This House Believes Measurement-based IMRT QA is Necessary in the Current Radiation Oncology Environment

Against the Motion

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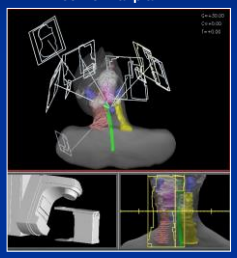
Disclosures

- I have research efforts funded by:
  - National Institute of Health
  - Varian Medical Systems
  - Blue Cross Blue Shield of Michigan
- I serve as a member (or chair) of committees in AAPM and ASTRO related to quality assurance. I am a member of the Radiation Oncology Safety Stakeholders (RO-SSI) group.

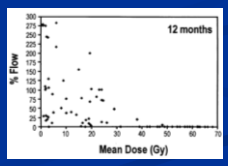
How did we get here?

The path to IMRT

Example multi-segment conformal plan

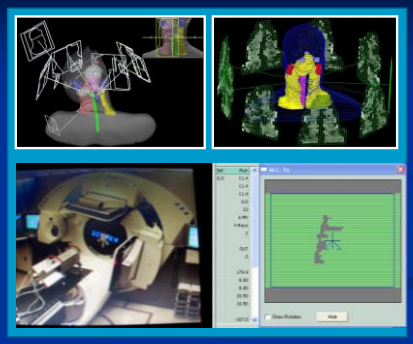


Salivary flow was measured for HN patients receiving RT. Measured dose response between parotid dose and xerostomia.



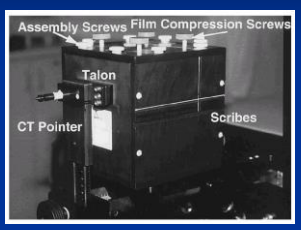
Eisbruch et al. Dose, volume, and function relationships in parotid salivary glands following conformal and intensity-modulated irradiation of head and neck cancer. IJROBP 45: 577-587, 1999.

The IMRT continuum



VMAT courtesy of Martha Matuszak

Measurements were essential but we lacked easy to use tools…

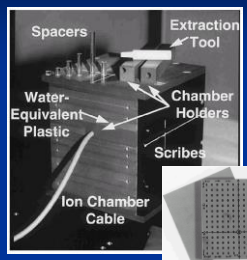


Nomos phantom

Film could be placed at multiple planes

D.A. Low et al. "Phantoms for IMRT Dose Distribution Measurement and Treatment Verification, IJROBP 40: 1231-1235 (1998).

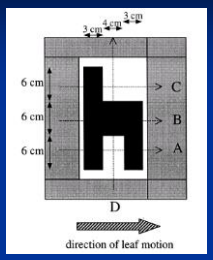
Phantom Adapted for Multiple Uses

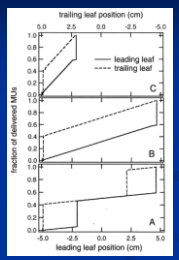


Shell added to convert to a pelvis geometry

D.A. Low et al. "Phantoms for IMRT Dose Distribution Measurement and Treatment Verification, IJROBP 40: 1231-1235 (1998).

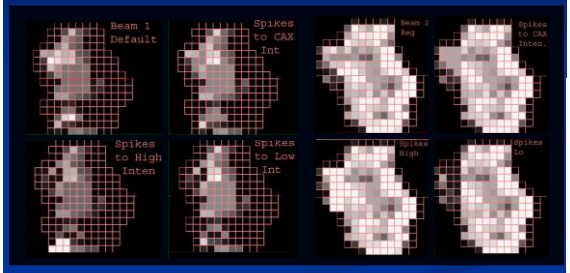
Geometric Tests





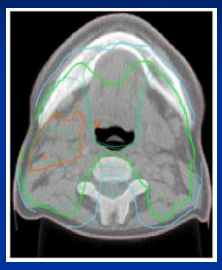
Acceptance tests and quality control (QC) procedures for the clinical implementation of intensity modulated radiotherapy (IMRT) using inverse planning and the sliding window technique: experience from five radiotherapy departments Van Esch et al Radiotherapy Oncology 65: 53-70 (2002).

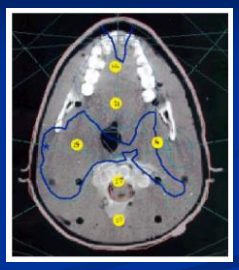
Complex Cases – Simple Geometry



Evaluate dose across field as a function of regional beamlet intensity

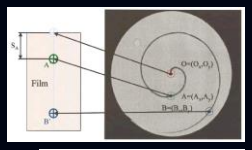
End to End Test in an Anthropomorphic Phantom

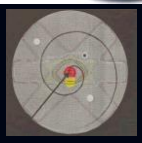


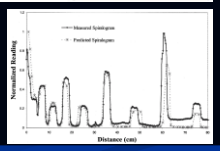


M. A. MacKenzie et al. "Dosimetric verification of inverse planned step and shoot MLC fields from a commercial planning system," J Appl Clin Med Phys 3: 97-109 (2002).

Spiral Phantom for Dosimetric Verification

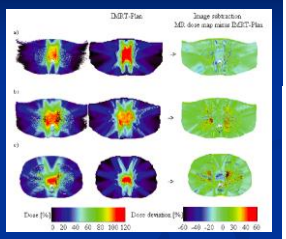






Paliwal et al "A spiral phantom for IMRT and tomotherapy treatment delivery verification" Medical Physics pp. 2503-2507 (2000).

Anthropomorphic Phantom for Gel Dosimetry



Gum et al. "Preliminary study on the use of an inhomogeneous anthropomorphic Fricke gel phantom and 3D magnetic resonance dosimetry for verification of IMRT treatment plans" PMB 47: N67-N77 (2002).

Early Days of IMRT

- 10 years ago – Initial guidance by Ezzell et al
- Aimed at clinical implementation of IMRT
- SMLC, DMLC, and TomoTherapy delivery

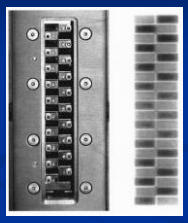


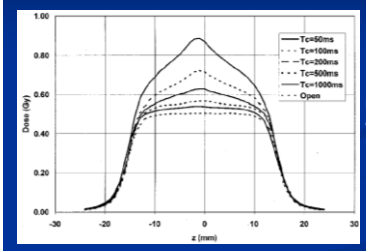
Fig. II. 4. Checkerboard pattern delivered with the MIMic collimator.

Ezzell et al, Medical Physics, Vol. 30, No. 8, August 2003.

Many Systems to be Commissioned

- CT-sim and data transfer to TPS
- Treatment planning system
  - Volume expansion, contouring, etc
- Optimization software, leaf sequencing algorithm
- Data transfer to machine (Treatment Management System) – more data with IMRT
- Delivery: communication between accelerator and MLC controller (for Linac-based systems)

Leaf Switch Rate Effects and Delay for the MiMiC Collimator



Profile measurements at multiple switch rates 100 mu delivered each time

Hossain et al Med Phys 29: 1693-1697, 2002.

Example Comparison

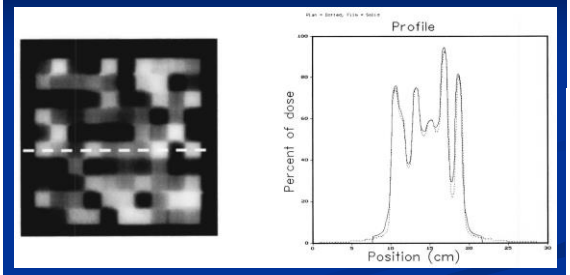


Fig. III. 4. Planned (dotted) vs film (solid) for a random intensity pattern.

