is Eric E. Klein, Ph.D. Dr. Klein is Professor of Radiation Oncology at Washington University, where has been for 21 years. He has published over 80 papers, half as first author and many on quality assurance issues. He is certified by the ABR in Therapeutic Radiologic Physics. Dr. Klein is very active in the AAPM and ASTRO, previously serving as chair of AAPM's Quality Assurance and Outcome Improvement Subcommittee and TG-142 (Linear Accelerator Quality Assurance). He was called as an expert witness to a Congressional hearing on the use of radiation in medicine in 2010. Dr. Klein has been involved with CAMPEP's Residency Review Committee since 1995 and directs the longest standing accredited residency program.

FOR THE PROPOSITION: Howard Ira Amols, Ph.D.

Opening statement

Imagine if automobile maintenance was still performed as it was 25 years ago. Changing tires, spark plugs, and

distributor points every 10 000 miles, repainting rusty chassis, and adding water to the battery weekly. Starting your car on a cold morning means "adjusting the choke," pumping the gas before turning on the ignition, and idling for 10 min before shifting into gear. We'd be pumping the brakes and spinning steering wheels whenever we went into a skid. But nobody does this anymore because it isn't necessary. Cars are built better and have different maintenance problems. Taking your car into the shop now usually means replacing a computer chip or sensor that didn't exist 25 years ago.

Linacs also are built better than they were 25 years ago, but we haven't changed our QA procedures accordingly. We still routinely check "vGy/mu," isocenter accuracy, laser drift, etc. Sure, we've added new QA procedures for modern accessories (EPIDs, MLCs, CBCT, etc.), but we never subtract. We never redesign the process to reflect the characteristics of modern equipment. We just increase the workload. How many patients have been reinstated recently because a laser drifted or a linac dose rate changed between Monday and Tuesday? None!

Big mistakes today usually result from:

1. Mistakes made during commissioning: Wrong dosimeter to calibrate a stereotactic radiosurgery (SRS) beam; corrupted computer file or software bug; not understanding a "hidden equation" underlying an Excel spread sheet, or the data format required for a computer program.
2. Being rushed or complacent and not following existing procedures.

Outdated QA procedures are fixated on 1–2% or mm drifts in things that rarely drift anymore. Why not spend less time testing "outdated" things and more time testing things that have been injuring patients recently?

The "name of the game" for new technology is acceptance testing, accuracy, commissioning, interconnectivity, and training; yet outdated QA procedures focus on labor-intensive measurements of precision. Case in point: the SRS beam that was miscalibrated because an inappropriate dosimeter was used to calibrate the small fields. I suspect that daily, monthly, etc., checks of linac output, etc. were precise and in compliance with recommended QA procedures, but the equipment was miscalibrated from day one, and no one checked accuracy (e.g., did an external audit).

At my own institution, like most others, we used to check laser alignment for every SRS patient. Recently, however, we changed our procedures and patient setup is now adjusted and confirmed using CBCT. Further, our new linac has isocentric accuracy ("star shots" geometric/mechanical measurements, etc.) of <0.5 mm. So why care if the lasers are properly aligned? Why waste time checking this when misstreatment of SRS patients is now more likely to result from computer errors?

Space does not permit a detailed listing of QA report recommendations that should no longer top the list of everyday checks, but, hopefully, I have made my point. Let us eliminate some "historical" QA tests to reflect the quantum changes in equipment design and focus more on QA tests that are more likely to prevent "modern" treatment errors.

AGAINST THE PROPOSITION: Eric E. Klein, Ph.D.

Opening statement

Three Mile Island, Chernobyl, Fukushima. Names synonymous with nuclear power plant catastrophes. Riverside OH, Tyler TX, Indiana PA, Cleveland (Plain Dealer), Epinal, Panama, Glasgow, Zarragosa, New York (Times),[1] etc. Names synonymous with radiotherapy events for which patients were either injured or killed. Events for which QA procedures were not followed. Perhaps QA procedures are outdated, but they are not negatively impacting error reduction. In fact, they are still preventing catastrophic errors.

Somehow, with limited resources, physicists must maintain current procedures while embracing a paradigm shift prioritizing error reduction.[2] The AAPM TG-142 report[3] accomplishes this by suggesting tests with more frequency and scrutiny for greater risk procedures (IMRT, SBRT), and less frequency for mundane tests that are benign with regard to error impact. Simultaneously, the long awaited AAPM TG-100 report[4] will guide the physicist on how to develop QA programs using failure mode and effects analysis (FMEA). This is not an easy task. TG-100 was constituted in 2004 and has yet to produce a final report. Ford *et al.* published an FMEA based manuscript[5] describing analysis of the 269 steps of taking a patient from consult to treatment. This was an expansive undertaking involving consultants. There is an effort to analyze the impact of human factors and culture on errors and error reduction, with training available through workshops and annual meetings. But no matter what strides are made, vendors will continue to sell complex equipment to facilities with understaffed and/or undermined physics personnel. Engineers will continue to adjust machinery without involving physicists for proper review. And software will still be written that is not robust enough to prevent unforeseen user misappropriation. It is no wonder that of the top ten worst software bugs ever reported, two involved radiotherapy.[6]

An example for which a procedural upheaval is immediately needed is IMRT QA. Every evening around the country, thousands of physicists (or QA technicians, residents, fellows, students) perform time-consuming measurements to validate that the correct dose is being delivered to a "box," a poor surrogate for the actual patient. In terms of prioritization, physicists should be spending time performing on-screen plan reviews to unmask potential problems that would go undetected with simplistic phantom QA. This includes incorrect image fusion, erroneous hot spots, improper beam/dot segmentation, etc. These problems could still go undetected with alternative QA techniques such as independent Monte Carlo calculations or leaf position-timing analysis.

Which brings up a final point vital to existing and future quality assurance procedures training. Physics residency programs, which are growing rapidly in number, must include teaching of human engineering and process analysis, beam modeling and critical review of treatment plans and, despite how outdated they may seem, routine quality assurance of imaging, planning, and delivery systems.

