LINAC and MLC QA for IMRT

Ping Xia, Ph.D.,

Department of Radiation Oncology

University of California

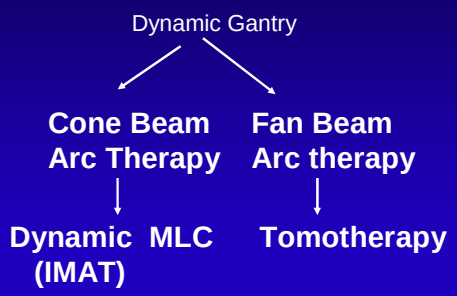
San Francisco

2006 AAPM Refresher Course QA For IMRT and IGRT II

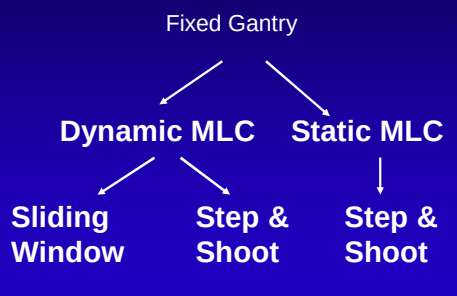
Outline

- IMRT delivery methods
- Commercial IMRT delivery systems
- Characteristics of MLC systems
- Machine Specific IMRT QA
- Dosimetric effect of MLC leaf positioning errors

IMRT Delivery Methods



IMRT Delivery Methods



Delivery Hardware

- Static MLC

  Leaves cannot be moved when the beam is on. Leaf motion and the radiation are executed sequentially.

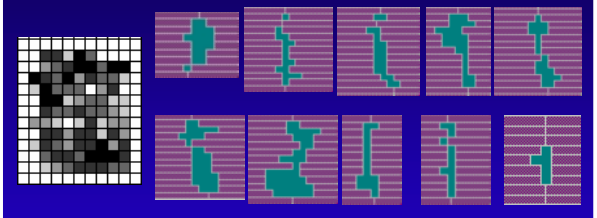
- Dynamic MLC

  Leaves can be moved when the beam is on. Leaf motion and the radiation are executed simultaneously.

Delivery Software

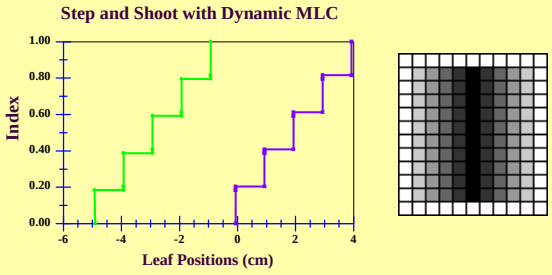
- **"Step & Shoot" is a nick name of the delivery method – suitable for static MLC**
- **"Step & Shoot" delivery method can also be used with dynamic MLC**
- **"Sliding window" is a nick name of the delivery method – MLC leaves move from one field side to another**
- **"Sliding window" method can be used with static MLC, although it is most suitable for dynamic MLC**

Step and Shoot for SMLC

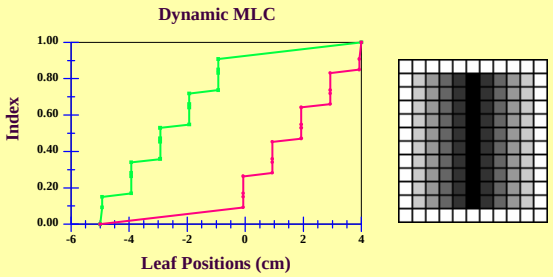


Similar to conventional treatment, and each segment is considered as a single field.

Step and Shoot Using DMLC



Sliding Window Using DMLC



Commercial LINAC Based IMRT Delivery Systems

Varian IMRT Delivery System

- Current version of VARIS
  - »Supports dynamic sliding window and step and shoot IMRT delivery
  - »No R&V verification between each segment
  - »Jaw positions fixed to cover maximum MLC opening for each field – affects transmission
  - »MLC controller and MU console are separated
  - »< 1.0 minutes/field including beam on time

Siemens 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
  - » ~ 7 sec inter-segment pausing time (2 sec pausing time is just released)
  - » Jaw follows MLCs to minimize leakage

Elekta IMRT Delivery System

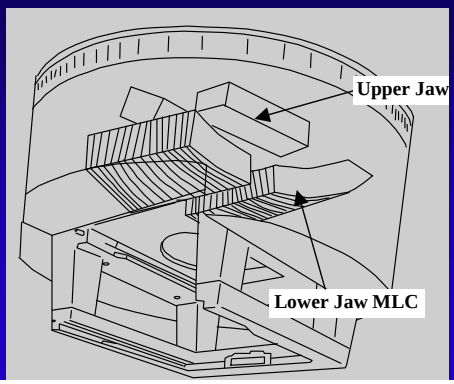
- It supports DMLC delivery with step and shoot technique.
- The status of each control point is verified by a record& verify system.
- The conventional jaws and diaphragms follow each segment to minimize the MLC leakage.
- 2 second "beam pause" is programmed for the transition from one control point to the next control point.