Ezzell et al, Medical Physics, Vol. 30, No. 8, August 2003

Early IMRT Guidance Documents

- AAPM: Ezzell et al Medical Physics – 2003
  - Broad overview of entire IMRT process, not only on quality assurance aspects
  - Overall process, dosimetric accuracy, integrity checks
- ASTRO-AAPM: Galvin et al IJROBP 2004
  - Describes the treatment team
  - Challenges in IMRT planning
- ACR 2007: Describes roles and responsibilities of the team members

Additional Guidance

- Ezzell et al AAPM Task Group 119 – 2009
  - Designed a series of tests; all members performed at their institutions; used common criteria to compare results
- Klein et al AAPM TG 142 – 2009
  - MLC QA for linacs delivering IMRT
- Low et al AAPM Task Group 120 – 2010
  - Dosimeters and analysis techniques for IMRT

Current State

- Software, hardware and our understanding of the interplay between systems have all improved
- Tremendous amount of clinical experience with IMRT/VMAT
- Change from time-consuming measurements of a single point to the to the use of real-time multi-dimensional systems in simple or complex phantoms

SAMS Question 1

A major concern with IMRT and VMAT deliveries is the risk of catastrophic failures. To guard against catastrophic failures the QA program needs to check:

17% A. The integrity of the file transfer
20% B. That the correct file types are present (e.g. MLC files with leaf sequences and/or MLC/gantry files)
10% C. That the planned prescription matches the plan delivery
23% D. The reliability and accuracy of MLC and gantry positioning
30% E. All of the above

SAMS Question 1

A major concern with IMRT and VMAT deliveries is the risk of catastrophic failures. To guard against catastrophic failures the QA program needs to check:

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c) That the planned prescription matches the plan delivery
d) The reliability and accuracy of MLC and gantry positioning
e) **Answer: All of the above**

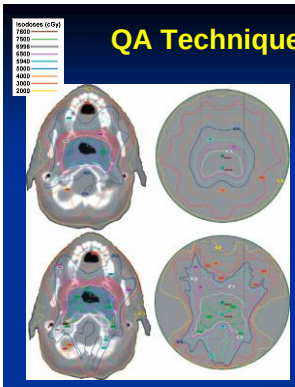
REF: Ezzell et al Guidance document on delivery, treatment planning, and clinical implementation of IMRT: Report of the IMRT subcommittee of the AAPM radiation therapy committee, 2003.

Great….

- We're measuring 10 plans per night using a multi-dimensional detector system
  - Getting >500 measurement points instead of a single ion chamber
  - Analyzing in real-time, so we know if the plan passes we're good, the plan is good, on to the next patient's QA.

But…

QA Technique Limitations

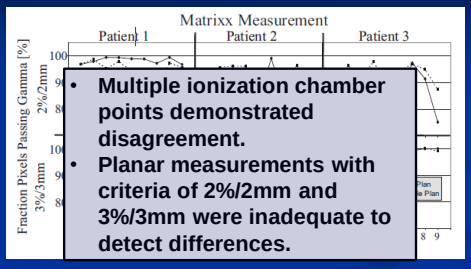


Methods

- 3 head and neck plans were re-optimized with aggressive constraints (increased modulation)
- QA measurements were performed with an ionization chamber, EPID, and MatriXX QA device

Fig. 1, Kruse Medical Physics 37: 2516-2524, 2010.

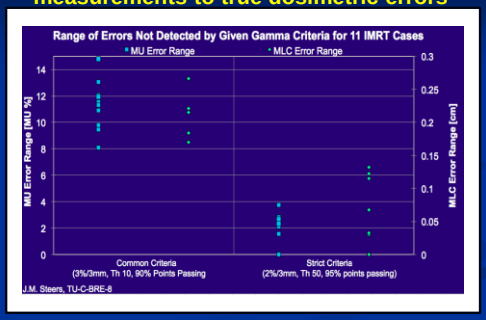
Planar Measurements Alone



- Multiple ionization chamber points demonstrated disagreement.
- Planar measurements with criteria of 2%/2mm and 3%/3mm were inadequate to detect differences.

Fig. 6, Kruse Medical Physics 37: 2516-2524, 2010.

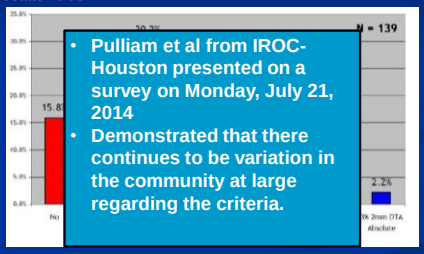
The Hazards of Our Analysis Criteria: Choice can lead to insensitivity of measurements to true dosimetric errors



Jennifer Steers, AAPM 2014 TU-C-BRE-8 , Cedar-Sinai & UCLA

What criteria should we use?

Survey by Nelms et al of the community regarding criteria for IMRT prostate fields



- Pulliam et al from IROC-Houston presented on a survey on Monday, July 21, 2014
- Demonstrated that there continues to be variation in the community at large regarding the criteria.

Fig. 6, Nelms et al JACMP 8(3): 76-90, 2007.

What is impact on the patient of our measurement/analysis?

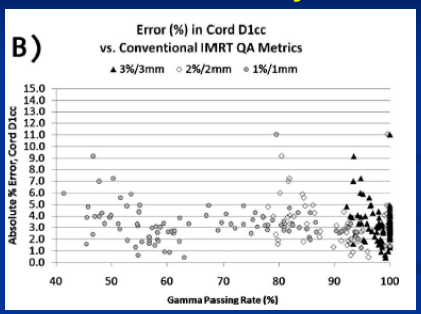


Fig. 3. Nelms et al Med Phys 38: 1037-1044, 2011.

Revisiting our Approach to QA

- Pay more attention to plan quality
  - Limit the search space to plans that will meet physician's needs and balance trade-offs
- Decrease variability in overall plan quality
  - Knowledge-guided therapy (J. Wu and others)
  - Outcomes database (J. Wong, T. McNutt, C. Mayo, and others)

Improved Planning Tools

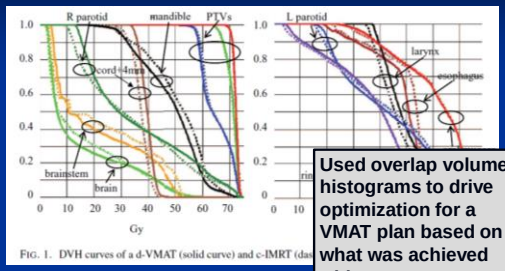


FIG. 1. DVH curves of a d-VMAT (solid curve) and c-IMRT (da

Used overlap volume histograms to drive optimization for a VMAT plan based on what was achieved with IMRT.

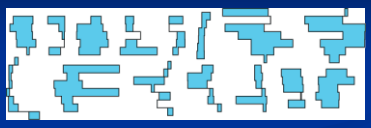
Fig. 1, B. Wu et al "IMRT-data-driven VMAT planning," Med Phys 40: 021714-1 to 021714-7, 2013.

