THE MULTILEAF COLLIMATOR
- A COMPLETE GUIDE

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A. INTRODUCTION

The multileaf collimator is an important new tool for radiation therapy dose delivery. Originally introduced as a substitute for alloy block field shaping, it is now recognized that this device can also be used for intensity modulated (IM) treatment. In either case, it is important to view this equipment as a sophisticated electrical/mechanical device that requires a number of distinct steps for introduction and continued use in the clinic. First, it is necessary to organized and carry out a series of acceptance tests for a new accelerator with MLC, or for an existing accelerator when an MLC is retrofitted. Second, additional commissioning measurements are needed to model the MLC for treatment planning. Third, a routine quality assurance program must be established to determine continued reliable operation of the entire MLC system. Fourth, the effect of the MLC on Meter Unit calculations must be determined and accounted for in each patient's treatment. This talk will present a set of tests and procedures that can be used to accept, commission, and guarantee proper functioning and application of MLC field defining equipment.

In addition to the considerations mentioned above, this talk will compare the different design features of the available MLC's. Although there are certain similarities for the multileaf collimators provided by different manufacturers, it must be recognized that significant differences can also be identified in each case. To a great degree, the differences can be directly related to the specifications that went into the design of each device. For example, the Varian MLC is placed as a tertiary system below the standard adjustable jaws and is much closer to the patient than the Elekta system which replaces the upper jaw of the standard collimator. Each approach gives rise to a series of advantages and compromises that are discussed in this report.

B. COMPARISON OF MULTILEAF COLLIMATORS

1. Collimator Geometry

The Varian MLC is positioned as a tertiary system below the standard adjustable jaws (see **Figure 1**). This design was used for two major reasons: First, the approach facilitates the retrofitting of the MLC onto existing units. Second, the designers of this system felt that any failure of the system should not be allowed to take the entire accelerator out of service, and provisions were made to manually move offending leaves out of the field so that alloy blocks could be used. Placing the MLC in a position closer to the patient than either the Siemens or Elekta collimators has both positive and negative results. A negative for this approach is that a collimator nearer the patient will have a greater overall bulk, especially in the direction of leaf motion. This is because beam divergence requires a larger system to cover the same 40x40 field size. A simple calculation, using the geometry shown in **Figure 1**, demonstrates the difference. A comparison can be made for a hypothetical design that allows the leaves of an MLC to reach a total of 15 cm across a field midline and retract to the outer edge of a 40 cm wide field. For the Varian geometry where the collimator is mounted in a tertiary position with the bottom of the collimator at 53.5 cm, the total width of the collimator system must be