Med. Phys. 38 (2011)

Re-Thinking about QA

POINT/COUNTERPOINT

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It is STILL necessary to validate each individual IMRT treatment plan with dosimetric measurements before delivery

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Colin G. Orton, Ph.D., Moderator

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[DOI: 10.1118/1.3512801]

OVERVIEW

Almost a decade ago, we published a Point/Counterpoint debate on the need for validation measurements for each individual IMRT patient [Med. Phys. **30**, 2271–2273 (2003)]. Now, after many more years of experience with this modality, the necessity for such patient-specific measurements has been questioned, and this is the topic discussed in the month's Point/Counterpoint debate.

Arguing for the Proposition is J. Charles Smith, M.S. Mr. Smith graduated from St. Joseph's University in Philadelphia in 1987 with a B.S. in Physics and a minor in Mathematics, and received his M.S. in Physics from the University of Maryland, College Park, in 1990. He entered the field of Medical Physics in 1991 with a consulting group in the Washington DC region, and took his current position at St. Joseph Mercy in Port Huron, MI, in 1993. There, he is the Radiation Therapy Physicist and RSO, and helps in Nuclear Medicine and Diagnostic Radiology as needed. He is certified in Radiation Therapy Physics by the American Board of Medical Physics.

Arguing against the Proposition is Sonja Dieterich, Ph.D. After completing her Ph.D. in Nuclear Physics at Rutgers University in 2002, Dr. Dieterich received training in Medical Physics at Georgetown University Hospital, Washington DC, from 2002 to 2003. In 2003, she accepted a faculty position at Georgetown, where she became Chief of the Cyberknife program in 2006. In 2007, she moved to Stanford University Hospital, Stanford, CA, as Clinical Associate Professor and Chief of Radiosurgery Physics. Dr. Dieterich is certified in Therapeutic Radiologic Physics by the ABR and is Chair of the AAPM Task Group 135 (QA for Robotic Radiosurgery). Her current interests are the development of QA/QM programs for new technologies, motion management, and SRS dosimetry.

FOR THE PROPOSITION: J. Charles Smith, M.S.

Opening Statement

Ultimately, all the Quality Control/Quality Assurance (QC/QA) we do is supposed to assure that we are delivering dose to the patient in the manner and amount planned.[1] With regard to IMRT, there has been debate over whether or not we have the proper tools to test this in a meaningful way.[2,3] Hopefully, systems-analysis tools will be developed to address this, and we will train ourselves to think in terms of

POINT/COUNTERPOINT

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Patient-specific QA for IMRT should be performed using software rather than hardware methods

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[http://dx.doi.org/10.1118/1.4794929]

OVERVIEW

Measurement-based patient-specific quality assurance (QA) for IMRT is both time-consuming and potentially inaccurate, since the measurements are made in phantoms rather than actual patients. It has been suggested that it would be more accurate and considerably less time consuming to perform such QA with software rather than hardware, and this is the topic debated in this month's Point/Counterpoint.

Arguing for the Proposition is Alfredo Siochi, Ph.D. Dr. Siochi received his Ph.D. in Physics from Virginia Tech in 1990 and his M.S. in Radiological Physics from the University of Cincinnati in 1995. He holds over 20 patents and has more than 40 publications in radiotherapy. He developed over 17 in-house software applications, including an IMRT QA plan check suite and an IMRT sequencing algorithm in use in several treatment planning systems. He is Director of Medical Physics Education and IT Operations in the Radiation Oncology Department at the University of Iowa, and a member of many AAPM Committees and Task Groups including Chair of the AAPM Work Group on Information Technology and TG201 (Quality Assurance of External Beam Treatment Data Transfer), and Co-chair of the Radiation Safety Stakeholders Initiative. Dr. Siochi is certified by the American Board of Radiology in Therapeutic Radiological Physics.

Arguing against the Proposition is Andrea Molineu, M.S. Ms. Molineu obtained her M.S. in Medical Physics from the University of Kentucky, Lexington in 1999 and then moved to the Department of Radiation Oncology, St. Elizabeth's Medical Center, Boston, where she held a Medical Physicist appointment until 2001. She then moved to the Radiological Physics Center, Department of Radiation Physics, Division of Radiation Oncology, UT M. D. Anderson Cancer Center, Houston, TX, where she is currently a Senior Medical Physicist and Associate Director of the MD Anderson Phantom Laboratory. She is certified by the American Board of Radiology in Therapeutic Radiological Physics and her major research interests include anthropomorphic phantoms and radiotherapy QA, especially IMRT. She is a member of many AAPM committees and Task Groups and is the current Chair of the Working Group on Clinical Trials.

FOR THE PROPOSITION: Ramon Alfredo C. Siochi, Ph.D.

Opening statement

"Patient-specific QA" is a misnomer. What we really need is "Quality Control (QC)".[1] Every service for each patient is tested to ensure that it meets our safety and quality specifications. There is general agreement that, in IMRT, the specification is that the actual delivered dose (or location) should be within 3% (or 3 mm) of that planned. But what is the

2011

2013

To cut pre-TX patient-QC? **Yes**

- What are we find?
  - TP errors

    If we are validating a lung cancer IMRT, how far is the phantom from the real patient?
  - TD errors

    System delivery performance of the verification session does not reproduce exactly for every therapy fractions
- Uncertainties of measurement procedure
- Comparison tools, agreement criteria and tolerance levels
- Effective sensitivity to errors
- How is it can predict the clinical impact?
- Open question: if there are any discrepancies, what are we choose? <u>The crucial question</u>: <u>have we to re-plan</u>?

GPR vs DVH-based metric

GPR has generally weak correlation to critical patient DVH errors. Algorithms were developed to accurately predict the DVH impact using conventional planar patient-QA results. Patient QA based on metrics seems to be both sensitive and specific

Per-beam, planar IMRT QA passing rates do not predict clinically relevant patient dose errors[a)]

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Pretreatment patient-specific IMRT quality assurance: A correlation study between gamma index and patient clinical dose volume histogram

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JOURNAL OF APPLIED CLINICAL MEDICAL PHYSICS, VOLUME 10, NUMBER 1, WINTER 2009

On the sensitivity of patient-specific IMRT QA to MLC positioning errors

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Moving from gamma passing rates to patient DVH-based QA metrics in pretreatment dose QA

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Evaluating IMRT and VMAT dose accuracy: Practical examples of failure to detect systematic errors when applying a commonly used metric and action levels

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On the use of biomathematical models in patient-specific IMRT dose QA

