

Clinical Pitfalls and Limitations of IMRT

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Where can we go wrong?

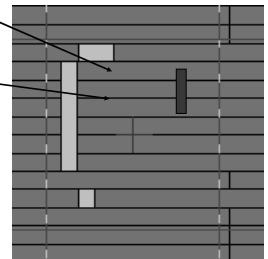
- Beam modeling and dose calculation
- Inverse planning
- Quality assurance of plans and machines

Beam modeling and dose calculation

- For IMRT, the MLC leaves move through the area of interest
- Final distribution is created by summing many beamlets
- New things become important
 - Leakage through MLC leaves
 - Penumbra defined by MLC leaves
 - Small fields

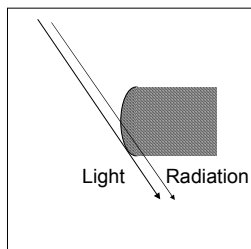
MLC leakage - measure average value

- Leakage through leaf (~2%)
- Between neighboring leaves (~5%)
- Measure using a pattern that fully closes all leaves - careful not to be under carriage or jaw

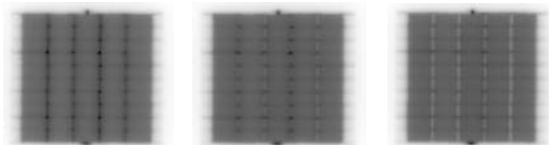


Radiation field "offset" for rounded leaf ends

- For rounded MLC leaf ends, there is an offset between the light and radiation field edges: ~0.6 mm
- Important in IMRT



Measuring the offset



No offset

0.6 mm offset

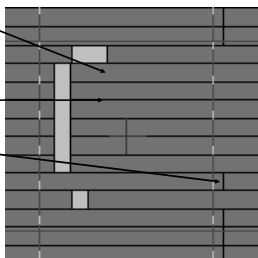
1.0 mm offset

Here, 0.6 is best, i.e. subtract 0.6 mm from MLC settings
Planning system should take care of this!

The alternative is to change the way the MLCs are calibrated, but who will ensure that is always done right?

MLCs - account for rounded ends

- Leakage through leaf (~2%)
- Between neighboring leaves (~5%)
- At abutting leaf pairs (~15% if rounded ends) - should be parked under a jaw!



MLCs and small fields

- Output for small fields very dependent on MLC accuracy
- 10%/mm for 1 cm wide segment

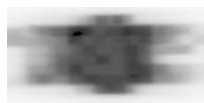


Small field issues

- Mayo Clinic Scottsdale has two "matched" Varian linacs, but IMRT doses differed by ~2.5%
- Needed to adjust MLC calibration on one machine by 0.13 mm
- Daily, monthly QA includes sweeping a 1 cm gap across a chamber

Penumbra

- Measure with film, diode, or microchamber, conventional scanning chamber too wide
- Subtle effects make a difference in IMRT

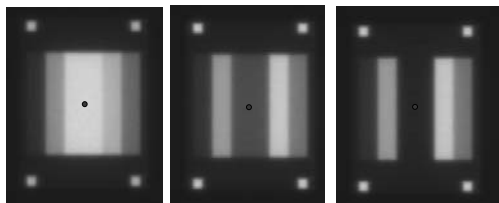


Beam model based on penumbra measured with 6 mm diameter chamber



Beam model based on penumbra measured with film

Dose calculation deficiencies: Test with different central intensities



| Center 100% | Center 20% | Center 0% |
|-------------|-------------|-------------|
| Meas 182.6 | Meas 42.4 | Meas 15.2 |
| Plan 180.0 | Plan 43.0 | Plan 8.1 |
| Ratio 1.014 | Ratio 0.986 | Ratio 1.878 |

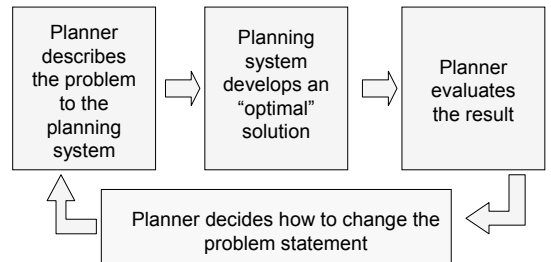
What to do about differences?

