DEBATE
IMRT Verification QA: TO MEASURE

Moyed Miften, PhD
University of Colorado

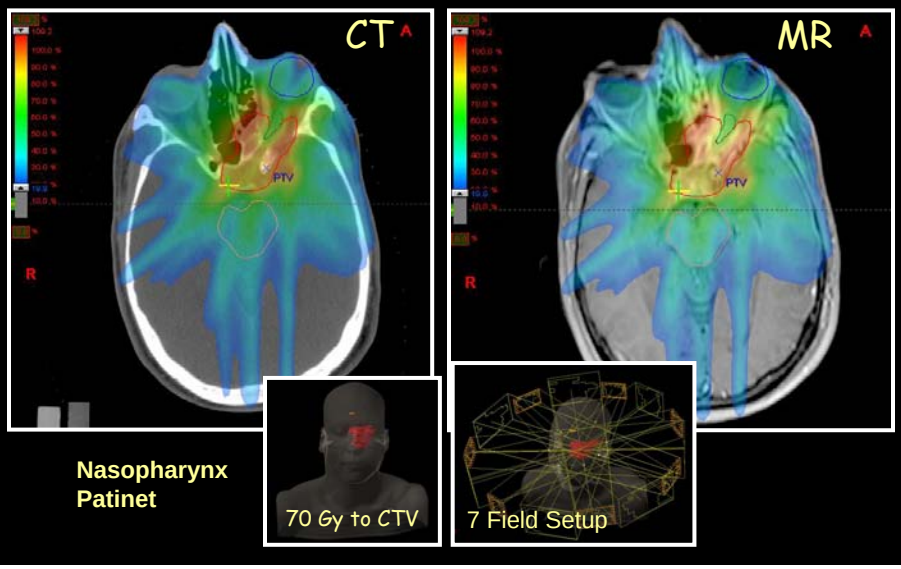
Acknowledgments

- Leah Schubert
- Jenia Vinogradskiy
- John Lucido
- AAPM TG218

My Proposition is EASY to Argue for – 3 Words:

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

If This Patient is one of Family Members



Nasopharynx
Patinet

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 outcome

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)

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Review of Safety Fundamentals

SAFTEY: A Primer

- 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

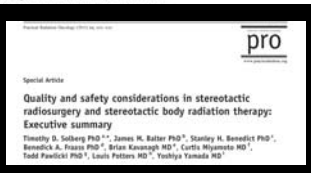
Recent Efforts to Improve Safety

- 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: recently published in Med Phys and PRO
  - HDR, IGRT, and Peer Review are in writing or editing stage


pro

Special Article

Safety considerations for IMRT: Executive summary


pro

Special Article

Quality and safety considerations in stereotactic radiosurgery and stereotactic body radiation therapy: Executive summary

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."

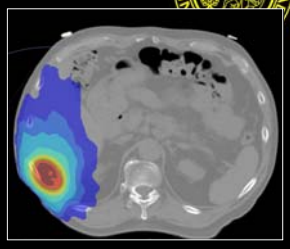
- Anthony Zietman, MD, ASTRO Chair, 2011 ASTRO Annual Meeting

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

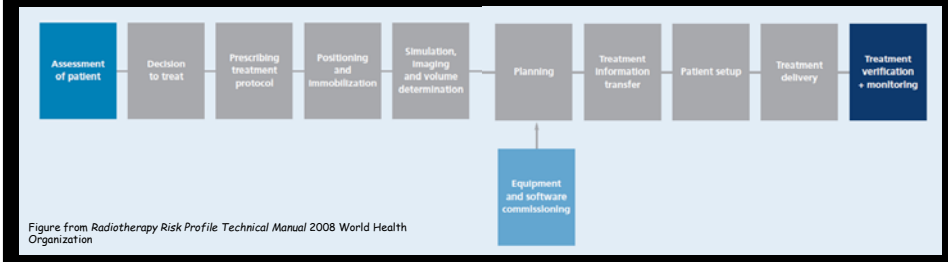


Figure from *Radiotherapy Risk Profile Technical Manual* 2008 World Health Organization