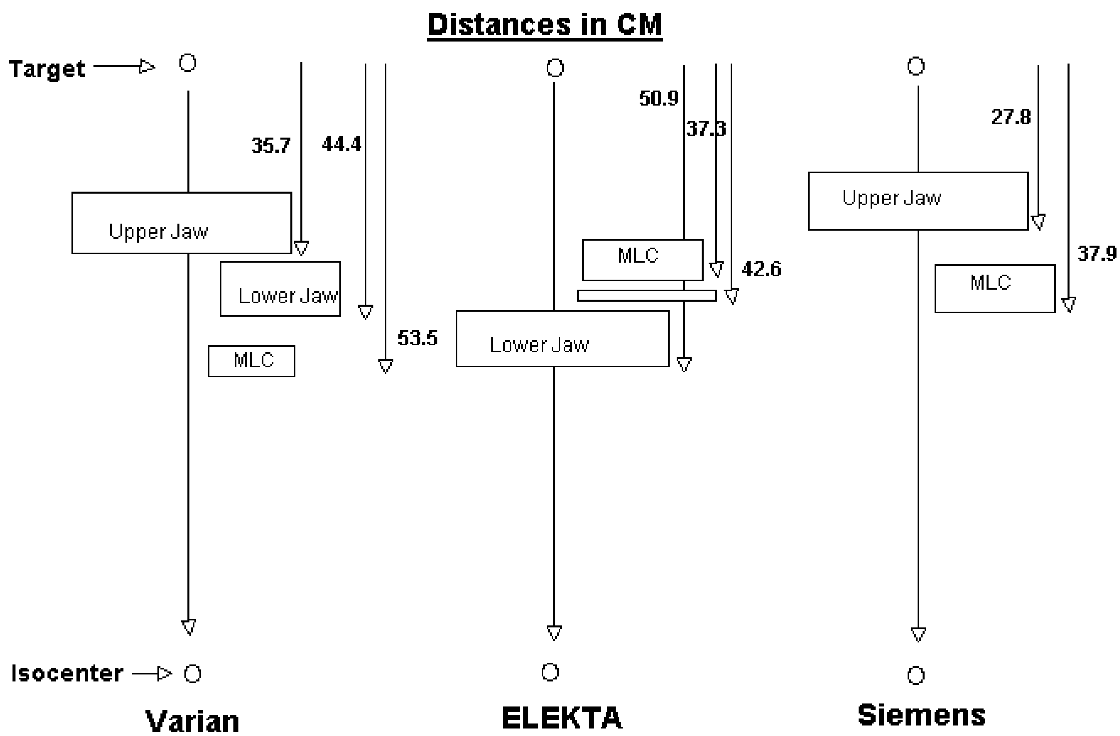

FIGURE 1

about 60 cm. Using the geometry shown in the figure for the Elekta collimator (lower surface of the MLC at 37.3 cm), this number is reduced by almost 20 cm. In fact, as discussed below, the Varian design is modified to bring the dimension to a size that is roughly equivalent to the Elekta number. One positive result of mounting the MLC further from the x-ray target and nearer the patient is that leaf width is larger. This offers distinct advantages in terms of manufacturing because it simplifies issues like the machining of the tongue and the groove into each leaf. Maintaining the same amount of "projected" leaf overlap is accomplished with a deeper groove and more extended tongue when the leaf is positioned further from the target and nearer the patient. This means that manufacturing tolerances are less. Wider leaves have another advantage in that there is more material for any attachments that hold the leaf in position and for lead screws that move the leaves. An additional advantage that results from placing the MLC further from the target is leaf positioning tolerances are relaxed. The slight separation between the side surfaces of neighboring leaves that is needed to avoid friction is easier to achieve when the MLC is mounted lower in the treatment head. Also, maintaining a 1.0 mm position accuracy for the leading edge of a leaf at isocenter translates to positioning accuracy of 0.37 mm at the MLC position for the Elekta geometry, while a 0.54 mm accuracy is needed for the Varian placement of the collimator. A disadvantage of mounting the leaves nearer to the x-ray target (or using thinner leaves as is done for micro-MLC systems and 0.5 cm systems) brings the between-leaf leakage regions closer together and can cause the transmission peaks to join so that average radiation leakage for the MLC is increased. This is seen for the apparent increased through-the-leaf leakage for the Elekta collimator compared to the Varian collimator. This is not the expected result given the significantly greater thickness of the Elekta collimator (7.5 cm compared to 5.5 cm for Varian) in the beam direction. It should be pointed out that this effect is also dependent on the spot size for the particular radiation beam and is not entirely due to the position of the collimator.

2. Divergent Versus Rounded Leaf Ends

Siemens has chosen to mount their MLC as a replacement for the lower standard jaw system. This geometry gives an intermediate leaf width dimension, relative to the other two manufacturers, for the same projected size at isocenter. This positioning creates a favorable geometry for the use of arcing trajectories so that the leading edge of each leaf follows beam divergence. The other MLCs do not employ this level of sophistication and instead use rounded leaf ends with a linear trajectory. The argument for having the leaves move along a plane is that the mechanics are greatly simplified so that failures should occur less frequently. It is not clear that the Siemens MLC has a major advantage over the Varian collimator when the penumbrae at the leaf ends are compared. Although the Varian collimator has rounded ends that should produce a larger 80 to 20% penumbra width relative to the Siemens system which has flat ends that follow beam divergence, the fact that the Varian collimator is closer to the patient tends to compensate. In fact, the geometry has an overriding effect and the Varian penumbra width is smaller than the Siemens width. Additionally, given the current state-of-the-art of patient immobilization, daily setup variations blur edges to the point where it is impossible to distinguish any edge. This applies to divergent block edges as well as either divergent or rounded MLC edges. It also applies to stepped MLC edges. That is, when setup errors are included, it is hard to tell the difference between divergent block edges and stepped edges defined by an MLC with either rounded or divergent leaf ends (**see reference 3**). This issue will be discussed in greater detail below.

3. The Varian Carriage Design

The design of the Varian collimator as described above is not complete in that an interesting modification was made to reduce the overall size of this device in the direction of leaf travel. It was recognized early in the design and engineering phase of the Varian collimator that the 60 cm width calculated above, for leaf travel alone and not considering other factors like the mounting of the motors that drive the leaves, is problematic. Based on this type of calculation, it was decided that the general bulk of the treatment head would be excessive if a leaf reach at isocenter of about 35 cm (20 cm to the center of a 40 cm wide field plus 15 cm across midline) was attempted. As an alternative, studies were conducted (**see reference 4**) to show that a different design that places leaves with a shorter reach on carriages on each side of the field could be used. The idea was that these carriages could be moved in and out of the field to extend leaf reach. It must be recognized that this design introduces a limitation (that was deemed acceptable by the study referenced above) in that the position of the most extended leaf on any one side of the field cannot exceed the most retracted leaf by more than 14.5 cm. This is because the total length of a leaf projected to the isocenter position is 14.5 cm. This is much shorter than the 32 cm reach of either the Elekta and Seimens systems. However, given the restriction in the reach, when the movement of the carriages is included, the Varian leaves can be positioned even further across the field midline (16 cm). The Varian design has a major advantage in that it is possible for a leaf moving from one side to pass its two neighboring leaves from the opposite side. This ability to interdigitate leaves results from the fact that maximum leaf extension from the last support point is only 8 cm for the Varian collimator compared to 12 cm for the Elekta MLC. The shorter reach allows for better control of leaf trajectories so that they do not deviate from their desired path as they extend toward the opposite bank. The ability of leaves to pass neighboring, opposed leaves is important for some intensity modulation segmentation techniques (**see reference 2**). Also, although Varian has not yet allowed movement of the carriage during dynamic MLC dose delivery, the carriage design has the potential of providing a larger field coverage for intensity modulated dose delivery.