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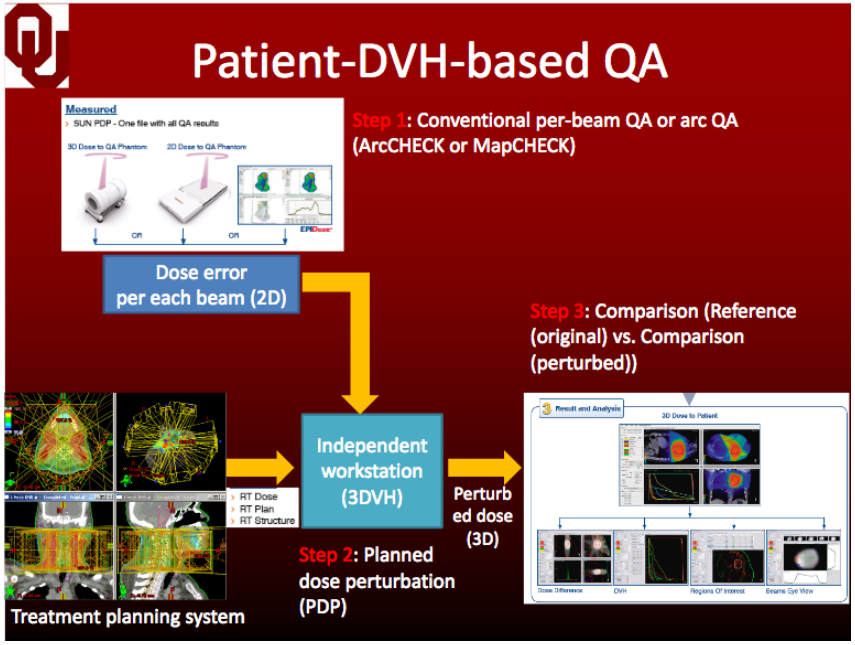
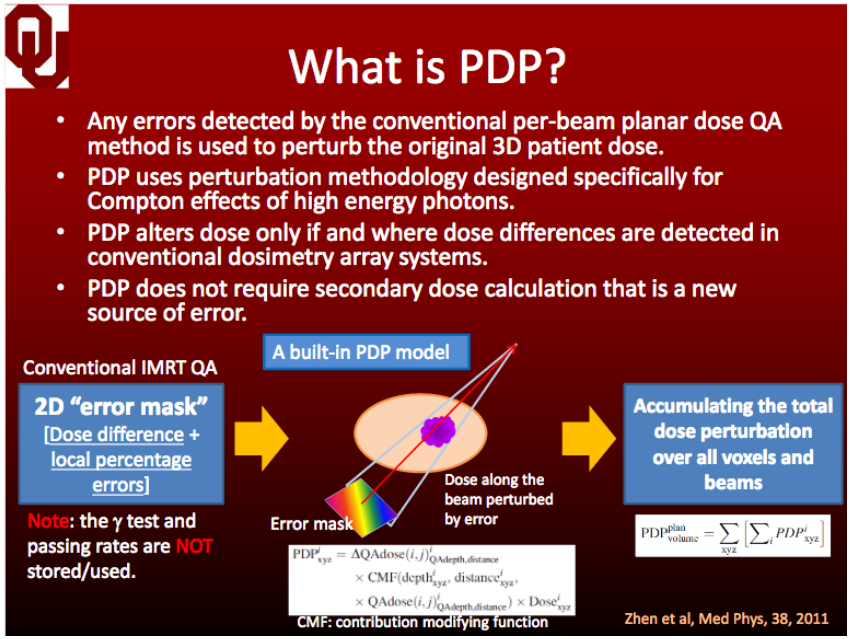
DVH-based metric: an application





Hosang Jin, 2012

DVH-based metric: advantages and limits

- It should be noted that high passing rates in conventional QA do not alone imply accurate dose calculation and/or delivery
- The PDP algorithm was shown to accurately predict the DVH impact and clinically relevant dose using conventional planar QA results.
- However, it could introduce more complex and inefficient QA in the busy clinic.
- Most importantly, acceptable tolerances, action levels, and potential changes in QA procedures should be explored extensively.
- Limitations of the PDP should be further investigated.

Hosang Jin, 2012

Error-catcher? I am not sure

Clinical Investigation: Quality Assurance

Quality Control Quantification (QCQ): A Tool to Measure the Value of Quality Control Checks in Radiation Oncology

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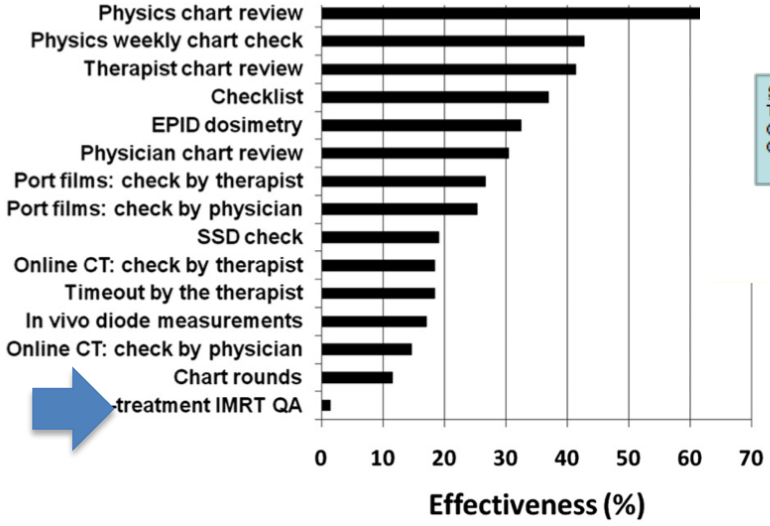
IJROBP, 84 (2012)



