Quality Assurance of IMRT Delivery Systems - Siemens

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Siemens Medical Systems, Concord, CA

NOMOS Corporation, Sewickley, PA

Introduction

- IMRT delivery requires special quality assurance due to:
  - Small number of MUs per field
  - Large number of small fields
- Need to investigate several beam properties in detail:
  - Dose linearity
  - Beam flatness and symmetry
- MLC properties to investigate:
  - Leaf leakage for closed pairs and leaf-to-leaf
  - Leaf position accuracy and offset

Introduction (con't)

- Assumption of inverse-planned IMRT
- Relatively complex plans (e.g., H/N) currently result in 10-20 beam segments per beam direction (CORVUS by NOMOS)
- Properties of Siemens MLC and beam delivery control system, affect the quality assurance methods

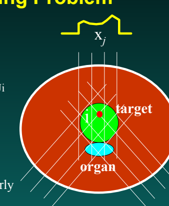
Issues of Quality Assurance

- Machine related QA
  - Dose linearity
  - Field symmetry and flatness
  - Leaf position accuracy
  - Dose accuracy of each segment
- Patient related QA
  - Measure phantom plans
  - Check Intensity map
  - Patient position verification

Inverse Planning Problem

Dose to point i

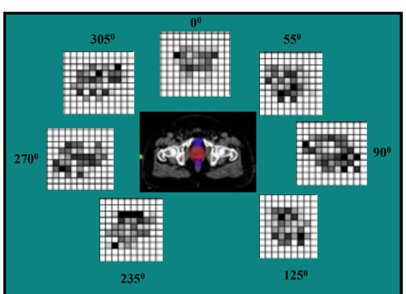
$$D_i = x_1 d_{1i} + \cdots + x_j d_{ji}$$
$$= x \cdot d_i$$

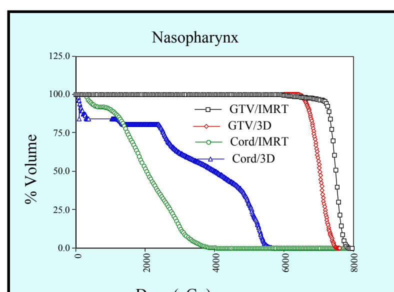


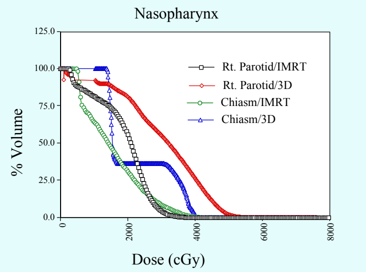
The dose deposited to the *i*th point in the body from the *j*th ray is linearly related to the intensity of that ray

Inverse Treatment Planning

- Prescription requires dose goals for target and normal tissues (possibly 3-point DVHs)
- Planner chooses beams and no. of intensity levels
- Opportunity to place margins between CTV and PTV
- Objective function minimized using penalties based on clinical input
- Output is discrete or continuously varying intensity profiles for each defined beam direction and MLC segments and weights for accelerator of choice
- Many commercial systems now available (CORVUS, Helios, Helax, Pinnacle, CMS, KonRad)

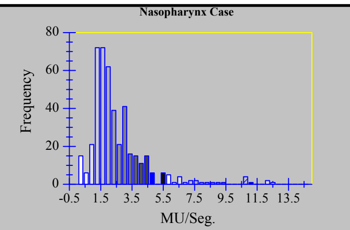






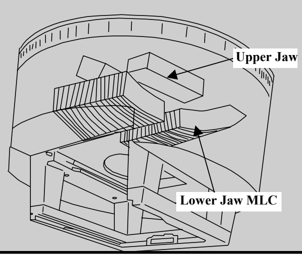
Conclusions from Nasopharynx Comparison

- Dose to cord limits GTV dose for 3D plan
- Significantly better cord sparing with IMRT plan than with 3D plan
- Significantly better parotid sparing with IMRT than with 3D plan
- Typically need approximately 120-140 segments over 7-9 directions for good conformality in H/N treatments

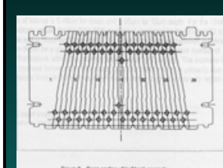


Rx technique: 15 gantry angles, 10 intensity levels, total # of segments = 491 – is this really necessary?

