TG-218: How to Handle Pretreatment Measurement IMRT Verification QA

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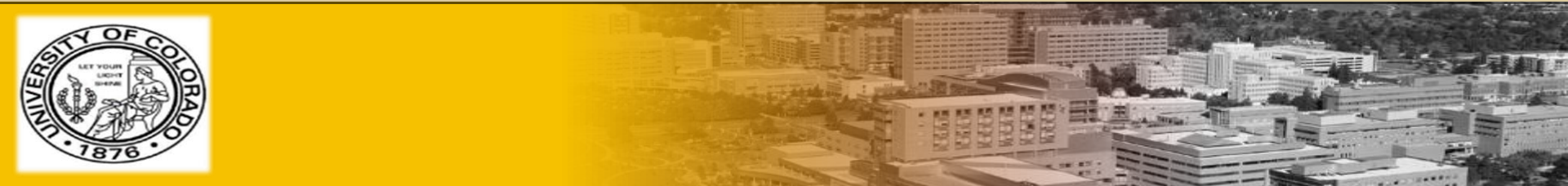

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Disclaimer

- TG218 report is under review by the AAPM

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

Patient Specific IMRT QA Guidance Documents

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

IROC Houston H&N Phantom Example

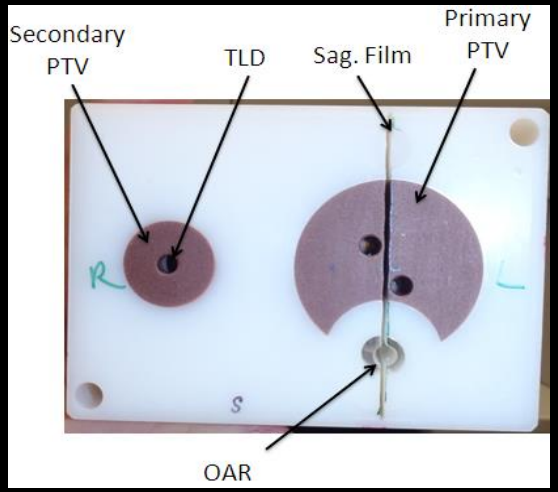
- Alter set up parameters or beam model to assess the impact on dose distributions
  - IROC IMRT H&N Phantom
    - Plans with errors compared to correct plans (measurement vs. plan evaluation)
    - Plans with errors compared to correct plans (DVHs evaluation)

Adapted from J. Faught

IROC-Houston IMRT H&N Phantom

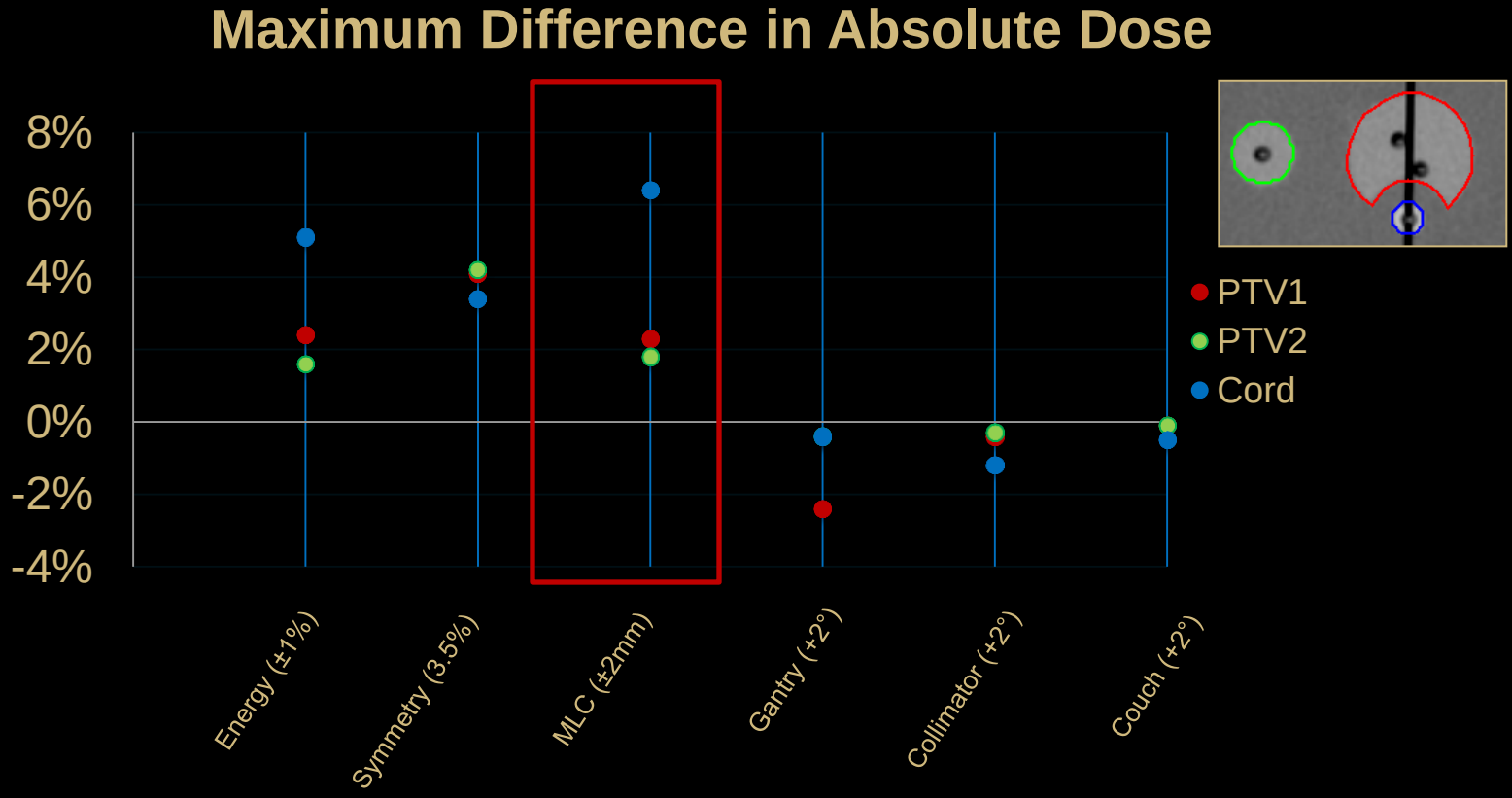
Structure	Dosimetric Criteria
Primary PTV	$D_{95\%} \geq 6.6$ Gy
	$D_{99\%} \geq 6.14$ Gy
Secondary PTV	$D_{95\%} \geq 5.4$ Gy
	$D_{99\%} \geq 5.03$ Gy
OAR (Spinal Cord)	Max Dose < 4.5 Gy
Normal Tissue	Max Dose ≤ 110%