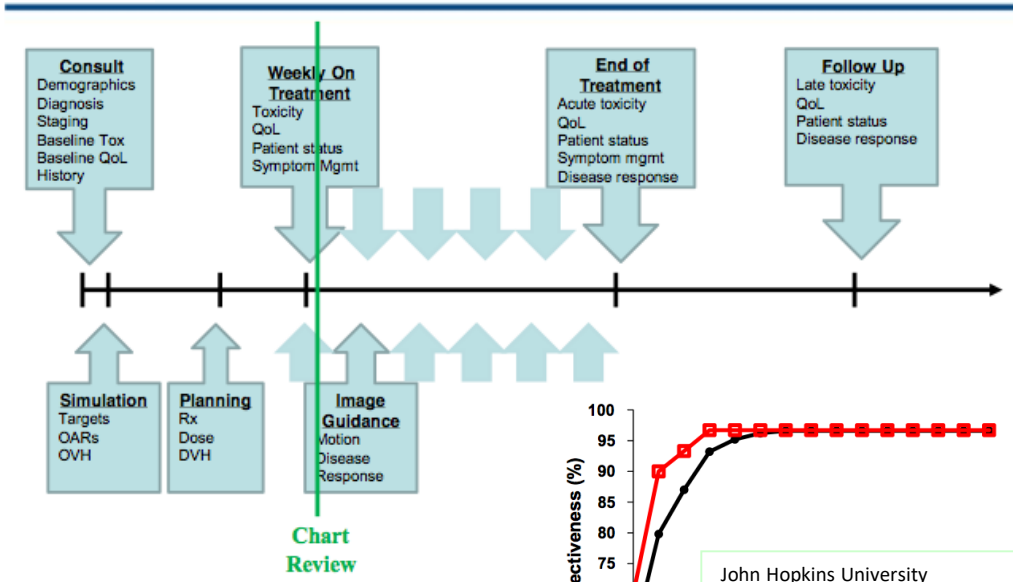


Fig. 3. The effectiveness for error detection as a function of the number of checks, k, in place. Effectiveness was calculated based on the best of the $\binom{n}{k}$ possible combinations of checks for each value of k. Low severity incidents are shown in red, and high severity incidents are shown in black.

To cut pre-TX patient-QC? **NO**

- Complementary to the machine-QA program
- End-to-end test/physics time out: they give a chance for a plan review
- Valid to detect gross errors
- Chiefs of Radiation Oncology Facilities understand patient-QC better than general QC
- …Better than nothing

International Journal of Radiation Oncology biology • physics
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Physics Contribution

Institutional Patient-specific IMRT QA Does Not Predict Unacceptable Plan Delivery

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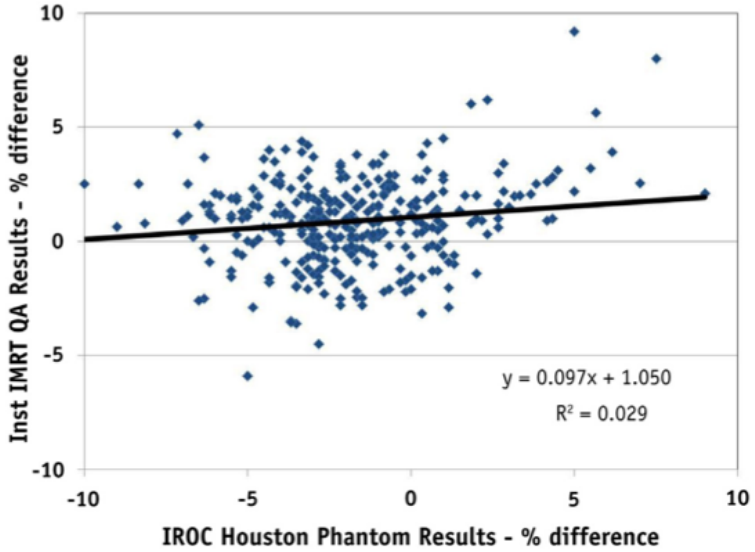


Fig. 3. Percent differences between dose measurements and treatment planning system calculations for institutional IMRT QA compared with the TLD in the IROC Houston phantom. The linear trend line should ideally have a slope of 1 but instead is nearly flat. IMRT QA = intensity modulated radiation therapy quality assurance; IROC = Imaging and Radiation Oncology Core; TLD = thermoluminescent dosimeters.

IJROBP, 88(2014)

Dosimetric audits performed by the Imaging and Radiation Oncology Core in Houston (IROC Houston)

(..) In-house patient-specific IMRT QA failed to detect unacceptable plan delivery as measured by the IROC Houston head and neck phantom.