4. Backup or Follower Jaws

Both the Elekta and Varian MLCs have additional backup jaws that travel in the same direction as the MLC and are full in the sense that they are not segmented. The Siemens MLC does not use this design. As pointed out previously, the approach used for the Varian collimator was to add the MLC below the existing full thickness field shaping jaws. The Elekta approach was to work with the same model previously employed for alloy blocks. That is, the MLC is designed to give a transmission through the portion of the field that is shaped that is on the order of 3 to 4% which is similar to the number for alloy blocks. A follower jaw closes to the position of the most retracted leaf and holds the leakage for the surrounding area to 0.5% of the open field value. Since the Elekta collimator extends from the edge of a 40x40 cm opening, it is not necessary to have a full thickness backup system because the two jaws always work together to bring the leakage radiation down to 0.5%. With this design, placing a thin follower jaw (see **Figure 1**) programmed to always align with the most retracted leaf saves space. This is an important part of the Elekta design because this company mounts an automatic wedge in the head of the machine. Like dynamic wedging, this device eliminates the need to enter the treatment room, by occupies significant space in the treatment head. Overall, however, the Elekta design provides more clearance than the Varian approach. The Varian approach shields the area surrounding the shaped portion of the field to a leakage level that is much lower than the required 0.5% of the open field value. This is necessary because the carriage design will cause "peek through" regions when the collimator is extended too far across the field.

5. Leaf Stepping and Dose Undulation at an MLC Edge

Varian has now introduced a new collimator with narrower (0.5 cm) leaves near the field center. As stated above, studies (including **reference 3**) have shown that daily setup variations blur divergent block edges and MLC edges to the extent that they are indistinguishable. It should be added that reference 3 was based on a previous study (**reference 6**) that demonstrated state-of-the-art immobilization and patient positioning at the time the study was undertaken. This would have been about 1990. With the current trend toward on-line imaging and possible daily CT localization, the argument that 1.0 cm wide leaves are acceptable may not hold. Another technique for removing the dose stepping that occurs at the edge of an MLC defined field was first presented by Galvin, Leavitt, and Smith (**reference 7**). The technique dithers the treatment table to remove the dose undulation. Siemens has automated this approach for use with their collimator. The problem with this technique is that while the collimator is in one of several irradiation positions, small portions of the field that need irradiation are shielded while other portion not needing radiation are treated. Although the shielded areas may be treated and the treated areas may be shielded in the next segment, since radiation cannot be subtracted from treated areas, the method will not produce a dose distribution that is equivalent to smaller leaves. That is, the distribution will not converge to the sharp, smooth edge obtained with divergent alloy blocks. Instead, adding more and more segments removes the dose scalloping, but the penumbra converges to a width of the "effective penumbra" which is wider than the block penumbra width in situations of severe leaf stepping. The effective penumbra is defined for an MLC edge with leaf stepping (see **reference 4**) as the perpendicular distance between a line joining the valleys of a low isodose line (say 20%) and a line joining the peaks of a high isodose line (say the 80%).

It is interesting to directly compare the dose undulation at MLC edges for the three available systems (see **reference 8**). This comparison was carried out with the Varian MLC with 1.0 cm leaves. Since the Varian collimator is nearer the patient, it produces the most dramatic dose undulation when the leaves are stepped. In comparison, the distribution for the Elekta collimator is blurred. The Siemens collimator is similar to the Varian distribution. This does not necessarily mean that the Elekta collimator is better. Daily setup variations in patient positioning will tend to blur all edges during the treatment. However, the more pronounced stepping seen on Varian port films is visually disturbing to some clinicians, and the blurred Elekta edge is more easily accepted. However, it is important to remember that what is seen on a port film does not necessarily represent what is happening in the patient when daily setup variations are taken into account and when a number of fields are added to the one seen on the film.

B. ACCEPTANCE TESTING, COMMISSIONING, AND QUALITY CONTROL

1. Tests for Standard Secondary Adjustable Jaws

The tests utilized for accepting, commissioning, and routine QA of a multileaf collimator are similar to the ones that have been used for many years for secondary adjustable jaws. An excellent method for testing and aligning standard adjustable jaws is given in **reference 1**. Some tests must be added to handle the differences that exist between the modern version of a multileaf collimator (the commercially available Elekta, Siemens and Varian MLCs) and more traditional, single-element jaw systems. One obvious difference is the result of separating a standard jaw into a series of individual segments for the multileaf. This means that each leaf must be viewed as a separate unit, and tested independently. Fortunately, for most of the procedures suggested here, it is possible to test the leaves together and look for situations where a particular leaf deviates from a desired pattern formed by the rest of the leaves. This greatly simplifies the process so that acceptance testing, commissioning and QA of an MLC is not much more difficult than what must be done for more traditional field shaping approaches. That is, compared to the tests that would typically be carried out for standard jaw systems used together with alloy block fabrication equipment, approximately the same amount of time and effort is required. It is important to remember that commissioning and QA for blocks has to included procedures that test proper construction of the blocks as well as accurate mounting on the block support trays.