Characteristics of MLC Systems

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

Siemens MLC



Siemens' Double Focused MLC

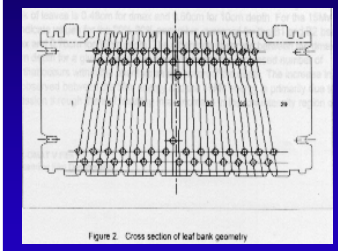
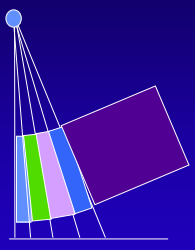


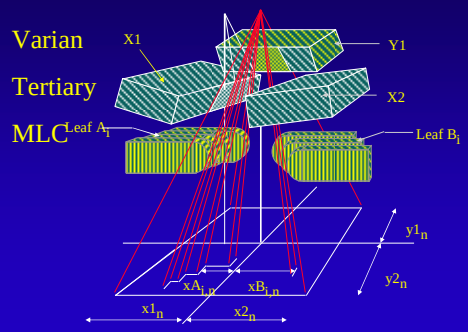
Figure 2. Cross section of leaf bank geometry



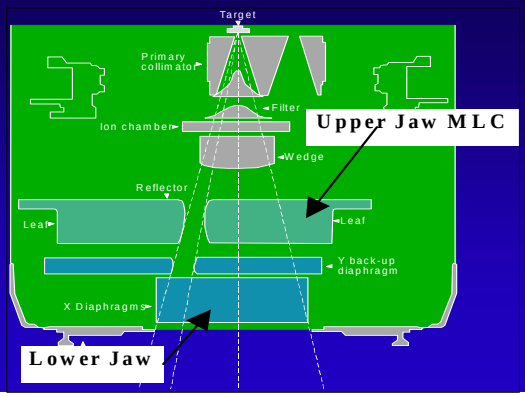
Focused in Y

Focused in X

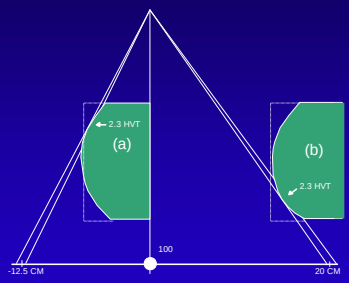
Varian MLC System



Elekta MLC System



Rounded Leaf End vs Penumbra



Elekta design (similar to Varian in leaf shape and leaf motion)

Modeling Rounded Leaf End

- Their results indicate a maximum underestimate of calculated dose of 12%with no leaf gap reduction. The discrepancy between measured and calculated phantom values is reduced to ±5% when a leaf gap reduction of 1.4 mm is used.
- Others found this gap is energy dependent.

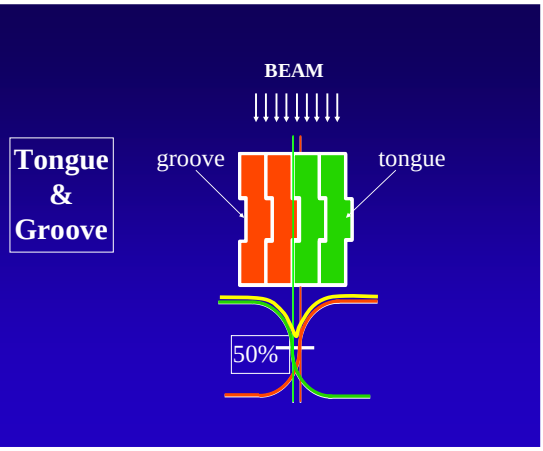
Cadman P, at. al. Phys. Med. Biol. **47** (2002) 3001–3010