Complexity Metric	Treatment Plan	
	Standard	Complex
MU	1948	3189
Segments	90	216
MCS	0.482	0.171



Courtesy of J. Faught

Phantom Measurement Comparison Results



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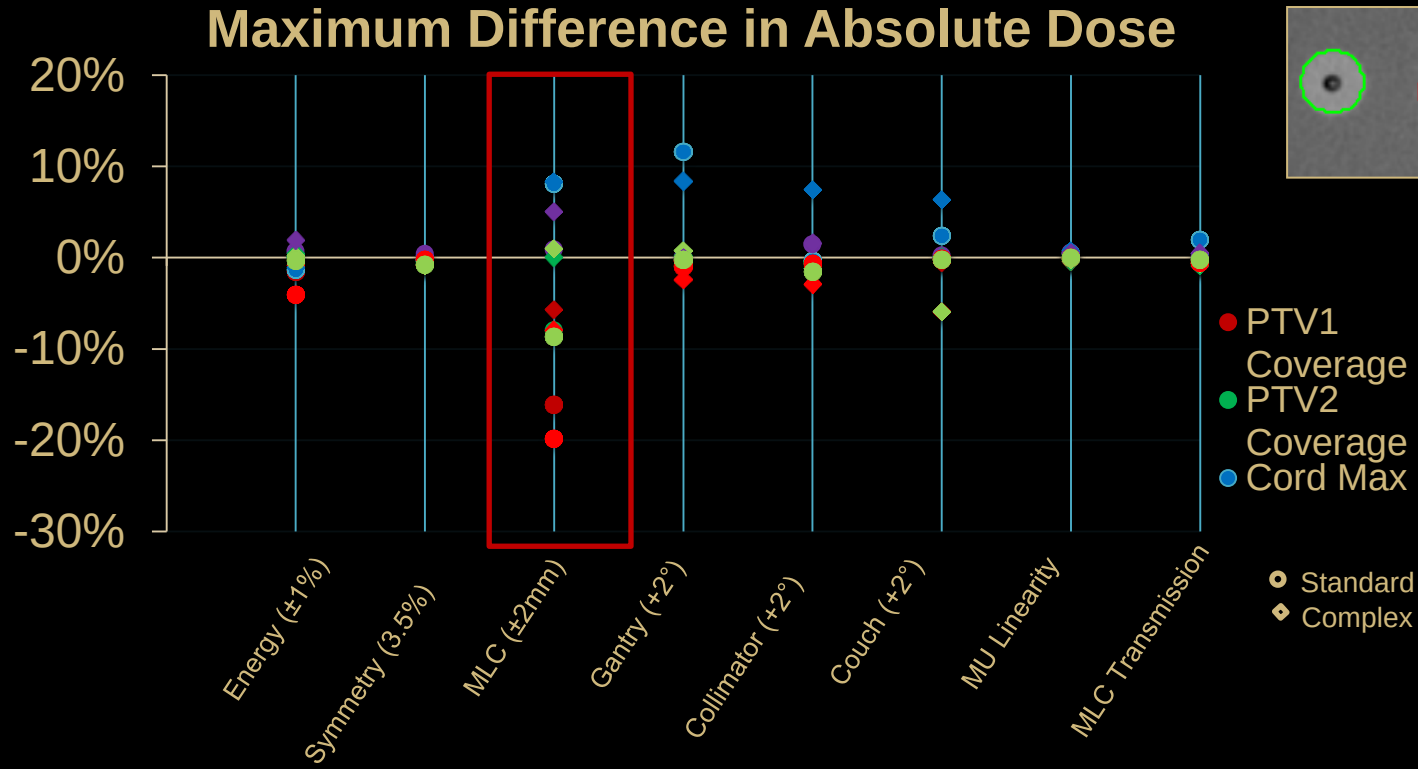
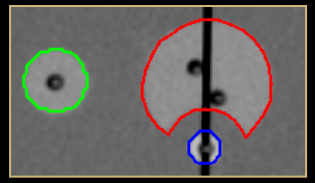
Phantom Treatment Planning Study Comparison Results (D95, cord max dose…etc)