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

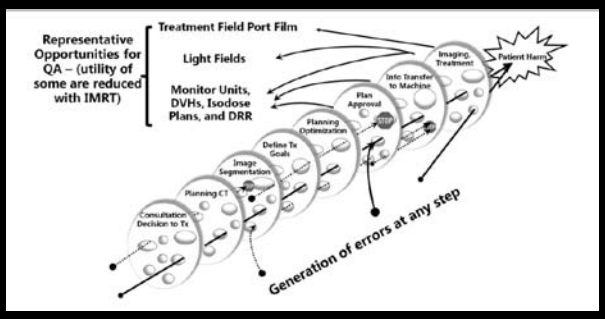
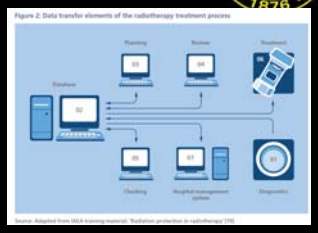


Figure from Marks PRO 2011

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).

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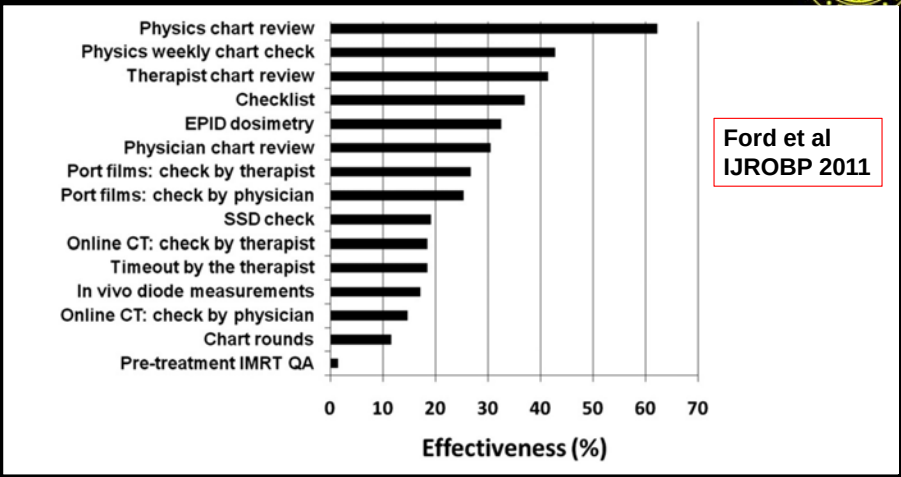
Patient-specific IMRT QA measurment has been hotly debated among physicists

- 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)

Ford et al: data from 2 institutions



Ford et al
IJROBP 2011

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)

For verifying with measurements


Jon Kruse


Andrea Molina


Chuck Mayo


Charles Smith


Jean Moran

For verifying with software & other tools


Alf Soichi

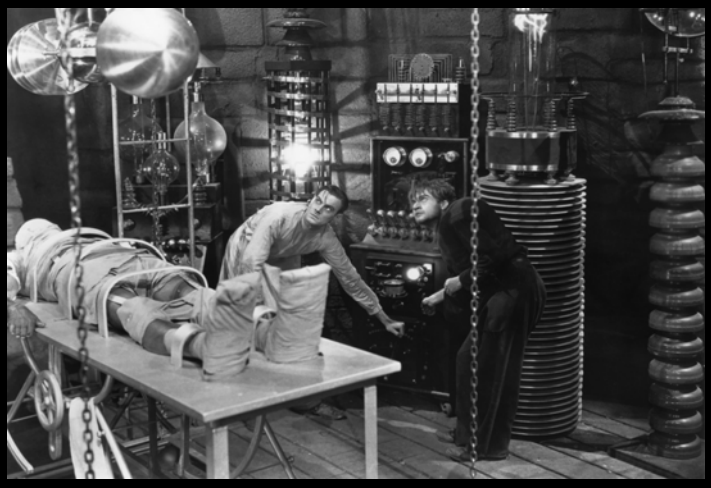

Sonja Dieterich


Eric Ford


Sasa Mutic


Jean Moran

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



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

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:

1. Understand diagnosis and treatment goals as they relate to patient setup

5. Example physicist checklist

Pre-treatment:

6. Example treatment therapist checklist:

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.[18,19,26,15]

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

5. All the above

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

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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.

