Multileaf collimator in radiotherapy

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Background. *Basic goal of radiotherapy treatment is the irradiation of a target volume while minimizing the amount of radiation absorbed in healthy tissue. Shaping the beam is an important way of minimizing the absorbed dose in healthy tissue and critical structures. Conventional collimator jaws are used for shaping a rectangular treatment field; but, as usually treatment volume is not rectangular, additional shaping is required. On a linear accelerator, lead blocks or individually made Cerrobend™ blocks are attached onto the treatment head under standard collimating system. Another option is the use of multileaf collimator (MLC).*
Conclusions. *Multileaf collimator is becoming the main tool for beam shaping on the linear accelerator. It is a simple and useful system in the preparation and performance of radiotherapy treatment. Multileaf collimators are reliable, as their manufacturers developed various mechanisms for their precision, control and reliability, together with reduction of leakage and transmission of radiation between and through the leaves. Multileaf collimator is known today as a very useful clinical system for simple field shaping, but its use is getting even more important in dynamic radiotherapy, with the leaves moving during irradiation. This enables a precise dose delivery on any part of a treated volume. Intensity modulated radiotherapy (IMRT), the therapy of the future, is based on the dynamic use of MLC.*

Key words: radiotherapy dosage; radiotherapy; multileaf collimator, field shaping

Introduction

Basic goal of radiotherapy treatment is the irradiation of a target volume while minimizing the amount of radiation absorbed in healthy tissue. Shaping of the beam is an important way of minimizing the absorbed dose in healthy tissue and critical structures.

Conventional collimator jaws are used for shaping a rectangular treatment field; but, as usually the treatment volume is not rectangular, additional shaping is required. On a linear accelerator, lead blocks or individually made Cerrobend™ blocks are attached onto the treatment head under standard collimating system. Another option that will be described in detail here is the use of multileaf collimator (MLC).

The MLC has movable leaves, which can block some fractions of the radiation beam.

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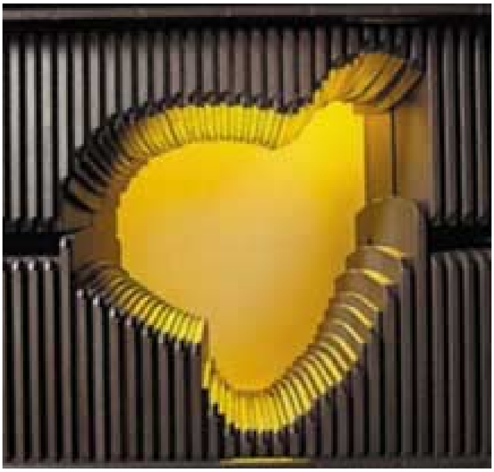

Figure 1. Multileaf collimator Varian Millenium MLC120.

Typical MLCs have 40 to 120 leaves, arranged in pairs (Figure 1). By moving and controlling a large number of narrow, closely abutting individual leaves, one can generate almost any desired field shape.[1]

The advantages of MLCs are simple and less time consuming preparation, use without needing to enter the treatment room, and simple change or correction of field shape. The therapy expenses are lower because individual shielding blocks are not needed, thus eliminating the need to handle the Wood's alloy, which is toxic. With MLC, we shorten the therapy time, and thus also the period during which patient must remain in still position. Other advantages are constant control and continuous adjusting of the field shape during irradiation in advanced conformal radiotherapy.[1-5]

MLC has also some disadvantages, which include a stepping edge effect, radiation leakage between leaves, wider penumbra, and problems with generating some complex field shapes.[2]

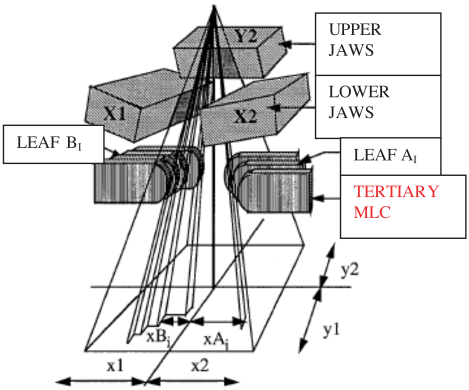

Figure 2. MLC and standard collimators positions in treatment head used in third level configurations.

MLC Configurations

MLC configurations may be categorized as to whether they are total or partial replacements of the upper jaws, the lower jaws, or as tertiary collimation configurations.

Upper jaw replacement

This configuration entails splitting the upper jaw into a set of leaves. In this design (used by Elekta™), the MLC leaves move in the y-direction (parallel to the axis of rotation of the gantry). A "back-up" collimator located beneath the leaves and above the lower jaws augments the attenuation provided by the individual leaves. The back-up diaphragm is essentially a thin upper jaw that can be set to follow the leaves if they are arranged together to form a straight edge, or else, set to the position of the outermost leaf if the leaves form an irregular shape.