QA Software Tools to Use Prior to Measurements

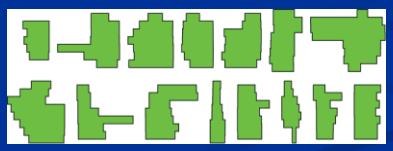
- McNiven et al (Med Phys 37, 2010):
  - Developed a Modulation Complexity Score (MCS) and tested it for multiple body sites
  - Compared MCS, MUs, QA results (3%/3mm and 3%/1mm)
  - Developed treatment site criteria that can be used to pre-test treatment plans prior to measurements

Understand Limits of Deliverability

Very modulated



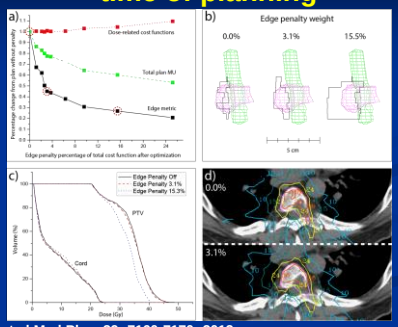
With a custom penalty applied to field edges



5 cm

Younge et al Med Phys 39: 7160-7170, 2012.

Improving Plan Deliverability….at time of planning

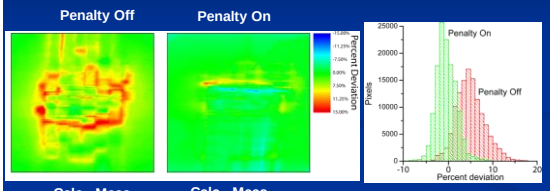


Younge et al Med Phys 39: 7160-7170, 2012.

Impact of Cost Function Related to Complexity: Edge Penalty

Penalty Off

Penalty On



Calc - Meas

Calc - Meas

% Passing a threshold of 5%:
52% for no penalty
96% with the penalty

Younge et al Med Phys 39: 7160-7170, 2012.

Commercial 2nd check programs

- These programs can be used solely to check monitor units
- As a sanity check on the 3D dose distribution
- As a recalculation of the delivered dose but on the patient's anatomy
- TG114 (Stern et al Med Phys 38, 2011) demonstrates several examples for conformal therapy where a second check is a useful sanity check

Use of a 2nd Check 3D Calculation for Positioning Error

P. Atkinson and S. Symonton – Allegiance, Jackson, MI

However, no clear correlation between abnormal RMS value and IMRTQA results

Are we ready for a measurement-free present?

- What computational methods are available in our clinics to assess deliverability?
- Are they enough to support patient safety?
- *Caution: Guidance is still being developed on the use of these techniques (TG219). Need more information regarding when such checks fail.*

2nd Check Programs

- These can be 1, 2 or 3D
- Most robust when the deliverable plan (from the Treatment Management Side) is evaluated

Quality and safety are interwoven together

- A plan could pass QA but be unsafe – if is to the wrong dose, treatment region, etc.
- A second computational check may not identify a collision with a patient whereas a possible collision with equipment might flag investigate.

SAMS Question 2

A second monitor unit check of the IMRT or VMAT plan:

17% A. Is only needed if the field has a lot of modulation
37% B. Is a sanity check that the correct dose is planned for the patient
20% C. Is nice to have but doesn't really fill a clear QA need
27% D. Is only needed to fulfill billing requirements

SAMS Question 2

- A second monitor unit check of the IMRT or VMAT plan:

a) Is only needed if the field has a lot of modulation
b) Is a sanity check that the correct dose is planned for the patient
c) Is nice to have but doesn't really fill a clear QA need
d) Is only needed to fulfill billing requirements

- **Answer: b**

REF: 1. Stern et al (TG114) Medical Physics 38: 2011.
Further guidance will be available in TG219 by Zhu, Sotirios et al

SAMS Question 3

If more widely available, tools such as a computational check that includes the full leaf sequencing file in a Monte Carlo second check, a calculation identifying the frequency of field edges, or a comparison of intensity maps to those of previous patients would most likely:

27% A. Be the only check required for IMRT fields or VMAT arcs
7% B. Help identify plans which may be less accurate to deliver
27% C. Absolutely identify plans which would fail measurement-based QA
40% D. Provide only incremental information in support of treatment plan QA

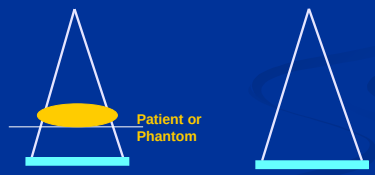
SAMS Question 3

- If more widely available, tools such as a computational check that includes the full leaf sequencing file in a Monte Carlo second check, a calculation identifying the frequency of field edges, or a comparison of intensity maps to those of previous patients would most likely:
  a) Be the only check required for IMRT fields or VMAT arcs
  b) Help identify plans which may be less accurate to deliver
  c) Absolutely identify plans which would fail measurement-based QA
  d) Provide only incremental information in support of treatment plan QA
- **Answer: b**
- REF: Younge et al Medical Physics, 39: 7160-7170, 2012; McNiven et al, Medical Physics 37: 2010, Wu et al on plans

- Could we alter our paradigm to pre-treatment calculation checks and then a check during treatment delivery?

EPID Systems for Dosimetry

- Active matrix flat panel imagers (AMFPIs)
- Portal "dosimetry"
- Often a fluence or response verification



Transit Dosimetry

Pre-Tx 2-D Measurements

What can we do?

- Instead of pre-treatment measurements, we can measure during treatment delivery.
  - Use of a transmission detector in the treatment head
  - EPID
- Are those measurements enough?
- What if a full treatment is delivered?

What other ways can plans be measured?

- Mans et al "Catching errors with *in vivo* EPID dosimetry"
- Analyzed results for 4337 patients
  - 17 cases showed deviations that required an intervention
  - Error types (Table Ib): "patient anatomy, plan transfer, suboptimally tuned TPS parameter, accidental plan modification, dosimetrically unachievable plan"

Incorrect jaw positions

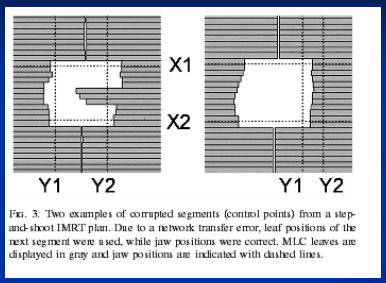


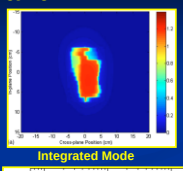
FIG. 3. Two examples of corrupted segments (control points) from a step-and-shoot IMRT plan. Due to a network transfer error, leaf positions of the next segment were used, while jaw positions were correct. MLC leaves are displayed in gray and jaw positions are indicated with dashed lines.

Jaw positions were not displayed at the treatment unit.

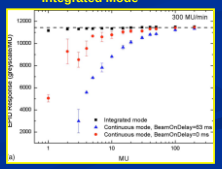
Mans et al Med Phys 37: 2638-2644, 2010.

EPID for IMRT and VMAT

- Response of system can depend on the mode of readout:
  - Continuous vs. integrated
  - Continuous require for time component
  - Some lost signal for continuous mode
- Non-linear response <10 mu if no beam on delay



Integrated Mode

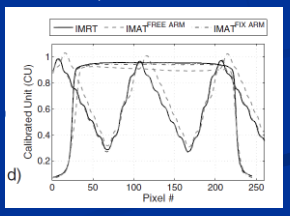


McCurdy et al Med Phys 36: 2009.