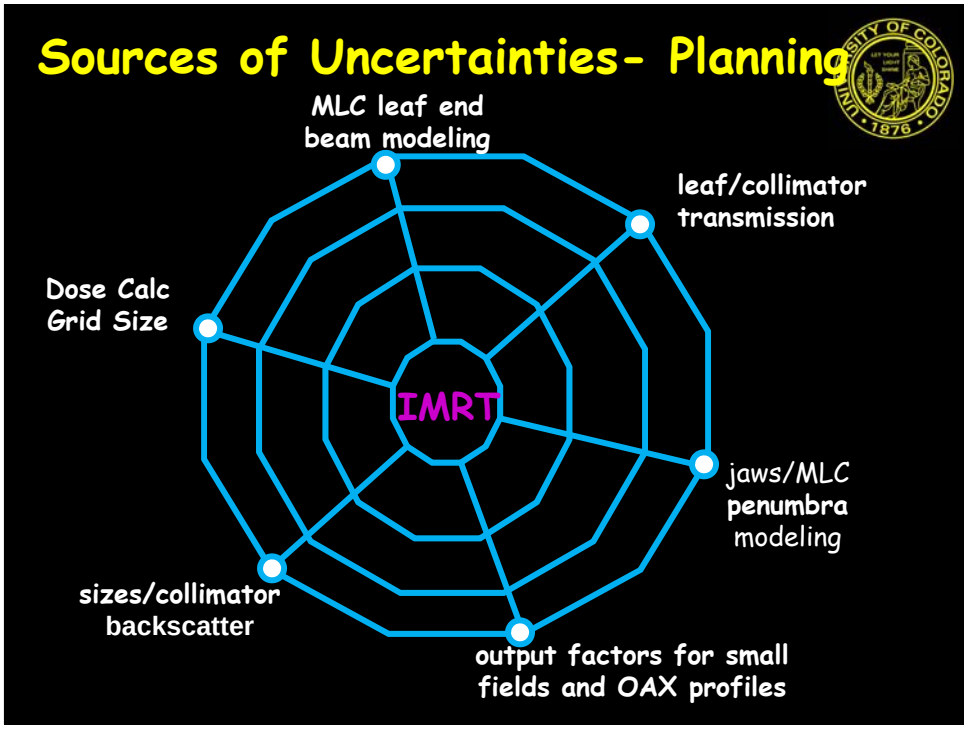
My position is patient-specific IMRT QA measurement is necessary for the foreseeable future. HERE IS WHY

- 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
- Planning systems, 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

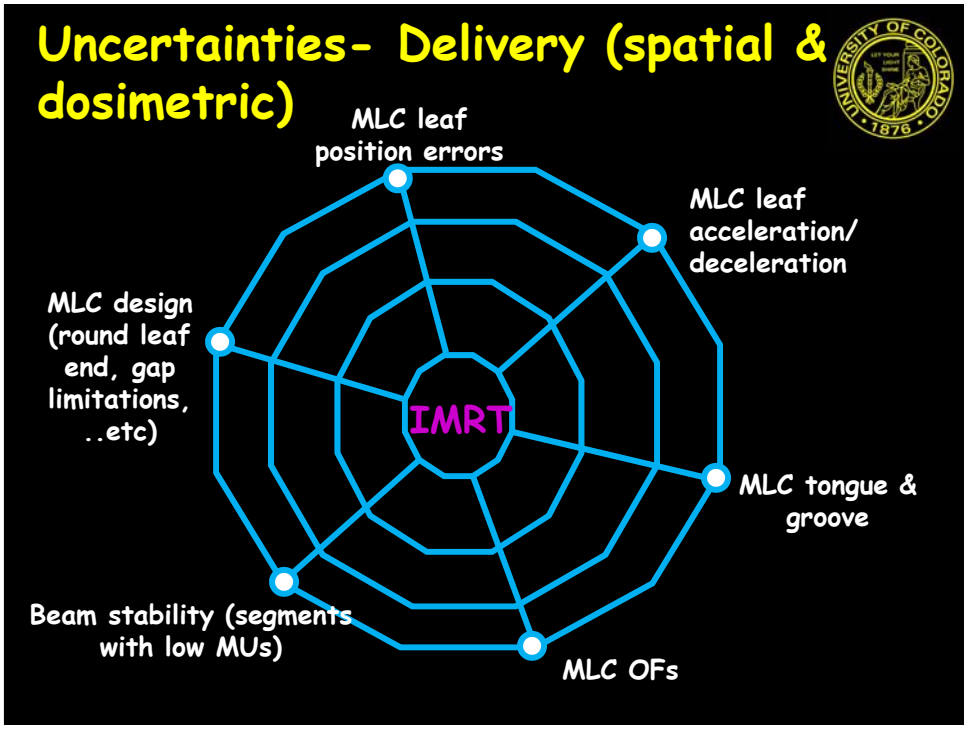
My Counter Arguments OR the TRUE PICTURE: TPS and Delivery Systems

