# Quality Assurance of IMRT delivery systems – Varian

Thomas LoSasso, PhD, Memorial Sloan Kettering Cancer Center

## Introduction

Intensity modulated radiation therapy (IMRT) provides the means for improved treatment for a wide variety of cancers. Piggybacked onto 3DCRT and MLC technologies, IMRT has developed quickly, but will undoubtedly see improvements in core hardware and software as well as in peripheral applications such as record and verify, gating, etc. At the core, individual treatment centers should expect a learning curve for understanding novel treatment planning and quality assurance (QA) issues. The urge to implement IMRT at individual therapy centers should be tempered while these issues come into focus and are addressed at each center. This presentation will discuss issues affecting dose calculation and delivery, i.e., the commissioning as well as routine QA of the Varian MLC, to provide SegmentedMLC (step and shoot) and DynamicMLC (sliding window) treatments. The QA program at MSKCC has evolved over seven years of clinical IMRT experience using DMLC.

## Commissioning

A prerequisite for accurate IMRT treatment is a careful assessment of the IMRT-specific collimator factors of the MLC. Before IMRT treatments began at MSKCC, we acknowledged three specific parameters, which needed to be re-commissioned for the IMRT dose calculations. These were 1) the MLC transmission (primary plus scatter) through the leaves and interleaf spaces, 2) the added transmission through the rounded leaf edges, and 3) output factor for small MLC-shaped fields simulated by an analytical source function. These factors have minor influences for conventional static fields as the average MLC transmission, 1.5 – 2.0%, is less than that for metal alloy blocks, ~3.5%, the round edge only slightly broadens the penumbra in these cases, and MLC output factor for a tertiary collimator can be ignored in most cases. In contrast for IMRT, transmissions through the leaves and the rounded leaf edges contribute 4% and 10%, respectively, to the delivered dose to the target volume in typical IMRT fields, and small variable gaps between leaves produce local output variations. As IMRT fields have increased in size, modulation, and irregularity, collimator factors were reevaluated. The average value for MLC scatter, based upon prostate and head and neck field sizes, was included in the MLC transmission that is applied to all fields; however, it is not accurate for larger IMRT fields. We have refined the source function, to more accurately calculate MLC output for very small gaps. Additionally, we modeled the interleaf spaces giving the planner the option to evaluate tongue and groove effects in individual plans.