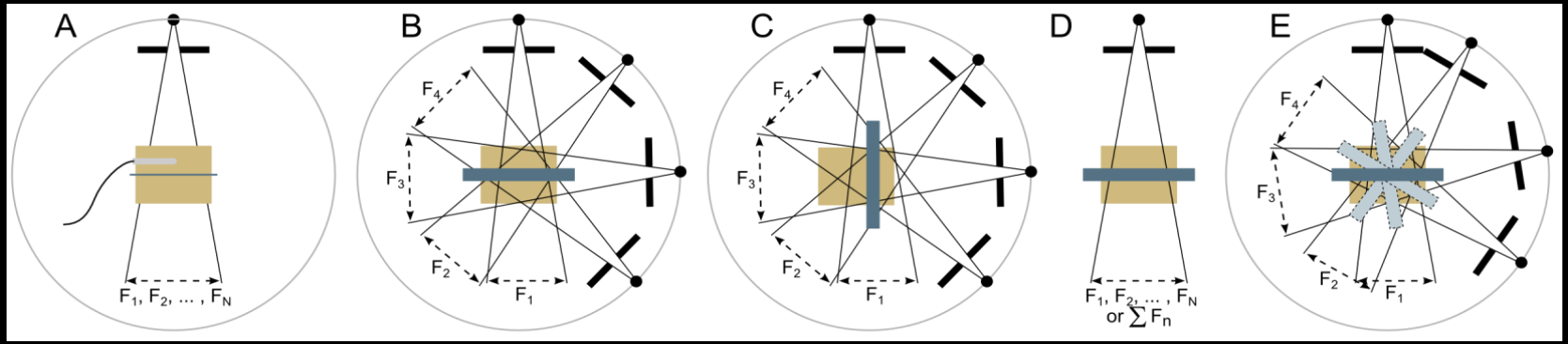


Courtesy of J. Faught

Why TG218

- Little systematic guidance on patient-specific IMRT QA
- No discussion on the pros & 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
- QA procedures differ in scope and depth, acceptable tolerance levels, delivery methods, verification tools, and analysis methodologies

Delivery Methods



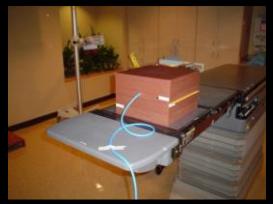
True Composite (film & chamber)

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)



Delivery Methods

- **Perpendicular Field-by-Field (PFF)**
  - beam is perpendicular to the measurement plane and device placed on couch or attached to the gantry head
  - dose from each IMRT beam is delivered and analyzed
- **Perpendicular Composite (PC)**
  - doses from all IMRT beams are delivered and summed
- **True Composite (TC)**
  - beams are delivered to a device using the actual treatment beam geometry for the patient
  - method most closely simulates the treatment delivery to the patient

Delivery Methods: Pros

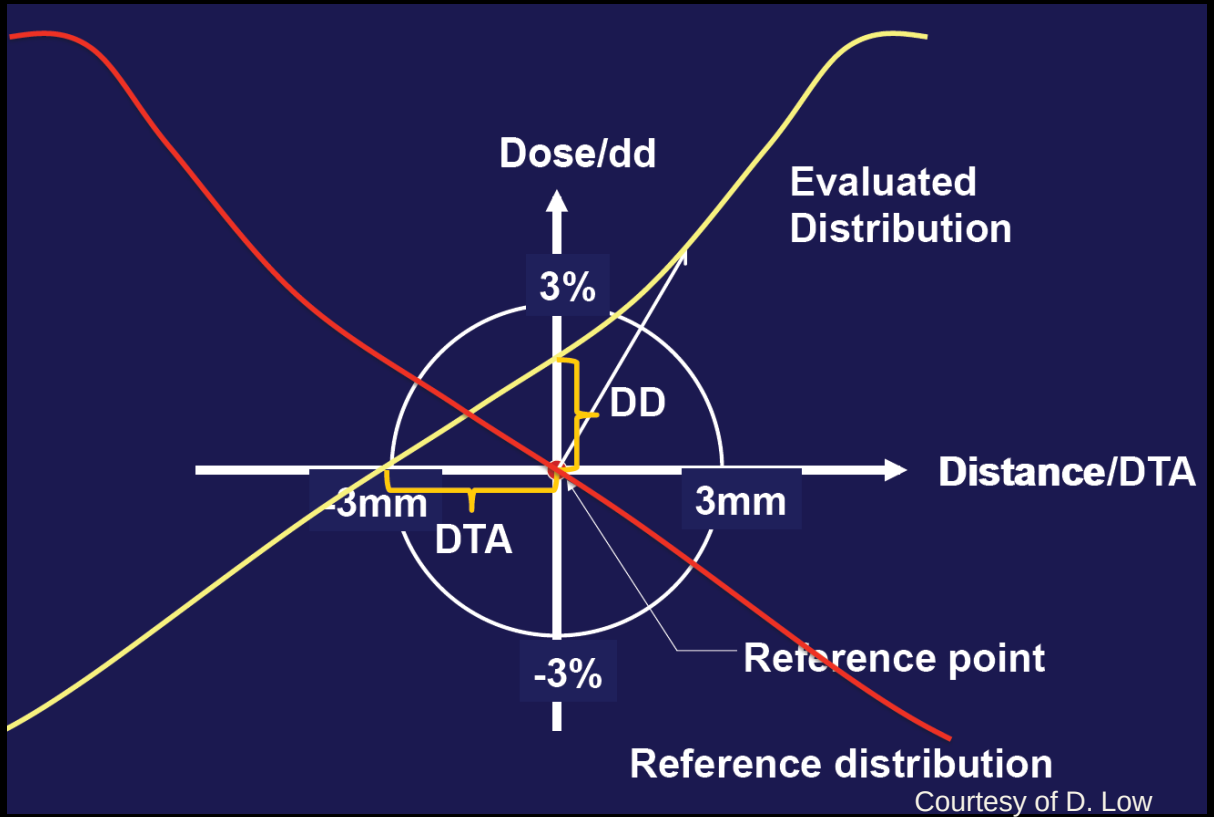
- PFF, PC → Every part of every field is sampled, fast acquisition
- PC → only one dose image to analyze. More uniform dose for analysis than PFF
- TC → provide an actual dose in a 2D plane of the 3D dose. Only one dose image to analyze