- Unlike 3D systems, comprehensive commissioning of an IMRT planning system is an extremely difficult task to accomplish
- Unlike 3D dose, 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



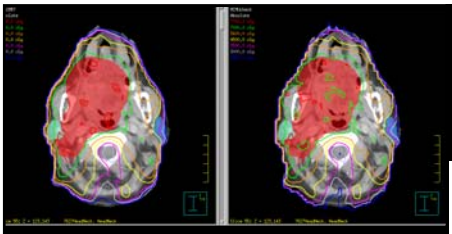
Uncertainties- Delivery (spatial & dosimetric)



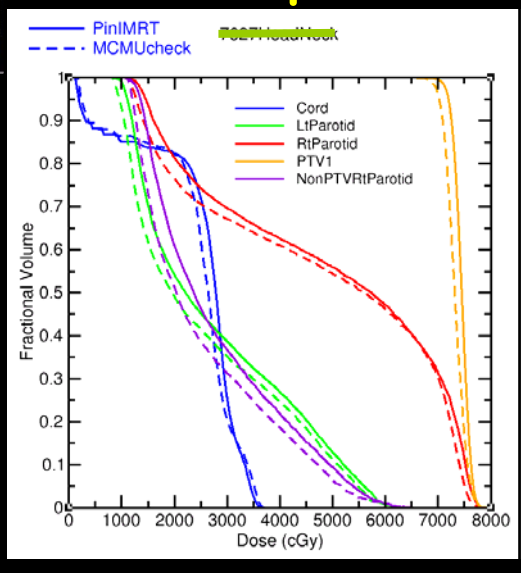
Software Solutions

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

Head and Neck Example

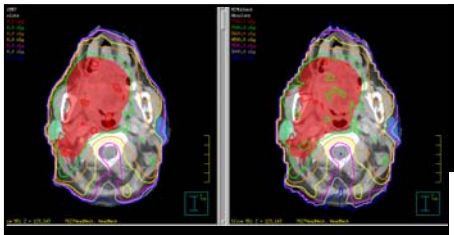


- PTV D_{98} Δ=-2.8%
- LtParotid D_{50} Δ=- 11%
- Cord D_1 Δ<1%



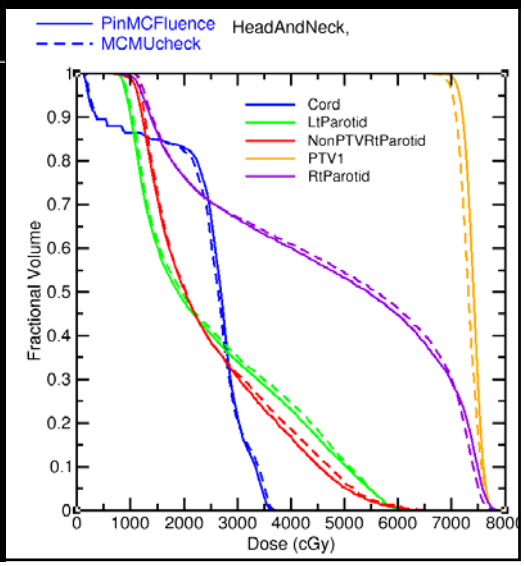
Courtesy of J. Siebers

Head and Neck