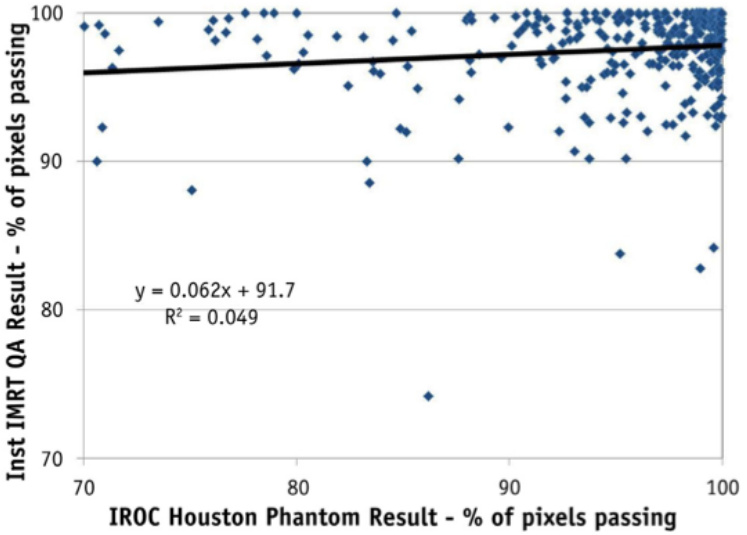
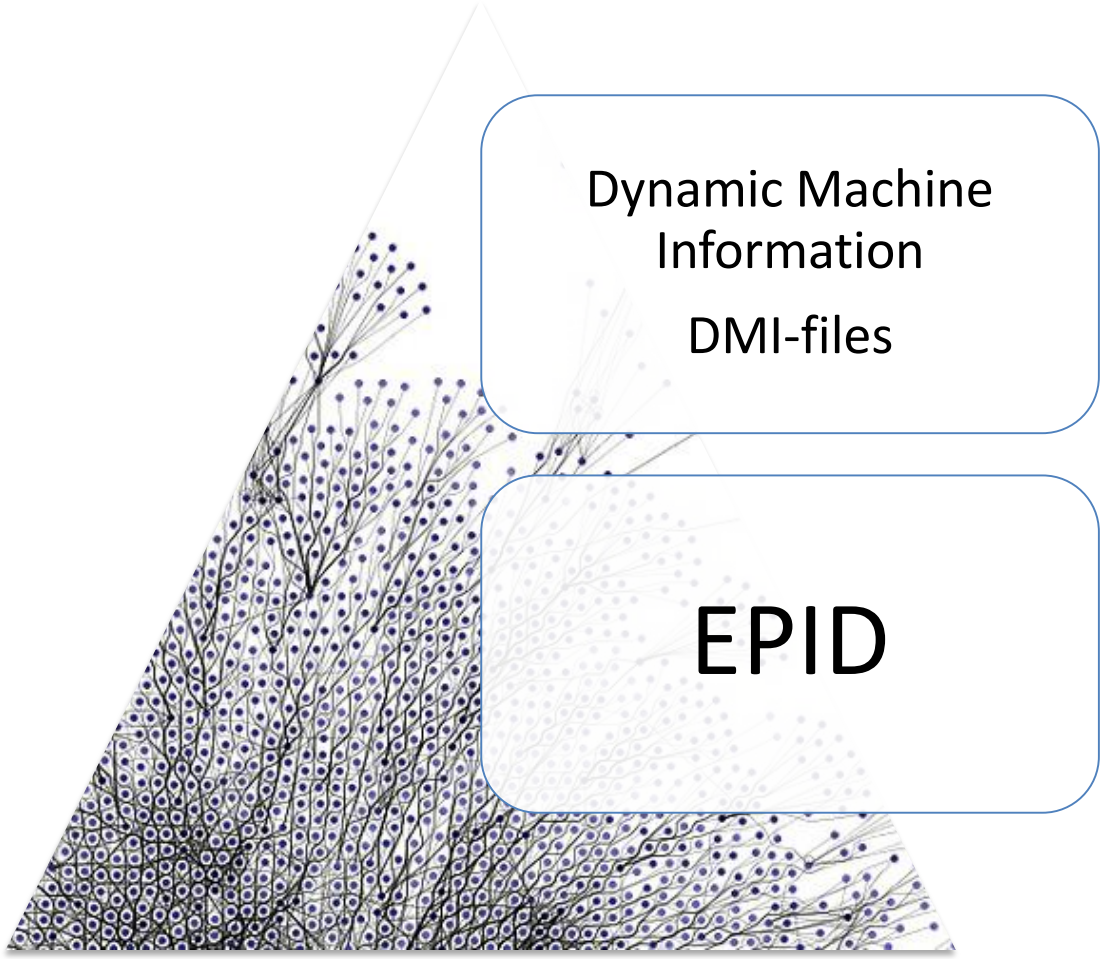


Fig. 4. Percent of pixels passing gamma for institutional IMRT QA compared with the IROC Houston phantom films. The linear trend line should ideally have a slope of 1, but instead is nearly flat. IMRT QA = intensity modulated radiation therapy quality assurance; IROC = Imaging and Radiation Oncology Core.

towards (real time) automation



In vivo automatic EPID-Dosimetry

IOP Publishing | Physics in Medicine and Biology
Phys. Med. Biol. **58** (2013) 8253–8264 | doi:10.1088/0031-9155/58/22/8253

Automatic *in vivo* portal dosimetry of all treatments

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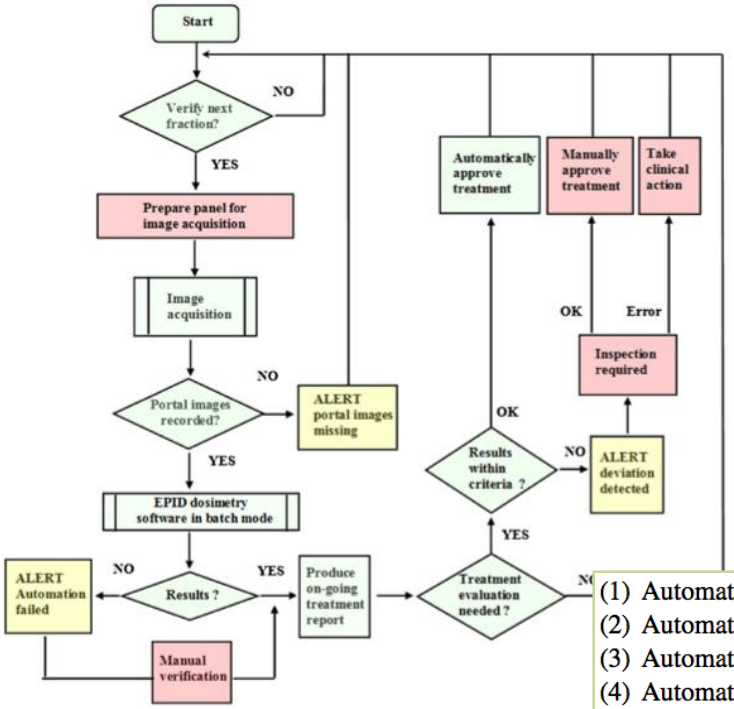

8th International Conference on 3D Radiation Dosimetry (IC3DDose) | IOP Publishing
Journal of Physics: Conference Series **573** (2015) 012004 | doi:10.1088/1742-6596/573/1/012004

Patient-specific QA using 4D Monte Carlo phase space predictions and EPID dosimetry

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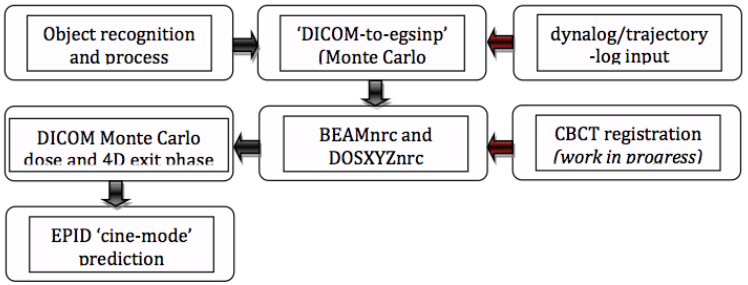

(1) Automatic tools that decide which fractions need to be analyzed for which treatments.
(2) Automatic acquisition of portal image data for these fractions.
(3) Automatic production of dosimetry reports.
(4) Automatically raising alerts and scheduling actions when deviations outside tolerance levels are detected.