The fact that the multileaf collimator consists of a number of separate elements, the leaves, does create some special considerations that must be included in the acceptance testing, commissioning measurements and QA procedures. Placing the leaves side-by-side to form a single bank introduces the possibility of radiation leakage between neighboring elements. A tongue-and-groove arrangement is used to minimize leakage between leaves, but this design creates another problem that was identified (**references 5 and 2**) soon after the introduction of the modern multileaf collimator. The tongue-and-groove effect is the result of the fact that the tongue of one leaf traverses the same space as the groove of its neighboring leaf. This overlap gives rise to a region of low dose when, for example, a multileaf collimator is used to abut two fields. An example would be the use of a single isocenter technique along with the MLC to abut an anterior field with two lateral fields. The region of low dose is not large, but it should be documented as part of the test procedure for a new collimator.

As discussed briefly above, an additional issue is the dose pattern that occurs at the edge of a field defined by MLC. Multileaf collimator field shaping differs from the use of divergent, shaped alloy blocks in that the leaves must be stepped in order to follow an irregular field edge. This stepping of the leaves causes a distinct scalloping of the dose pattern that should be understood by the physicists, dosimetrists and physicians using a multileaf collimator. This means that the commissioning process should include some effort to represent the true dose distribution Information for some collimators exists in the literature (see, for example, **reference 3**), and can be used to educate clinicians about the differences between multileaf and alloy block field shaping.

For the tests and procedures listed below, there is not a single set of measurements that apply to all three of the available collimators. This is because, as pointed out above, designs are different. In the tests given, the adjustments to the procedures that are needed to account for differing designs will be pointed out.

The tests recommended for standard adjustable jaw systems are listed as follows:

TESTS FOR STANDARD ADJUSTABLE COLLIMATORS

1. Collimator position accuracy including readout and isocentricity.
2. Penumbra width as a function of leaf position.
3. Light/x-ray field agreement.
4. Radiation leakage through collimator.
5. Interlocks.
6. Collimator speed including acceleration and deceleration.

All of the tests listed should be performed during acceptance testing. Leakage through the collimator need not be repeated during commissioning or as part of routine QA. The assumption is that leakage through the collimator will not change with time. As discussed in detail below, this may not be the case for MLC devices. The remaining tests should be part of all three processes, but the methodology used for each case may differ. The example, a simple visual check of radiographs of different field openings is usually adequate documentation that jaw faces properly track beam divergence. Thus, for routine QA, this simple test can be used in place of the more extensive scanning that should be carried out as part of the commissioning process or the somewhat abbreviated scanning done at the time of acceptance testing. Detailed descriptions of the tests recommended for each of the three different processes (acceptance, commissioning, and QA) are given below.

2. Tests for Multileaf Collimators

In addition to the standard tests described above, the special considerations for multileaf systems are listed as follows:

TESTS SPECIFICALLY FOR MLC

1. Between-leaf leakage and leakage with “follower” jaws (if provided).
2. Dose distribution at tongue and groove overlap region.
3. Interlocks for “follower” jaws.
4. Generation of leaf shapes and the file transfer process.
5. Dose distribution at stepped edge.

When backup or follower jaws are used, tests must be included to guarantee that they are always adjusted, along with the orthogonal jaws, to the smallest rectangle conforming to the irregular shape described by the MLC. Interlocks that either warn or prevent treating with the follower jaws retracted, more than necessary, must be checked. During MLC testing, it is also necessary to incorporate some procedures that verify the ability of the system to correctly handle the transfer of MLC coordinate files and to faithfully reproduce a series of standard shapes. These tests are analogous to those used for cerrobend block fabrication and mounting equipment.

Measurement of between-leaf leakage is an important part of acceptance testing for MLC. These acceptance test results can be made a part of the commissioning report, or repeat measurements can be taken during commissioning. Unlike the situation for standard adjustable jaws, it is not true that MLC leakage will remain unchanged with time. While through-the-leaf leakage will not change, wear of the mechanisms that control the trajectory of the leaves across the field can allow some leaves to shift and close the gap used to reduce friction. Leaves moving together will cause enlarged separations somewhere else in the leaf bank, and the pattern of between-leaf leakage will change. For this reason, between-leaf leakage should be measured initially and repeated periodically throughout the life of the MLC. The measurement procedure should be carefully controlled so that the initial data forms the baseline for comparison to later measurements. A visual comparison of the leakage pattern as seen on a transmission radiograph of the MLC is usually sufficient to detect problems. Although, scanning of the pattern obtained when the MLC is first commissioned is desirable so that this data can be compared to a subsequent scan when it is suspected that the MLC needs overhaul or replacement. As a technique for detecting shift of leaves due to gravity, comparison of transmission radiographs for the four major gantry angles (0, 90, 180, 270 degrees) is recommended.