Adapted from A. Olch

Delivery Methods: Cons

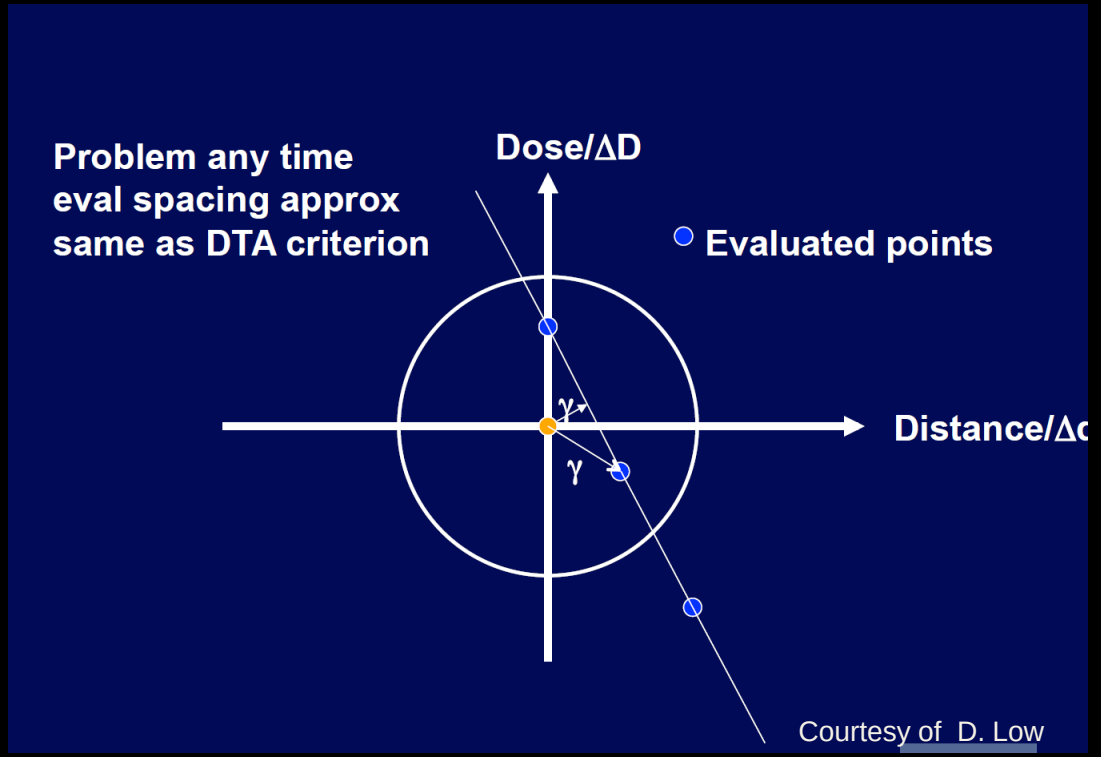
- PFF, PC → no 3D summation. Can't know significance of regional errors in each beam
- PFF, PC → can get any γ result you want for relative dose mode by normalizing to a different place
- PC → errors from each field may cancel on summation
- TC → does not sample every part of each beam

Dose difference, DTA, and γ analysis



γ Analysis

- Practical considerations
  - Normalization
  - Spatial resolution
  - Interpretation



γ IMRT QA Evaluation

- 100% passing is ideal but not practical
- γ statistics should be checked in a structure by structure basis
- γ tool should be used as an indicator of problems, not as a single indicator of plan quality
- Quality measures are intended to set a requirement for the performance of a system

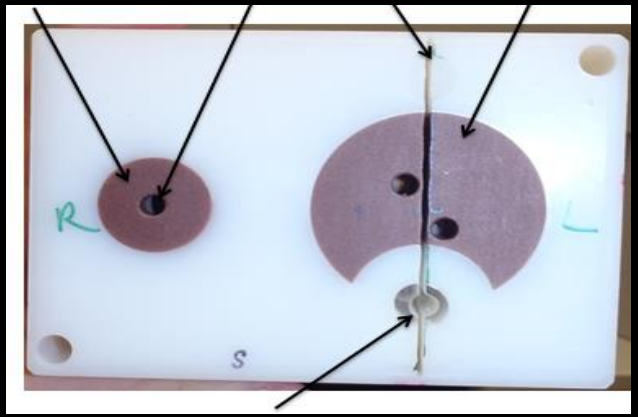
Adapted from D. Low

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)
  - Clinical interpretation of γ failure results is a challenging QA process

H&N Phantom Example

- Assume we have 100 points to be evaluated compared to reference (95 points in targets and 5 in OAR)
  - If all points in targets pass and if all points in OAR fail, the global passing rate is 95%
  - If a structure by structure evaluation is made, the OAR will have 0% passing rate