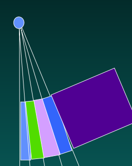
Siemens MLC



Siemens Double Focused MLC



Focused in Y



Focused in X

Siemens MLC Properties

- Doubly focused, effective arc motion
- 27 leaf pairs projecting to 1 cm, 2 leaf pairs at extremes projecting to 6.5 cm
- Conventional field size 40 x 40 cm
- IMRT field size 28 long x 21 wide determined by overtravel limits of MLC (10 cm) and y-jaw (10 cm)
- Interdigitation of leaves not allowed
- Closure of leaf pair possible
- No velocity control, only step-and-shoot

Issues of Quality Assurance

- Machine related QA
  - Dose linearity
  - Field symmetry and flatness
  - Leaf position accuracy
  - Dose accuracy of each segment
- Patient related QA
  - Measure phantom plans
  - Check Intensity map

Dose Linearity Check

- In theory, radiation dose is linear, but because of end effect, this linearity may not be strictly true
- Step and shoot IMRT delivery introduces many small MU segments.
- Dose linearity should be verified using IMRT delivery technique with small MUs

Dose Linearity Check

- Siemens Linacs:
  - Measured a point dose using an ion chamber for an IM square field, consisting of 99, 15x15 cm^2 segments with 1MU /seg
  - Compared with that of a regular 15x15 field delivered with 99 MU
  - Special soft pots can be adjusted to achieve better dose linearity

Results of Linearity Check

Total MU	MU/Seg	Energy	Reading	Δ (%)
99	99	6MV	0.4705	
99	1	6MV	0.4750	1.0
99	99	18MV	0.4780	
99	1	18MV	0.4844	1.3

KD-2, Dmax, 100 cm SSD, 15x15 cm^2

Dose Linearity Check

- Varian Linacs:
  - Measured point doses of special IM field consisting of 190 and 95, 15x15 cm^2 segments with 0.1 MU/seg 0.2 MU/seg, and 1 MU/seg, respectively.
  - Programmed with stop and shoot delivery
  - Purposely programmed 2 mm shift between segments to simulate beam on and off
  - Compared with the results of regular 15x15 cm^2 field with 190 MU and 95 MU respectively

Results of Linearity Check

Total MU	# of Seg	MU/seg	Reading	Δ (%)
19	1	19	0.0905	
19	190	0.1	0.0904	-0.07
38	1	38	0.1804	
38	190	0.2	0.1805	0.06
95	1	95	0.4523	
95	190	0.5	0.4517	-0.19
95	95	1	0.4525	-0.05

CL_2300, 6MV, 1.5 cm depth, 100 cm SSD, 15x15 cm^2

Results of Linearity Check

Total MU	# of Seg	MU/seg	Reading	Δ (%)
19	1	19	0.0934	
19	190	0.1	0.0933	-0.11
38	1	38	0.1863	
38	190	0.2	0.1864	0.04
95	1	95	0.4657	
95	190	0.5	0.4658	0.04
95	95	1	0.4656	0.01

CL_2300, 18MV, 3.2 cm depth, 100 cm SSD, 15x15 cm^2

Field Symmetry and Flatness Check

- Field symmetry and flatness are tuned through a feedback loop from the internal ion chambers.
- Small MU delivered to each segment may affect the field symmetry and flatness
- Conventional profile measurement can not be used because of insufficient MUs.
- The ion chamber is placed at following symmetry points (+5, +5), (+5, -5), (-5, +5), and (-5, -5) in a 15 x 15 cm^2 field delivered in IMRT fashion.

Results of Symmetry and Flatness

Location	Total MU	MU/seg	Readings	Δ (%)
(0,0)	99	99	0.4705	0
(0,0)	99	1	0.4750	0.96
(-5, 5)	99	1	0.4853	3.15
(-5, -5)	99	1	0.4889	3.91
(5, 5)	99	1	0.4801	2.04
(5, -5)	99	1	0.4836	2.78

KD2, 6MV, 1.5 cm depth, 100 cm SSD, 15x15 cm^2

Results of Symmetry and Flatness

Location	Total MU	MU/seg	Readings	Δ (%)
(0,0)	99	99	0.4780	0
(0,0)	99	1	0.4844	1.34
(-5, 5)	99	1	0.5006	4.73
(-5, -5)	99	1	0.5029	5.21
(5, 5)	99	1	0.5016	4.94
(5, -5)	99	1	0.4981	4.21

KD2, 18MV, 3.2 cm depth, 100 cm SSD, 15x15 cm^2

Results of Symmetry and flatness

Location	Total MU	MU/seg	Readings	Δ (%)
(0,0)	19	19	0.0905	0.0
(0,0)	19	0.1	0.0904	-0.1
(-5, 5)	19	0.1	0.0918	1.4
(-5, -5)	19	0.1	0.0912	0.8
(5, 5)	19	0.1	0.0916	1.1
(5, -5)	19	0.1	0.0912	0.8