Calc using MC Fluence



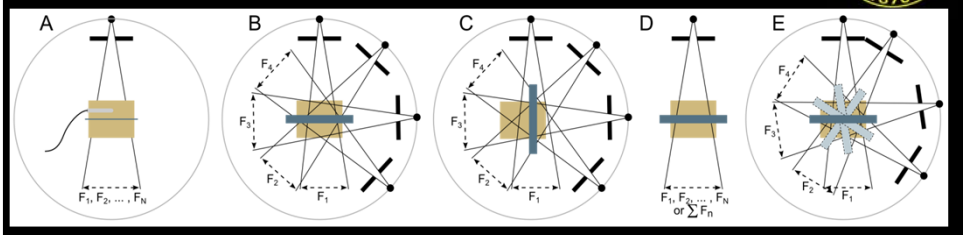
- PTV D_{98} Δ=- 2%
- LtParotid D_{50} Δ=- 3.5%

Courtesy of J. Siebers



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

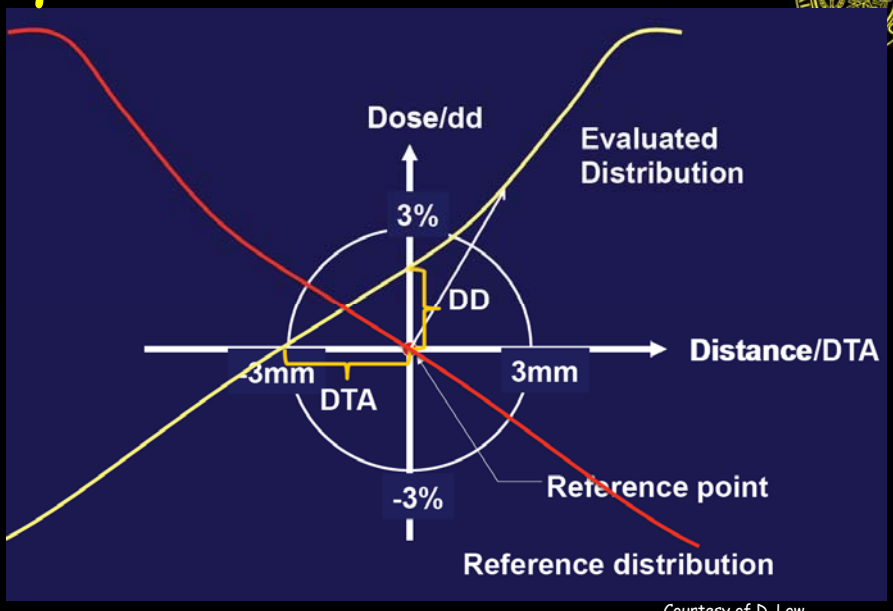
- Dose Difference (Ddiff)
- Distance-to-Agreement (DTA)
- γ

What is γ?

- γ is the rescaled Euclidean distance between a calculated distribution & each point in a reference (measured) distribution
- Each spatial and dose axis is normalized by a criterion
- Renormalized "distance" defaults to DTA and Ddiff in shallow and steep dose gradient regions, respectively.