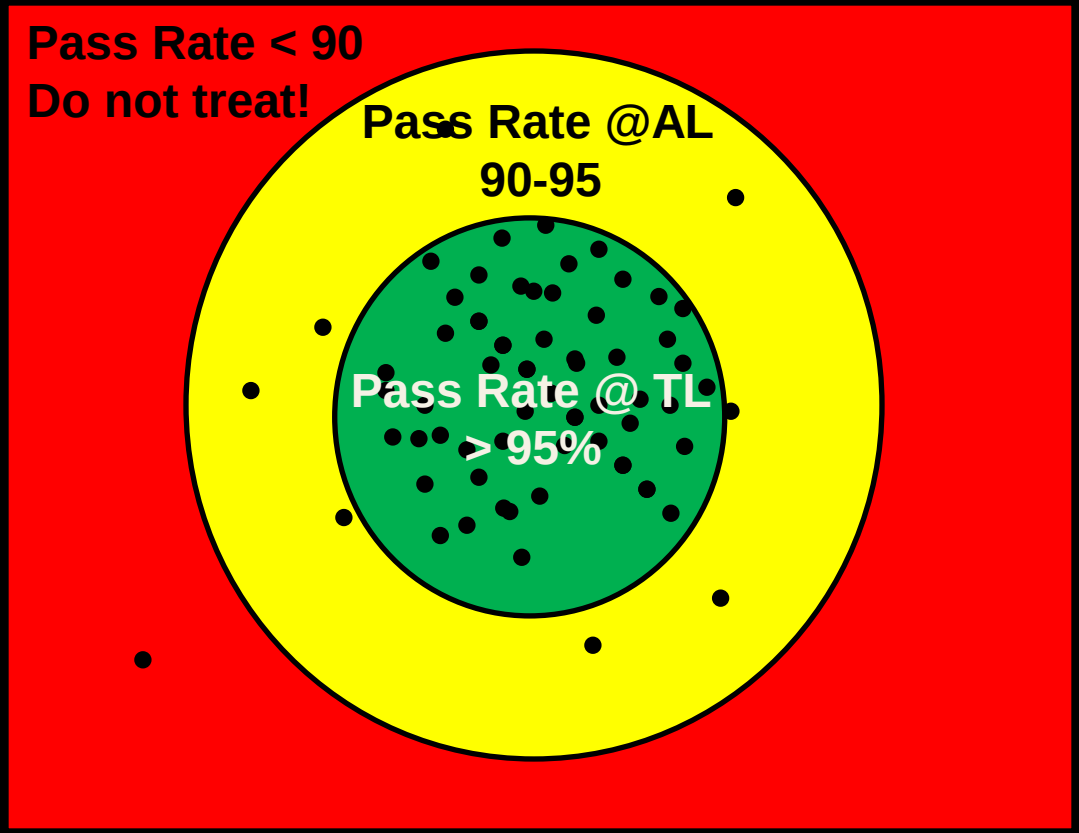
Action Limits (ALs)

- 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

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?



Literature Review

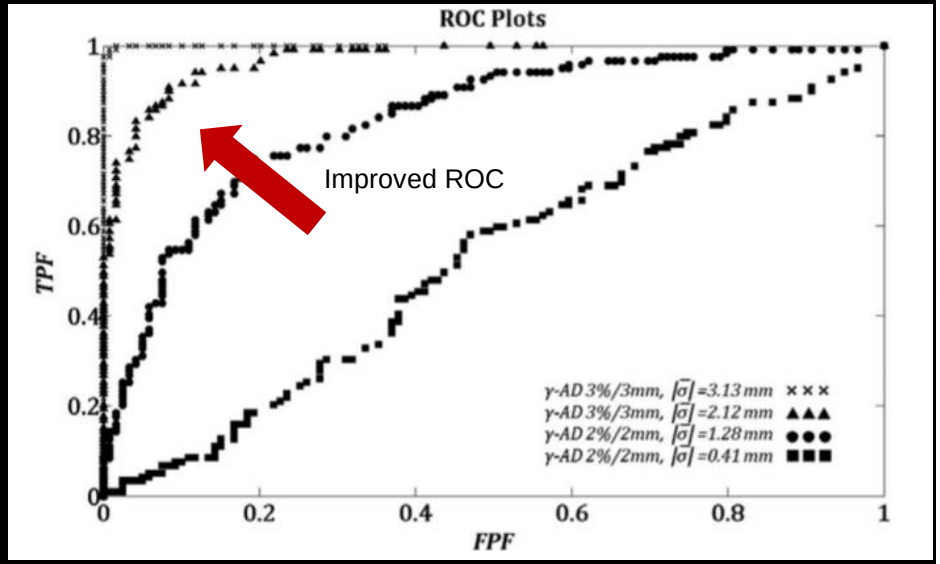
Author year	Delivery technique	Dosimeter	Number of irradiation	Reported results
Dong 2003[75]	Fixed-gantry and serial tomotherapy	IC	751 cases and 1591 measurements	0.37% ± 1.7% (-4.5% to 9.5%)
Both 2007[102]	Fixed gantry	2D Diode array	747 fields	3%/3 mm relative: 96.22±2.89% for HN, 99.30±1.41% for prostate and other; absolute point dose error: 1.41± 1.10% for HN, 0.419±0.420 % for prostate and other
Ibbott 2008[33]	Not specified	Film, TLDs	250 (multi-institution)	179 (72%) pass (7%/4mm absolute/ global)
Molineu 2013[115]	Not specified	Film, TLD	1139 irradiations, 763 mutli-institution	929 (81.6%) pass (7%/4mm absolute/global)
Basran 2008[133]	Fixed-gantry	2D diode array	115 plans	3%/3mm absolute/global: 95.5±3.5% for HN, 98.8±2.0% for GU, 97.3±1.6% for lung
Ezzell 2009[16]	Fixed gantry and Tomotherapy	Film, IC, 2D diode array	10 institutions, 5 from-easy-to-difficult cases per institution	high dose point: -0.2±2.2%; low dose point: 0.3±2.2% (composite); per-field: 97.9±2.5% (3%/3mm absolute/global); composite film: 96.3±4.4% (3%/3mm absolute/global)
Geurts 2009[123]	Tomotherapy	3D diode array	264 plans	3%/3mm: 97.5%, range 90.0-100%; absolute/relative or global/local not indicated
Langen 2010[119]	Tomotherapy	IC, planar dosimeter	TG-148 member institutions	IC: 3%; planar: >90% (3%/3mm absolute/global); range or SD not given
Masi 2011[64]	VMAT	IC, film, 2D diode array, 2D IC array	50 plans	IC: 1.1±1.0%; electronic planar: >97.4% (3%/3mm or 3%/2mm absolute/both global and local), range 92.0-100%; EDR2: 95.1%, range 83.0-100%; EBT2: 91.1%, range 80.0-98.5%
Baily 2011[103]	Fixed-gantry	2D diode array, EPID	25 prostate fields, 79 HN fields	2%/2mm absolute/global: 75.6% (prostate), 70.2% (HN); 2%/2mm absolute/local: 60.5% (prostate), 48.1% (HN); 3%/3mm absolute/global: 96.7% (prostate), 93.5% (HN); 3%/3mm absolute/local: 90% (prostate), 70.6% (HN)
Lang 2012[104]	Fixed-gantry or VMAT with FFF	IC, Film, 3D diode array, 2D IC array	224 plans (52 plans with IC)	99.3±1.1% (3%/3mm absolute/global); point dose: 0.34% (±2% for 88% of cases)

