IMRT

References:
[1] AAPM Report 82. TG-IMRT "Guidance Document on delivery, TP and clinical implementation of IMRT
[2] AAPM TG-50, MLC
[3] AAPM TG-119, Commission of IMRT
[4] NCI IMRT collaborative work group on IMRT (Red Journal)

1. Delivery systems:
   - MLC based:
     - Step-and-stop (Segmented)
       - Easy to understand (a simple extension of current 3D-CRT practice)
       - No requirement to control individual leaf speeds and thus simplifying the MLC control system
       - Fewer MUs are required in comparison with DMLC (may not be true); [According to AAPM R82. DMLC effectively min the total number of MU required for treatment at the const of increase segments (control points)
       - Shorter beam-on-time (MU) compared to DMLC
       - Longer delivery time (min.) compared to DMLC (depending on planning software and machine/MLC characteristics)
       - Loss of spatial & intensity resolution
     - Sliding window (Dynamic) => dose controlled by beam on time and leaf movement
       - Shorter treatment time for complex intensity modulated beam
       - Reduction of dosimetric errors introduced by SMLC due to the discretization of a continuous intensity profile (better spatial and intensity resolution)
       - has more degrees of freedom, hence an equal or better solution will always be found
   - Compensator based
     Higher resolution in the direction normal to MLC leaf motion
     Simple QA, but cumbersome and time-consuming manufacturing process
     No matching problem
   - Tomo-therapy

2. Optimization and dose calculation
   - Objective/cost function
     Clinical objectives are specified mathematically in the form of an objective function
     - Dose/Dose-volume based function
       - Quadratic variance function only has a single min or max.
       - Dose-volume based function can have multiple min/max
     - Dose response (TCP, NTCP, EUD) based function (more clinical relevant; also have multiple min/max)
     - May need to incorporate other non-clinical factors: plan complexity
   - Optimization search algorithm:
     - Deterministic (Gradient Search)
       - Move from one proposed solution to the next using computed first or second derivatives of cost function;
       - the direction and step depends on the computed gradients
       - Fast but cannot escape from a local minimum
     - Stochastic (Simulated Annealing) Search

        - Move from one proposed solution to next by randomly changing beamlet intensities according to some scheme
        - Allow the optimization process to escape local minimal, but tend to be slow

- Computation:
  a. Correction based
     - First calculate based on water data
     - Correct for dose distribution for beam modifiers, contour, heterogeneity of treatment circumstances
     - Depend on measured data
  b. Model based
     - Compute the dose per unit energy fluence incident on patient
     - Take into account the transport of secondary particles
     - Better accounting of electron disequilibrium, head scatter, secondary scatters, inhomogeneity

- Leaf sequence calculation

  Define shapes (SMLC) or trajectories (DMLC) required to create a deliverable intensity as close as to the optimized distribution

  Take into account: field flatness, output for small field, penumbra, leave leakage, and backscatter to ion chamber….

3. Acceptance/Commission and QA
   - **MLC**

     1) MLC configuration:
     - Upper Y jaw (Elakta): the range of motion of leaves required to traverse the field is small because the MLC is close to source. However, the leaf width is also smaller and tolerance on the dimension of leafs and leaf travel must be tighter.
     - Lowe X jaw (Siemens): leaf ends are straight and focused with x-ray source, so the leaf ends and leaf side match the beam divergence.
     - Tertiary collimator system (Varian): to avoid downtime in the system malfunction, but add bulk and reduce clearance. Moving MLC away from source requires increase in leave size and travel distance.

     2) MLC transmission:
     - For the upper and low jaw MLC, the transmission requirements are the same as jaws (1% ~ 7HVLs)
     - For tertiary collimator: to the same extent as blocks (3-5% ~ 4-5HVLs = 5cm Tungsten alloys)
     - Varian MLC: intra-leaf (1.5%-2% for 6MV, 2% for 15MV and 1.5-2.5% for 18MV). Inter-leaf: additional 0.25-0.75%; abutted leaf-end 28% for 18MV at central axis, reducing to 12% at OAX.