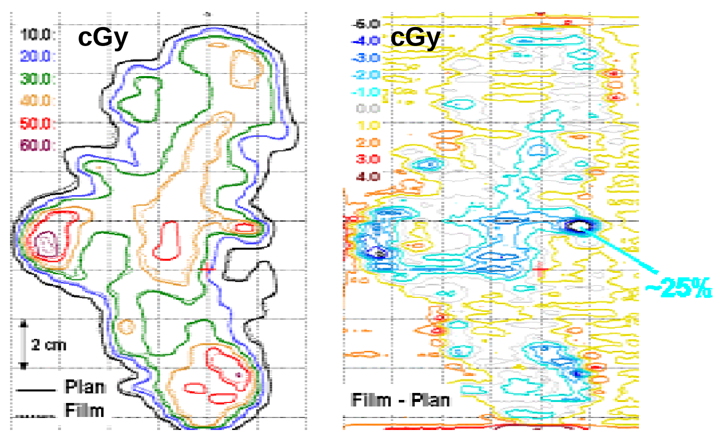


Figure 1

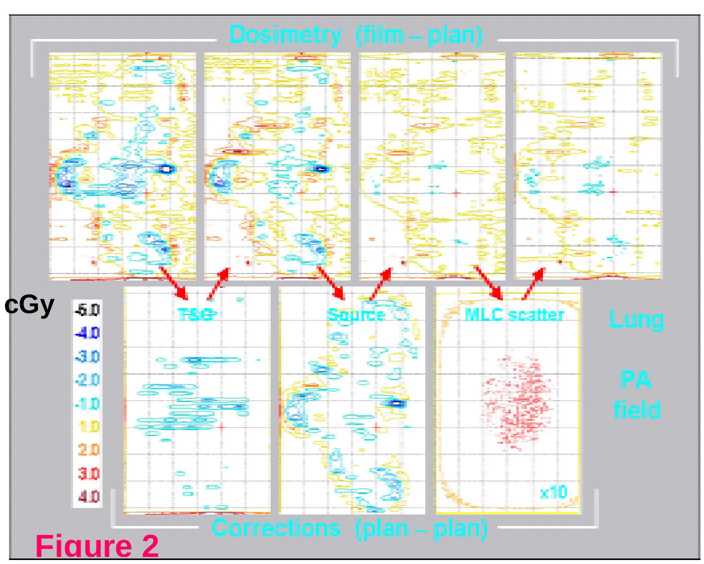


Figure 2

Dose measurements indicate potential problems in highly modulated and irregularly shaped fields. One of the more extreme cases (**Figure 1**), an IMRT lung field, calculated and measured in a flat homogeneous phantom, illustrates the dose calculation issues. On the left, the overlay of calculations and measurements shows large variations in dose, 15-60cGy within the field, with an average dose of about 30 cGy. On the right, the dose difference shows that discrepancies can be 25% of the average dose (15% of the local dose) in such fields. Some differences, associated with the peak dose regions, can be attributed to inaccuracies in the source distribution. At interleaf spaces, underdosed regions are due to tongue and groove effects, and overdosed regions are due to interleaf leakage. Previously, neither tongue and groove effects nor interleaf leakage were calculated. It should be noted that these discrepancies would be less in the composite dose distribution due to the influence of other fields. We successively applied some of the preliminary data to the dose calculation (**Figure 2**). The interleaf fluence and source distribution modifications had the greatest

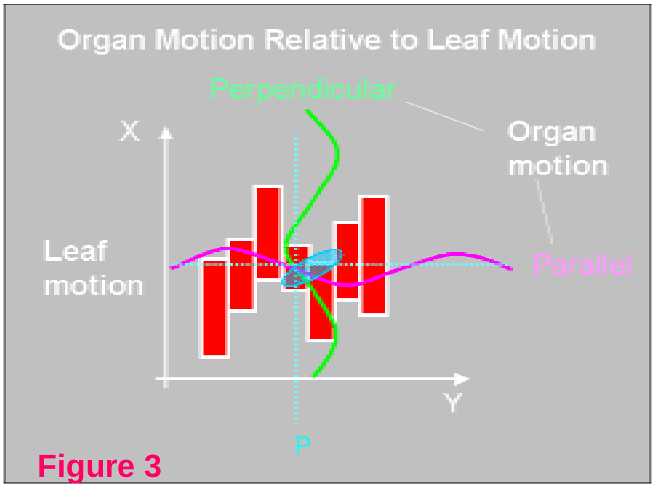

Figure 3

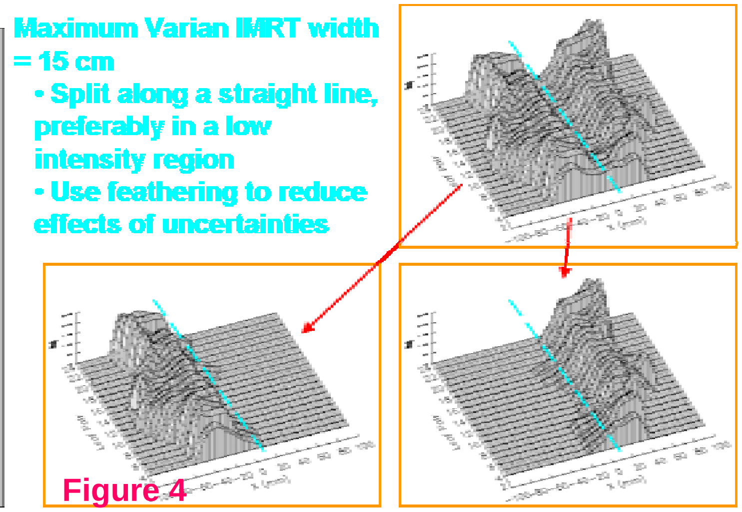

Figure 4

impact in this case. For this collimator opening, the new MLC scatter algorithm increased the dose by ~1% over the previous method. For larger IMRT fields, MLC scatter could alter the calculated dose by up to 5%.

Where the tumor and/or critical organs are potentially affected by respiratory motion, respiratory gating is applied during simulation, scanning, and treatment to immobilize these structures. This is particularly important for IMRT, as intrafraction organ motion can distort the dose delivery. **Figure 3** illustrates the cyclical motion of a point in the field, perpendicular and parallel to the leaf motion, caused by respiration. The impact of gating the beam has been tested.

For large target volumes it is necessary to split fields into 2 or 3 subfields **(Figure 4**) due to the 15 cm wide IMRT field limit. Dose distribution accuracy in the overlap region of split fields has been tested in a variety of clinical cases.