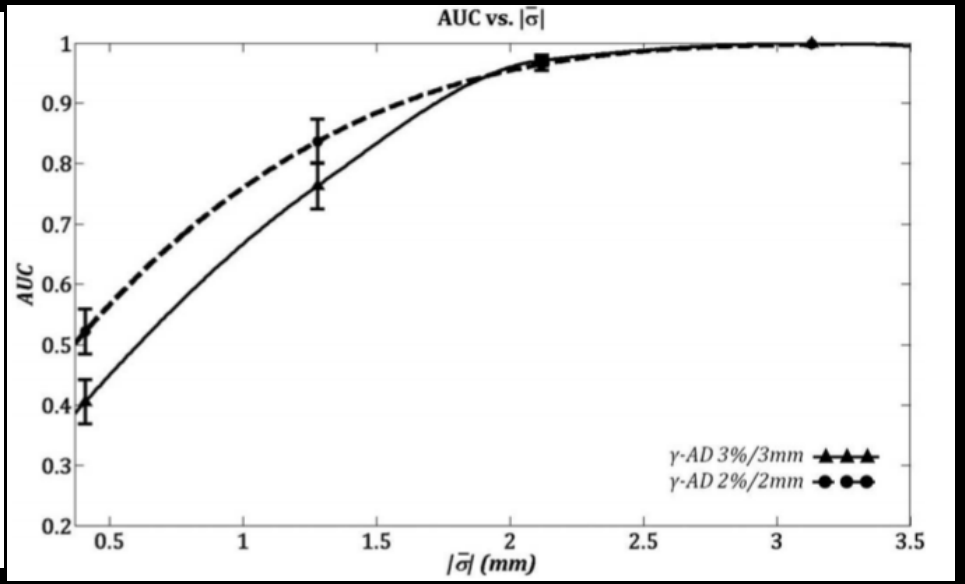
Table 3. IMRT verification QA confidence limits (CL), action limits (AL), tolerance limits (TL) and corresponding γ thresholds reported in the literature.

Author year	Delivery technique	Dosimeter	Number of irradiation	Reported/Recommended Tolerance Levels
Palta 2003[35]	Fixed-gantry	Not Specified	Results from an IMRT questionnaire of 30 institutions	CL and AL: ±10%/2mm and ±15%/3mm (high dose, steep gradient); CL and AL: ±3% and ±5% (high dose, low gradient); CL and AL: ±4% and ±7% (low dose, low gradient)
Low 2003[43]	Fixed-gantry	N/A	simulated fields mimicking clinical fields	γ index tolerance criteria: 5%/2-3 mm
Childress 2005[66]	Fixed-gantry	Film	858 fields	γ index tolerance criteria: 5%/3 mm
Stock 2005[134]	Fixed-gantry	Film, IC	10 plans	γ index (3%/3mm): $\gamma_{mean} < 0.5$, $\gamma_{max} < 1.5$, and fraction of $\gamma_{>1}$ 0-5%
De Martin 2007[137]	Fixed-gantry	Film, IC	57 HN plans	γ index (4%/3mm): γ_{Δ} (γ_{mean} + 1.5 SD(γ)) < 1; γ threshold (4%/3mm): $\gamma_{<1}$ > 95.3% , $\gamma_{<1.5}$ > 98.9%, $\gamma_{>2}$ < 0.4%
ESTRO 2008[38]	Fixed-gantry	IC	Not specified	TL: 3% AL: 5%
Basran 2008[133]	Fixed-gantry	2D diode array	115 plans	TL: 3% overall, 3% per-field (independent of disease site); γ threshold (3%/3mm): ≥ 95% (non-HN cases); γ threshold (3%/3mm): ≥ 88% (HN cases)
Ezzell 2009[16]	Fixed-gantry and Tomotherapy	Film, IC, 2D diode array	10 institutions, 5 from-easy-to-difficult cases per institution	CL: ±4.5% (high dose point in PTV); CL: ±4.7% (low dose point in OAR); CL: ±12.4% (film composite), 87.6% passing (3%/3mm);
Carlone 2013[138]	Fixed-gantry	2D diode array	85 prostate plans (68 modified with random MLC errors)	γ threshold (2%/2mm): 78.9% (σ~±3 mm), 84.6% (σ~±2 mm), 89.2% (σ~±1 mm); γ threshold (3%/3mm): 92.9% (σ ~±3 mm), 96.5% (σ~±2 mm), and 98.2% (σ~±1 mm).

ROC Analysis to Derive Optimal Passing Rate Thresholds: Carlone et al 2013 (Med Phys)

- 17 prostate plans (passed QA on an array device)
- Generated modified plans by introducing MLC errors ranging from 0.4-3mm
- Examined passaging criteria 1%/1mm, 2%/2mm, 3%/3mm, and 4%/4mm





Recommendations: IMRT QA Measurements

- should be performed using TC
  - QA device has negligible angular dependence or the angular dependence is accurately accounted for in software
- should be performed using PFF if the QA device is not suitable for TC measurements/verification analysis
- should not be performed using PC which is prone to masking delivery errors
- should be performed in absolute dose mode, not relative dose

Recommendations: Calibration

- 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

Recommendations: Normalization

- Global normalization
  - should be used; deemed more clinically relevant than local normalization
  - normalization point should be selected in a low gradient region with a value ≥ 90% of the max dose in the plane of measurement
- Local normalization
  - more stringent than global normalization for routine IMRT QA
  - can be used during the IMRT commissioning process and for troubleshooting IMRT QA