     Measurement of MLC transmission:
     - Ion chamber in phantom, MLC open verse MLC close, relative measurement; reading average at different positions under the leaves.
     - Film to acquire profile. Should be performed at multiple gantry and collimator angels.

     MLC transmission factors in our TPS: 6x: 1.6%, 18x: 1.8% (To check with Lu)

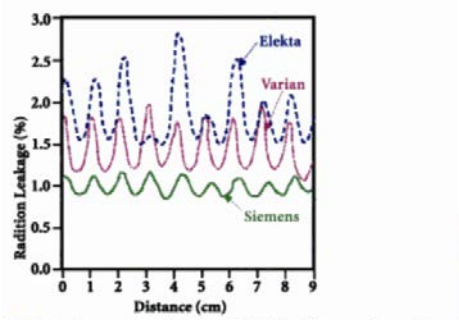


Fig. 1. Leakage patterns for the major MLC collimators. From: Huq MS, Das IJ, Steinberg T, Galvin JM (2002) A dosimetric comparison of various multileaf collimators. Phys Med Biol 47(12):N159–N170.

Manufacturer	Inter-leaf (%)	Intra-leaf (%)	Leaf-end (%)
Siemens	1.1	0.8	1.6
Elekta	2.5	1.6	>20%
Varian	1.8	1.2	>20%

4) Leaf position accuracy (<1mm)
Detection and calibration of MLC leaf position:

- Detection of MLC leaf position: linear encoder (Varian) – high precision potentiometers; video-optical system (Philip)
- Calibration of leaf position: Varian use narrow infrared beam. As the leaf intersect the infrared beam, the value return by its position encoder are acquired. The measured signals and the actual leaf position establish a one-to-one relationship.

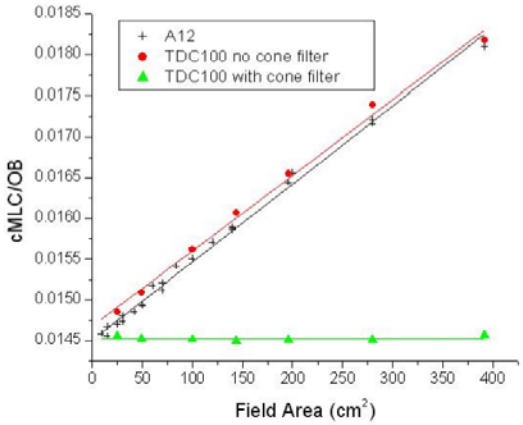
Rounded leaf ends to maintain a contrast geometric penumbra at different leaf positions in the beam. (There is offset btw beam edge as defined by light field and 50% decrement line of radiation field). Typically 0.4-1.1mm depending on MLC type, beam energy, location w.r.t. central axis.

MLC performance:

- Projected leaf width at iso: verified during acceptance
- Leaf position check: (1mm on 4 Gantry angles, ±1mm repeatability per TG-142)
  - Film: Alignment of 2-5cm wide strips formed by MLC irradiating abutting rectangular fields. The degree of dose uniformity along the match lines is a sensitive measurement of the alignment of leaf position indicator, light field and radiation field. (Deviation of optical density along the match line of about 20% above or below the average indicates a positioning problem.
  - A variation of 0.2mm in the gap width can result in dose variation of 3%.
  - In Varian system, a tolerance is set (0.5-5mm); when max difference between the planned and accurate leaf positions exceed this tolerance, beam will be hold-off until the leaf positions are within tolerance.
- Leaf travel and speed (loss of leaf speed <0.5cm/s per TG-142; <0.35cm max error RMS)
  - The leaves and/or carriages should reach their max specified range
  - The max and stability of leaf speed should be verified.
    A film can be used to check the stability of leaf speed; individual pairs of opposed leaves are designed to move at different but constant speed. If the leaf speed is stable, the generated intensity profile align with the leaf pairs will be uniform. Another profile across the leaf bank will show step function pattern since each leaf pair move at different speed
  - Leaf acceleration and deceleration: the above test can be repeated and intentionally interrupt the beam a few times, the resulted dose profile should remain the same.
- Leaf transmission (±0.5% from baseline per TG-142)
  - Ion chamber and film as described above.