- May need to adjust the beam model
- May need to live with it
 - That is, take known deficiencies into account when evaluating plans
 - Very important to know about it, especially for critical structures

Issues with inverse planning: Trouble can be just around the bend



Inverse planning flowchart



Why is the process iterative?

- Differentiate between three things sometimes called “prescription”
 - Statement of clinician’s goals
 - Planning parameters given to the RTP system
 - Final dose distribution accepted for treatment
- These usually differ from each other because we do not get what we ask for

Why is the process iterative?

- Clinical goals may not be achievable
- Results may differ from the goals as presented to the planning system
- Goals may not be explicitly described
 - e.g. avoid hotspots outside of target

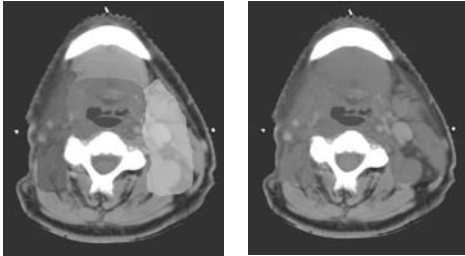
Modeling the clinical problem

- All treatment planning is numerical modeling
 - patient, beams, interactions, dose
- With inverse planning, also include model of “what we want to achieve”
 - goals, limits, value judgments
 - some is hidden from the user in the details of the “objective function” and search process

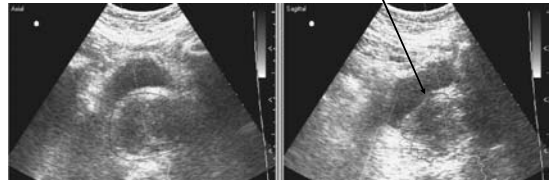
Defining targets

- All targets need to be explicitly defined
 - not too small (geographic miss)
 - not too large (nowhere to throw low dose shadows)
- May need
 - contrast (consequence for CTsim?)
 - fusion with pre-op studies

How generous to make the target?



With ultrasound localization of prostate, defining the base is critical!



May need contrast in the bladder to identify the base on CT.
Over-contouring the prostate can lead to misalignment on US

Careful of automatic CTV expansions

- Automatic CTV expansions may cross tissue boundaries unrealistically
- Human planners trim beams accordingly, inverse planners to not.

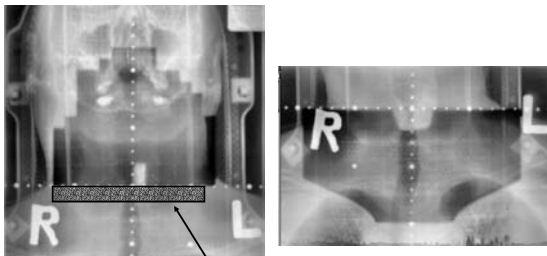


Realistic for CTV?

Human planners trim beams

- Combining IMRT fields with conventional fields?
 - e.g. supraclavicular with H&N IMRT
- Watch out for overlaps if the IMRT plan wants to open the jaws into the supraclavicular area
 - may need to adjust that jaw!