Routine QA

Routine QA for IMRT tests the mechanical stability of the MLC. Of importance is the accuracy of leaf positioning, which in turn, determines the accuracy of the gap width and the delivered dose. For static fields, error in the field width, whether defined by the MLC, blocks, or the jaws, only affects the borders of the field; 1-2 mm errors can be tolerated. However, the dose delivered with IMRT is very sensitive to the width of the gap defined by each leaf pair. **Figure 5** shows this relationship for DMLC fields, where the range of average gap width for DMLC fields is 1-4 cm at isocenter. In fact, 2 cm is the average gap width based upon our experience for DMLC prostate and head and neck fields. Then a systematic gap error of 1mm will produce an average dose delivery error of ~5%. Considering this, our goal is to maintain gap errors below 0.2 mm. In SMLC fields the average dose error will be similar although it will be concentrated at the edges of the subfields.

At MSKCC we have identified sources of leaf positioning error, and we have developed QA tests and frequencies to detect these mechanical problems before dose errors become significant. Two problems appear to affect leaf motor operation, whereby leaves near the center of the MLC, which typically take more active roles in treatment, develop symptoms of wear. These symptoms include loss of motor encoder counts over the course of the treatment day and a binding of the motor bearings, affecting the motor's calibration and maximum speed, respectively. A film test such as shown in **Figure 6** allows a quick visual assessment of the leaf calibration. This film

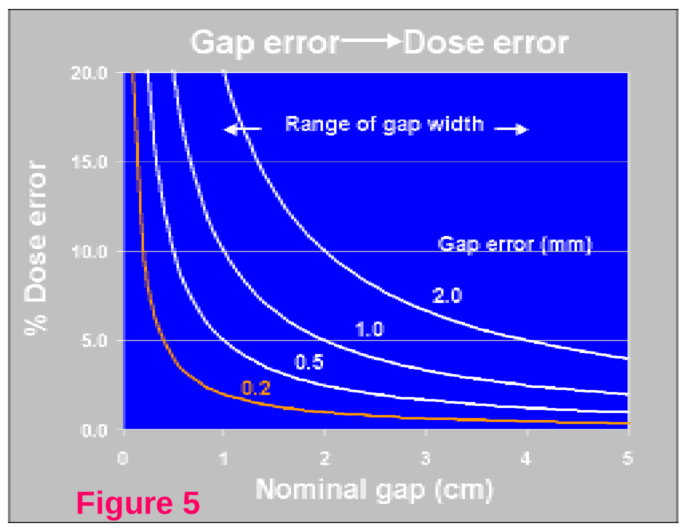

Figure 5

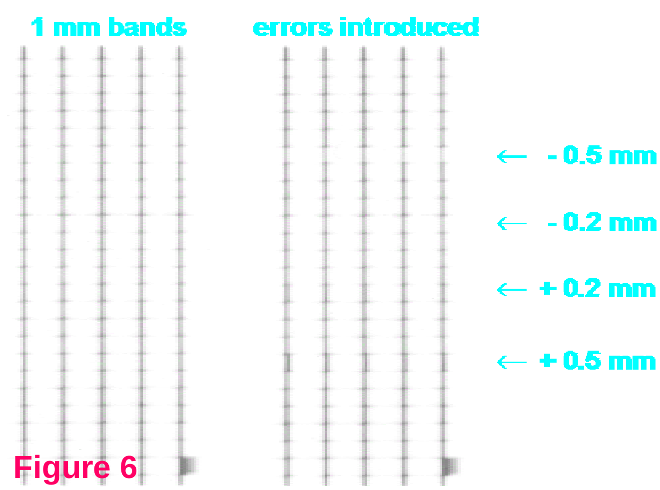

Figure 6

is exposed with 6MV xrays at isocenter without buildup in order to obtain a sharp image. The semi-weekly test is performed by our therapists preferably at the end of the treatment day, but at least 6 hours following initialization. Using this test it is possible to detect leaf position errors as small as 0.2 mm at isocenter. Motors with speed impairment can be visually detected by observing the display or the MLC directly with leaf exercise patterns. New software introduced by Varian in 2001, requiring a 0.5 mm minimum gap for all moving leaves, is intended to alleviate these motor problems. **Figure 7** shows the motor replacement history for 3 MLC at MSKCC. The influence of the 0.5 mm minimum gap (vertical line) on the replacement rate is apparent.

