Leibel Memorial Symposium:

Advanced IMRT Planning and Delivery and Future Directions

Commissioning, routine quality assurance and safety considerations for clinical use of advanced IMRT planning and delivery techniques.

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Introduction

Since the early years of IMRT (1990s),
it has been my position that dose measurements
should not be a requirement
for routine patient-specific IMRT QA.

The IMRT QA methods in use at MSKCC,
most of which evolved during
Dr. Steven Leibel's tenure as Vice-Chairman and then Chairman
of the Department of Radiation Oncology at MSKCC,
have always reflected this sentiment.

Types of IMRT error

- catastrophic errors, e.g., wrong field
  - data transfer
  - can be 2-4X dose if open field
- physical errors
  - calibration or commissioning
  - typically <10%

In an ideal world:

- Treatment planning systems (TPS) used for IMRT are designed and commissioned to accurately simulate the beam delivery system
- Machine QA targets MLC calibration and known mechanical problems for each MLC and delivery type.
- Patient-specific QA focuses on potential catastrophic errors

Error data from The Netherlands Cancer Institute

Total # IMRT patients (4337) verified using EPID dosimetry

IMRT related

- plan transfer (4)
- suboptimally tuned TPS parameter (2)
- accidental plan modification in R&V (2)
- failed delivery of 1 segment (1)
- dosimetrically undeliverable plan (1)

} ~1 in 500

Non-IMRT

- patient anatomy changes (7)

Mans et al, Med Phys. 2010

For an accurately commissioned planning and delivery system IMRT errors are infrequent.

- Humans are not designed to detect infrequent events.

Uncertainties in IMRT dosimetry

"The characteristics of the beam delivery system are the major contributors to the uncertainty of measurement-based IMRT QA because most of them are not fully considered in the currently available treatment planning systems."

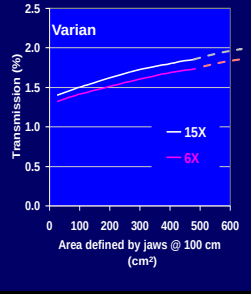
– Li et al, Med Phys 2010

For seven IMRT plans recalculated with Monte Carlo, the maximum per plan changes are

	Δ mean dose to PTV	Δ maximum voxel dose
Multifocal source	1.5%	14%
MLC leakage	5.6%	11%
T&G effects	5.3%	14%
Effective leaf offset	7.8%	33%

MLC Leakage (Varian)

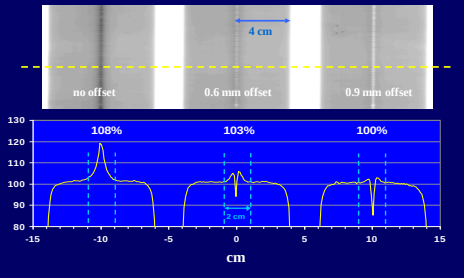
vs field size and energy



- CS = 10x10 (area =100 cm²)
  ~ 1.5% (4.5% for IMRT*)
- CS = 25x25 (area = 625 cm²)
  ~ 2.0% (6.0% for IMRT*)
- 6X vs 15X
  ~ 0.15% (0.5% for IMRT*)

* Based upon 25% duty cycle

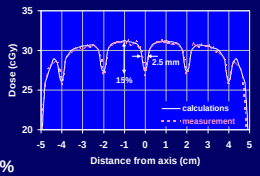
Leaf offset (Varian) – abutting fields

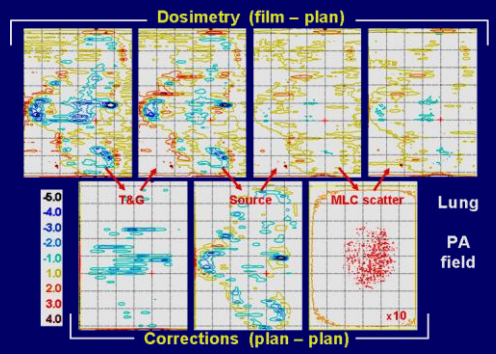


- Minimizing the peak-valley dose variation (center) or superimposing the 50% decrement lines is not optimal,
- The integral dose in the abutment region (right) should be matched to that in an adjacent region

Tongue and groove (Varian)

- Localized underdose up to 15% (FWHM ~ 2.5 mm)
- More serious for plans with
  - greater modulation
  - non-uniform target shapes
- Integral underdoses observed
  - IMRT prostate up to 2%
  - IMRT head and neck up to 4%
  - VMAT up to 5%
- Leaf sequencing strategies can reduce effects but can not eliminate them





Interleaf effects, multi-component source, and MLC leakage are significant.