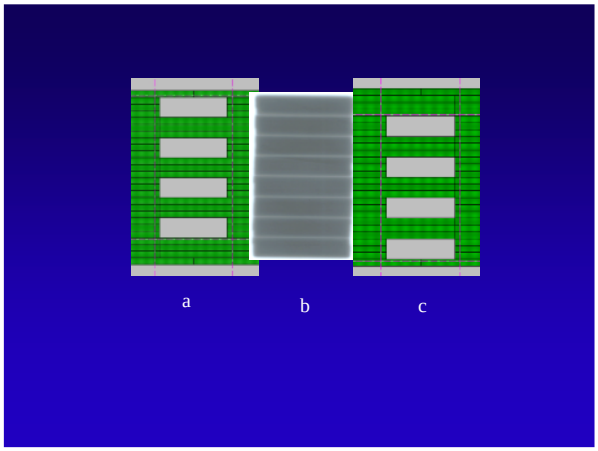
Physical Leaf Length vs. Over-travel Distance

- **The MLC physics leaf length (project to iso-center) is 16 cm, 30 cm, 32.5 cm for Varian, Siemens, and Elekta Machines, respectively.**
- **The distance that each individual leaf passes over iso-center is called over-travel distance, without leaving a uncovered region behind the leaf.**
- **For Siemens and Elekta machines, the over-travel distances are 10cm and 12.5 cm, respectively.**

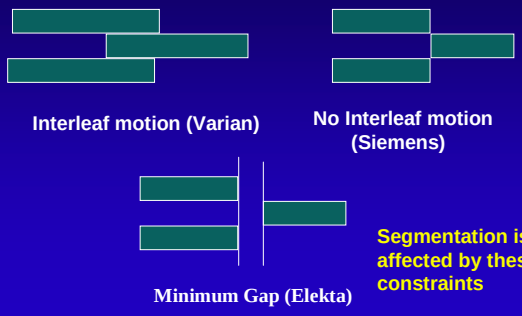
IMRT Field Sizes

- **IMRT field sizes could be smaller than conventional MLC field sizes in order to realize full intensity modulation within the field.**
  - **20 cm X 27 cm (40 cm) Siemens**
  - **25 cm x 40 cm Elekta**
  - **Varian:**
  - **15 cm X 40 cm without carriage move**
  - **40 cm x 40 cm with 3 carriage moves.**





Leaf Motion Constraints



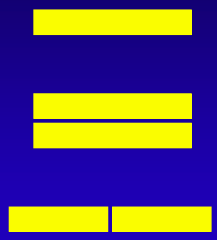
Interleaf motion (Varian)

No Interleaf motion (Siemens)

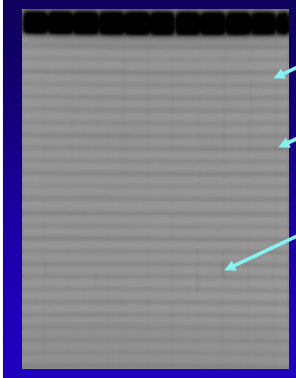
Minimum Gap (Elekta)

Segmentation is affected by these constraints

MLC Leakages



- Intra-leaf leakage
  - Thickness
- Inter-leaf leakage
  - Tongue & groove
- Leaf-end leakage
  - Rounded leaf end
  - Flat leaf end

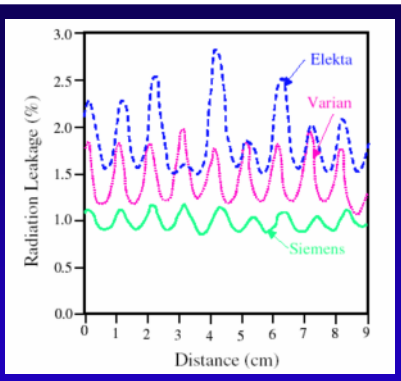


Intra-leaf leakage 0.8%

Inter-leaf leakage (1.5%)

Leaf end leakage (1.5%)

Siemens Primus 6MV



Huq, MS, et.al. *Phys Med Biol* 2002; 47: N159-70.

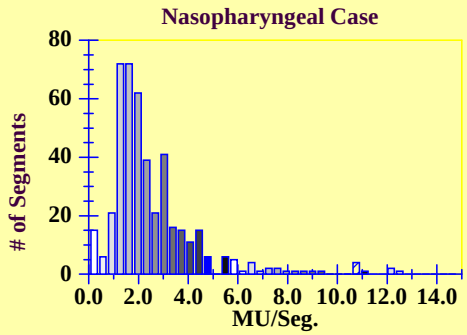
Machine Specific QA

Why A Special Machine QA is Needed for IMRT ?