CL_2300, 6MV, 1.5 cm depth, 100 cm SSD, 15x15 cm^2

Results of Symmetry and Flatness

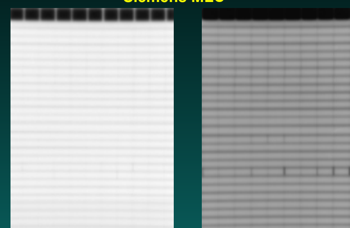
Location	Total MU	MU/seg	Readings	Δ (%)
(0,0)	19	19	0.0934	0.0
(0,0)	19	0.1	0.0933	0.11
(-5, 5)	19	0.1	0.0920	1.52
(-5, -5)	19	0.1	0.0915	2.03
(5, 5)	19	0.1	0.0913	2.25
(5, -5)	19	0.1	0.0920	1.50

CL_2300, 18MV, 3.2 cm depth, 100 cm SSD, 15x15 cm^2

MLC Leaf Position Check and Field Penumbra

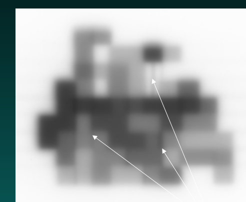
- MLC leaf position accuracy and field penumbra become more important in IMRT treatment, because it can affect dose through the entire field as the multiple segments abutting together, not just on the edge of the field as in conventional delivery
- Leaf position accuracy for Siemens and Varian Linacs meets their specifications

Siemens MLC



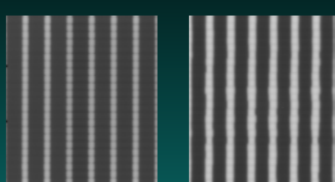
Leakage after calibration — Leakage without calibration

Siemens MLC



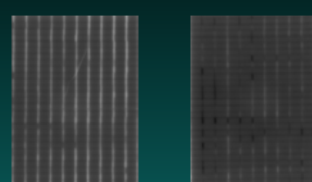
Intensity pattern showing need for calibration

Siemens MLC



after calibration — without calibration

Siemens MLC

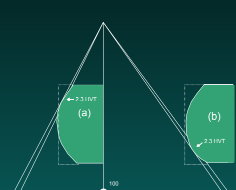


2.0 cm strip, systematic gap — 2.1 cm strip, some gap (0.5 mm offset per leaf)

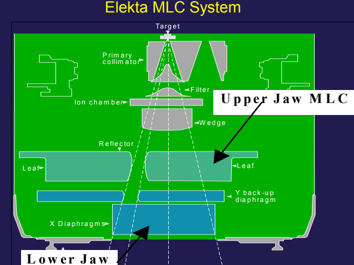
Multileaf Collimator Designs

- Each manufacturer has a different design for their MLC
  - Location, leaf width, and leaf end design
  - Single focused or double focused
  - Restrictions on motion (path, over-travel, interleaf)
  - Field size
- These factors have an impact on dose delivery and must be considered in treatment planning

Rounded Leaf End vs Penumbra



Elekta MLC System

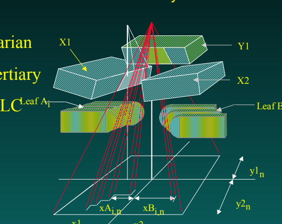


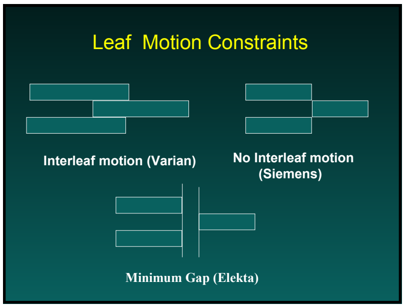
Varian MLC System

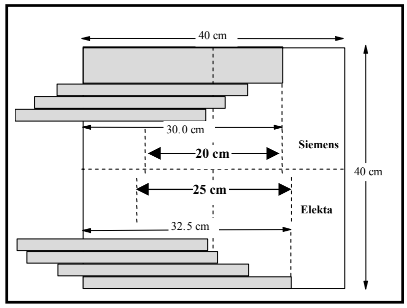
Varian

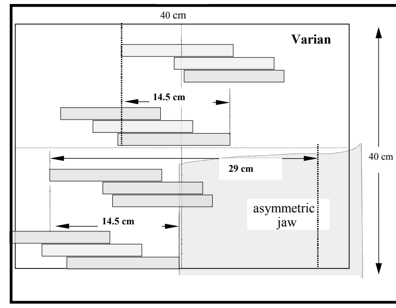
Tertiary

MLC









MLC Field Size for IMRT

Linac	IMRT Field Size	Nominal Field Size
Varian	29 x 26 (40) cm^2 (2 x 14.5 cm)	40 x 26 (40) cm^2
Siemens	21 x 20 (27) cm^2	40 x 27 (40) cm^2
Elekta	25 x 25 cm^2	40 x 40 cm^2