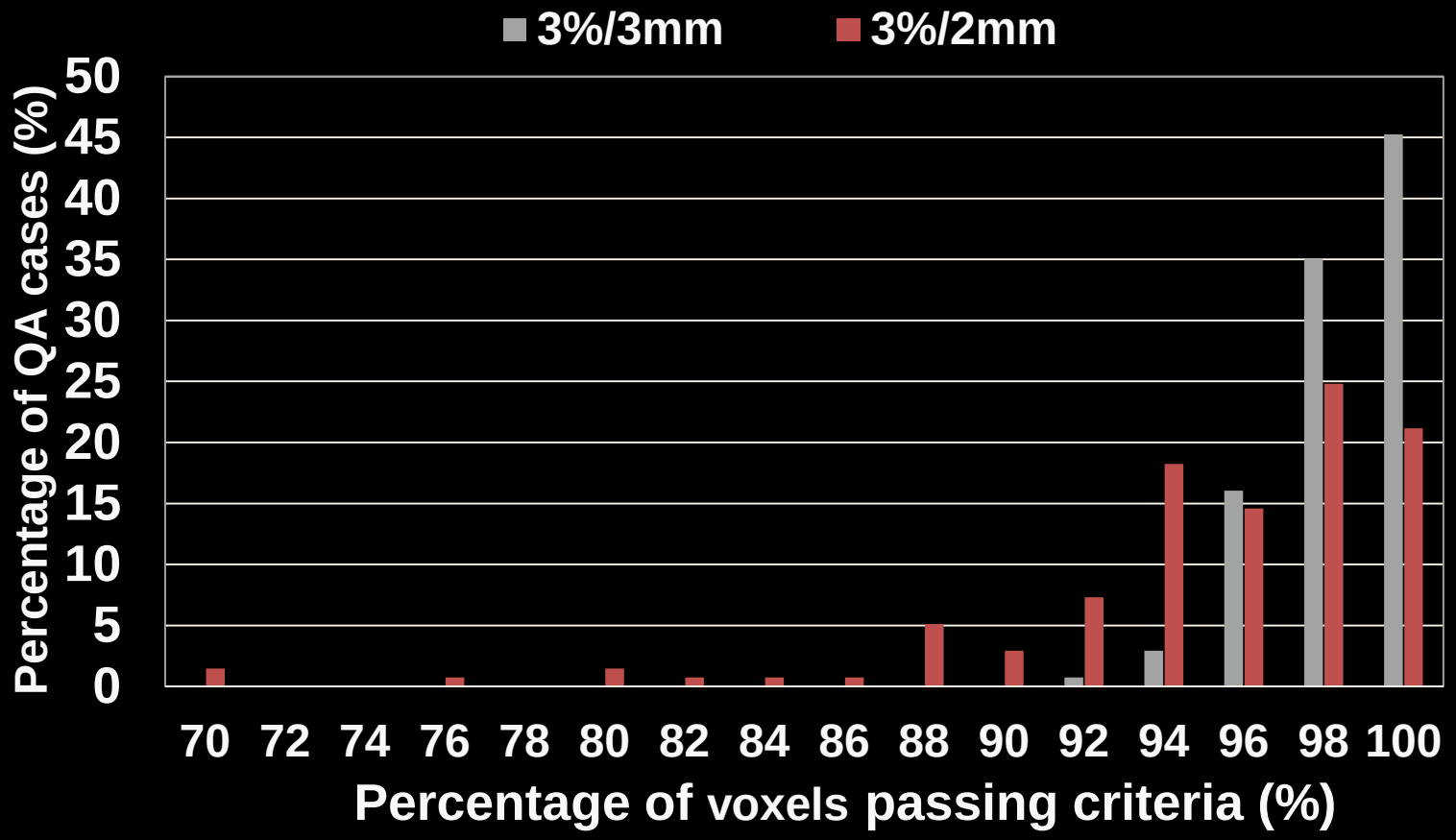
Recommendations: Dose Thresholds

- 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

Recommendations: Tolerance & Action Limits

- Universal TLs: the γ passing rate should be ≥ 95%, with 3%/2mm and a 10% dose threshold
- Universal ALs: the γ passing rate should be ≥ 90%, with 3%/2mm and a 10% dose threshold
- Equipment- and site-specific limits can be determined using a statistical approach
  - If ALs are significantly lower than the universal ALs, action should be taken to improve the IMRT QA process
  - Strict adherence to standardized procedures and equipment as well as additional training may also be necessary

Data from 150 QA Plans



Recommendations: Plan Fails 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 OARs and are at dose levels that are clinically relevant → plan should not be used
- It may be necessary to review results with a different detector or different measurement geometry

Recommendations: γ Analysis

- 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

Recommendations: γ Analysis

- 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
- DVH analysis can be used to evaluate the clinical relevance of QA results

Steps to Check Marginal/Failed IMRT QA

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

Setup and Beam

- Phantom setup
- Correct QA plan generated, and data transferred from TPS to IMRT QA software
- Beam flatness, symmetry, and output on the measurement day
- Beam stability when delivering many segments with low MUs
- Accuracy, stability, and calibration of the measurement device
- Detector size and inter-detector spacing with respect to the size of the IMRT fields

IMRT QA Software

- Performance of the IMRT QA verification software reporting and handling of the plan and measured data
- Recheck values used for dose and DTA tolerance, dose threshold, and registration of the measured and calculated dose distributions

MLC

- Review results of periodic patient-specific IMRT QA
- Leaf tolerances (speed, position, acceleration, etc…)
- Tongue-and-groove effects which may require a measurement with a high resolution detector
- Beam profile data for both collimator- and MLC-defined fields
- Dynamic leaf-gap for rounded-leaf ends and Intra- & inter-leaf transmission
- Jaw tracking positions (to minimize leaf transmission)