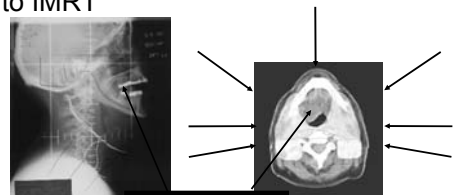
Human planners sometimes have to trim IMRT beams

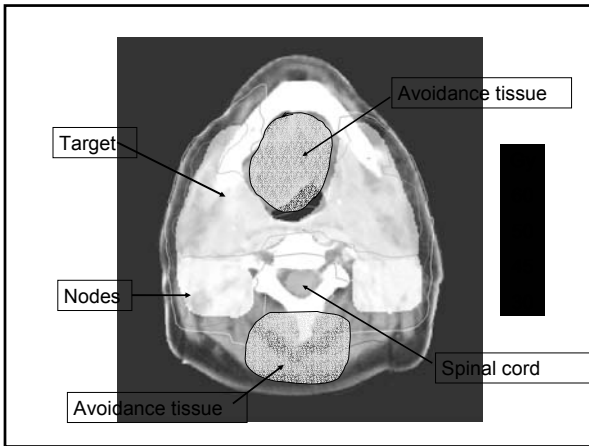


This row might be used by the IMRT plan if the target is drawn too close to the isocenter plane

Defining normal tissues

- Tissues to be spared need to be explicitly defined; e.g. oral mucosa when changing from parallel-opposed to IMRT



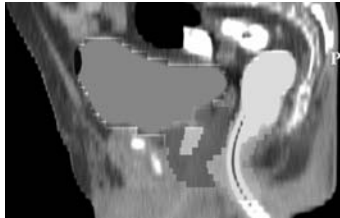


Defining normal tissues

- Consistent definitions of structures must be used if dose-volume criteria are taken from the literature

Mayo Scottsdale: Prostate Criteria for acceptability

- Rectum (contents, 1.5 below to sigmoid flexure)
 - $D_{40} \leq 65$ Gy,
 - $D_{30} \leq 70$ Gy,
 - $D_{10} \leq 75$ Gy,
 - $D_{max}^* \leq 81$ Gy
- Bladder
 - $D_{30} \leq 70$ Gy,
 - $D_{max}^* \leq 81$ Gy



* D_{max} = dose to clinically significant volume

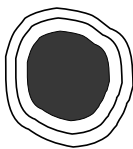
Margins

- IMRT does not inherently demand or permit tight margins
- CTV and PTV margins are independent of beam delivery technique - depend on patient and immobilization/localization techniques
- To achieve tight margins, may need to improve imaging for planning, immobilization, imaging for verification

Margins (other issues)

- Distance to block edge \neq PTV expansion

GTV \rightarrow CTV \rightarrow PTV \rightarrow penumbra \Rightarrow block edge



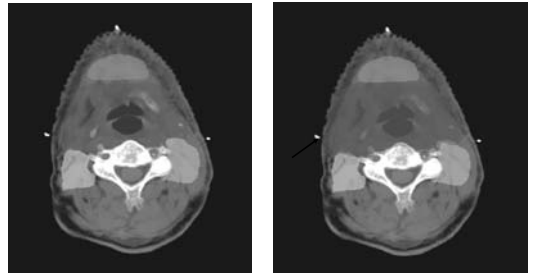
Block edge to PTV expansion

- Suggestion: compare to 3D conformal alternative planned with specified block margins
- Determine the distance from the CTV to the 95% isodose line
- Call that the PTV expansion

Target volumes in buildup regions

- Inverse planner will try to compensate for the low doses by increasing intensities of some beamlets
- Especially watch for PTV expansions that encroach on the buildup region
- May cause excessive skin reactions and compromise the plan quality in general

PTV in buildup region



Breast treatments and “Flash”

- Most inverse planning systems do not allow the user to expand a field outside the skin
- How to do breast IMRT without a forward planning component?
 - Somehow need to expand the target outside the original skin
 - Somehow need to avoid buildup region problems

Choosing beam directions

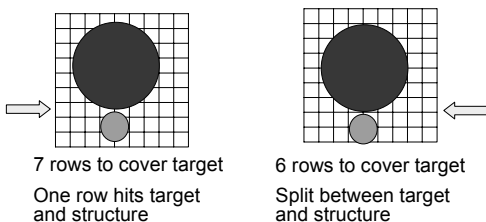
- Choice of beam directions still matters
 - Don't modulate any more than necessary



Axial or nonaxial beams?