- IMRT plans deliver a large fraction of total MUs with field segments that have very small MUs.
- IMRT plans often produce small, irregular, and off-center fields when compared to the conventional fields.

Machine Specific QA

- Machine QA
  - Beam characteristic
    - Output for small field size
    - Linearity for small MU (1-10)
    - Flatness & Symmetry
    - MLC defined penumbra
  - Multi-leaf Collimator (MLC)
    - Position, Speed



Treatment technique: 15 gantry angles, 10 intensity levels, total # of segments = 491, 400MU/min.

Siemens Linear Accelerators

- **Suggested References:**

1. C. W. Cheng, and I. J. Das, **Med. Phys. 29,** 226-230 (**2002).**
2. J. E. Bayouth, and S. M. Morrill, Med. Phys. 30 2545-2552.
3. C. W. Cheng, I. J. Das, and A. M. Ndlovu, Med. Phys. 29, 1974-1979 (2002).

Beam "Pausing" Status

- In the step-and-shoot delivery of an IMRT plan with a Siemens Primus accelerator, radiation is turned off by desynchronizing the injector while the field parameters are being changed. When the machine is ready again a trigger pulse is sent to the injector to start the beam instantaneously.

Suppress Dark Current Radiation

- With the Initial Pulse Forming Network (IPFN) at >80% of the PFN value, a spurious radiation associated with dark current at approximately 0.7% of the dose at isocenter for a 10x10 cm2 field is detected during the ''PAUSE'' state of the accelerator for 15 MV x rays. When the IPFN is lowered to ,80% of the PFN value, no dark current radiation (DCR) is detected.
- For 6 MV x rays, no measurable DCR was detected regardless of the IPFN setting.

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, and off-axial fields
- Dose linearity should be verified using IMRT delivery technique with small MUs

Dose Linearity Check

- Siemens Liancs:
  - 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

Field Symmetry and Flatness Check

- 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

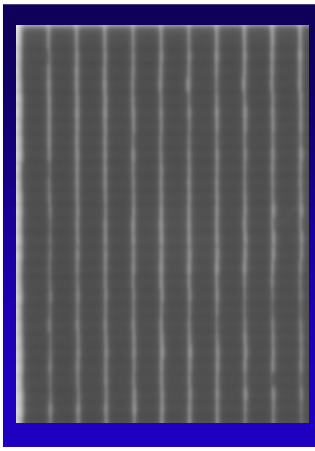
Results of Symmetry and Flatness

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

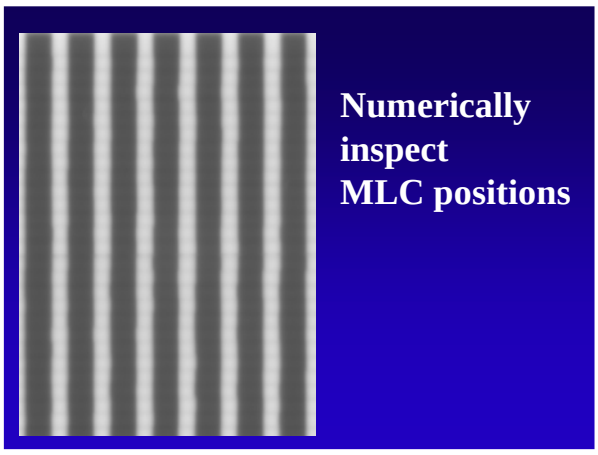
KD2, 18MV, 3.2 cm depth, 100 cm SSD, 15x15 cm^2