Moran 2010 48

Investigation of Rotational effects on using EPID for IMAT

A holder was added for rotational stability. Foam was placed between the EPID housing and the holder. Performance was evaluated for IMRT, free rotation, and fixed rotation.



Iori et al Med Phys 37: 2010.

- Are measurements the only way to assess deliverability?

Beam on?

- At the treatment unit therapists are charged with multiple tasks such as
  - Verifying the correct patient, plan and prescription
  - Setting up, immobilizing and imaging the patient (MV, kV, CBCT?)
  - Using special 3rd party systems for gating
  - Monitoring the patient…
- All in an environment of software changes, error messages, distractions (a physicist, a family member, another patient,…)

IHE-RO Efforts

- Plan Veto
  - Prior to beam on, a plan will have to pass an integrity check for the monitor units, any beam modifiers, etc
  - Work is ongoing by Bruce Curran and other members of IHE-RO

SAMS Question 4

A number of investigators have developed or are developing QA methods which rely on EPID measurements. Which statement best represents the current state?

38% A. Transit dosimetry EPID solutions are widely available and used in many clinics

10% B. EPIDs accurately measure patient dose without the need for corrections.

10% C. If patient measurements are performed with an EPID, no additional QA is needed to evaluate linac performance

25% D. EPIDs may be used to monitor the delivered dose to the patient in addition to having a rigorous linac QA program

SAMS Question 4

- A number of investigators have developed or are developing QA methods which rely on EPID measurements. Which statement best represents the current state?
  - a) Transit dosimetry EPID solutions are widely available and used in many clinics
  - b) EPIDs accurately measure patient dose without the need for corrections.
  - c) If patient measurements are performed with an EPID, no additional QA is needed to evaluate linac performance
  - d) EPIDs may be used to monitor the delivered dose to the patient in addition to having a rigorous linac QA program
- Refs: Mans et al "3D dosimetric verification of volumetric-modulated arc therapy by portal dosimetry", 2010. Mans et al "Catching errors with in vivo EPID dosimetry", Med Phys 37: 2638, 2010. Chytyk-Prazik, "Model-based prediction of portal dose images during patient treatment" Medical Physics, 2013. McCurdy and Greer "Dosimetric properties of an amorphous-silicon EPID used in continuous acquisition mode for application to dynamic and arc IMRT", 36: 3028, 2009.

How long will we require pre-treatment measurements for IMRT?

- Time consuming
- Only check a portion of the process
- Do not check the true patient dose, e.g. what is the delivered dose to a lung tumor? Is motion adequately assessed?
- Is the treatment plan a good plan?

DEBATE
IMRT Verification QA: TO MEASURE

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Department of Radiation Oncology
University of Colorado

Disclosure

- Research Support by Varian Medical Systems

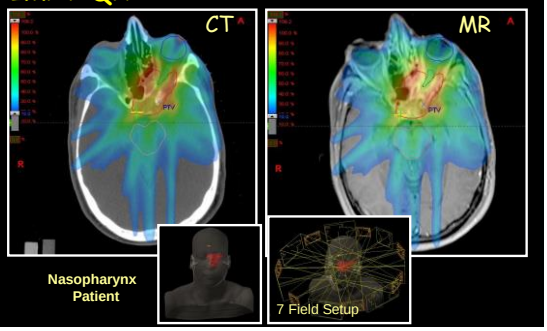
Acknowledgments

- Leah Schubert
- Jenia Vinogradskiy
- AAPM TG218

My proposition is EASY to debate for – 3 words:

Measurement is the gold standard– No ifs, ands, or buts…

I want the gold-standard (measurement) to be used for my IMRT QA



Patient-specific IMRT Verification QA Measurement

- Designed to identify discrepancies between planned and delivered doses
- Detect gross errors in the radiation delivery
- Minimizes reliance on the concept that all potential sources of error in the IMRT process are known, characterized, and contained
- Ensuring the safety of patient, fidelity of treatment, and that the patient receives the desired treatment plan

Q1. Which of the following regarding patient-specific IMRT QA verification measurement is *true*?

20% 1. It is used to identify discrepancies between planned and delivered doses
20% 2. It is used to detect gross errors in the IMRT process
20% 3. It is used to ensure the fidelity of the IMRT treatment
20% 4. It minimizes the reliance on the concept that all potential sources of error in the IMRT process are known and controlled
20% 5. All the above

REF: 1. Kruse and Mayo, "Comment on "Catching errors with patient-specific pretreatment machine log file analysis," PRO (2013).
2. Siochi and Molineu, "Patient-specific QA for IMRT should be performed using software rather than hardware methods," Med Phys (2013)

Review of Safety Fundamentals

Safety in Radiation Therapy

- Approximately 50% of cancer patients receive radiation during the course of their treatment
- Majority of treatments are delivered safely
- Radiation error rate is ~ 0.2% per patient, or 1 in 500 (Ford, et. al IJROBP 2010)
- When errors occur, they can have serious consequences, not only resulting in direct harm to the patient, but an undermining of the public's confidence in treatment

Recent Efforts to Improve Safety

- Response to publicity instigated new involvement in QA and safety issues within ASTRO and AAPM
- Safety symposia at recent ASTRO/AAPM meetings
- ASTRO's Target Safely campaign
- Safety white papers
  - IMRT and SBRT: published in PRO
  - HDR, IGRT, and Peer Review recently published of or in editing stage

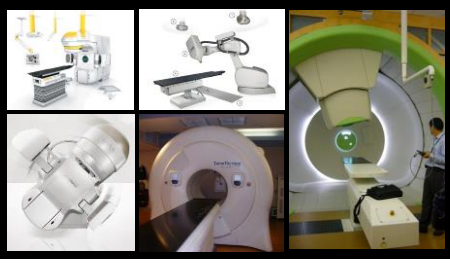
Recent Efforts to Improve Safety

"The 21st century is a new age of transparency and accountability. It's a time of increasingly complex treatments – propelled by ever-changing technology – that are creating new potential hazards for working with radiation."

- Anthony Zietman, MD, ASTRO Chair, 2011 ASTRO Annual Meeting

Complex Technologies in Radiotherapy

- Rapid adoption of new technology using sophisticated equipment
- Increase complexity of planning and delivery

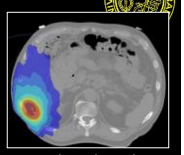


Complex technology is sometimes indistinguishable from a black box: we don't know what we don't know

Errors in Radiotherapy

Success of radiotherapy

- Dependent on accuracy of delivered dose



Process of radiotherapy

- Complex, multi-step process
- Wide range of conditions treated, technologies used, technical equipment, and professional expertise involved

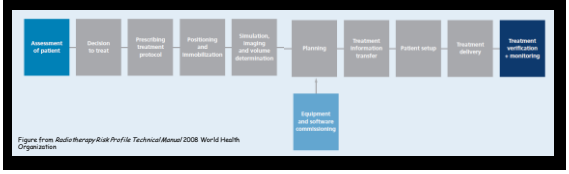


Figure from *Radiotherapy Risk Profile Technical Manual* 2008 World Health Organization

When Do Events Occur?