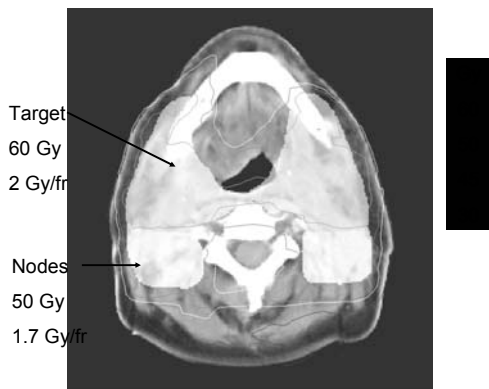
Spatial quantization effects

- Shift isocenter to provide best separation between target and tissues



Radiobiological issues

- More dose inhomogeneity in targets than with previous clinical experience
 - may get more acute reactions, especially in H&N treatments
- Targets given different doses get different doses/fraction
 - may need to adjust total doses accordingly



Plan evaluation

- Plan evaluation cannot just be based on DVHs, since all positional information is lost
 - Target: cold spot inside vs at edge
 - Normal tissues: hot spots near target vs unexpectedly elsewhere



Developing a planning strategy

General principles (1)

- Don't ask for the impossible
 - If you ask for NO dose to the cord, 60 Gy may appear just as bad as 40 Gy to the optimizer
 - Look at a good 3D conformal alternative to get a starting point

General principles (2)

- Explain the problem sufficiently to the system
 - Define what needs to be treated
 - Define what needs to be avoided
- The system is going to choose the beam shapes according to the structures defined

General principles (3)

- Define the problem sufficiently to the human who is doing the planning
 - What is absolutely necessary
 - What is desirable
 - Where you are able to compromise

General principles (4)

- Understand the difference between three kinds of “prescriptions”:
 - What you want and tell the human planner to get
 - What the planner tells the system to try for
 - What you eventually get and treat with

Example: H&N treatment with Corvus

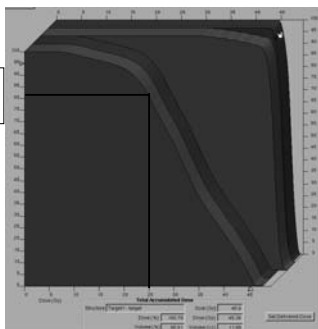
- Physician wants 45 Gy to target, 50% of parotid below 25 Gy

| Target Name | Type | Goal (Gy) | Vol Below Goal (%) | Min (Gy) | Max (Gy) | I |
|------------------|------------|-----------|--------------------|----------|----------|---|
| Target1 - target | Homogenous | 45.0 | 5 | 44.0 | 46.0 | |

| Sensitive Structure Name | Type | Limit (Gy) | Vol Above Limit (%) | Min (Gy) | Max (Gy) | I |
|--------------------------|-------------------|------------|---------------------|----------|----------|---|
| Tissue | Homogenous Tissue | 45.0 | 0 | 0.0 | 45.0 | |
| Parotid (L) | Basic Structure | 20.0 | 15 | 15.0 | 40.0 | |
| Avoidance (mucosa) | Basic Structure | 30.0 | 33 | 20.0 | 45.0 | |

Results - DVH

82% > 25 Gy,
no good!



General principles (5)

- Learn what “knobs” there are
 - DVH criteria for targets and structures
 - Relative weights or tissue types
 - Number of intensity levels
 - Number and direction of beams
 - ...
- Try each individually and systematically
 - on idealized and actual patients

General principles (6)

- Dose uniformity vs Conformality
- Target dose uniformity can be expected to decrease with
 - increasing concavity
 - increasing dose gradient
 - decreasing number of beams

General principles (7)

- Don't assume IMRT is the way to go
- 3D conformal, judged by the same criteria, may be better
 - parallel-opposed beam pairs are often best
 - IMRT system may have limitations
 - 1x1 beamlets
 - insufficient weight to dose uniformity

