IMRT Treatment Plan Validation & Independent MU Calculation

Lei Xing, Ph.D.

Department of Radiation Oncology
Stanford University School of Medicine

Acknowledgements: Y. Yang, J. Li, Y. Chen, G. Luxton, A. Boyer

DISCLOSURE

The IMRT plan validation software described in this talk is being commercialized by Prodigm Inc. (Chico, California). The company has licensed the software from the presenter's group.

Outline

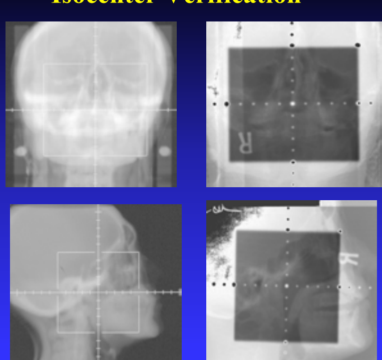
1. Machine and MLC specific QA.
2. Patient Specific QA.
   - (a) Geometric.
   - (b) Dosimetric.

Patient Specific QA

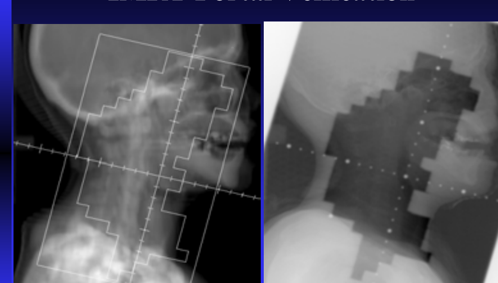
1. Geometric verification
   - a. Isocenter setup.
   - b. portal verification → Field aperture.

2. Dosimetric verification
   - a. Point dose (MU) check
     - ---multiple points are HIGHLY recommended.
   - b. Fluence map check
     - ---extremely important!

Isocenter Verification



IMRT Portal Veification



Patient Specific QA

1. Geometric verification
   a. Isocenter setup.
   b. portal verification → Field aperture.

2. Dosimetric verification
   a. Point dose (MU) check
      ---multiple points are HIGHLY recommended.
   b. Fluence map check
      ---extremely important!

IMRT pre-treatment QA

• Verification of 3D dose distribution

or

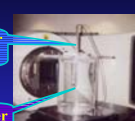
•Verification of point doses +

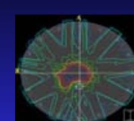
• Verification of fluence maps/leaf-sequence files

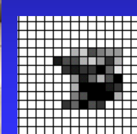
Dose/MU verification

Ion chamber holder

Ion chamber







IMRT TODAY

An ordinary day at IMRT corner ☺

Alternative: Independent Dose/MU Calculation

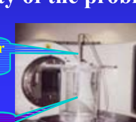
1. Independent MU verification is done using hand-calculation in conventional Rx.

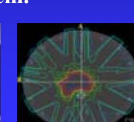
2. A similar independent MU check procedure is needed for IMRT---ion chamber or independent cal.

3. A computerized MU calculation has to be used due to the intrinsic complexity of the problem.

Ion chamber holder

Ion chamber



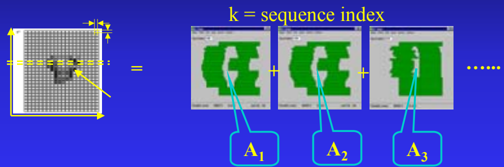


Cumulative IMRT Dose:

Sum the contributions from all segments.

$$D = \sum_k^K MU_k D_k = MU \sum_k^K f_k D_k$$

$$f_k = \text{MU}_k / \text{MU}$$



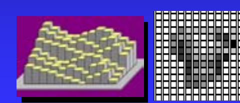
(L. Xing, et al., Phys. Med. Biol. 45, N1-7, 2000).

Point Dose Calculation in IMRT

1. Open field.
2. Wedged field.
3. IMRT.
4. General approach: sum contributions from all beamlets.

$$D = MU \sum_m^M C_m d_m^0$$

How to calculate the dynamic modulation factor C_m ??