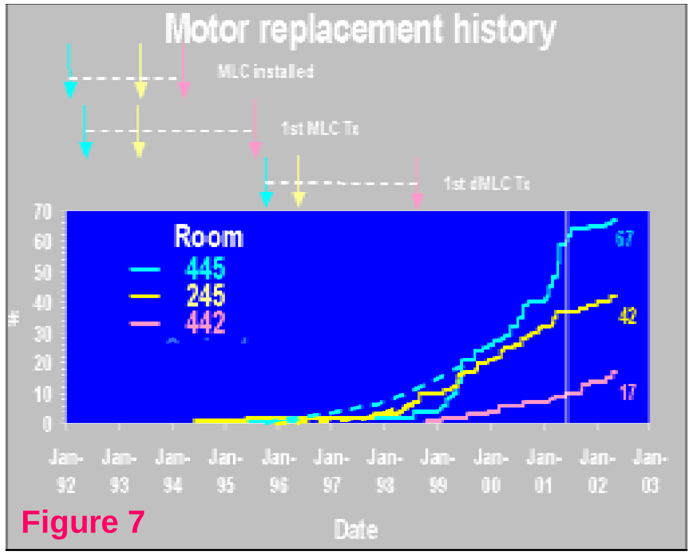

Figure 7

Some mechanical backlash in the MLC carriages due to gravity can usually be observed at gantry angles of 90° and 270° relative to 0°. Since this backlash affects gap width, it is checked monthly. The output for a 0.5 mm sliding window is very sensitive to small variations in the gap width. This field is scanned across a cylindrical ion chamber with buildup cap at isocenter. Outputs for each gantry/collimator angle, normalized to the output for a static 10x10 field at the same angle, are shown in **Figure 8** for 4 MLC. Occasional adjustment of the carriage bearings is required, particularly for the older Mark 1 MLC, when the output variation between 90° and 270° increases beyond 3% (corresponding to ~ 0.2 mm @ isocenter. In addition to variation in carriage position with gantry angle, this test compares the output (MLC calibration) over time. Intentional adjustments in the MCLXCAL file are indicated by vertical dashed lines.

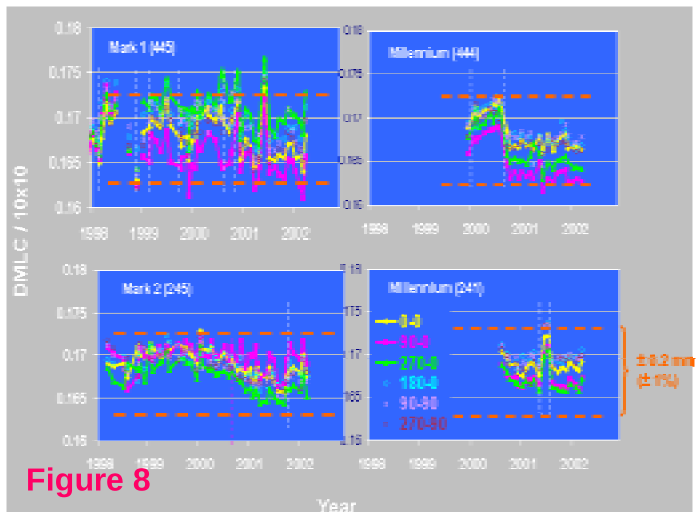

Figure 8

In addition to the above tests, other tests are used at acceptance testing and on a less than annual schedule. A uniform field generated with a narrow sliding window, 5-10 mm wide, is compared with a static open field as shown in **Figure 9**. The variable off-axis transmission through the leaves in the DMLC field is independently measured and subtracted. The symmetry and flatness of the two fields should be similar, indicating that the hardware is functioning properly and the software in the MLCTABLE is being applied correctly. Since the DMLC field is limited in width, asymmetric fields are necessary to examine positions far from the axis.