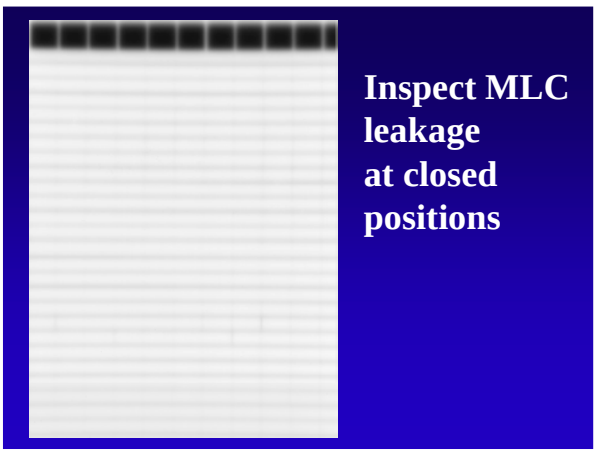
MLC Calibration

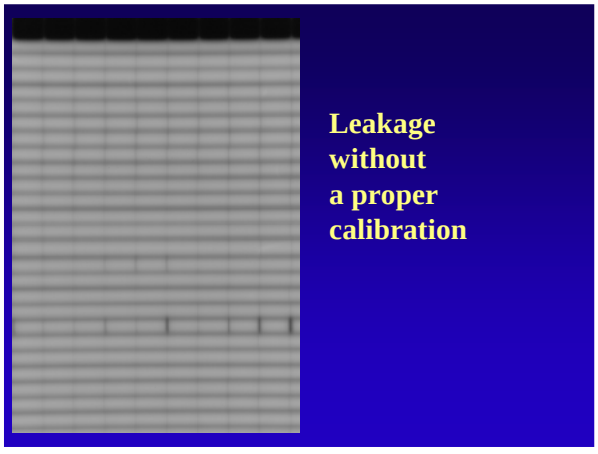
- Leaf position calibration
  - Difference radiation field vs light field
  - Off-set this difference in treatment planning
  - Gantry angle dependence and off-axis distance dependence
  - Closing leaf end calibration
- Leaf speed calibration

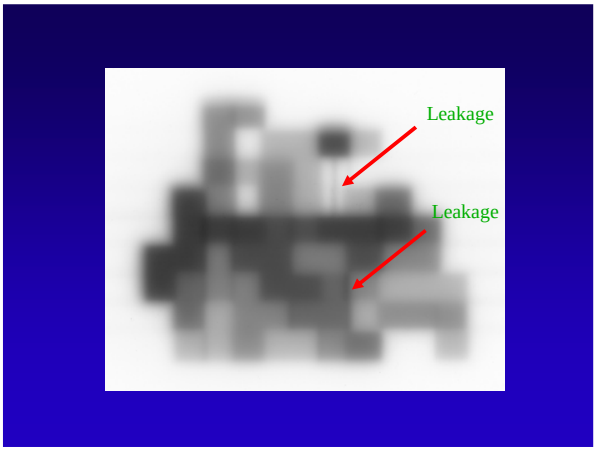


Off-set between the light field and radiation field


Numerically
inspect
MLC positions


Inspect MLC
leakage
at closed
positions


Leakage
without
a proper
calibration


Leakage
Leakage

Varian's Linear Accelerators

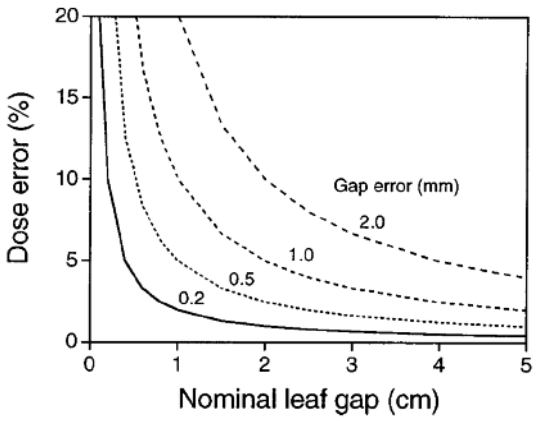
Suggested references:

1. Thomas LoSasso,a) Chen-Shou Chui, and C. Clifton Ling, **Med. Phys. 25 , 1919-1927 (1998).**
2. **Thomas LoSasso, Chen-Shou Chui, and C. Clifton Ling**, **Medical Physics, Vol. 28, 2209-2219 (2001).**
3. Ping Xia, Cynthia F. Chuang, and Lynn J. Verhey, Med. Phys. 29, 412-423 (2002).

DMLC Delivery

- In the sliding window technique of DMLC application, the delivered dose is directly related to the gap between opposed leaves as they sweep across the field.
- A variation of ±0.2mm in gap width for a 1.0 cm nominal gap can result in a dose variation of ±3% for each DMLC field
- The MLC position precision is better than 0.1 mm.

Thomas LoSasso,et. al. Med. Phys. 25 , 1919-1927 (1998).