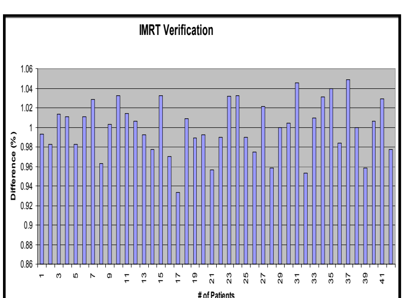
Siemens SMLC-IMRT Delivery System

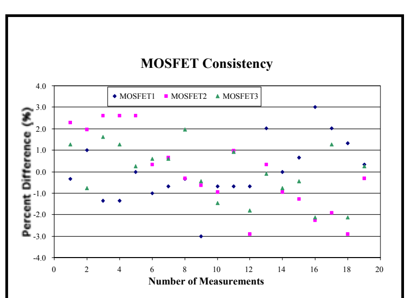
- Automatic field sequencing system (Primeview/SIMTEC)
  - For both conventional and IMRT delivery
  - Automatically deliver all gantry angles including segments in each IM field
  - Supports step and shoot SMLC delivery
  - ~ 5 - 6 sec. R/V overhead per segment
  - Treat 100 - 120 segments in 20 minutes
  - Only integer MU can be specified per segment
  - Supports network RTP

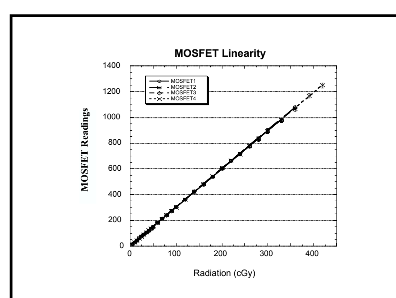
Dosimetric Verification Procedures at UCSF

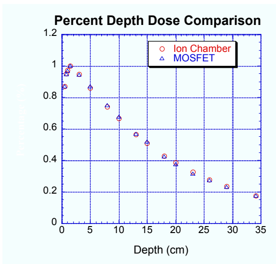
* In the beginning, dosimetric verification was performed prior to each patient's first treatment using solid water phantom with ion chambers and film (Results - The measured point doses near the maximum were all within 5% of predicted doses)

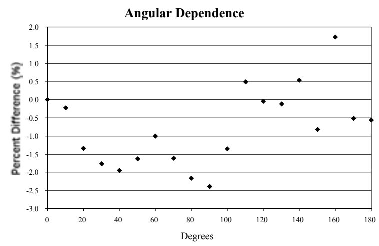
* Now designing system for q/a checks using cylindrical plastic phantom with multiple holes for MOS-FET dosimetry. Will move to this method in the future.

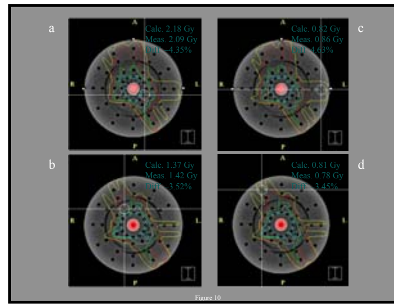












Dosimetric Verification- Results

- Observations <u>independent</u> of delivery system
  - High dose regions of plan (typically >85% max) were generally within 2% of calculated
  - Lower dose regions (typically planned for 30 - 50 % of max) were 10 - 15 % higher than planned
  - In general, higher complexity (more intensity levels and segments) gave higher discrepancies

Dosimetric Verification - Interpretation

- Dose discrepancies approximately the same for plans delivered with Siemens and Varian accelerators - i.e., independent of dose delivery system
- Probable cause is dose calculation algorithm within planning system which does not deal well with small fields and leaf transmission and scatter - soon Monte Carlo can answer question
- Dose errors due to DMLC control delays probably not clinically significant though more research needed

What have we learned so far with our IMRT experience?