Building experience with artificial problems

- Designed to illustrate performance for certain types of situations
- Observe how changing various planning parameters affects plan quality and delivery efficiency
- For each, decide on relevant measures of plan quality

Simple cylindrical geometry

- Single target with 1 cm PTV expansion (PTV is 8 cm diam, 8 cm long)
- Goal: target dose uniformity
 - PTV max/min
 - PTV D2/D98
- Compare to:
 - 3 open fields
 - evenly weighted



Target dose uniformity

- As you vary the requested degree of target dose uniformity, how do the results change?

Corvus V5 "Prescription Panel"

| Target Name | Type | Goal (Gy) | Vol Below Goal (%) | Min (Gy) | Max (Gy) |
|-------------------|-------|-----------|--------------------|----------|----------|
| Target 1 - target | Basic | 100.0 | 5 | 98.0 | 102.0 |

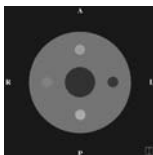
| Sensitive Structure Name | Type | Limit (Gy) | Vol Above Limit (%) | Min (Gy) | Max (Gy) |
|--------------------------|--------------|------------|---------------------|----------|----------|
| Tissue | Basic Tissue | 100.0 | 0 | 0.0 | 100.0 |

Goal: target uniformity (Corvus V5)

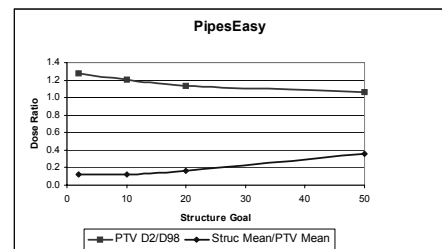
| | Inverse plans | | | | Forward plans | |
|-------------|---------------|------|------|------|---------------|-------|
| Goal | 100 | 100 | 100 | 100 | 100 | 100 |
| % vol below | 5 | 5 | 5 | 5 | 10x10 | 10x12 |
| Min | 95 | 98 | 99 | 100 | | |
| Max | 105 | 102 | 101 | 100 | | |
| Rx Max/Min | 1.11 | 1.04 | 1.02 | 1.00 | | |
| Max/Min | 1.11 | 1.08 | 1.08 | 1.07 | 1.06 | 1.03 |
| D2/D98 | 1.04 | 1.04 | 1.04 | 1.04 | 1.05 | 1.02 |
| # segments | 23 | 33 | 33 | 31 | 3 | 3 |
| # MU | 352 | 301 | 319 | 291 | 245 | 241 |

Simple cylinder with 4 structures PipesEasy

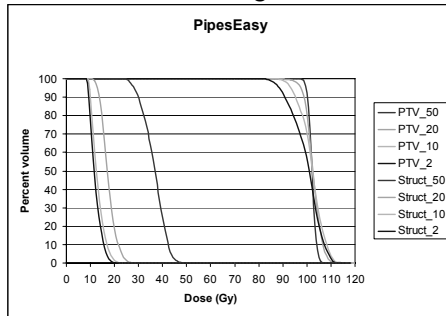
- Goal: structure sparing vs target uniformity
 - PTV D2/D98
 - Structure mean/PTV mean
- 15 fields equispaced
- Try different structure goals
 - 50, 20, 10, 2% of target dose



PipesEasy: Effect of changing structure goals

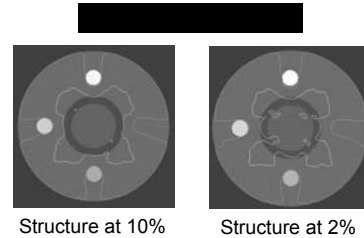


PipesEasy: Effect of changing structure goals

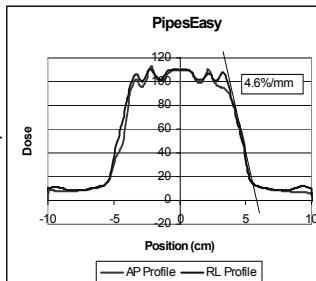
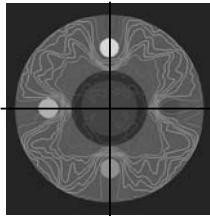