As stated above, the dose distribution at a stepped MLC edge is important for educating clinicians about the difference between this new field shaping technique and the use of divergent cerrobend blocks. These distributions will not change with time and need not be repeated after the commissioning process. However, as discussed in detail below, these distributions are hard to determine because a small detector is required to resolve the rapid dose changes. It is better to use information currently available in the literature (see **references 3 and 10**) to represent the stepped edge dose distribution than to try to measure these distributions with an inappropriate detector. Distributions for a different manufacturer should not be used because of the strong dependence of the dose scalloping on MLC positioning relative to the x-ray target.

A simple film double-exposure method (see **reference 5**) can be used for quantifying the dose reduction in the overlap region of the tongue and groove. This distribution is helpful for understanding the dose variations that occur when MLC is used to abut fields. However, it is important to point out that daily setup variations will spread the approximately 25% dose depression that results from tongue-and-groove overlap at the edge of two abutted fields so that the overall effect is unimportant for fractionated treatment.

As was the case for the standard tests described previously, these special MLC tests must be assigned to one or more of the categories of acceptance testing, commissioning, and routine QA. This separation is made below, and the details of the different test are also given.

3. Tests for Intensity Modulated Radiation Therapy (IMRT)

The acceptance, commissioning and routine quality assurance for a multileaf collimator intended for IMRT can be different than what is suggested above for simple block replacement. IMRT can require much tighter tolerances on the control of leaf movement in terms of leaf speed, positioning accuracy, between-leaf transmission, and through-leaf leakage. For example, if a 10 cm wide field is to be homogeneously irradiated by sweeping a 1.0 cm wide slit from one side to the other, a 1.0 mm error in the positioning of one leaf bank will result in an approximately 10% error in the delivered dose. Additionally, as pointed out some time ago, leakage radiation reaching the patient's whole body and individuals outside the treatment room will increase substantially (see **references 9 and 2**). In this case, leakage dose will increase by about a factor of 9 relative to the situation where a single open field is used. Between-leaf leakage, leaf speed control, and leaf positioning accuracy can change with time and must be periodically checked and compared to acceptance and commissioning values. Using a step-and-shoot sliding window instead of a dynamically moving slit lifts the requirement that leaf speed be tightly controlled. The superimposed field technique for IMRT field segmentation (see **reference 2**) will produce lines of over and under exposure running perpendicular to the direction of leaf movement when the leaves are not accurately positioned. For this reason, when an MLC is used for IMRT, the ±2mm position accuracy recommended for alloy blocks should be reduced to ±0.5 mm. Thus, tests that can demonstrate positional accuracy at this level must be used.

SPECIAL TESTS FOR IMRT

1. Leaf speed control (for dynamic dose delivery).
2. Leaf position accuracy and isocentricity. (same tests as above, but tolerance reduced to ±5 mm)

4. Importance of Detector Size

Many of the measurements described here require a very small detector size. This is because the dose fall-off at the edge of any beam defining device can be extremely sharp (approximately 15% per mm). Another example is the very narrow peak in the transmitted dose that occurs between closed leaves. Measurement of between-leaf leakage with a detector of inappropriate size will lead to results that differ widely from those reported in the literature. Film is an ideal dosimeter for most of the measurements described here, but a scanning densitometer with a sufficiently small spot size must be used for analysis. A spot size of 0.5 mm diameter is recommended. If equipment with this level of resolution is not available, all measurement must be interpreted with great care.

5. Recommended Tests and Tolerance Limits

ACCEPTANCE TESTING

1. Leaf Position Readout and Isocentricity

   Test: see procedure A
   Tolerance limits: ±1.0 mm for isocenter (zero position) & ±2.0 mm for other leaf positions

2. Penumbra Width as a Function of Leaf Position

   Test: D_{max} and 10 cm depth beam profiles for different field sizes using an appropriately small detector
   Tolerance limits: 80 to 20% penumbra changes by less than 1.5 mm for a range of 10 cm over field center line to 15 cm back from center

3. Light/x-ray Field Alignment

   Test: use any of the many traditional tests available
   Tolerance limits: ±2.0 mm agreement for any edge for small, medium & large fields

4. Radiation Leakage Through Collimator and Between Leaves With and Without Backup Collimators

   Test: see procedure B
   Tolerance limits: leakage peaks between leaves should not exceed transmission through a standard 3 inch thick cerrobend block for the photon energy tested

5. Interlocks

   Test: see procedure C
   Tolerance limits: see manufacturer specs

COMMISSIONING

1. Leaf Position Readout and Isocentricity

   Test: see procedure A
   Tolerance limits: a) ±1.0 mm for isocenter (zero position) & ±2.0 mm for other leaf positions for block replacement
   b) ±0.5 mm for IMRT