Dose Linearity Check

•Varian's Linac:

- 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 19, 38 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

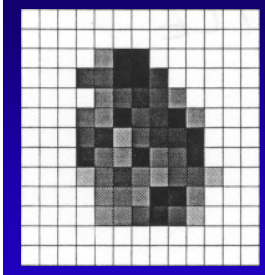
CL_2300, 6MV, 1.5 cm depth, 100 cm SSD, 15x15 cm^2

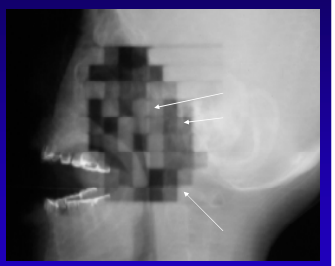
Results of Symmetry and Flatness

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

Intensity Map Port Film





E.H.

Differences in intensity patterns from plan to port film

Step and Shoot Delivery Using DMLC

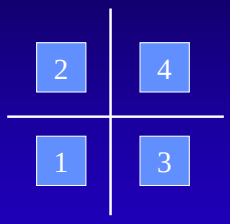
Every 50 ms

Positions of each segment

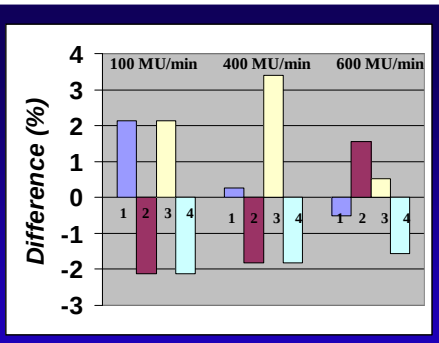
Control total MU

Communication delay ~ up to 100 ms between segments

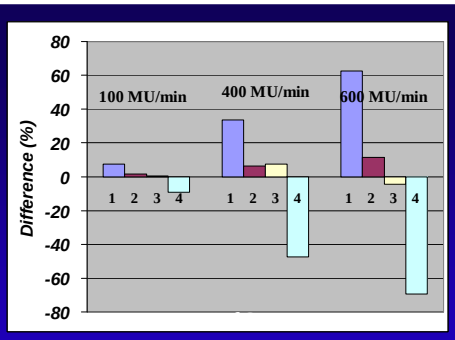
Experiment



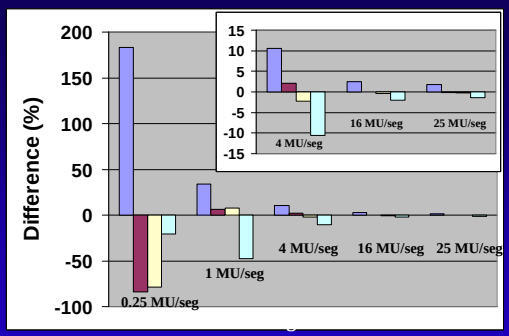
0.25 MU/seg
1.0 MU/seg
4.0 MU/seg
16.0 MU/seg
25.0 MU/seg
at
100 MU/min
400 MU/min
600 MU/min



1MU/seg delivered with static mode
(CL2300, 6MV, 100 SSD, 1.5 cm depth)



1 MU /seg delivered with dose mode
(Cl2300, 6MV, 100 SSD, 1.5 cm depth)



Delivered with dose mode at 400MU/min
(CL2300, 6MV, 100 SSD, 1.5 cm depth)

Communication Delay

The dose error in each segment:

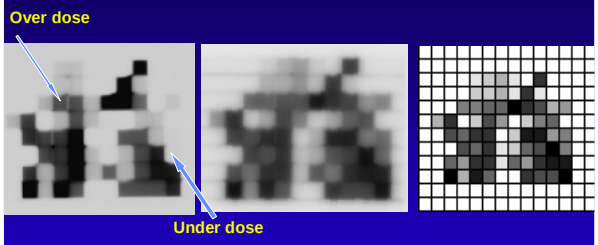
$$\Delta = RT/M$$

(R: dose rate, T: time delay, M:MU/segment)

e.g. R = 400 MU/min, T=50 ms, M=1 MU/seg

$$\Delta = 400/60 * 0.05 = 0.33$$

Δ can be significant if R is large and M is small.