Linac Delivery Log-files

JOURNAL OF APPLIED CLINICAL MEDICAL PHYSICS, VOLUME 13, NUMBER 5, 2012

Evaluation of the efficiency and effectiveness of independent dose calculation followed by machine log file analysis against conventional measurement based IMRT QA

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JOURNAL OF APPLIED CLINICAL MEDICAL PHYSICS, VOLUME 15, NUMBER 6, 2014

Correlation of phantom-based and log file patient-specific QA with complexity scores for VMAT

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IOP Publishing — Physics in Medicine and Biology

Phys. Med. Biol. 55 (2010) 3597–3610 — doi:10.1088/0031-9155/55/13/002

Dose reconstruction for volumetric modulated arc therapy (VMAT) using cone-beam CT and dynamic log files*

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Quality assurance

Linking log files with dosimetric accuracy – A multi-institutional study on quality assurance of volumetric modulated arc therapy

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IOP Publishing — Physics in Medicine and Biology

Phys. Med. Biol. 57 (2012) 6761–6777 — doi:10.1088/0031-9155/57/21/6761

Implementation of phantom-less IMRT delivery verification using Varian DynaLog files and R/V output

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Determination of the optimal tolerance for MLC positioning in sliding window and VMAT techniques

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Real-time treatment monitor

An integral quality monitoring system for real-time verification of intensity modulated radiation therapy

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JOURNAL OF APPLIED CLINICAL MEDICAL PHYSICS, VOLUME 15, NUMBER 4, 2014

A simple model for predicting the signal for a head-mounted transmission chamber system, allowing IMRT in-vivo dosimetry without pretreatment linac time

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Patient-specific online dose verification based on transmission detector measurements

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ABSTRACT

Background and purpose: Since IMRT-techniques lead to an increasingly complicated environment, a patient specific IMRT-plan verification is recommended. Furthermore, verifications during patient irradiation and 3D dose reconstruction have the potential to improve treatment delivery, accuracy and safety. This study provides a detailed investigation of the new transmission detector (DTD) Dolphin (IBA Dosimetry, Germany) for online dosimetry.

Materials and methods: The clinical performance of the DTD was tested by dosimetric plan verification in 2D and 3D for 18 IMRT-sequences. In 2D, DTD measurements were compared to a pre-treatment verification method and a treatment planning system by gamma index and dose difference evaluations. In 3D, dose–volume-histogram (DVH) indices and gamma analysis were evaluated. Furthermore, the error detection ability was tested with leaf position uncertainties and deviations in the linear accelerator (LINAC) output.

Results: The DTD measurements were in excellent agreement to reference measurements in both 2D ($\gamma_{3\%,3mm}$ = (99.7 ± 0.6)% <1, $\Delta D_{\pm 3\%}$ = (99.5 ± 0.5)%) and 3D. Only a small dose underestimation (<2%) within the target volume was observed when analyzing DVH-indices. Positional errors of the leaf banks larger than 1 mm and errors in LINAC output larger than 2% were identified with the DTD.

Conclusions: The DTD measures the delivered dose with sufficient accuracy and is therefore suitable for clinical routine.

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Diode-based transmission detector for IMRT delivery monitoring: a validation study

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The purpose of this work was to evaluate the potential of a new transmission detector for real-time quality assurance of dynamic-MLC-based radiotherapy. The accuracy of detecting dose variation and static/dynamic MLC position deviations was measured, as well as the impact of the device on the radiation field (surface dose, transmission). Measured dose variations agreed with the known variations within 0.3%. The measurement of static and dynamic MLC position deviations matched the known deviations with high accuracy (0.7–1.2 mm). The absorption of the device was minimal (~ 1%). The increased surface dose was small (1%–9%) but, when added to existing collimator scatter effects could become significant at large field sizes (≥ 30 × 30 cm^2). Overall the accuracy and speed of the device show good potential for real-time quality assurance.

PACS number(s): 87.55.Qr

Key words: transmission detector, real-time quality assurance, IMRT quality assurance, *in vivo* dosimetry

Real-time treatment monitor

Physics Contribution

First Experience With Real-Time EPID-Based Delivery Verification During IMRT and VMAT Sessions

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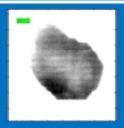
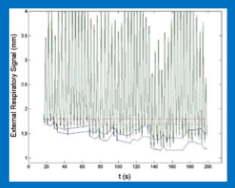
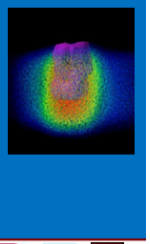
IJROBP, 2015

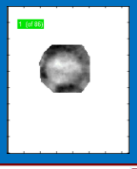
Applications of in-treatment imaging

- ✓Tx verification
- ✓Adaptive/dynamic gating
- ✓Delivered dose calculation
- ✓Adaptive radiation therapy
- ✓Beam tracking









Direct measurement for MLC tracking verification

Time-resolved dose distributions to moving targets during volumetric modulated arc therapy with and without dynamic MLC tracking