2. Penumbra Width as a Function of Leaf Position

   Test: D_{max} and 10 cm depth beam profiles for different field sizes using an appropriately small detector
   Tolerance limits: 80 to 20% penumbra changes by less than 1.5 mm for a range of 10 cm over field centerline to 15 cm back from center

3. Light/x-ray Field Alignment

   Test: use any of the many traditional tests available
   Tolerance limits: ±2.0 mm agreement for any edge for small, medium & large fields

4. Radiation Leakage Through Collimator and Between Leaves With and Without Backup Collimators

   Test: see procedure B
   Tolerance limits: leakage peaks between leaves should not exceed transmission through a standard 3 inch thick cerrobend block for the photon energy tested

5. Interlocks

   Test: see procedure C
   Tolerance limits: see manufacturer specs

NOTE: Tests 2, 3, 4, & 5 are exactly the same as the ones listed for Acceptance Testing. Test 1 is the same as long as the MLC is not to be used for IMRT. Tests performed during Acceptance Testing do not need to be repeated as long as a copy of the test results for Acceptance is included as part of the Commissioning Report.

ROUTINE QUALITY ASSURANCE

1. Leaf Position Readout and Isocentricity

   Test: see procedure A
   Tolerance limits: a) ±1.0 mm for isocenter & ±2.0 mm for leaf position for block replacement
   b) ±0.5 mm for IMRT
   Frequency: monthly for block replacement and weekly for IMRT

2. Penumbra Width as a Function of Leaf Position

   Test: D_{max} and 10 cm depth beam profiles for different field sizes using an appropriately small detector
   Tolerance limits: 80 to 20% penumbra changes by less than 1.5 mm for a range of 10 cm over field center line to 15 cm back from center
   Frequency: semiannually

3. Light/x-ray Field Alignment

   Test: use any of the many traditional tests available
   Tolerance limits: ±2.0 mm agreement for any edge for small, medium & large fields
   Frequency: monthly

4. Radiation Leakage Through Collimator and Between Leaves With and Without Backup Collimators

   Test: see procedure B
   Tolerance limits: leakage peaks between leaves should not exceed transmission through a standard 3 inch thick cerrobend block for the photon energy tested
   Frequency: semiannually

5. Interlocks

   Test: see procedure C
   Tolerance limits: see manufacturer specs
   Frequency: monthly

6. File Transfer and Faithfulness of Standard Field Shapes

   Test: see procedure D
   Tolerance limits: ±2 mm
   Frequency: monthly

6. Specific Procedures

Procedure A - Leaf Position Readout and Isocentricity

LEAF POSITIONING AS A FUNCTION OF COLLIMATOR ROTATION

1. Define a 10x5 cm field using the MLC and with one leaf bank at the zero position as shown in **Figure 2**. That is, produce a "center-blocked" 10x5 cm field.
2. Place a film in a paper envelope on the patient support system at the isocenter distance. Place appropriate build-up material on top of the film. With the treatment unit directed vertically downward, expose film to produce a medium optical density.
3. Without moving the film, rotate the collimator by 180 degrees. Expose film with same number of Monitor Units used for step #2.
4. Develop film and observe the line were two fields abut. The film can be scanned with a densitometer to quantify the results.
5. Dose homogeneity across the abutment region demonstrates proper leaf calibration for the zero position. A low-density region indicates that the leaf is positioned too far into the field, and an increased density shows that the leaf is withdrawn from the true field centerline.
6. Measure from the center of the abutment line to the opposed leaf bank to determine calibration accuracy for the "5 cm withdrawn" position for these leaves.
7. Rotate collimator by 90 degrees and repeat steps 1 to 6.
8. Repeat steps 1 to 7 with the leaf positions reversed. That is, with a mirror image "center-blocked" 10x5 cm field.
9. The above measurements check the calibration of the central 10 leaves of each leaf bank for the zero and 5 cm withdrawn positions. The procedure checks calibration as a function of collimator rotation. Calibration of the remaining leaves and for other leaf positions is accomplished by comparing to these four known positions. This is accomplished by irradiating other known field sizes and always including a previously calibrated position as one side of the field. For example, if a radiograph of a 40x15 cm field with one edge falling at the beam centerline is obtained, the leaf bank withdrawn by 15 cm can be calibrated against the opposed bank which is positioned along the field centerline. The procedure can be repeated until all leaves are calibrated at the following positions: 10 and 5 cm over the field center, at the field center, 5, 10, 15 and 20 withdrawn from the center.

LEAF POSITIONING AS A FUNCTION OF GANTRY ROTATION

1. Define a 10x5 cm field with the MLC and with one leaf bank at the zero position as shown in **Figure 2**. That is, produce a "center-blocked" 10x5 cm field.
2. Place a film in a paper envelope "on end" on the patient support system at the isocenter distance. Use plastic sheets to provide build-up material and to support film in the vertical position. Turn the gantry to point horizontally across the treatment room. Expose film to produce medium optical density.