- Analysis of over 3000 incidents and near-misses occurring between 1976-2007
- Significant harm
  - 55% planning stage
  - 45% during introduction of new systems/equipment
- Near-misses without known harm
  - 9% planning stage
  - 38% information transfer
  - 18% treatment delivery
  - 35% other

Shafiq et. al R&O 2009

Systems that are Hard-Wired for Success

- Use of more than one single protective measure
- Expects that mistakes will be made
- Puts into place mechanisms for identifying mistakes before they affect the patient's treatment

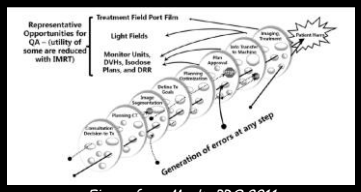
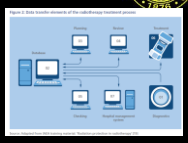


Figure from Marks PRO 2011

High Potential for IMRT Errors

- Treatment process is complex
- Treatment relies on highly technical systems
- Technology can malfunction
- Data transfer between systems can malfunction
- Miscommunication between people can occur
- Potential for human errors



Q2. The potential for IMRT errors are high because

20% 1. Treatment is complex and relies on many complex variables

20% 2. Treatment clinical workflow is not well defined

20% 3. planning systems use pencil-beam dose calculation algorithms

20% 4. Treatment are now more delivered with VMAT

20% 5. Treatment data transfer systems are not used appropriately

Hartford et al, "American Society for Therapeutic Radiology and Oncology (ASTRO) and American College of Radiology (ACR) Practice Guidelines for Intensity-Modulated Radiation Therapy (IMRT)," IJROBP (2009).

Patient-specific IMRT QA measurment has been hotly debated among physicists

- Smith & Dieterich, "It is STILL necessary to validate each individual IMRT treatment plan with dosimetric measurements before delivery," Med Phys (2011)
- Siochi and Molineu, "Patient-specific QA for IMRT should be performed using software rather than hardware methods," Med Phys (2013)
- Pawlicki et al, "Moving from IMRT QA measurements toward independent computer calculations using control charts," Radiother Oncol (2008)
- Ford et al, "Quality Control Quantification (QCQ): A Tool to Measure the Value of Quality Control Checks in Radiation Oncology," IJROBP (2013)
- Kruse and Mayo, "Comment on "Catching errors with patient-specific pretreatment machine log file analysis," PRO (2013)

For verifying with measurements


Jon Kruse


Andrea Molina


Chuck Mayo


Charles Smith


Jean Moran

For verifying with software & other tools


Alf Soichi


Sonja Dieterich


Eric Ford


Sasa Mutic


Jean Moran

The need for or sensitivity of IMRT QA measurement has been questioned

Nelms et al, "Per-beam, planar IMRT QA passing rates do not predict clinically relevant patient dose errors," Med Phys (2011).

H. Zhen et al, "Moving from gamma passing rates to patient DVH-based QA metrics in pretreatment dose QA," Med Phys (2011)

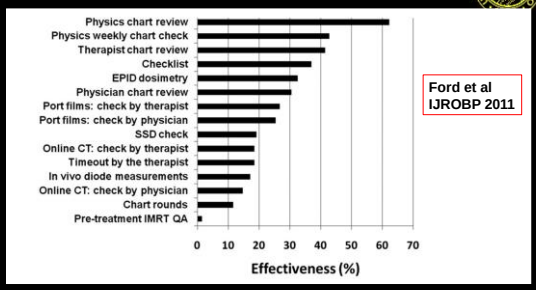
Stasi et al "Pretreatment patient-specific IMRT quality assurance: A correlation study between gamma index and patient clinical dose volume histogram," Med Phys (2012)

Ford et al, "Quality Control Quantification (QCQ): A Tool to Measure the Value of Quality Control Checks in Radiation Oncology" IJROBP (2013)

Kruse, "On the insensitivity of single field planar dosimetry to IMRT inaccuracies," Med Phys (2010)

Yan et al, "On the sensitivity of patient-specific IMRT QA to MLC positioning errors," JACMP (2009)

Ford et al: data from 2 institutions



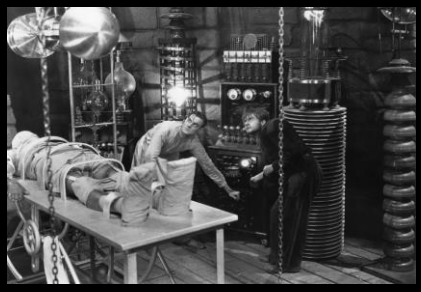
Arguments Made to Walk Away from IMRT QA Measurements

- Neither effective nor efficient
- Labor intensive, time consuming, and less accurate
- Relying on outdated QA procedures that focus on labor-intensive measurement of precision
- Measurement inaccuracies
- Identifying the inaccuracy from a combined system (delivery, TPS, measurement device…etc) is difficult
- New paradigm for new technology is comprehensive acceptance testing, comprehensive commissioning, and interconnectivity testing

Arguments Made to Walk Away from IMRT QA Measurements

- Beam-by-beam delivery provides no composite data
- 3%/3mm/gamma does not identify clinically relevant patient dose errors; what is the actual dose?
- Create a false sense of safety with other, more sever failure modes being overlooked
- Software tools are better
  - Machine log file analysis
  - MU programs

We ALL agree that we don't want to have catastrophic errors or significant dosimetric inaccuracies

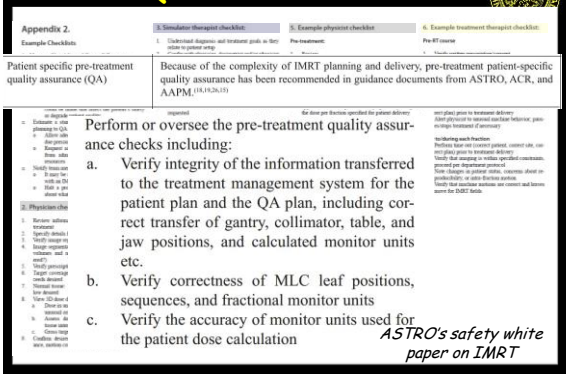


Steps Involved in IMRT Process

From ASTRO's safety white paper on IMRT

Moran et. al PRO 2011

IMRT QA Checklist



Appendix 2.

Example Checklists

3. Simulator therapist checklist:	5. Example physicist checklist	6. Example treatment therapist checklist:
1. Understand diagnosis and treatment goals as they relate to patient setup	Pre-treatment:	Pre-RT course

Patient specific pre-treatment quality assurance (QA)	Because of the complexity of IMRT planning and delivery, pre-treatment patient-specific quality assurance has been recommended in guidance documents from ASTRO, ACR, and AAPM.[18,19,26,33]

Perform or oversee the pre-treatment quality assurance checks including:

a. Verify integrity of the information transferred to the treatment management system for the patient plan and the QA plan, including correct transfer of gantry, collimator, table, and jaw positions, and calculated monitor units etc.

b. Verify correctness of MLC leaf positions, sequences, and fractional monitor units

c. Verify the accuracy of monitor units used for the patient dose calculation

ASTRO's safety white paper on IMRT

Q3. The ASTRO white report, "Safety Considerations for IMRT," by Moran et al stated that pre-treatment QA checks should include

20% 1. Creation/calculation of the approved treatment plan for the QA geometry using the dose per fraction specified for patient delivery

20% 2. Verifying the integrity of the information transferred to the treatment management system

20% 3. Verifying the correctness of MLC leaf positions, sequences, and fractional MUs