8 MU port film **96 MU EDR film** **Fluence Map**

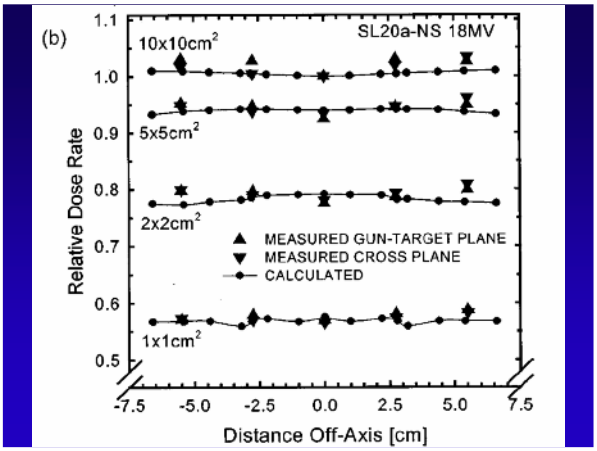
Elekta Linear Accelerators

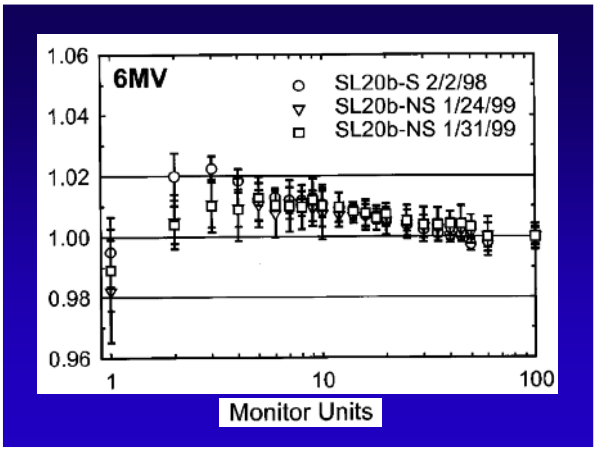
- Suggested References:

1 M. B. Sharpe, B. M. Miller, D. Yan, and J. W. Wong, **"Monitor unit settings for intensity modulated beams delivered using a step-and-shoot approach" Med. Phys. 27, 2719-2725 (2000).**

Beam Stabilities

- The dose linearity per MU was found to be within ±2% for exposures larger than 4 MU.
- Beam flatness and symmetry also met accepted quality assurance standards for a minimum exposure of 4 MU.
- For the non slitted flight tube the field flatness is stable after 0.6 s, which corresponds to an exposure of approximately 4 MU at a dose rate of 400 MU per minute.
- The slitted flight tube took just over 1 s to stabilize, or approximately 7 MU.





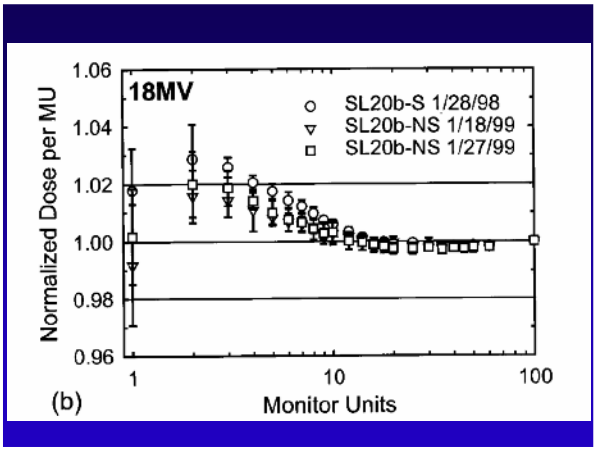
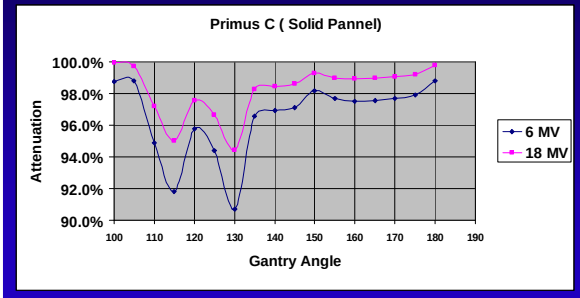


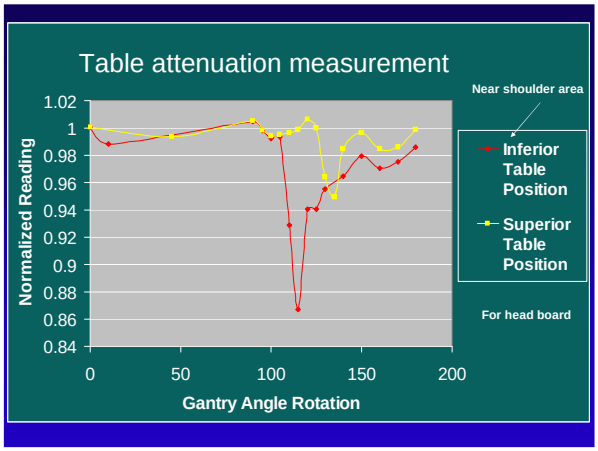
Table Attenuation

- IMRT requires more beam angles than that of conventional treatment to achieve high conformity in dose distributions.
- Carbon fiber tabletop can reduce beam attenuation but the attenuation may vary depending on the thickness of materials.