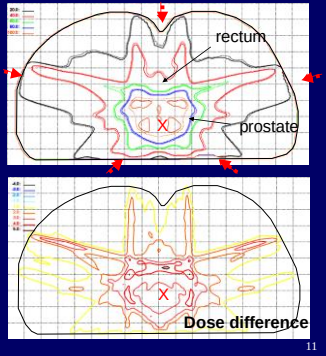
MLC calibration

Prostate

Gap –
1 mm too wide

Target dose ↑ 3-5%

Largest increase is at the target-rectum interface where the beam narrows to sharpen the dose falloff.



TG 142 recommendations for IMRT QA

Weekly:	Picket fence	quick visual evaluation
Monthly:	MLC field size	variation with gantry angle
	Backup diaphragm settings	
	Travel speed	
	Leaf position accuracy	
Annual:	MLC transmission	transmission and alignment
	Leaf position repeatability	
	MLC spoke shot	
	L-R coincidence	
	RMS of leaf position deviations	

"Institutional deviations from some of these recommendations are expected based upon the institution's policy and procedures; the clinical significance of these deviations may be mitigated by other control methods that are not anticipated in this document."

- Klein et al, Med Phys 2009

Commissioning and QA for Rotational IMRT

Accuracy of VMAT dose delivery for continuously variable
- gantry speed
- dose rate
- MLC leaf positions

Ling et al, IJROBP 2008
Bedford et al, PMB 2009

Detector options for patient specific QA

Ion chambers
- **size, placement, composite dosimetry**

2D detectors
- **Ion chamber and diode arrays**
  - **individual fields, poor resolution, fast**
- **EPID**
  - **individual fields, good resolution, rotates with the gantry**
- **Film**
  - **composite dosimetry, high resolution, labor intensive**

"3D" detectors
- **ArcCHECK, Delta4, Gel**
  - **VMAT friendly, composite dosimetry, labor intensive**

TG 119

end-to-end test suite for IMRT commissioning

"…difficult to offer definitive guidance regarding acceptance levels for gamma analysis results."

- **Decreased gamma pass rate with increasing plan complexity**
- **Gamma pass rate depends upon details of implementation of data analysis**
  - **ROI vs threshold to avoid low dose region**
  - **maximum vs local vs prescribed dose as reference dose**

- Ezzell et al, Med Phys 2009

Sensitivity of planar dosimetry for IMRT QA?

" … gamma analysis of single field measurements is insensitive to important dosimetric inaccuracies ..." and

"… distance to agreement blunts the sensitivity of the analysis to true dosimetric errors…"

"… the accuracy of IMRT planning systems dictates a continued need for patient-specific QA…"

- Kruse, Med. Phys. 2010

"There is a lack of correlation between conventional IMRT QA performance metrics (i.e. Gamma passing rates) and dose errors in anatomic regions-of-interest."

- Nelms et al, Med Phys 2011

Log file analyses for verification

TABLE II. Leaf specific quantities and displays.

Quantities and Displays	
Calculate position deviation vs time for each leaf	Histograms of position deviations for each leaf
Calculate RMS position deviation for each leaf	Histogram of leaf position deviations when beam is on and/or not held off
Calculate expected and actual velocity vs time of each leaf	Histograms of actual velocities for each leaf
Calculate expected and actual acceleration vs time of each leaf	Histograms of actual acceleration for each leaf
Calculate and display expected gap vs time for each leaf pair	Histogram of expected and actual velocity when beam is on and/or not held off
Calculate and display actual gap vs time for each leaf pair	Histograms of actual velocities for each leaf
Calculate and display gap deviation vs time for each leaf pair	Histogram expected and actual gap and gap deviation for each leaf pair
Calculate average and RMS gap	Histogram gap deviations for conditions +ii, −ii, and −iii
Calculate and display expected and delivered leaf trajectories	Statistical comparison of all expected and actual quantities for each leaf
Calculate and display expected and delivered dose profiles for each leaf pair	Tables summarizing each leaf's position deviations
Calculate and display dose discrepancy profiles for each leaf pair	Tables summarizing each leaf's expected and actual velocities
MU scaling of leaf trajectory and dose related quantities and graphics	Tables summarizing each leaf's expected and actual accelerations
	Tables summarizing each leaf's expected and actual gap sizes and gap deviation statistics