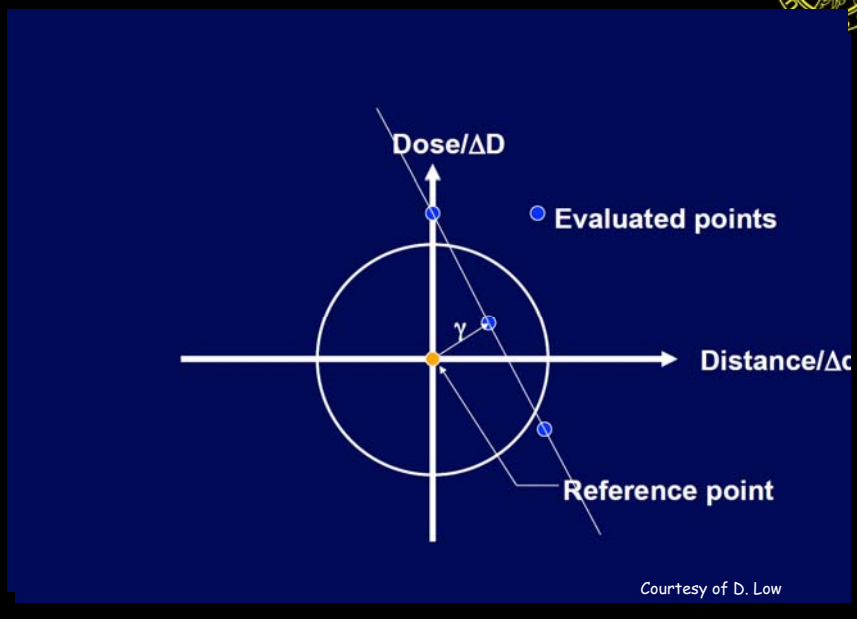
Courtesy of D. Low

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 would be nice!
- Not practical
- γ tool should be used as an indicator of problems, not as a single indicator of plan quality

D-diff/DTA/γ & passing rates don't predict clinically relevant errors or appropriate evaluating for 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 emphasizes that
  - Details of how the agreement between measured and calculated results is determined are often poorly understood
  - Passing rates have no spatial sensitivity, like DVHs, the location of the failed points is not provided with the failing rate.

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 g histograms
- 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)

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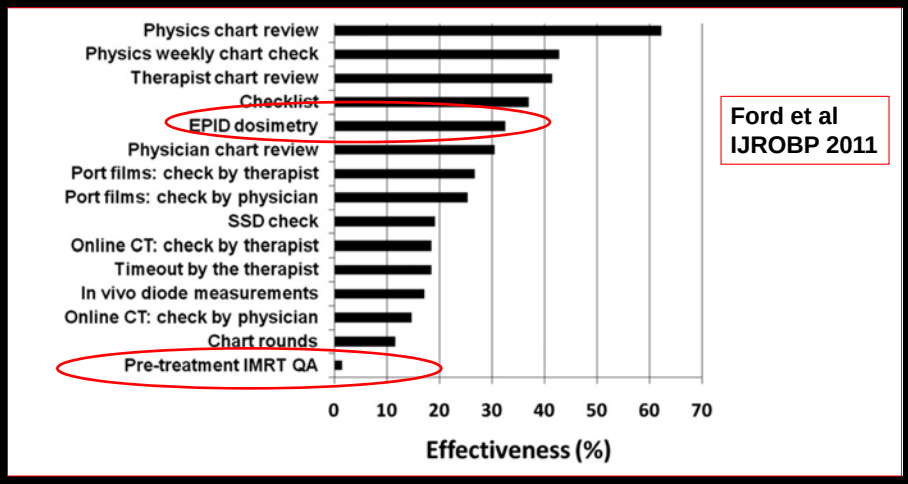
Let us look at the data carefully



Ford et al
IJROBP 2011

Action Limits and Tolerance Levels

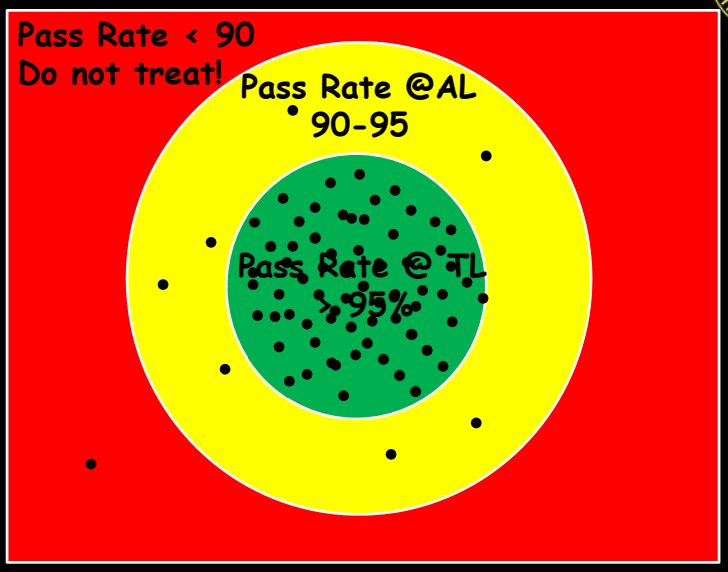
Action Limits (ALs)