MU Verification in IMRT

$$D = MU \sum_k^K f_k d_k \qquad f_k = \text{MU}_k / \text{MU}$$

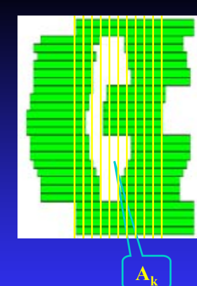
$$d_k = \underbrace{\sum_{m \in A_k}^M d^0{}_m}_{\text{Open}} + \underbrace{\sum_{m \notin A_k}^M d^t_m}_{\text{Blocked}}$$

$$d^t{}_m = \alpha \; d^0{}_m \qquad \alpha \cdots transmission$$

$$D = MU \sum_m^M C_m d_m^0$$

$$C_m = \sum_k^K \left[\delta_{m,A_k} + \alpha\left(1 - \delta_{m,A_k}\right)\right] f_k$$

$$\delta_{m,A_k} = \begin{cases} 1 & \text{if} \quad m \in A_k \\ 0 & \text{if} \quad m \notin A_k \end{cases}$$

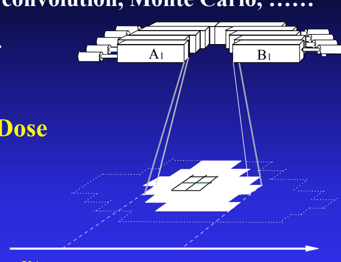


C_m can be calculated using the information contained in MLC leaf sequence file.

Calculation of beamlet calculation.

1. Beamlet kernel from convolution, Monte Carlo, ……
2. Clarkson calculation.

Primary Dose



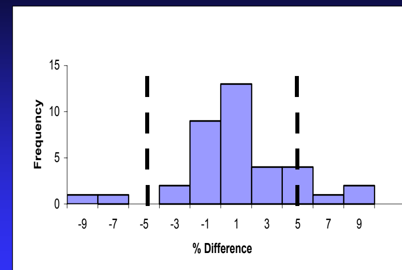
$$d^0{}_{CAX}(\text{cGy}) = MU \times C_f(\text{cGy/MU}) \times S_c(l_{eq}) \times S_p(l = 2\text{ cm}) \times TMR(d, l = 2\text{ cm})$$

Contributions from "scatter beamlets"

Summary of dose verification for a prostate case

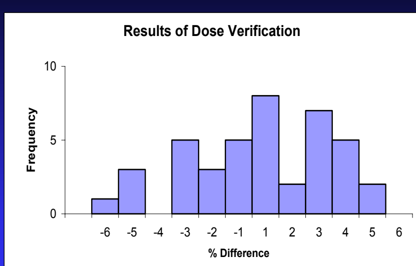
Gantry angle	TPS calculation	Primary dose	Scatter dose	Beam dose	Ion chamber measurement
30	45.4	41.9	3.0	45.0	43.8
65	22.8	20.5	1.9	22.5	24.1
95	30.0	27.8	1.8	29.6	28.8
135	29.4	26.2	2.0	28.2	29.0
225	33.7	30.4	2.1	32.5	33.3
265	25.3	23.4	1.9	25.3	24.5
295	20.7	18.3	1.8	20.1	20.8
330	46.3	43.0	2.9	46.0	45.1
Total dose	253.6	231.7	17.5	249.2	249.6

Results of Calculation



Difference between independent calculation and TPS

Results of Chamber Measurements

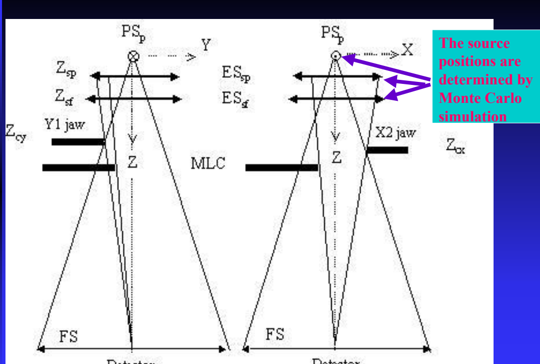


Difference between measurement and TPS

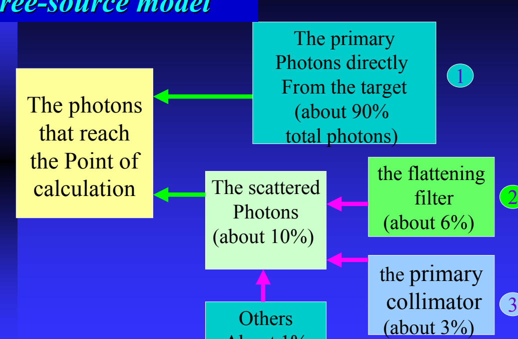
Calculation of Head Scatter

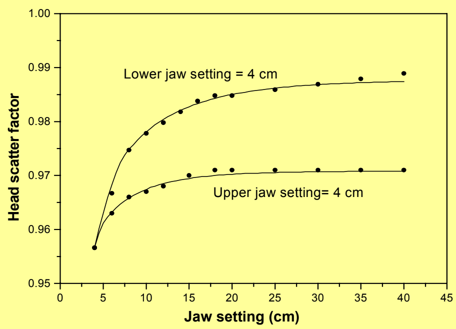
Head scatter calculation--- three-source model:

- **A primary photon source for the primary photons from the target.**
- **A planar annulus extra-focal photon source for the scattered photons from the primary collimator.**
- **A planar disk extra-focal photon source for the scattered photons from the flattening filter.**



Three-source model



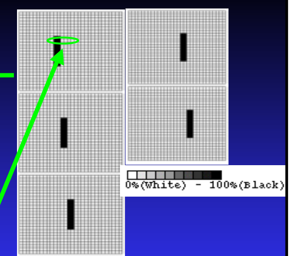


The data of symmetric rectangular fields for the 6MV (within 0.3%)---------Y. Yang, L. Xing et al., Med. Phys. 29, 2024-33, 2002.

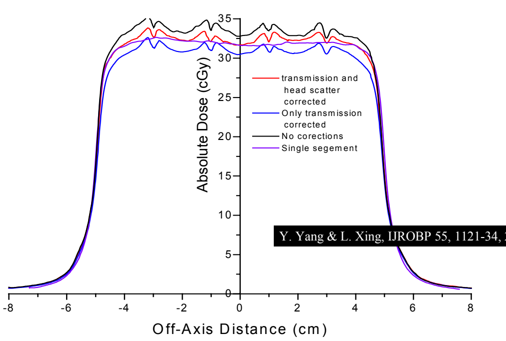
L. Xing

Results

1. 10x10cm Field



Desired:	30.0	30.0	30.0
No correct:	30.9	30.9	31.0
Correct for Transmission only:	28.9	28.9	29.0
Correct for Head Scatter only:	32.0	32.0	32.1
Correct for both effects:	30.0	30.0	30.0



The measured absolute dose profiles at depth 5cm

Importance of head scatter contribution

With and without head scatter (Varian MLC)

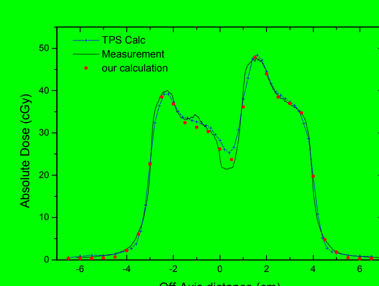
~2% for small field IMRT
~4% for large field IMRT

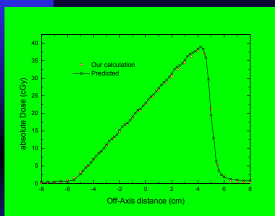
L. Xing

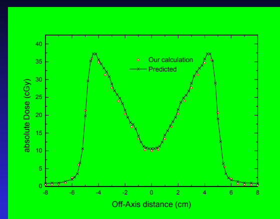
Steps of independent MU calculation for intensity modulated field

1. Read in MLC file.
2. Calculate dynamic modulation factors.
3. Input SSD.
4. Head scatter and modulation factor calculation.
5. Clarkson summation weighted by the beamlet dynamic modulation factors.
6. Compare with the dose from TPS.

The method works for different MLCs-----52-, 80-, 120-leaf MLCs, MIMiC, with different beamlet sizes.



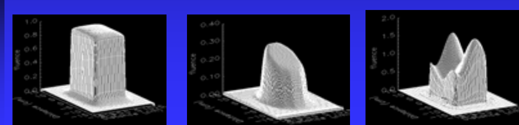


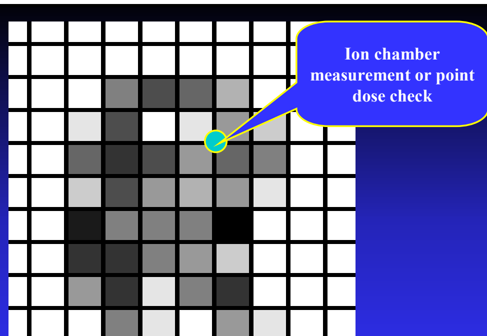


Point dose verification is not enough for IMRT.

Planar dose distribution must be verified to validate an IMRT treatment plan!

