FIELD COMPENSATION; DOSIMETRIC ASPECTS OF DYNAMIC DELIVERY WITH INDEPENDENT COLLIMATORS AND MLC

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Objectives:

1. Describe the application and dosimetric aspects of independent collimators
2. Describe the principles and dosimetric aspects of filterless wedges
3. Describe the general principles of field compensation and intensity modulation
4. Describe dosimetric aspects that are specific to intensity modulation with a MLC system

Application and Dosimetric Aspects of Independent Collimators

All modern linear accelerators (linac's) contain collimators with the ability to move independently. Both the upper, or Y-collimators (defined here as Y1 and Y2), and the lower, or X-collimators (X1 and X2) are capable of a range of motion independent of the position of the opposite jaw. This ability has greatly enhanced the flexibility of treatment planning, both for conventional and newer techniques.

A number of specific examples demonstrate the practical benefit of this ability. Conventional split-field techniques such as used for head and neck treatments are improved by the use of single isocenter to avoid the "cold triangles" contained within more traditional techniques. Newer field matching techniques have demonstrated benefit matching IMRT field arrangements with conventional fields using the independent collimator[1,2]. Gaps traditionally made when matching with previously-treated field can be reduced or eliminated entirely when independent jaws are used to minimize divergence differences between the fields. Feathering fields during treatment is often more easily accomplished with independent jaws. Finally, independent collimation obviates the requirement for accurate isocenter placement, which may become more frequent as CT-simulation replaces conventional simulation equipment.

With asymmetric fields, the point of calculation is often displaced from the central axis by some distance. Care must be made when determining and/or verifying dosimetry of off-axis points. A number of techniques have been proposed for manually determining the dose to off-axis dose, which may be divided into two classes: determination of off-axis dosimetry functions (e.g., TMR, Sp), or use of an off-axis ratio (OAR) along with central-axis dosimetry functions. The latter technique is perhaps most widely used, primarily with the use of large field profile data as described by Khan *et al.*,[3]. However profile data contains both primary and scatter components, the latter of which decreases with off-axis position due to the reduced effective field size. Chui and Mohan[4] modified this approach by using primary off-center ratios (POCR) to describe the modification of the primary dose, along with boundary factors to account for points near blocks and/or collimators. Primary off-axis ratios may be directly measured in-air under good geometry conditions[5], or extracted from profile data. Several analytic approaches have also been introduced[5-7] which attempt to remove the scatter component from the measured dose profile. A comparison of techniques for a number of off-axis position, field sizes, and energies demonstrates good overall agreement using dose profile data (average error 2.5%), with the largest discrepancies occurring at large depths and off-axis distances (maximum error 6.7%). Primary off-axis ratios used independently demonstrate improved results, with an average error of 0.8% and a maximum error of <2%.[5]

Principles and Dosimetric Aspects of Filterless Wedges

After Elekta's release of the Omni-wedge[8] upgrade, each of the three major manufacturers now offer some form of filterless wedge. Filterless wedges create wedged-shape isodose distributions by sweeping a collimator or diaphragm across the field in order to produce a differential fluence profile equivalent to that produced by a physical wedge attenuator. Initially proposed by Kijewski[9] the dynamic wedge (DW) was first introduced by Varian in the early 1990s[10]. This utility is driven by a segmented treatment table, or STT, which governs the jaw position as a function of delivered monitor units (MUs). The dynamic wedge STT specifies the moving jaw position in equally spaced steps as a function of the cumulative fractional dose; beginning with the open field size and ending with the jaws in the final ‘‘closed’’ position. Stored within the accelerator's computer are STTs for each available energy, field size, and wedge angle. Although this approach allows for the optimization of the wedge design for each particular field arrangement, the required commissioning tasks place a practical limit to the number of possible DW treatment parameters. In the initial release 128 different STTs were stored for each available photon energy.

More recently, Varian has released the enhanced dynamic wedge (EDW) treatment modality[11-13]. Like the DW, the EDW uses segmented treatment tables to govern the position of the moving jaw with delivered monitor units. The EDW, unlike its predecessor, is based on the concept of a universal wedge in which an isodose distribution from an intermediate size wedge may be produced by the linear combination of the distributions from an open field and a maximum (e.g., 60°) wedge field. This approach has greatly reduced the amount of stored data required for the EDW as well as increased its performance. Any field size within the limits of jaw motion is possible, whether or not symmetric. Any wedge angle less than 60^o may be calculated, although the current implementation limits to seven programmed wedge angles. Programmed MUs are equivalent to the total MUs delivered in the beam.