Leaf position
Velocity
Acceleration
Gap
Trajectories
Dose profiles

- Litzenberg et al, JACMP 2002

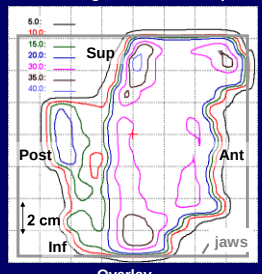
Campus: Main
Room Name: 445
MRN: xxxxxxxx
Patient Name: xxxxxx,xxxxxxx
Plan Name: ABDOMEN_QQ
BeamNumber in RTPlan: 4
BeamName in RTPlan: 04, BeamName in Log: 04
BeamDescription: 04RAO_D
MU Planned in Log: 120, Delivered last MU: 120.0244, MU in RTPlan: 120
Trajectory .bin file Date/Time: 2011072607284 2
Trajectory .txt file Date/Time: 2011072607284 2
RTPLAN folder: \\sraopspin1\release\Data\3dfpDicom\00717533\ABDOMEN_QQ\RTPLAN.DCM

Carriage A no error
Carriage B no error
Jaw positions no error
Gantry Angle no error
Coll. Rtn. no error
Planned MU is within tolerance
Delivered last MU is within tolerance

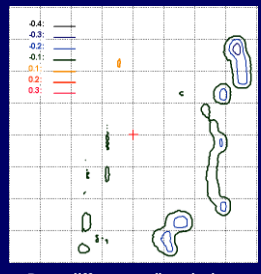
- MSK nightly trajectory log analysis

Patient-specific IMRT QA using log files

Log file → Leaf sequence file → dose distribution



Overlay



Dose differences (log-dva)

- LoSasso et al Med Phys 2001

Patient-specific QA at MSK

TPS

↓

ARIA

↓

TX MACHINE

DMLC fluence:
Graphical, numerical, and index (run) comparison of TPS and ARIA

→ Independent MU calculation

For hypo/single fractions:
Pre-beam-on comparison between RTPlan file and plan loaded on machine

→ ARIA apertures are superimposed with burned-in DRR apertures in RTChart

Log file analyses:
Nightly comparison for all fields with RTPlan file

→ Apertures are filmed and approved for all IMRT fields

"End-to-end" IMRT testing at MSK

- Each month, reference IMRT test plans are regenerated from the pre-optimization stage for one machine category
- All machine/energy categories in the department are covered in a 6 month period
- Planar dose distributions are generated for these test cases and compared to independent calculations and measurements (gamma analyses and dose difference plots)

Comparison of patient-specific IMRT QA

Dose measurements

- the most common approach
- individual field and composite dosimetry
- corrects MUs for individual patients
- well-suited to facilities with few IMRT patients

Alternative non-dosimeric approach

- more stringent TPS modeling and commissioning
- targeted MLC QA identifies the source of delivery error
- log file analyses monitor daily deliveries
- reduced time and effort for large numbers of IMRT patients

Conclusions

- If dose calculations are inadequate, then physicists are compelled to perform absolute dose measurements, mainly to adjust MUs, for each IMRT field.
- If 1) TPS accurately calculates dose,
  2) TPS parameters are commissioned properly,
  3) targeted machine QA is performed,
  then patient-specific IMRT QA is only needed to detect infrequent catastrophic errors.

  Such errors do not require dose measurements for detection.

Future directions

- TPS vendors should 1) accurately model IMRT-sensitive MLC parameters and 2) provide default values for these parameters.
- Linac vendors should provide software tools to manage the verification of the performance of their products (e.g., log file analyses).
- Physicists should understand the weaknesses of their planning and delivery systems and provide appropriate QA.
- AAPM Task Group recommendations for patient-specific QA should acknowledge alternative comprehensive QA methods.