We propose to verify: **Point dose + fluence map**

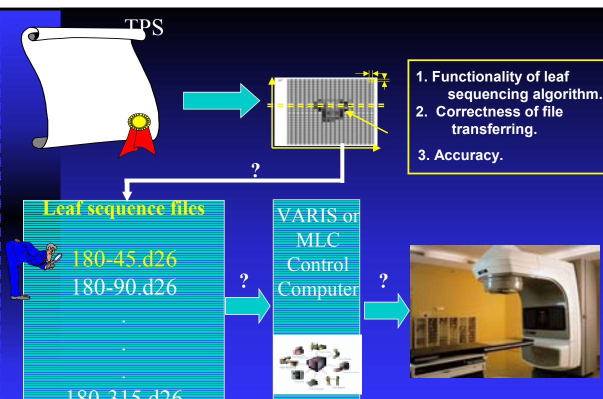




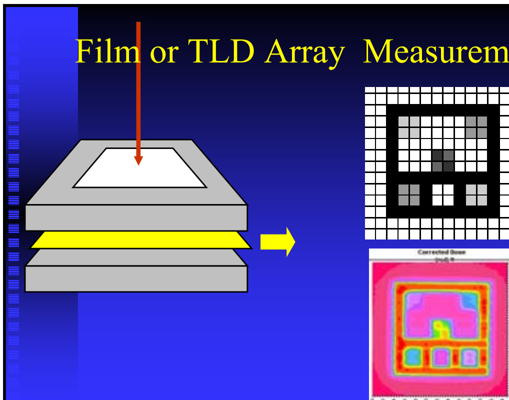
Point dose + fluence map check is the solution!

Computer verification of fluence maps

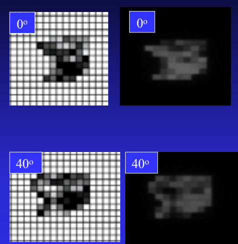
1. Point dose verification is not enough for IMRT.
2. Planar dose distribution or fluence maps need to be verified.
3. Film/PID/BIS for fluence verification is time-consuming. Furthermore, it may have problem in verifying dynamic delivery.
4. Computer verification saves time and effort (L. Xing& J.Li, Med. Phys. 27, 2084-92).

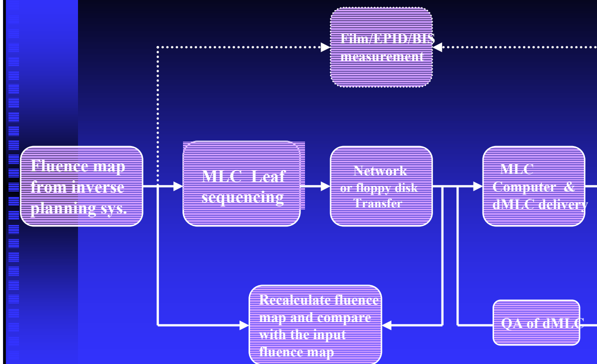


Film or TLD Array Measurements



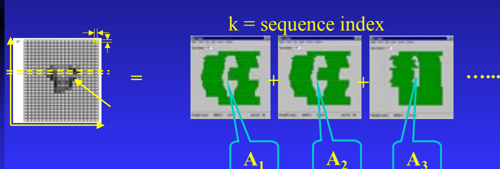
Verification of leaf-sequence files for IMRT





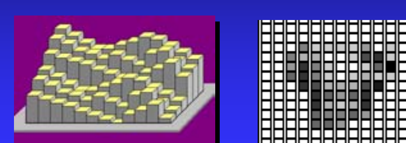
Fluence calculation

1. Sum the contributions from all segments.



Fluence calculation

1. Sum the contributions from each beamlet----beamlet modulation factor.



Fluence calculation

Open Blocked

$$F_k = \sum_{m \in A_k}^{M} F^0{}_m + \sum_{m \notin A_k}^{M} F^t_m$$

$$d^t{}_m = \alpha \; d^0{}_m \qquad \alpha \cdots transmission$$

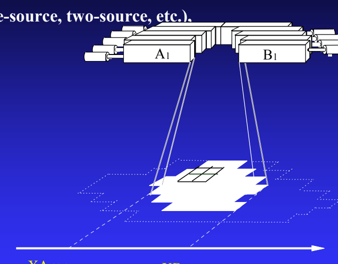
$$C_m = \sum_k^K \left[\delta_{m,A_k} + \alpha\left(1 - \delta_{m,A_k}\right)\right] f_k$$

$$\delta_{m,A_k} = \begin{cases} 1 & \text{if} \quad m \in A_k \\ 0 & \text{if} \quad m \notin A_k \end{cases}$$

Calculation of fluence.