The primary advantage of the upper jaw replacement configuration is that the range of motion of the leaves required to traverse the collimated field width is smaller. This allows a shorter leaf length and therefore a more compact treatment head diameter. The disadvantage of having the MLC leaves so near the source of radiation is that the leaf width must be somewhat smaller and the tolerances on the dimensions of the leaves and the leaf travel must be tighter than in other configurations.[1]

Leaves of this collimator have total travel distance 32.5 cm, which means they can extend 12.5 cm across the centre line.

Lower jaw replacement
The lower jaws can be split into a set of leaves as well. This design is used by Siemens™ and is double-focused. Both leaf ends and leaf sides match the beam divergence. That means that the collimator leaves move along the circumference of a circle centred at the x-ray target of the linear accelerator, such that the end of the collimator is always tangential to the radius of the circle.[1]

The leaves of Siemens MLC can extend 10 cm across the field centreline, which allows a maximum leaf travel of 30 cm.

Third level configurations
MLC can be positioned just below the level of the standard upper and lower adjustable jaws (Figure 2). This design is used by Varian™ and was chosen to avoid lengthy downtime in the event of a MLC system malfunction. Using this approach, it is possible to move leaves manually out of the field should a failure occur. The treatment can continue after the replacement Cerrobend™ individual blocks have been manufactured. The major disadvantage of placing the MLC below the standard jaw system is the added bulk and clearance to the mechanical isocentre.

Moving the MLC further away from the x-ray target requires increasing the leaves size and a longer travel distance.[1]

The leaves in the Varian collimator travel on a carriage that serves to extend their movement across the field. However, the distance between the most extended leaf and the most retracted leaf on the same side can only be 14.5 cm.

Materials and properties

The material of choice for leaf construction is tungsten alloy because it has one of the highest densities of any metal. Tungsten alloys are also hard, simple to fashion, reasonably inexpensive, and have a low coefficient of thermal expansion.

Interleaf transmission

There are two situations to consider for interleaf transmission: (1) between the sides of adjacent leaves, and (2) between the ends of the leaves.

In order to minimize the leakage between the sides, it is necessary to overlap the leaves usually by specially shaped side profile that steps out and then steps back again.[6]

To minimize leakage between the ends of closed opposite ends, it is important to know that the transmission decreases with increasing the off-axis distance.[7]

Leaf end shape

Multileaf collimators that are double focused (Siemens design) have flat leaf ends that follow the beam divergence. The leaf ends of Elektra and Varian MLC design are rounded.

There are two concerns over collimation by non-focused leaf ends. First, the penumbra

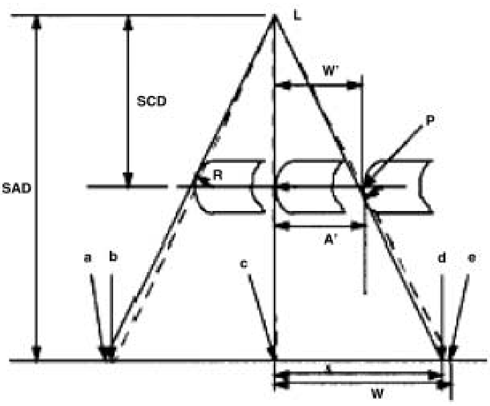

Figure 3. Rounded leaf ends and their influence on penumbra based on the position in the field.

width is larger than the penumbra generated by a focused or divergent edge. Second, the penumbra width might change as a function of the distance of the leaf end from the field midline (Figure 3). The measurements on the Elekta and Varian configurations have shown that these designs result in a little variation in the penumbra width as a function of leaf position and that the penumbra at any position is within 1-3 mm of that obtained with a focused system or with alloy blocks with divergent sides.[6-10]

MLC control features

MLCs produced by various manufacturers employ special mechanisms to move the leaves accurately to their prescribed positions.

Detection of the leaf position

The leaf position must be detected in real-time to achieve a safe and reliable position control. Linear encoders and video optical systems are most commonly used for detection.

Linear encoders

We can use many different linear encoders, but for detection of leaf positions in MLC systems high precision potentiometers are commonly used. These potentiometers can detect positions of any individual leaf in the system.

For safer work two potentiometers with correlated readings are used in this system.

Video-optical system

This system of detection uses the same light source for patient positioning and for leaf position recognition. A retro-reflector is mounted near the end of each leaf, and the light is reflected from it back to the camera. The obtained signal is digitized and processed with an image processor in the MLC controller.

The mechanism that drives a leaf

Each leaf has a small motor, which drives it precisely in the directions from the main unit. These rotations must than be translated to linear motion which moves the leaf to the desired position. Linear screw bars are normally used to translate rotations to linear motion. The speed of the leaf travel varies between 0.2 mm/s to as high as 50 mm/s, depending on the design.[1]

Clinical applications

Leaf placement strategies

To realize potential benefits of MLC, it is important that its use is incorporated into the