3. Without moving the film, rotate the gantry by 180 degrees. Expose film with same number of Monitor Units used for step #2.
4. Develop film and observe line were two fields abut. The film can be scanned with a densitometer to quantify the results.
5. Acceptable leaf calibration at the zero position is confirmed by dose homogeneity across the abutment region. A low-density region indicates that the leaf is positioned too far into the field, and an increased density shows that the leaf is withdrawn from the true field centerline.
6. Repeat steps 1 to 6 with the leaf positions reversed. That is, with the mirror image "center-blocked" field.
7. Repeat steps 1 to 6 with film lying flat on patient support system and starting with treatment unit pointing vertically downward.
8. For both films, measure distance from field center to opposite leaf bank. This measurement can be used to detect any change in leaf position due to gravity.

Procedure B – Leaf Transmission and Between-leaf Leakage

NOTE: The design of MLC systems for different manufacturers is significantly different. For this reason, a different procedure must be used to measure transmission and leakage for each system. The Varian system is most simple because of the tertiary design. In this case, the standard adjustable jaws can be used to define a 10x10 cm field. The MLC leaves can be moved in and out of this opening to produce a transmission radiograph of the leaves, and a calibration measurement for the open field. The ELEKTA system is more complex because the leaves cannot close against each other and the "follower" diaphragms automatically track to the most retracted leaf on a particular side. Siemens is different in that they do not use a backup jaw for the leaves. Given these differences, the physicists must be creative in obtaining the field shapes required for the procedure that follows.

1. Define a 10x10 cm field and irradiate a series of films at D_{max} depth to obtain a film calibration curve. Place this film at a distance corresponding to the calibration conditions for the treatment unit.
2. Extend the leaves across the field to close the opening. Irradiate a film at D_{max} depth to obtain a transmission radiograph of the leaves. The Monitor Units used for this exposure are calculated using the following guidelines. Between-leaf leakage will fall in the range of 2-5% depending on the manufacturer of the MLC. Transmission through the leaves will be on the order of 1-4%.
3. Scan the transmission film and convert the measured densities to dose. Determine the dose per Monitor Unit for different regions. Divide the Monitor units into the measured dose at each point to find the transmission and leakage for the collimator.

Procedure C - Interlocks

The difference in the design of MLC systems for different manufacturers complicates these tests also. Basically, the interlock tests are aimed at determining that backup jaw move to the correct position so that leakage radiation is minimized. Unlike the other systems, the Varian design has the potential for allowing “peak through” when a leaf is extended too far ahead of its neighbor. Interlocks are provided to guarantee that this does not occur. These interlocks must be tested. Varian does not force the backup jaw to conform to the smallest possible rectangle surrounding the irregular opening, but warnings are provided when this is not the case. It is necessary to acknowledge this warning before proceeding with the treatment of a larger than necessary rectangular opening. This system should be tested. For the Siemens MLC, a backup jaw is not used. However, interlocks are provided to assure that the orthogonal jaw system closes to a position just outside the irregular shape defined by the MLC. This interlock should be tested.