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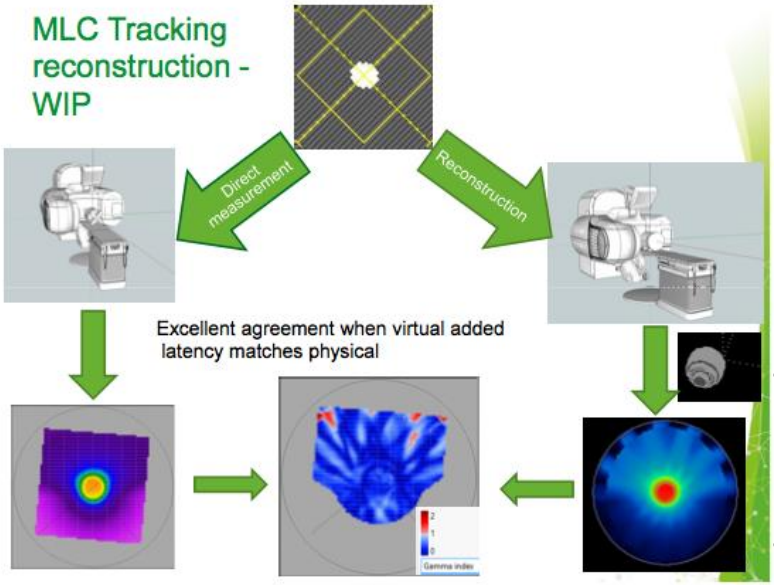
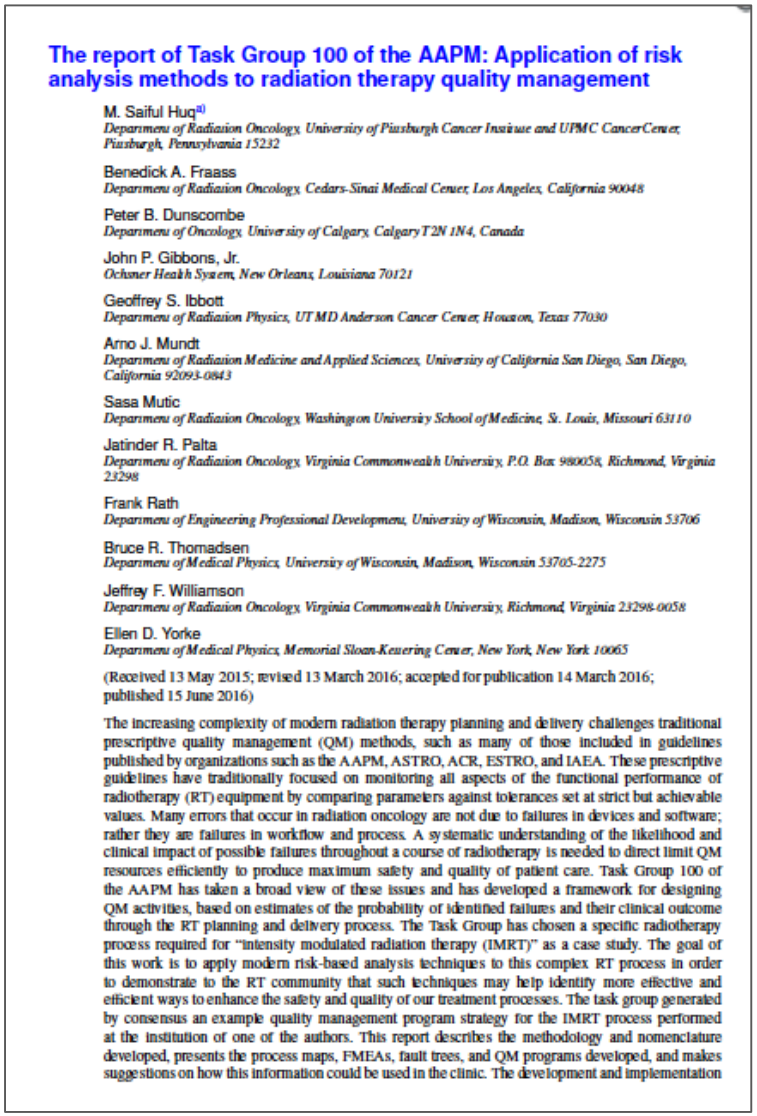


Feygelman, Estro Physics Pre-meeting 2015

The new deal: TG100 (july 2016)



The report of Task Group 100 of the AAPM: Application of risk analysis methods to radiation therapy quality management

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The increasing complexity of modern radiation therapy planning and delivery challenges traditional prescriptive quality management (QM) methods, such as many of those included in guidelines published by organizations such as the AAPM, ASTRO, ACR, ESTRO, and IAEA. These prescriptive guidelines have traditionally focused on monitoring all aspects of the functional performance of radiotherapy (RT) equipment by comparing parameters against tolerances set at strict but achievable values. Many errors that occur in radiation oncology are not due to failures in devices and software; rather they are failures in workflow and process. A systematic understanding of the likelihood and clinical impact of possible failures throughout a course of radiotherapy is needed to direct limit QM resources efficiently to produce maximum safety and quality of patient care. Task Group 100 of the AAPM has taken a broad view of these issues and has developed a framework for designing QM activities, based on estimates of the probability of identified failures and their clinical outcome through the RT planning and delivery process. The Task Group has chosen a specific radiotherapy process required for "intensity modulated radiation therapy (IMRT)" as a case study. The goal of this work is to apply modern risk-based analysis techniques to this complex RT process in order to demonstrate to the RT community that such techniques may help identify more effective and efficient ways to enhance the safety and quality of our treatment processes. The task group generated by consensus an example quality management program strategy for the IMRT process performed at the institution of one of the authors. This report describes the methodology and nomenclature developed, presents the process maps, FMEAs, fault trees, and QM programs developed, and makes suggestions on how this information could be used in the clinic. The development and implementation

A new way of thinking about the needs of safety and quality of RT process to propose a prospective and process-based analysis of QM needs

AAPM #218 – Tolerance levels and Methodologies for IMRT Verification QA

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Charge To review literature and reports containing data on the achieved agreement between measurements and calculations for fixed-gantry IMRT, Tomotherapy, and VMAT techniques. To review measurement methods commonly employed, composite of all beams-actual parameters, composite perpendicular, and beam-by-beam perpendicular. Discuss pros and cons of each. To review single-point (small-averaged volume), 1D and 2D analysis methodologies for absolute dose verification with ion-chamber and the more complex 2D detector arrays, mainly performed with dose differences comparison, distance-to-agreement (DTA) comparison between measured and calculated dose distributions, and a combination of these two metrics (gamma method). To investigate the dose-difference/DTA and gamma verification metrics, their use and vendor-implementation variability, including the choice of various parameters (normalization method, choice of dose thresholding, points shift) used to perform the analysis.

Chair

Moyed Miften
Task Group Chair

Bylaws: Not Referenced. **Rules:**

Approved Date(s) Start: 5/10/2011 End: 12/31/2015

Committee TG218

Most recent status update: Final revised draft report has been completed. Draft accounted for the WG and SC review comments and is currently being reviewed by the lead SC reviewer. Next step is the review by TPC. - [7/20/2015 by Moyed Miften] Click to update.