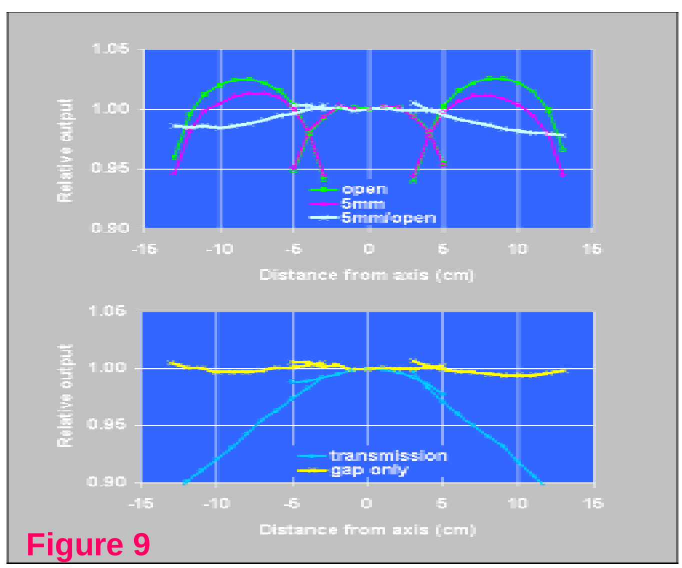

Figure 9

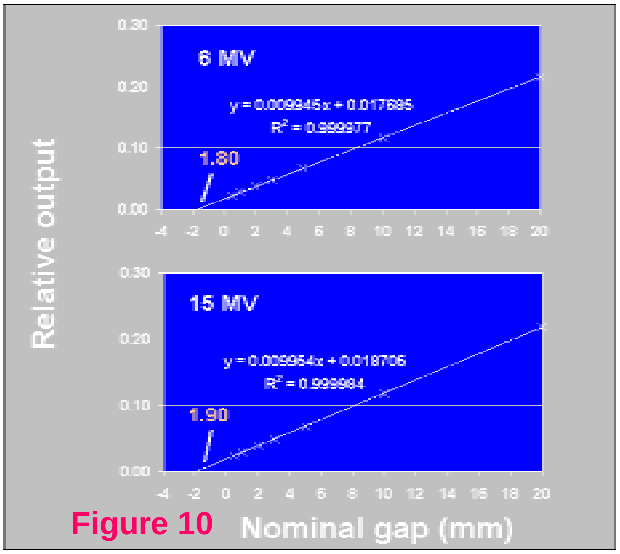


Figure 10

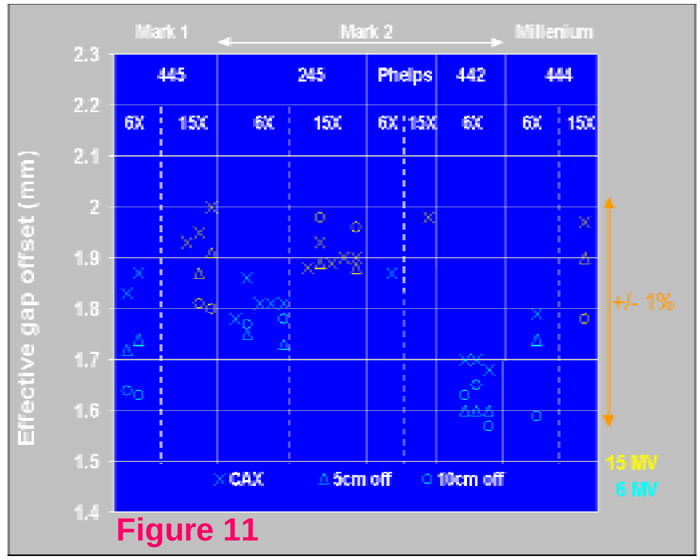


Figure 11

The effective gap offsets from different MLC are compared in **Figures 10 and 11**. The outputs for a series of sliding windows with different fixed gap widths are measured. After subtracting the transmitted component, a straight line fit extrapolated to zero dose yields the effective offset. Variations in effective offset between MLC can be due to calibration, but possibly represent subtle variations in MLC model and in energy between machines.

Due to the complexity of IMRT, our routine patient-specific QA is reliant on computer-based checks. We independently check the MU calculations. Procedures check unique plan/version IDs attached to various plan components to ensure that the data for individual fields has not been mismatched or altered inadvertently, check sums are performed daily to check the integrity of the leaf sequence files, and port images and R&V systems check initial and final leaf positions. Furthermore, leaf position monitors are designed to detect leaf position errors (>2mm) during treatment, ensuring that significant dose errors cannot occur in an individual Tx fraction.

Summary

Acceptance testing checks that the MLC is capable of accurate IMRT delivery. Commissioning establishes that the MLC is correctly modeled in the treatment planning system, assuring that if the leaves are accurately positioned, then the dose delivered is accurate. Periodic MLC QA checks the mechanical aspects of the MLC, assuring that the actual leaf positions are consistent with monitored positions. Finally, patient specific QA confirms that the MU are correctly calculated, and that the patient data is correctly transferred to and delivered by the treatment machine. These four components are complimentary to each other and together ensure IMRT dose accuracy.