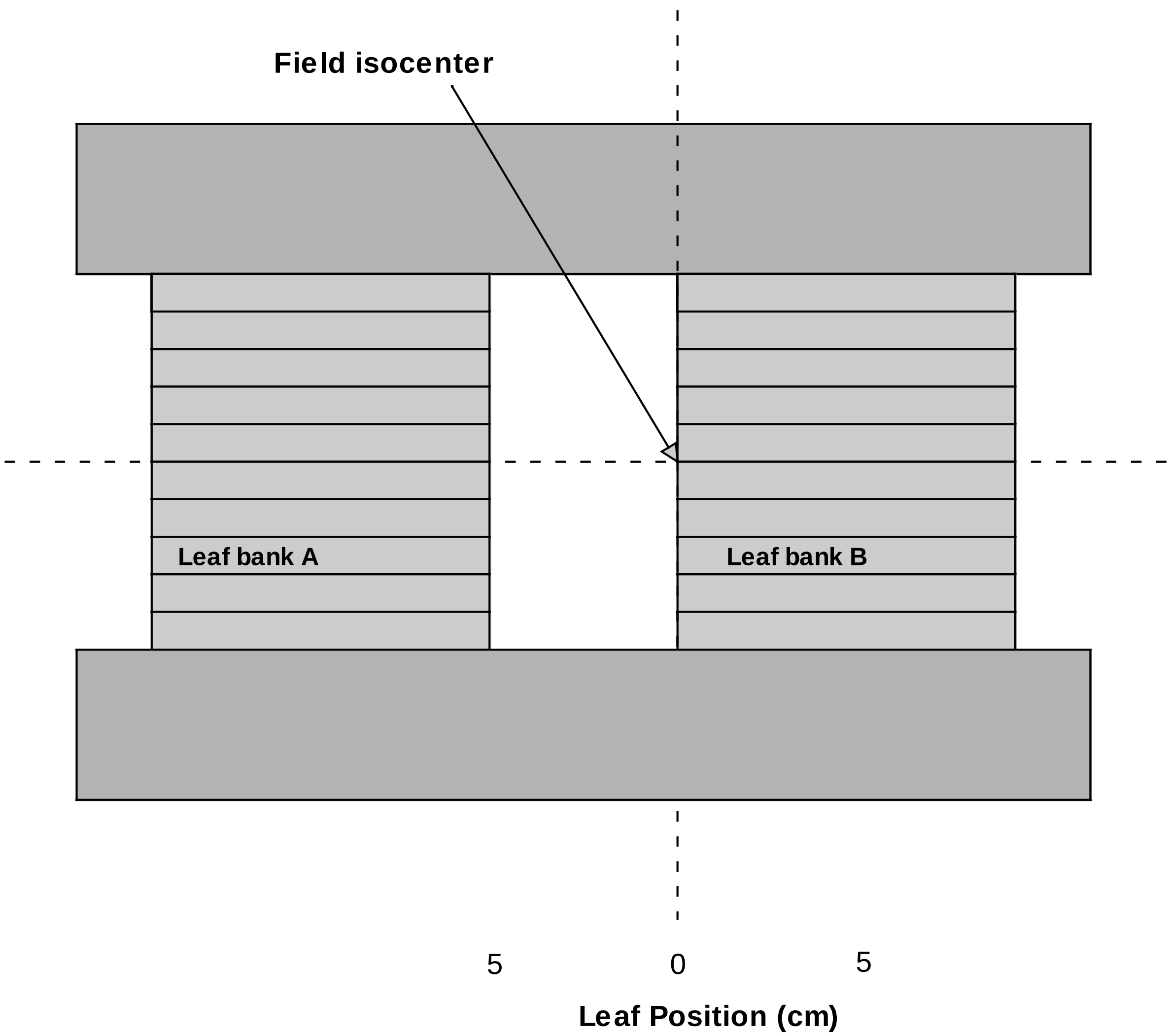

FIGURE 2

Each manufacturer should provide methods for testing the interlocks provided on their particular system. The physicist should examine the procedures to determine a reasonable set of tests to determine that all interlocks are functioning properly.

Procedure D – Testing of File Transfer and Faithfulness of Reproduction of Standard Field Shapes

1. Create a set of irregular field shapes by tracing on clear film and/or by producing contours within planning system.
1. Input the field shapes drawn on film using equipment provided by manufacturer or by direct file transfer from the planning system.
2. Direct MLC to move to shape.
3. Back-project shape using light field to check agreement with drawing on film or printout from planning system.

C. METER UNIT CALCULATIONS

The calculation of Monitor Units (*MU*) when blocks are used to shape a treatment field is accomplished using the following equation (see **references 11 and 12**). In this equation, *TD* is the prescribed dose, *TPR* is the tissue phantom ratio, *D* is the calibration dose,

$$MU = \frac{TD / TPR(r_{eq})}{D_{cal} \bullet S_c(r_c) \bullet S_p(r_{eq}, d_{ref}) \bullet TTF \bullet \left(\frac{SAD}{SPD} \right)^2}$$

TTF is the total transmission factor, *SAD* is the source-to-axis distance, *SPD* is the source-to-phantom distance, and S_c and S_p are the collimator and phantom scatter factors respectively. This equation involves two specifications of field size: r_{eq} as the equivalent size of an irregularly shaped field and r_c as the settings of the rectangular field that surrounds the irregular shape. *TPR* and S_p depend on the amount of photon scatter within the patient, and will change as the field shape changes. The magnitude of S_c is determined mostly by the amount of extended source that can be seen by a point of calculation. Since the extension of the source beyond the x-ray target is chiefly due to photons scattered from the flattening filter, any change in collimation that changes the amount of extended source seen at a point of calculation is important. However, because a view back toward the target diverges in the opposite direction relative to x-ray beam divergence, collimating devices nearer the patient are less important than collimators near the target. This means that blocks placed near the patient have little effect on S_c and the secondary adjustable jaws have a major effect. For this reason, S_c depends on the collimator settings r_c and not the equivalent square of the block shape r_{eq}. This same argument applies to the mounting of an MLC as a tertiary device below the secondary adjustable jaws. It does not apply to the replacement of one of the secondary jaws with the MLC. In this case, changing the shape of the field with the MLC will change the amount of the extended source seen by a calculation point in the patient. Palta et al (see **reference 12**) suggested a modification of the equation given above to reflect this difference.

$$MU = \frac{TD / TPR(r_{eq})}{D_{cal} \bullet S_c(r_{eq}) \bullet S_p(r_{eq}, d_{ref}) \bullet TTF \bullet \left(\frac{SAD}{SPD} \right)^2}$$

This equation should be used for any non-tertiary MLC arrangement. Notice that S_c in this equation depends on r_{eq} and not r_c. This means that an equivalent square calculation based on the irregular field shape must be done in order to select the correct value of S_c.

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