1. **Average MLC transmission model.**
2. **Other fluence models (one-source, two-source, etc.).**

……

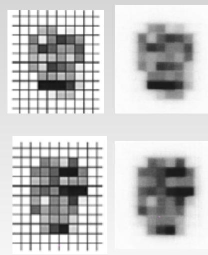


Quantitative comparison of two fluence maps

1. Maximum difference in pixel values---local quantity.

2. Correlation coefficient—global quantity.

$$r = \sum_n (F_n - \overline{F})(R_n - \overline{R}) \Big/ \sqrt{\sum_n (F_n - \overline{F})^2} \sqrt{\sum_n (R_n - \overline{R})^2}$$



L. Xing

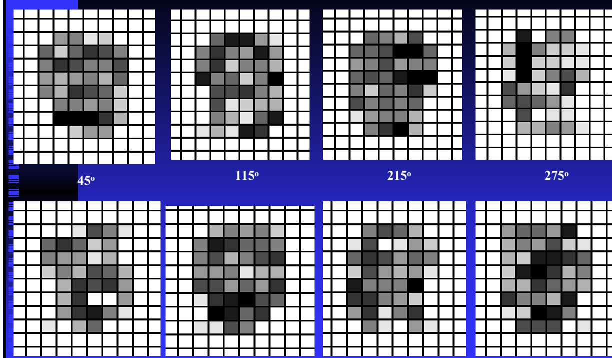
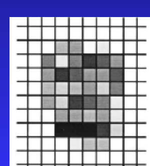


Fig. 2

L. Xing

Comparison of independent calculation & TPS calculation

	-2.5	-1.5	-0.5	0.5	1.5	2.5
3.5	0	40	50	10	20	0
	2.12	40.06	50.08	9.99	20.01	2.12
2.5	60	20	60	80	70	50
	60.11	20.01	60.11	79.95	70.13	50.08
1.5	50	80	70	50	50	70
	50.08	79.95	70.13	50.08	50.08	70.13
0.5	40	30	40	50	30	60
	40.06	30.04	40.06	50.08	30.04	60.11
-0.5	50	30	80	70	60	20
	50.08	30.04	79.95	70.13	60.11	20.01
-1.5	0	50	50	40	50	20
	2.12	50.08	50.08	40.06	50.08	20.01
-2.5	0	100	100	100	80	30
	2.12	100.0	100.0	100.0	79.95	30.04
-3.5	0	0	20	40	40	0
	2.12	2.12	20.01	40.06	40.06	2.12



L. Xing

Max. discrepancy in the pixel value

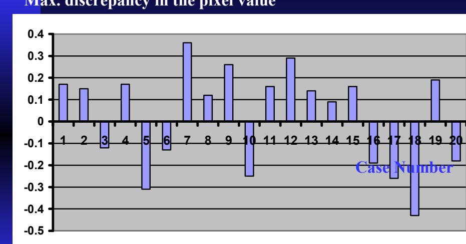


Figure 3

L. Xing

After the planning: QA

RTP exchange file

Intensity maps

ACQSIM plan file

QA program
- checks leaf sequence against the intensity map (for every field)
- checks point doses

VARIS

L. Xing

QUALITY ASSURANCE OF IMRT TREATMENT PLAN
DEPARTMENT OF RADIATION ONCOLOGY ,STANFORD UNIVERSITY SCHOOL OF MEDICINE

PATIENT NAME: xxx, xxxxxxx
PATIENT ID: xxx-xx-xx
TPS PLAN #: 2512
Treatment Machine: LA7
Beam Energy: 15 MV
Calibration Setup: SSD
Delivery Mode: Step and Shoot
Beamlet Size: 1.0 x 1.0 (cm x cm)
Calibration Factor: 1.000

Isocenter Dose Verification Report

Field	MU	x1	x2	y1	y2	SSD	beam-dose
F 180-000	170	7.80	6.80	4.20	16.20	88.79	50.2
F 180-080	118	4.80	6.80	4.20	17.20	82.03	40.6
F 180-145	108	8.00	1.00	5.00	18.00	90.87	24.0
F 180-215	80	9.00	0.00	3.00	18.00	90.49	1.6
F 180-280	115	6.80	5.80	4.20	17.20	81.68	41.2

Calculated Isocenter Dose: 224.2 cGy
TPS Isocenter Dose: 221.3 cGy
Percentage Difference: 1.3 (%).

Leaf Sequence Verification Report

Field ID	Gantry Angle	Correlation Coefficient	Maximum Difference
1	0	1.0000	0.5112 (%)
2	80	1.0000	0.4017 (%)
3	145	1.0000	0.6799 (%)
4	215	1.0000	0.7275 (%)
5	280	1.0000	0.4034 (%)

Physicist: ____________________

DATE: 7/20/2001

L. Xing

Summary

- IMRT QA: Routine MLC QA + Patient Specific QA.
- Patient Specific QA: multiple point doses + fluence maps.
- Point dose check is not enough---do not forget intensity maps.
- Head scatter need to be considered.
- Integrated software for IMRT QA has been developed.

GO WITH COMPUTER!

L. Xing