20% 4. Verifying the accuracy of monitor units used for the patient dose calculation

20% 5. All the above

REF: Moran et al, "Safety Considerations for IMRT," PRO (2011)

I AM ALSO UNAWARE

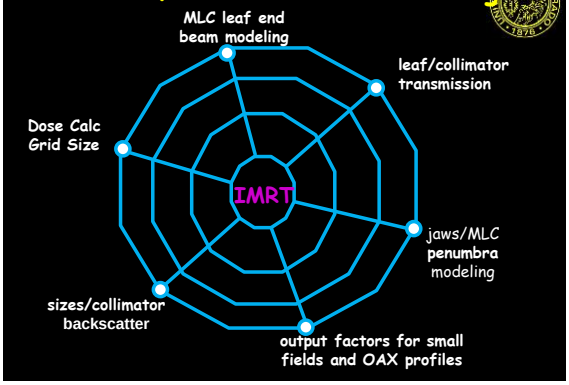
From Charles Smith, Point counterpoint, Med Phys (2011):

- "Beside measurements, I am unaware of any methods that can verify the delivered IMRT fields have been modeled well enough to generate the desired dose."
- "I am aware of no one who has successfully discovered or characterized them."
- "Nor are there any TPS systems that can model all the parts of a linac and how their behavior changes with use."

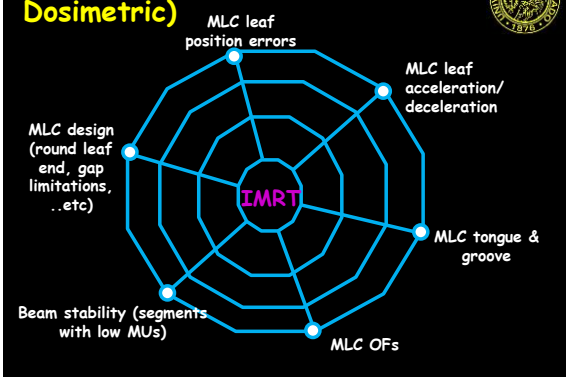
My Counter Arguments OR the TRUE PICTURE: TPS and Delivery Systems

- Comprehensive commissioning of an IMRT planning system is an extremely difficult task to accomplish.
- IMRT dose distributions are delivered via many micro MLC shapes and dynamic motion of many components (MLC , gantry motions, dose rate); very different from the TPS commissioning data.
- TPSs commissioning are based on measured data acquired from PDDs, profiles, and OFs of mainly large open fields.
- Modeling dose delivery from finite MLC openings with measured data based from large open beams is extremely difficult.

Sources of Uncertainties- Planning



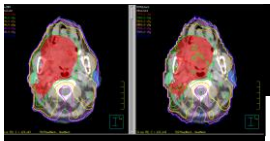
Uncertainties- Delivery (Spatial & Dosimetric)



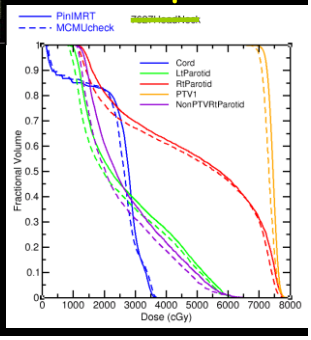
Software Solutions

- MU software may be appropriate for 3D plan QA, however this may not be the case for IMRT
- Machine log files
  - have massive amount of data that can be difficult to interpret
  - may have incomplete data, missing data, or other defects
- Tools using TPS dose algorithms will have similar limitations to TPSs
- Tools based on measurements that reconstruct the dose in the patient could be advantageous but may have dose calc errors

Head and Neck Example

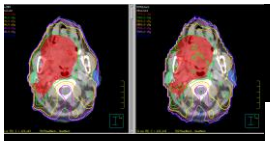


- PTV D_{98} Δ=-2.8%
- LtParotid D_{50} Δ=- 11%
- Cord D_1 Δ<1%

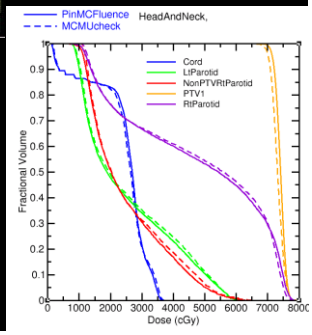


Courtesy of J. Siebers

Head and Neck
Calc using MC Fluence



- PTV D_{98} Δ=- 2%
- LtParotid D_{50} Δ=- 3.5%



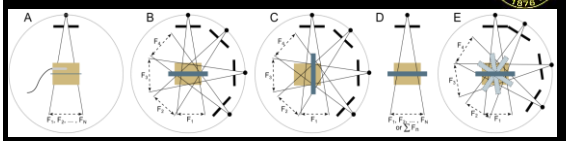
Courtesy of J. Siebers

D-diff/DTA/ γ & passing rates don't predict clinically relevant errors or appropriate for evaluating treatment plan acceptability

- Point-measurement and beam-by-beam evaluation may obfuscate clinically relevant dose errors
- While the published reports may cast doubt on the value of measurements, it reveals to me that
  - Details of how the agreement between measured and calculated results is determined are often poorly understood
- Passing rates have no spatial sensitivity
- The location of the failed points is not provided with the failing rate

Dose Comparisons

Delivery Methods

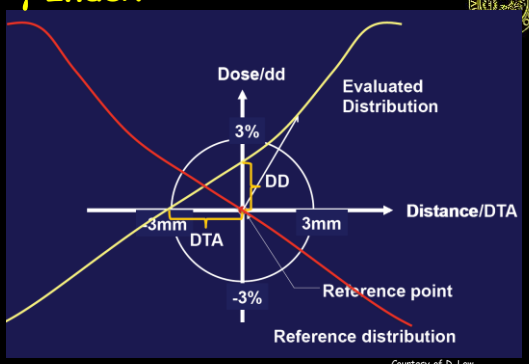


True Composite (film & chamber)	True Composite (Device in coronal direction)	True Composite (Device in sagittal direction)	Field-by-Field OR Composite ALL Fields Summed (gantry @ 0°)	Composite ALL Fields Summed (device perpendicular to gantry)

Methods to Compare Planned and Delivered Dose

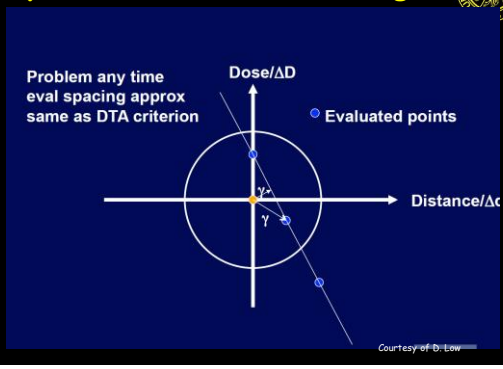
- Dose Difference (Ddiff)
- Distance-to-Agreement (DTA)
- γ

γ Index



Courtesy of D. Low

Spatial Resolution Challenges



Courtesy of D. Low

Clinical Issues Using γ

- Spatial resolution in evaluated distribution is important unless some type of interpolation is used
- Dose difference criterion is intuitive
- DTA criterion
  - Spatial uncertainty (measurements)
  - How do we interpret γ failures?