MLC transmission increases with FS and depth

Fig. 2 shows an example of R_{cMLC} (ratio of closed MLC dose to open-beam dose) as a function of the field area ($c_x \times c_y$). Measurements were made in air with and without cones to show that MLC scatter is responsible for the field-size dependence of R_{cMLC}. By placing a stack of cones above the detector, the MLC scatter was effectively removed.



- Rounded leaf effect
  - The effect is modeled as an apparent gap (dosimetric leaf separation DLS) in Eclipse system
  - The value can be measured using different gaps and the method described by LoSasso
  - Or tweak in TPS to match measure data

- Small MU per segments and dose rate
  - MLC controller and machine feedback system controls the delivery by feedback every 50mS.
  - Relative error: error = DR · T(50mS) / MU per segment
  - If DR ↑, MU per segment ↓, relative error ↑

- Interdigitation: refers to the end of a trailing leaf extending past the end of an **adjacent** leading leaf; such a pattern is more likely to cause a collision and is forbidden for some MLCs

- Tongue-and-groove effect: refers to underdose if the tongue on one leaf extends beyond its neibring's groove and later the situation is reversed with groove extending beyond the tongue

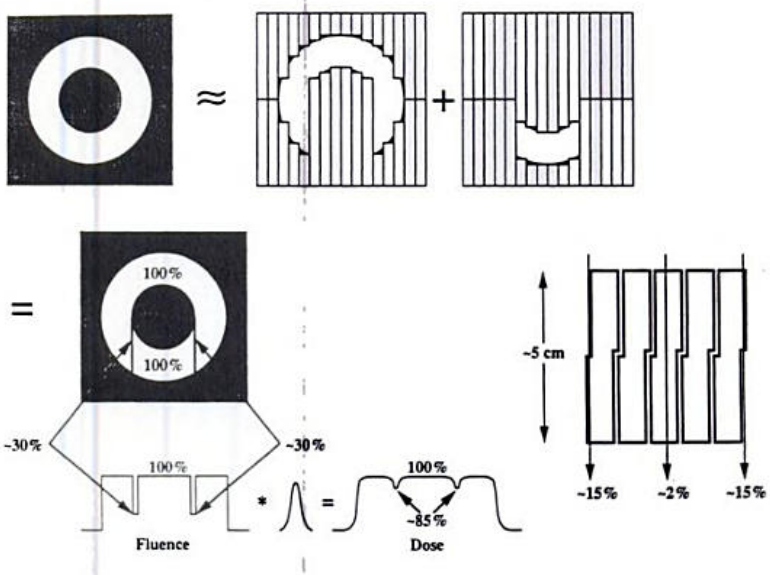
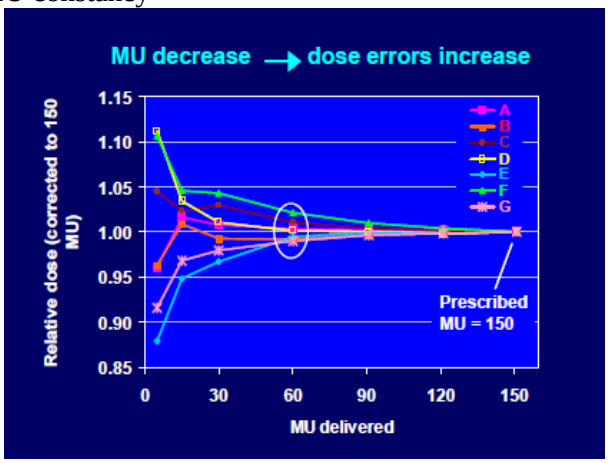