PipesEasy: comments

- Asking for too much sparing degrades target uniformity with little improvement



What is achievable? Limiting dose gradient

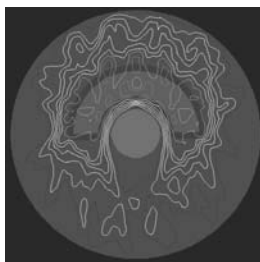


C Shape

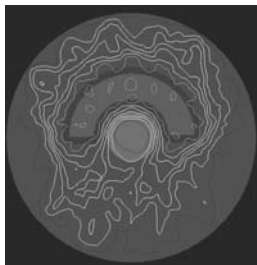
- Goal: structure sparing vs target uniformity
 - PTV D2/D98
 - Structure D5/PTV 98
- 15 fields equispaced
- Try different structure goals
 - 60, 50, ..., 10% of target dose



Corvus: C Shaped Target



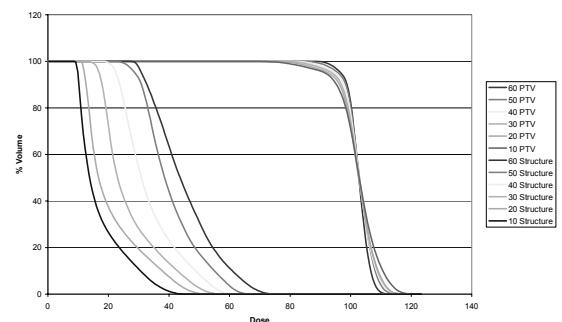
Structure at 10%



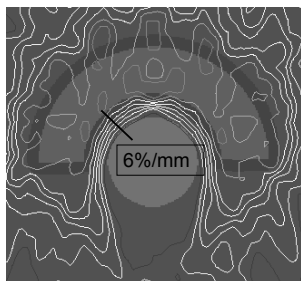
Structure at 60%

Corvus

C Shape Target Around Central Structure
Structure Goal from 10 to 60 Gy

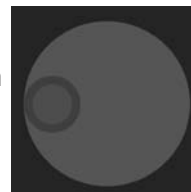


Limiting dose gradient



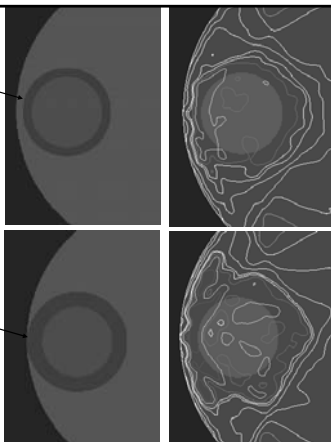
Buildup

- Expand PTV by 2-10 mm
- Evaluate dose uniformity
 - CTV max/min
 - Volume max/CTV mean

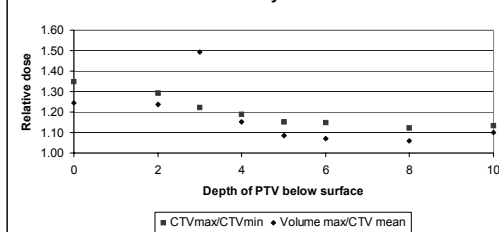


5 mm
below

0 mm
below



Dose uniformity measures



Comments on these artificial problems

- Good for gaining some feel
 - for the “knobs”
 - for the limiting conditions (e.g. maximum dose gradients)
 - for the consequences of being unrealistic in the problem statement

Dealing with real clinical plans

- Determine method/conventions for defining structures and targets
- Determine margins (CTV and PTV)