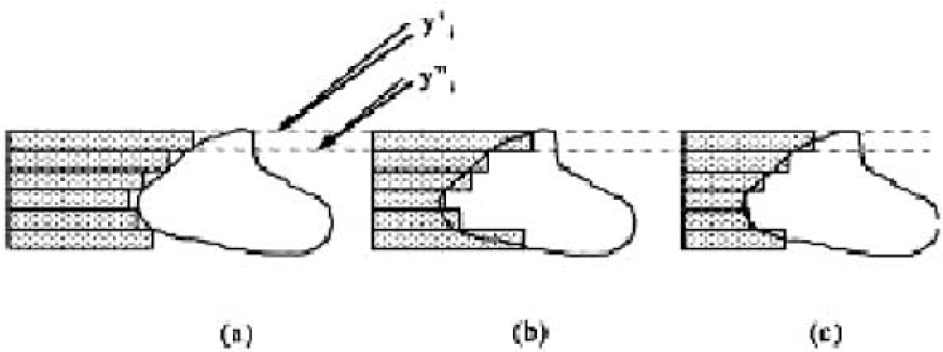

Figure 4. Three leaf coverage strategies in relation to the PTV, (a)"out-of-field" strategy; (b)"in-field" strategy; c)"cross-boundary" strategy.

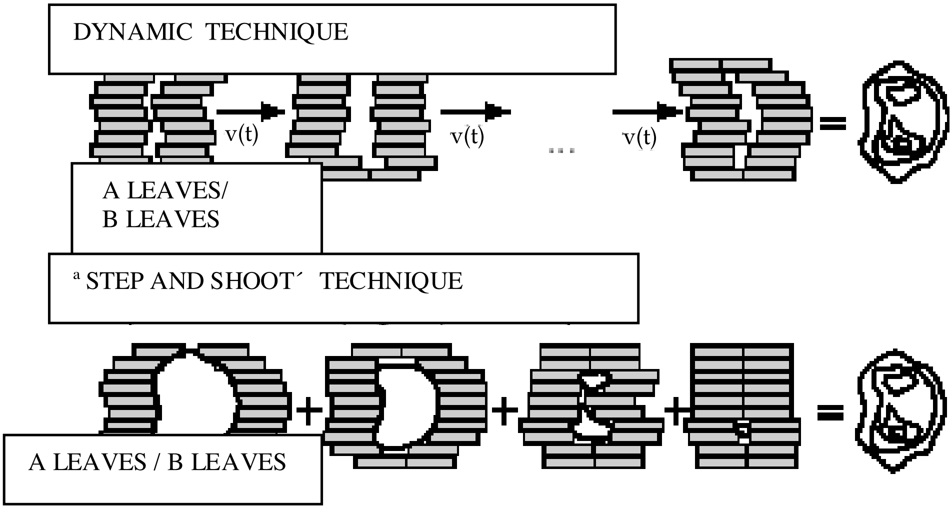

Figure 5. IMRT techniques with the use of MLC.

treatment planning process as efficiently as possible.

During the treatment planning process, manual placement of each of the 40-120 leaves is not acceptable due to time constraints. Therefore some automated method must be used in a treatment planning system (TPS). That way in TPS, the position of each leaf is defined so that the field encompasses the planning target volume (PTV). More specifically, the determination of the MLC positions is carried out by means of the following steps:

Definition of target area

Treatment planning system facilitates shaping leaves around PTV, as defined by a radiation oncologist. An accurate definition of PTV is crucial for the success of the therapy.[11]

Optimization of MLC conformation

To place automatically the leaves of MLC in conformity with the target contour shape, three leaf coverage strategies can be used (Figure 4).

Each strategy uses different position of the leaf in relation to the contour of the field that we want to irradiate.

The "out of field" strategy (4a) avoids shielding any part of the planning target volume-PTV, which is than irradiated completely.

When using the "in field" strategy (4b), PTV is not irradiated completely, but any part out of PTV stays shielded.

The most widely used method is cross-boundary technique indicated in panel (c) of Figure 4. One condition for optimizing the leaf positions was criterion that the in-field area was equal to the out-of-field area.[4]

Optimization of collimator rotation

One can optimize matching the leaf shape to target volume by rotating the collimator, and therefore, the direction of leaf travel. An example is the alignment of the leaf faces with the spinal cord axis, when the cord is close to the target volume. Brahme, in his conclusion of work said, that optimal direction for the leaf motion is the direction along the narrower axis. For a simple ellipse, the optimal leaf direction is parallel to the short axis.[12]

Intensity modulated radiotherapy (IMRT) with multileaf collimator

The basic goal of IMRT treatment is precise dose delivery on any part of treated area thus avoiding the surrounding healthy tissue. In IMRT treatment, the leaves of MLC, while moving during the irradiation, ensure the appropriate dose that is delivered on the parts of treated area (Figure 5).

From the differences between the dose volumes delivered during the whole treatment and the dose volumes in which the leaf is shielding some part of the treated area, we can determine what dose has been delivered on this particular part. MLC for intensity modulation should be very precise, motion of leaves must be fast and constant, leaves should be precisely controlled and must have a long reach in the field. Three dimension (3D) treatment planning systems must be used for IMRT.

Two strategies of IMRT with multileaf collimator are used. One is dynamic technique, with continuous movement of leaves during the treatment; the second is step and shot technique with moving the leaves when radiation is stopped. Both strategies with this travel determine dose delivered on the parts of treatment volume.[2]

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