Courtesy of D. Low

γ Failures

- 100% passing is ideal but not practical
- γ tool should be used as an indicator of problems, not as a single indicator of plan quality

γ Evaluation

- γ statistics should be provided in a structure by structure basis.
- γ distribution should be reviewed rather than relying only on distilled statistical evaluations such as γ histograms or single metrics
- Clinical interpretation of failure results is a challenging QA process
- Remember quality measures are intended to set a requirement for the performance of a system

Q4. Which of the following regarding the gamma metric is *true*?

20% 1. It can be used as a *single* indicator of IMRT plan quality specified for patient delivery

20% 2. It is a *poor* indicator of problems in the IMRT process

20% 3. It is *independent* of the dose distribution spatial resolution

20% 4. It could *underestimate* the clinical consequences of certain dose delivery errors when the dose distribution is not evaluated on strcuture-by-srcture basis

20% 5. It is appropriate to ONLY check the gamma passing rate when evaluating the IMRT QA plan

REF: 1. Low et al, "A technique for the quantitative evaluation of dose distributions," Med Phys (1998)
2. Low and Dempsey, "Evaluation of the gamma dose distribution comparison method," Med Phys (2003)

Action Limits and Tolerance Levels for IMRT QA

Action Limits (ALs)

- Quality measures (QMs) → set a requirement for the performance of IMRT QA
- Action Limits
  - → degree to which the quality measures 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

Tolerance Limits (TLs)

- TLs → boundary within which a process is considered to be operating normally
- Measurements outside of a TL provide a warning that a system is deviating
  - investigate to see if an issue can be identified and fixed
- Intent → fix issues before they become a clinical problem (i.e. data outside of ALs)

TG218 - Tolerance Levels and Methodologies for IMRT Verification QA

- To review literature and reports containing data on the achieved agreement between measurements and calculations for IMRT delivery techniques.
- To review measurement methods commonly employed in IMRT QA, and discuss pros and cons of each.
- To review analysis methodologies for absolute dose verification
- To investigate the dose-difference/DTA and gamma verification metrics, their use and vendor-implementation variability

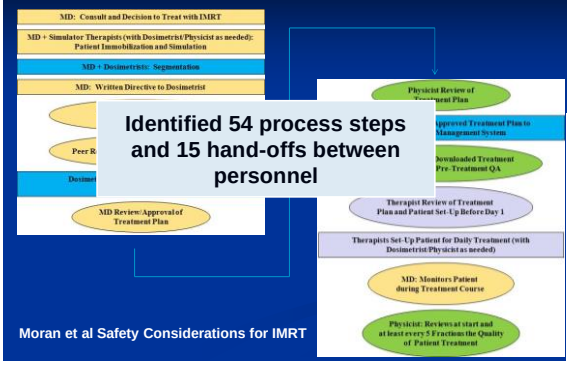
Patient-specific IMRT QA measurement is necessary for the foreseeable future. HERE IS WHY

- We must AGREE that detecting errors which have significant dosimetric impact is essential.
- Given the complexity and steps of the IMRT process, errors affecting dose can be made and have been made.
- TPSs, delivery technologies, R&V systems, system interconnectivity…etc can fail or problems can happen.
- Quality measures using measurements are an indicator of problems and how big the error is.
- Source of uncertainty among centers using measurement-based IMRT QA programs are the measurement and analysis tools used to interpret the QA results.

Rebuttal – Jean M. Moran

- No more *pre-treatment* measurements!

Example IMRT Process



Identified 54 process steps and 15 hand-offs between personnel

Moran et al Safety Considerations for IMRT

- We need to work together as a community with manufacturers and users to build robust QA systems and revisit our processes

Altering our QA Paradigm for the Future

- We must move forward
- Need a rigorous QA program for all elements – not just for data transfer
- Adaptive therapy
  - Will we miss opportunities to adapt and reduce normal tissue doses because we don't have a rapid way to safely implement plans that improve coverage and/or limit normal tissue doses?

Use of Transit Dosimetry

- Differences may be due to…
  - Plan…could use an independent calculation
  - Delivery…could recalculate patient *estimated* dose with the delivery log file
  - Geometry…CBCT can be used for anatomy checks, image registration review and a 3D recalc
  - (Algorithm accuracy – scatter corrections,etc)
- Can we use it to prevent a catastrophic failure?

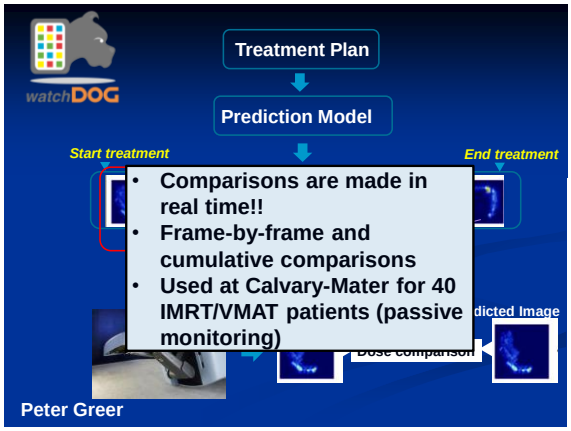
Peter Greer- Watch Dog Project

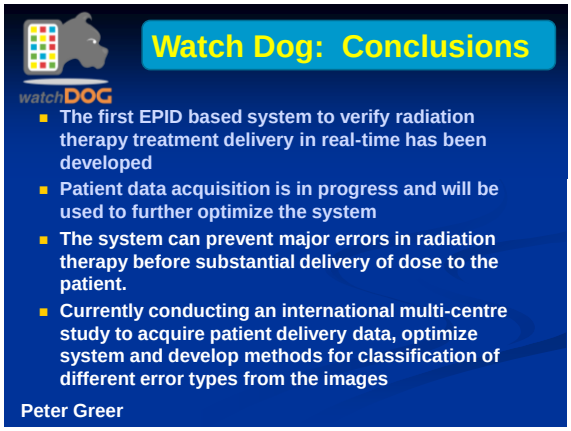
watchDOG

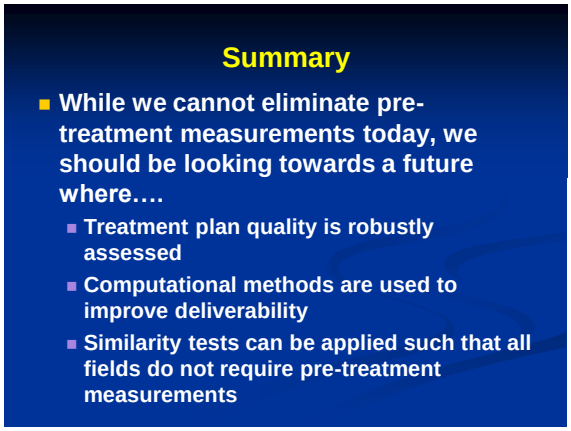
- Multi-institutional
- Real-time monitoring of delivery

Center
Calvary Mater Newcastle (CMN) – Lead Site
Memorial Sloan Kettering Cancer Center (MSKCC)
Cancer Care Manitoba (CCM)
University of Virginia (UVA)
Northern Sydney Cancer Centre (NSCC)
Central Coast Cancer Center (CCCC)