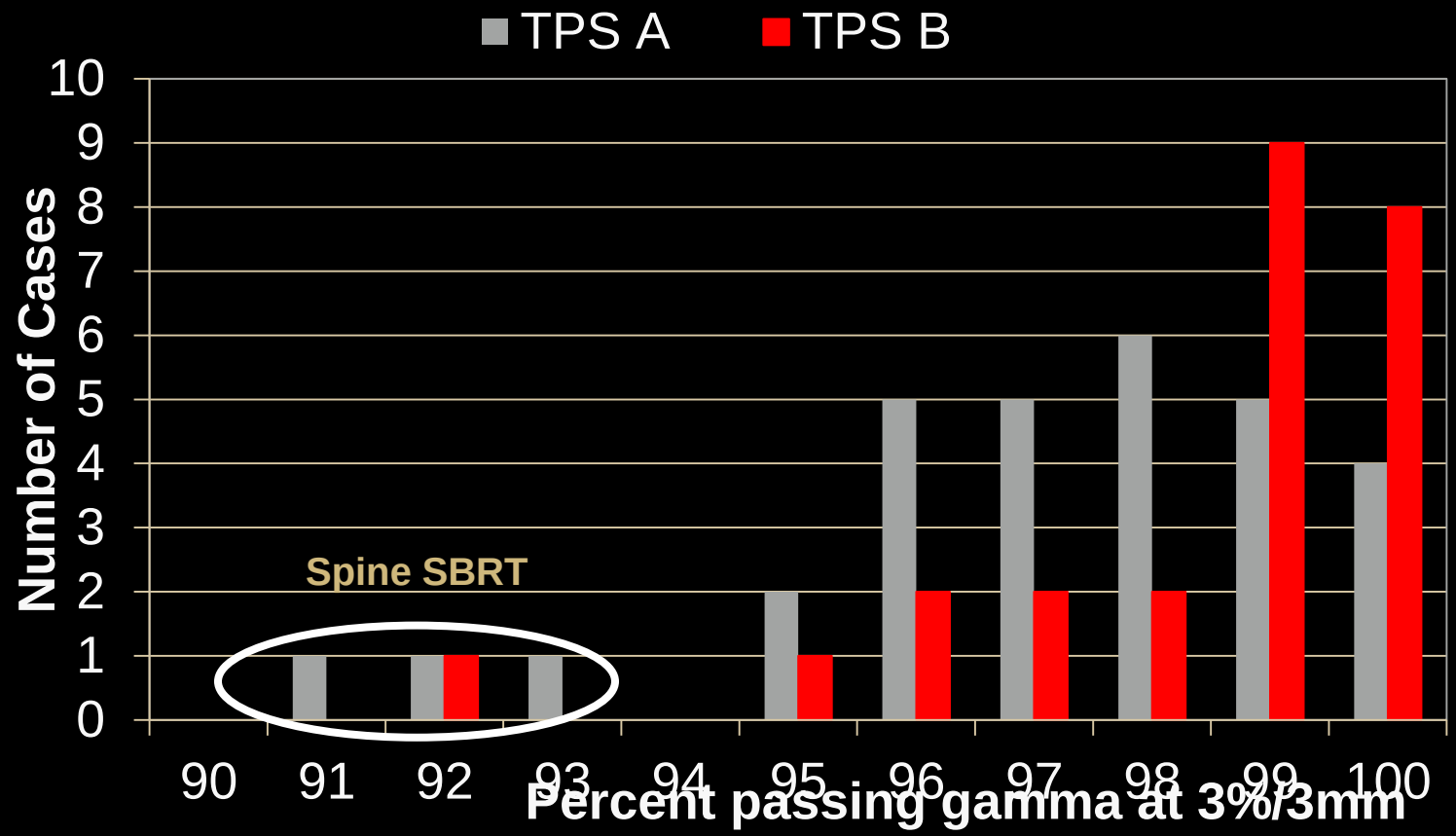
TPS

- The amount of modulation and the complexity of intensity patterns
- The total # of small segments, including small elongated fields
- The total # of MUs which affects the total transmission dose and is related to plan complexity
- TPS modeling accuracy for small-fields, including OFs, profiles, and penumbra
- Characterization of the leaf-parameters in the TPS, including MLC transmission, gap and rounded leaf ends

TPS

- Dose calculation grid size or the variance setting for MC algorithms
- The IMRT QA device CT numbers to electron density conversion
- Gantry-angle spacing for VMAT delivery
- All IMRT parameters should be thoroughly checked as part of the IMRT TPS commissioning process
  - The commissioning should also include verification of IMRT plans for a full range of clinical cases, dose calculation algorithm and optimization parameters

Passing rates for 2 TPS: same linac, CNS cases



TPS

- If the IMRT verification plan fails and there is more complex modulation than normal in your clinical practice,
  - planner should consider re-planning the IMRT case and attempt to achieve the planning objectives with less complex intensity patterns
  - In most systems, the planner can use tools to smooth the patterns during delivery without compromising plan quality

Summary

- Advantages and disadvantages are associated with each IMRT QA method
- Methods have varying ability to detect differences between plan and delivery
- True composite provides at least a 2D plane out of a 3D dose distribution
- PFF and TC methods don’t identify the 3D dose delivery error to the PTV or OARs
- Deriving clinical indications from failing γ points is challenging

Take Home Message

- Quality measures are intended to set a requirement for the performance of a system
- Defining IMRT tolerance and action levels improve the IMRT QA process
- TG218 provides suggested standards that can be implemented at the clinical level to
  - evaluate the acceptability of patient-specific IMRT QA plans
  - aid in the establishment of universal and comparable criteria among institutions

Thank You

CU Anschutz Medical Campus

Optimal Passing Rate Thresholds

γ threshold (2%/2mm): 79% (σ~±3 mm), 85% (σ~±2 mm), 89% (σ~±1 mm)

γ threshold (3%/3mm): 93% (σ ~±3 mm), 97% (σ~±2 mm), and 98 % (σ~±1 mm)