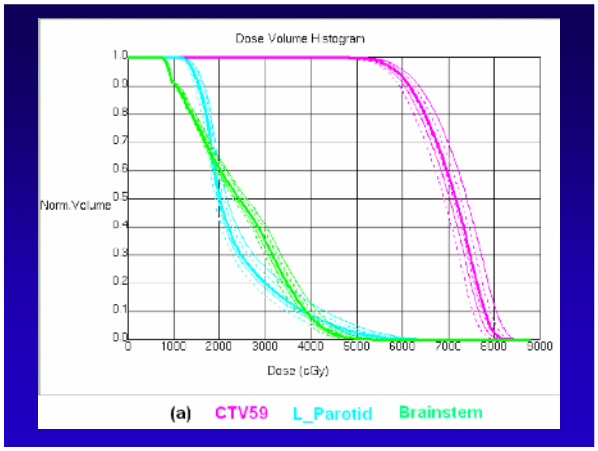
Conforming Tabletop

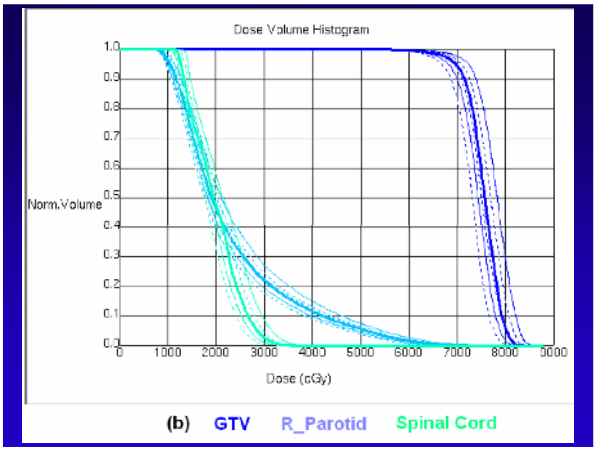
Table Attenuation





Dosimetric Effect of Leaf Position Errors





Dosimetric Effect of Random Leaf Position Errors

- With random errors up to 2 mm in MLC positions, the average dose change to the 95% of the GTV was (-0.33 ±0.47)%, to the CTV59 was (-0.26 ± 1.71))%.
- For serial structures, the dose changes to the 0.1 cc of the brainstem were (0.61 ± 0.88)% and for the spinal cord (0.22 ± 0.91)%, respectively.
- The mean dose changes to the parotid glands were on average (0.36 ± 1.67)% for the left parotid and (1.19 ± 2.21)% for the right parotid.

Dosimetric Effect of Systemic Leaf Position Errors

- For systematic errors up to 1 mm (equivalent to 2 mm changes in MLC opening), the dose changes to 95% of the GTV were (-3.16 ± 1.05)% for -1mm shift and (2.54 ± 0.77)% for +1mm shift.
- D95 changes of the CTV59 were (-1.56 ± 2.65)% and (1.27 ± 2.54)%.

Dosimetric Effect of Systemic Leaf Position Errors

- The dose changes to D0.1cc were (-2.83 ± 1.18)% and (3.28 ± 1.33)% for the brainstem, and (-3.27 ± 2.60)% and (3.65 ± 2.43)% for the spinal cord.
- The mean dose changes of the parotids overall were (-7.89 ± 2.21)% and (8.58 ± 2.23)% for the left parotids, (-7.94 ± 2.16)% and (8.67 ± 2.13)% for the right parotids.

Summary

IMRT QA consists of :

- **Treatment planning**
- **Delivery methods**
- **Delivery systems**
- **Machine specific QA**
- **Patient specific QA**
- **Radiation protection**

LINAC and MLC QA for IMRT

- Dose linearity
- Beam symmetry and flatness under condition of small MUs
- Delivery accuracy with very small MUs.
- MLC Leaf position accuracy

  Off-set between radiation field and light field

  Modeling rounded leaf end
- Simplify IMRT plans and avoid the use of small MUs and small field sizes.