Currently funded by ASTRO Radiation Oncology Institute Grant


watchDOG
Treatment Plan
Prediction Model
Start treatment
End treatment
• Comparisons are made in real time!!
• Frame-by-frame and cumulative comparisons
• Used at Calvary-Mater for 40 IMRT/VMAT patients (passive monitoring)
dicted Image
Peter Greer


watchDOG
Watch Dog: Conclusions
The first EPID based system to verify radiation therapy treatment delivery in real-time has been developed
Patient data acquisition is in progress and will be used to further optimize the system
The system can prevent major errors in radiation therapy before substantial delivery of dose to the patient.
Currently conducting an international multi-centre study to acquire patient delivery data, optimize system and develop methods for classification of different error types from the images
Peter Greer


Summary
While we cannot eliminate pre-treatment measurements today, we should be looking towards a future where….
Treatment plan quality is robustly assessed
Computational methods are used to improve deliverability
Similarity tests can be applied such that all fields do not require pre-treatment measurements

Summary (continued)

- We need to protect against catastrophic failures of the complex system
  - Transit dosimetry techniques by NKI group and others
  - Next step: WatchDog project by Greer et al – real-time EPID evaluation
  - IHE-RO: Plan Veto at the linac
- Could consider spot checks to monitor the overall accuracy of the IMRT/VMAT system
  - Supplement linac QA with monthly end-to-end test(s)

Finally…

- We have to make sure we're not missing the big picture with respect to safety and quality of IMRT plans
- A plan can pass QA measurements but it could …
  - Be a poor quality plan with respect to target coverage or OAR doses
  - Have heterogeneities or motion considerations that limit the applicability for that patient
  - Have the wrong doses with respect to the physician's prescription
  - Have an inappropriate energy e.g. high energy beams for a pediatric or a pacemaker patient

Moving Forward

- We have to be good stewards of QA resources
  - Time, effort, and money for software and hardware
- There is still room for scientific discovery
  - Optimization and planning techniques
  - Tools to monitor quality (Statistical Process Control and other methods)
  - FMEA
  - Novel imaging techniques such as surface imaging, Cerenkov radiation
- We have to collectively improve our QA paradigm through hard work, innovation and….*debate!!*

Acknowledgements

- Dick Fraass
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- Randy Ten Haken
- Karen Vineberg
- Ian Gallager
- Don Roberts
- Kelly Younge
- Kathryn Masi
- Kathy Lash
- Andrea Molineu
- Jennifer Steers

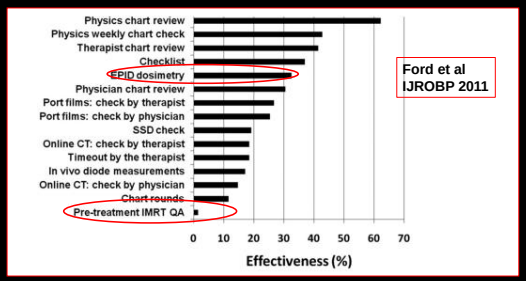
Rebuttal

Moyed Miften, PhD
University of Colorado

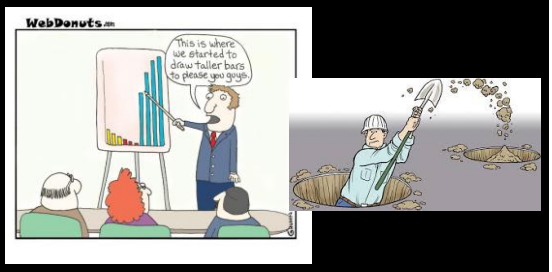
Let Us Revisit

- We must AGREE that detecting errors which have significant dosimetric impact is essential
- Given the complexity and steps of the IMRT process, errors affecting dose can be made and have been made
- TPSs, delivery technologies, R&V systems, system interconnectivity…etc can fail or problems can happen
- Quality measures using measurements are an indicator of problems and how big the error is
- Source of uncertainty among clinics using measurement-based IMRT QA programs are the measurement and analysis tools used to interpret the QA results

Let us look at the data carefully: the untold story

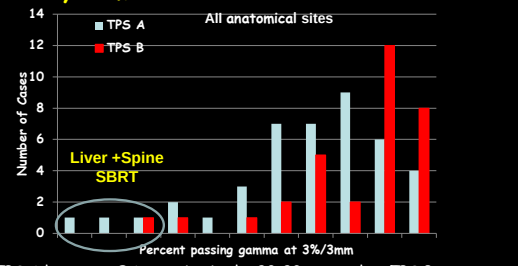


None of the tools described in the "Not to Measure" proposition can fully identify all discrepancies between planned dose and delivered dose



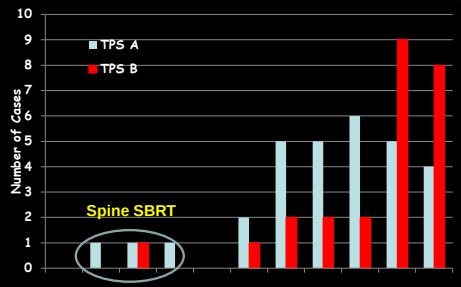
Examples to why we need measurement-based approaches for patient-specific IMRT QA and to why other approaches will fail

Example 1: uncertainties of modeling small fields in TPS, passing rates for 2 TPSs, same Linac



- TPS A has more QAs passing in the 90-92 range than TPS B
- The 90-92% QAs were from Liver and Spine SBRTs

Passing rates for 2 TPS, same linac fractionated CNS cases



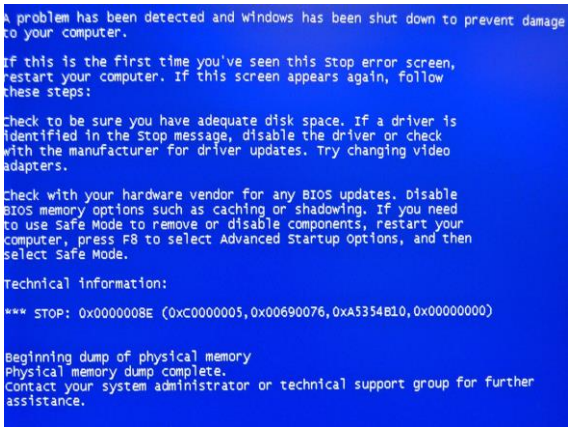
- TPS has more QAs passing in the 90-92 range than TPS B
- The 90-92% QAs for TPS A were from Spine SBRTs

Example 2: data transfer error

- VMAT QA plan has low passing of 89% (3%/3mm)
- VMAT plan and plan-printout have the same total number of MLC control points
- Number of control points changed when the plan data was exported from the TPS
- Possible cause: low dose per fraction and low modulation with high # of control points cause very low MU/control point
- Very unpredictable behavior
- No explanation from vendor

Small Change in Beam Symmetry

- Two linacs with matched beams
- For the same IMRT plans, passing rates on linac A was > 95% but for linac B was around ≤ 90%
- Machine B checked repeatedly according to TG40 but no issues were identified
- After 1 week, the problem was identified as a subtle change in the beam symmetry



What We NEED

- Guidelines to improve the understanding and consistency of the IMRT QA process using measurements
- Approaches involve using both measurement and software tools
- This may sound that we are doing more work but we can be efficient
- Sometime the right path is not always the easiest one

The FUTURE is in our hands

- We should develop advanced software integrated with measurements, improve measurement methods and analysis tools for IMRT QA, but this does not mean we should walk away from measurements
- Measurement should continue to be the centerpiece of IMRT QA programs
- I BELIEVE measurement is and will continue to be the best technique for IMRT verification QA

Thank You

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