These do not change whether
IMRT or 3D conformal

Dealing with real clinical plans

- Decide on criteria for an acceptable plan
 - e.g. PTV dose must be sufficiently uniform: $PTV\ D2/D98 \leq 1.15$
- Decide on parameter to be optimized
 - e.g. minimize mean parotid dose

These will often be competing and cannot both be “optimized”

Dealing with real clinical plans

- Start with a 3D conformal plan to get a sense of what is achievable
- Use these results as a starting point for DVH goals for the inverse planner
- Start with relaxed goals and gradually tighten them

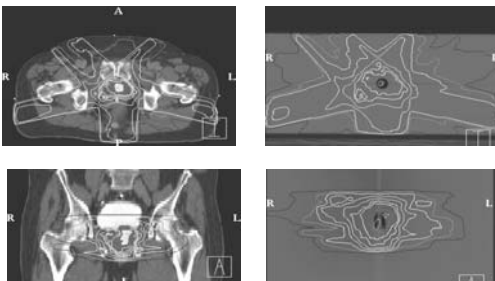
QA issues

- Dosimetric QA is necessary but not sufficient
 - Always need to evaluate plan quality to make sure inverse plan is not a “perverse” plan
 - Do doses and margins make clinical sense?

We do not know the failure modes

- Planning can be inaccurate
 - dose calculation
 - linac/MLC modeling
 - leaf sequencing
- Delivery can be inaccurate
 - information transfer
 - linac/MLC performance

Our current practice ...



Compare isodoses (film) and absolute dose (chamber)

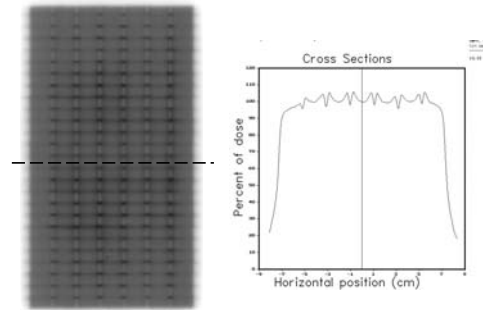
Our current practice needs improvement

- Per-patient measurements of doses transferred to a phantom
 - Don't sample entire volume
 - Can't find planning blunders
 - Can't isolate the source of errors

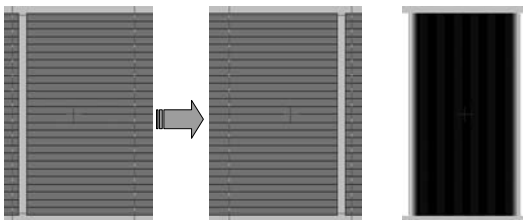
QA system should include Measurements

- Standardized tests of delivery system performance
 - daily, weekly, monthly
 - testing for problems in MLC/MU delivery control
 - e.g. frequent films of abutting strips taken at multiple gantry angles

Check standard patterns for constancy

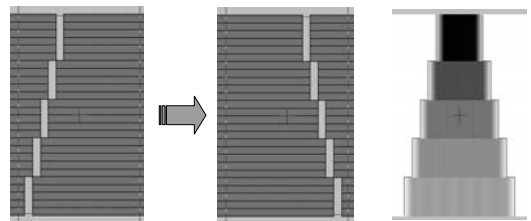


DMLC tests: Sweep all leaves at same rate



Chamber reading at center should be proportional to MU
Film should show uniformity

DMLC tests: Sweep leaves at different rates



e.g. Travel 5, 7, 9, 11, 13 cm in same MU
Check relative dose

QA system should include Calculations for each patient

- Based on:
 - leaf sequence used for treatment extracted from delivery system
 - measurements of SSD and depth NOT taken from planning system
- Checking
 - dose to target
 - dose to critical structures

Summary

- Detailed phantom measurements should be part of commissioning
- On-going QA should have
 - machine measurements designed to test equipment performance
 - per-patient calculations designed to find planning and information-transfer errors