Why TG218

- There is little systematic guidance on patient-specific IMRT verification QA
- There are no discussion on the pros and cons of the different delivery methods for QA measurements
- How to assess the clinical relevance of failed IMRT plans
- What are the course of actions a clinical physicist can undertake to deal with failed patient-specific IMRT QA plans
- Radiation oncology clinics have developed their own patient-specific IMRT QA procedures
- QA procedures differ in scope and depth, acceptable tolerance levels, delivery methods, verification tools, analysis methodologies, and the type of verified calculation vs. measured data

Mitfen, AAPM Meeting 2016

AAPM #218 – Charge (1)

- To review literature and reports containing data on the achieved agreement between measurements and calculations for IMRT, VMAT, and tomotherapy techniques.
- To review commonly used measurement methods: composite of all beams using the actual treatment parameters, perpendicular composite, and perpendicular field-by-field. Discuss pros and cons of each method.
- To review methodologies for absolute dose verification with ion-chamber and 2D detector arrays
- To investigate the dose-difference/DTA and γ verification metrics, their use and vendor-implementation variability, including the choice of various parameters used to perform the IMRT QA analysis.

Mitfen, AAPM Meeting 2016

AAPM #218 – Charge (2)

- To review literature and reports containing data on the achieved agreement between measurements and calculations for IMRT, VMAT, and tomotherapy techniques.
- To review commonly used measurement methods: composite of all beams using the actual treatment parameters, perpendicular composite, and perpendicular field-by-field. Discuss pros and cons of each method.
- To review methodologies for absolute dose verification with ion-chamber and 2D detector arrays
- To investigate the dose-difference/DTA and γ verification metrics, their use and vendor-implementation variability, including the choice of various parameters used to perform the IMRT QA analysis.

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Methodologies

Perpendicular Field-by-Field (PFF)

- The radiation beam is perpendicular to the plane of the measurement device
- The device can be placed on the couch or attached to the gantry head.
- The dose from each of the IMRT beams is delivered and analyzed.

Perpendicular Composite (PC)

- The radiation beam is always perpendicular to the measurement device detector plane.
- The device can be placed on the couch or attached to the gantry head.
- The doses from all IMRT radiation beams are delivered and subsequently summed.

True Composite (TC)

- All of the radiation beams are delivered to a stationary measurement device in a phantom placed on the couch using the actual treatment beam geometry for the patient.
- This method most closely simulates the treatment delivery to the patient.

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Delivery Methods

Delivery Methods: Pros

- PFF and PC: Every part of every field is sampled, fast acquisition.
- PC: only one dose image to analyze. More uniform dose for analysis than PFF.
- TC: provide an actual dose summation in a 2D slice of the 3D dose. Only one dose image to analyze.

Delivery Methods: Cons

- PFF, PC: no 3D summation. Can't know significance of regional errors in each beam.
- PFF, PC: can get any γ result you want for relative dose mode by normalizing to a different place.
- PC: errors from each field may cancel on summation.
- TC: Does not sample every part of each beam.

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Action limits

- Quality measures (QMs) → set a requirement for the performance of IMRT QA
- Action Limits
  - → degree to which the QMs are allowed to vary
  - → thresholds for when an action is required
  - → based on clinical judgment
    - acceptability of a certain level of deviation from a QM

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TG218 Recommendations
True Composite approach

- IMRT QA measurements should be performed using TC
  - QA device has negligible angular dependence or the angular dependence is accurately accounted for in the vendor software.
- IMRT QA measurements should be performed using PFF if the QA device is not suitable for TC measurements, or for TC verification error analysis.
- IMRT QA measurements should not be performed using PC which is prone to masking delivery errors.

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TG218 Recommendations
γ for routine QC: *global* normalization

- Analysis of IMRT QA measurement and plan should be performed in absolute dose mode, not relative dose.
- A dose calibration measurement compared against a standard dose should be performed before each measurement session
  - factor the variation of the detector response and accelerator output into the IMRT QA measurement.
- Global normalization should be used. Global normalization is deemed more clinically relevant than local normalization.
  - global normalization point should be selected whenever possible in a low gradient region with a value that is ≥ 90% of the maximum dose in the plane of measurement.

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TG218 Recommendations
γ for commissioning: *local* normalization

- 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.
- Dose threshold should be set to exclude low dose areas that have no or little clinical relevance but can bias the analysis.
  - setting the threshold to 10% in a case where the OAR dose tolerance exceeds 10% of the prescription dose.
  - allows the γ passing rate analysis to ignore the large area of dose points that lie in very low dose regions which, if included, would increase the passing rate

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TG218 Recommendations

GPR=90% (based on γ: 3%-2mm; 10%Th)

- 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.
  - If the plan fails this AL, evaluate the γ failure distribution and determine if the failed points lie in regions where the dose differences are clinically irrelevant
  - If the γ failure points are distributed throughout the target or critical structures and are at dose levels that are clinically relevant, the plan should not be used
  - It may be necessary to review results with a different detector or different measurement geometry

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TG218 Recommendations not only statistical evaluation

- For any case with γ passing rate < 100%,
  - the γ distribution should be carefully reviewed rather than relying *only* on distilled statistical evaluations
  - review of γ results should not be limited to only the %points that fail, but should include other relevant γ values
  - an analysis of the maximum γ value and the %points that exceed a γ value of 1.5 should be performed.
  - For a 3%/2 mm, a γ value of 1.5 could indicate a dose diff of 4.5% in a shallow dose gradient region or a DTA of ~3.0 mm in a steep dose gradient region.

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TG218 Recommendations
DVH-based metric is better

- Reviewing dose differences directly without γ or using local dose normalization and tighter dose difference/DTA criteria.
- γ should be reviewed on a structure by structure basis
- Track γ passing rates across patients and for the same tumor sites to look for systematic errors in the system.
- Software tools that compare measured and calculated DVHs of structures are preferred over analysis in phantoms.
- DVH analysis can be used to evaluate the clinical relevance of QA results, especially when the γ passing rate fails the tolerance limits or is inconsistent.

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TG218 Recommendations

Steps to Check Marginal/Failed IMRT QA

- Phantom/device setup
- Beam characteristics
- MLC
- TPS

Mitfen, AAPM Meeting 2016


obrigado
Dank U
Merci
mahalo
Köszi
спасибо
Grazie
Thank you
mauruuru
Takk
Gracias
Dziękuję
Děkuju
danke
Kiitos