- 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

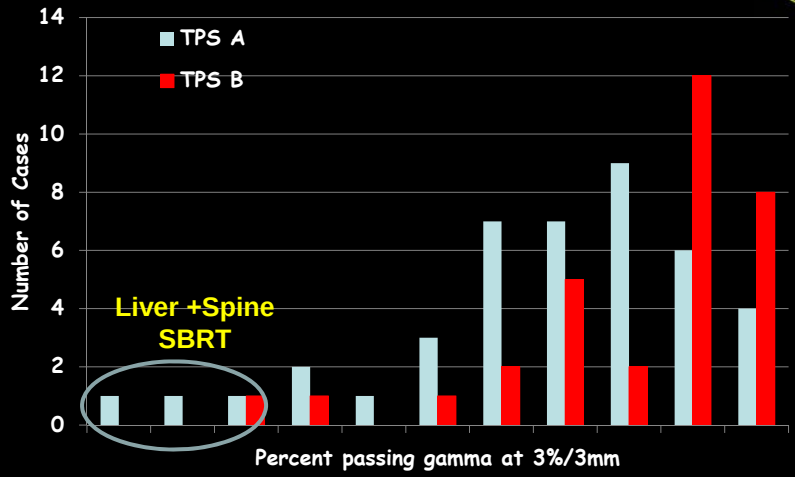
Tolerance Limits (TLs)

- 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)

What Should We Expect?

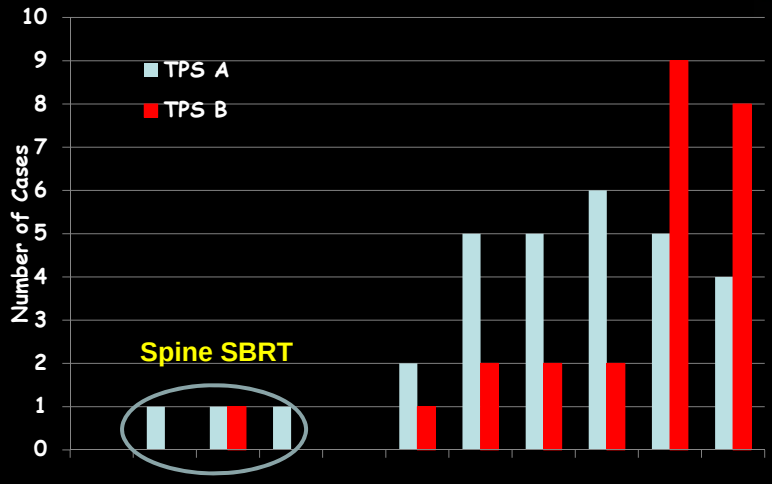


Passing rates for 2 TPS, same Linac All anatomical sites



- TPS 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

Conclusions

- The IMRT QA process should be designed to detect significant errors within the limit of our quality measures
- We should always strive to improve our knowledge base but also recognize that there are things known and things unknown; measurement is the ultimate end test
- Relying on software or computer-based solutions may prevent us from detecting errors that are the outcome of software-bugs/poor software-design

Conclusions

- Source of uncertainty among clinics using measurement-based patient specific IMRT QA programs are the measurement and analysis tools used to interpret the QA results
- We should develop advanced software, improve measurement methods, and analysis tools for IMRT QA but this does not mean we should walk away form 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 QA

Future of IMRT QA

- Guidelines to improve the understanding and consistency of the IMRT QA process using measurements are needed
- Future approaches should 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

Thank You

CU Anschutz Medical Campus