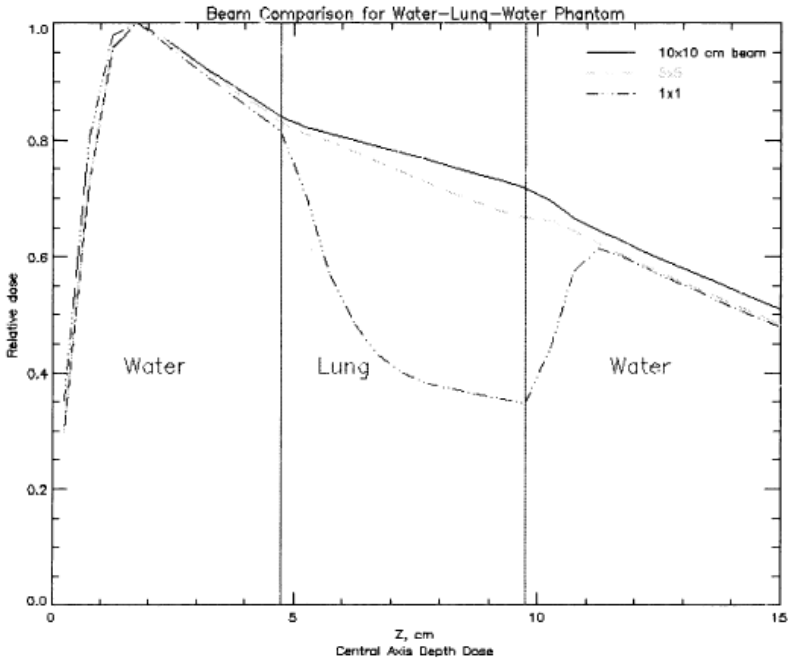
Figure 3.8. *This shows how the tongue-and-groove arrangement may lead to underdosage when an MLC is used to create a centrally blocked field. A circular field with a central block is generated by combining the two fields shown. There are two narrow regions at the boundaries of the constituent fields where either the tongue or the groove is present and reduces the fluence below the expected 100%. In this figurative example the tongue and groove only transmit 15% of the radiation (lower right of figure), giving 30% in total (see lower left of figure). In practice lateral scattering and electron transport (represented by the convolution symbol) reduce the problem but there is still significant underdose to the linear regions shown by the arrows. The same problem would arise if an MLC were used for intensity modulation without synchronisation of leaf movement. (From Mohan 1995.)*

- **Linac performance**
  - dose per MU constancy



  - beam penumbra; beam flatness and symmetry
    - should be measured by film, diode or very small chamber
    - Energy, flatness, symmetry for small field and gantry rotation.

  - small field dosimetry (lack of electron equilibrium)
    - Small dimension of beamlets -> no electronic equilibrium
      The effect of electronic disequilibrium increases with beam E.
      Heterogeneity correction different than large field (see figure below)



- Small collimator opening -> not accurate head-scatter modeling
- Backscatter into MU chamber from jaws
- Obscuration (shielding) effect of target source

- **TPS commission and verification**
  - Commission of upstream (CT image, contours, CT number etc…)
  - Obtain input parameters for beam modeling and dose calculation (to check Lu)
  - Specify desired intensity patterns and apply to phantom so that the resulting doses can be measured and confirmed. [test cases] (ref TG-119)

- **Patient specific QA**
  - Dose and MU verification
  - Information transfer from TPS to R/V system
  - Point dose and fluence verification on phantom
  - This only verifies correct transcript of IMRT delivery parameters, leaf sequence, and MU calculation. It does not check some assumptions used in the planning process.

4. Clinical implementation
   Planning:
   - Contouring is very important; be careful of automatic contour expansion
   - Target volume should not be drawn in the buildup region. (calculation is not accurate in buildup region, planning will be mess-up trying to delivery dose to build-up region)
   - Conventional plan add beam margin in air (flash) to account for daily changes in shape. But inverse planning algorithm only treats defined targets. For Breast IMRT, both flash and buildup problems present significant difficulties.
   - Dose uniformity: cold spot in target and hot spot outside PTV