- There is no perfect system – limitations of planning system, IMRT delivery system and dose verification must be considered
- Clinical needs drive us to complex IMRT plans (many fields and segments) therefore, delivery speed is important
- Dose accuracy not as good for high complexity due to large numbers of small fields and small dose per segment
- IMRT field length and field width requirements can limit use

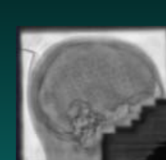
Current Limitations with use of IMRT for Precision H/N Radiotherapy

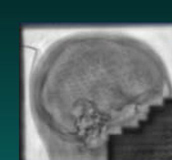
- Patient immobilization and target localization
- 3D dose verification
- Treatment parameter verification
- Control of optimization process
- Efficient registration of biological imaging to Rx planning CT
- Accelerator control system efficiency
- MLC leaf positioning accuracy
- Dose calculation accuracy
- Dose delivery technology

Patient immobilization and target localization

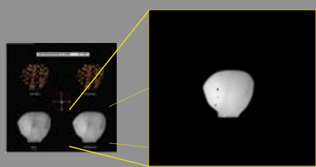
- Dose gradients for IMRT are large in all directions so immobilization and target localization even more important than for 3DCRT
- Work in progress includes:
  - Imbedded markers, use of portal imagers and automated search routines to localize targets
  - Image subtraction for video images of patient vs. setup
  - Couch motions activated to reposition correctly on a daily basis using feedback
  - CT in treatment room (or on gantry) to verify plan before treatment
  - Motion prevention such as gated therapy for lung and thorax tumors

Lateral Head & Neck 6 MV images acquired with Am-Si Flat Panel


2 MU Localization image

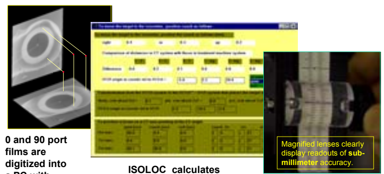

Verification image

Automated Radioopaque Marker Detection



Courtesy of Jean Pouliot, Ph.D.

Target Alignment



0 and 90 port films are digitized into a PC with ISOLOC, the localization software

ISOLOC calculates target location and necessary moves to bring the target to the isocenter

The pReference micropositioner is used to dial-in the moves

pReference, NMPE Inc.

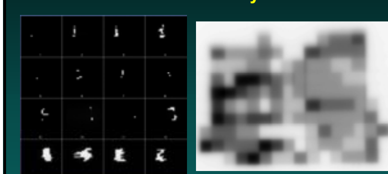
3-D Dose Verification

- Can only do single point or plane (film) dose verification at this time
- In the future:
  - Bang Gels read out by MR
  - Instrumented phantoms with multiple fixed points using diodes or very small ion chambers or MOS-FET (This is UCSF choice)
  - Portal imagers to image transmitted dose and programs to back-project information to patient
  - MV-CT using treatment beam

Treatment parameter verification

- Difficult to verify set of MLC position information for IMRT treatments
- In the future:
  - Use portal imagers to image intensity pattern and to verify MLC positions "on the fly"
  - Special programs to verify MU calculation per beam segment

Intensity Pattern Verification for IMRT Delivery



Individual beam segments

Reconstructed intensity map

Dose calculation accuracy

- Currently, inverse planning programs have very simple dose calculation algorithms due to requirements of speed
- In the future:
  - Multiple calculation algorithms will be available to check plan during optimization process
  - Monte Carlo dose calculation program will become routinely available to evaluate the optimized plan
  - Speed of Monte Carlo will become so fast that it can be done <u>during</u> the optimization process (CORVUS will incorporate Peregrine Monte Carlo dose algorithm in the near future)

Workload - IMRT vs. 3DCRT

- Comparisons recently made of physics effort and treatment times for IMRT vs. 3DCRT for complex treatment plans
- Physics times were on average a factor of 2-3 higher than for 3DCRT (8 hours vs. 3 hours)
- IMRT treatment times somewhat longer on average than for 3DCRT (20 - 45 vs. < 15 min)
- Physician time somewhat greater for IMRT, mostly due to target contouring time (not documented)

UCSF Experience with IMRT- Conclusions to date

- Routine Monte Carlo calculations of expected dose distributions will be available in very near future with Peregrine and other programs
- Portal imager will soon be able to provide rapid, high contrast images to help verify patient and/or target position automatically
- Linac manufacturers working hard to make IMRT faster and dose delivery more accurate
- IMRT still not simple enough to be used in all clinics, but we are on the right track