The Siemens Virtual Wedge uses an analytic equation as described by van Santvoort[14] to determine the jaw position. This differs from the tabular control mechanism of either the Varian or Elekta approaches. Dose rate is varied by up to a factor of eight as the jaw sweeps across the field to produce the exponential fluence distribution. Unlike EDW, the jaw speed is constant, with the treatment parameters (jaw speed, dose rate, etc..) optimized to minimize the total treatment time. Siemens virtual wedge has the same restrictions as Varian in the Y, or upper jaw motion limitations, but allows X jaw motion as well, if no MLC is present. A continuous number of wedge angles are possible, specified from 15^o to 60^o. Unique to the virtual wedge is a wedge factor near unity (WF = 1 ± 0.05) for all field sizes and wedge angles. This is produced by taking the programmed MUs as the number of MUs the central axis is contained within the field.

Recently, Elekta has released the Omni-wedge[8] package which combines its traditional internal, or Autowedge, with a filterless wedge produced by the moving diaphragm under the MLC leaves[15]. Unlike Varian or Siemens, Elekta uses a step-and-shoot approach where the diaphragm is moved (approximately 1 cm projected to isocenters) between beam on intervals. The table is similar to the golden STT used by Varian, although corrections are made to account for the larger transmission (approximately 10%) through the diaphragm.

A brief comparison of the three systems is displayed in Table 1.

Table 1. Comparison of Three Filterless Wedge Systems

Description	Varian	Siemens	Elekta
Max Field Size	30 x 40 (Y)	30 x 40 (Y) 20 x 40 (X)*	27 x 40 (Y)
Wedge Angles	10,15,20,25,30, 45,60	15-60, continuous	15-60, continuous
Algorithm	STT Table	Analytic	Table
Initial State	Open Field	1 cm Field	Open Field
Programmed MU	Total MU delivered	MU CAX within field	Total MU for full field size
Wedge Factor	Strong Field Size dependence	Weak Dependence (≅1)	Weak dependence (≠1)

Dosimetry for the three systems varies due to differences in system design. Typical commissioning measurements involve at a minimum the measurement of profiles and wedge factors (WFs). Naturally, water scanning equipment may not be used in a conventional manner as the fluence distribution is not defined until the completion of treatment. Fortunately, filterless wedges have been shown to be equivalent to open field profiles for both depth dose[10,11] and non-gradient off-axis profiles. Wedge profiles have been measured by point integration[16], film[17], as well as detector arrays of diodes and ion chambers[18]. Agreement of any systems with ion chamber measurements is prudent to confirm the accuracy of the detection method. Displayed in figure 1 are results from Zhu et al.(ref), which demonstrate agreement between a commercial diode array system and an ion chamber measurement.

Wedge factors for the EDW vary significantly with field size. Figure 2 displays measured WFs versus field size for a 6 photon beams. The field size dependence differs substantially from that demonstrated by either the Siemens or Elekta implementation, which are displayed in Figures 3 and 4 respectively.

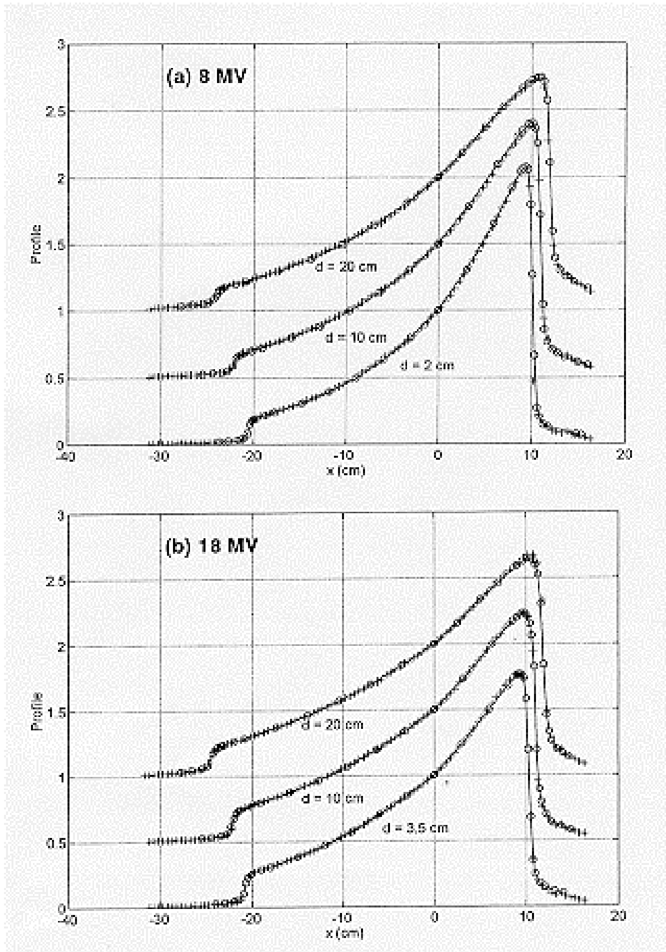
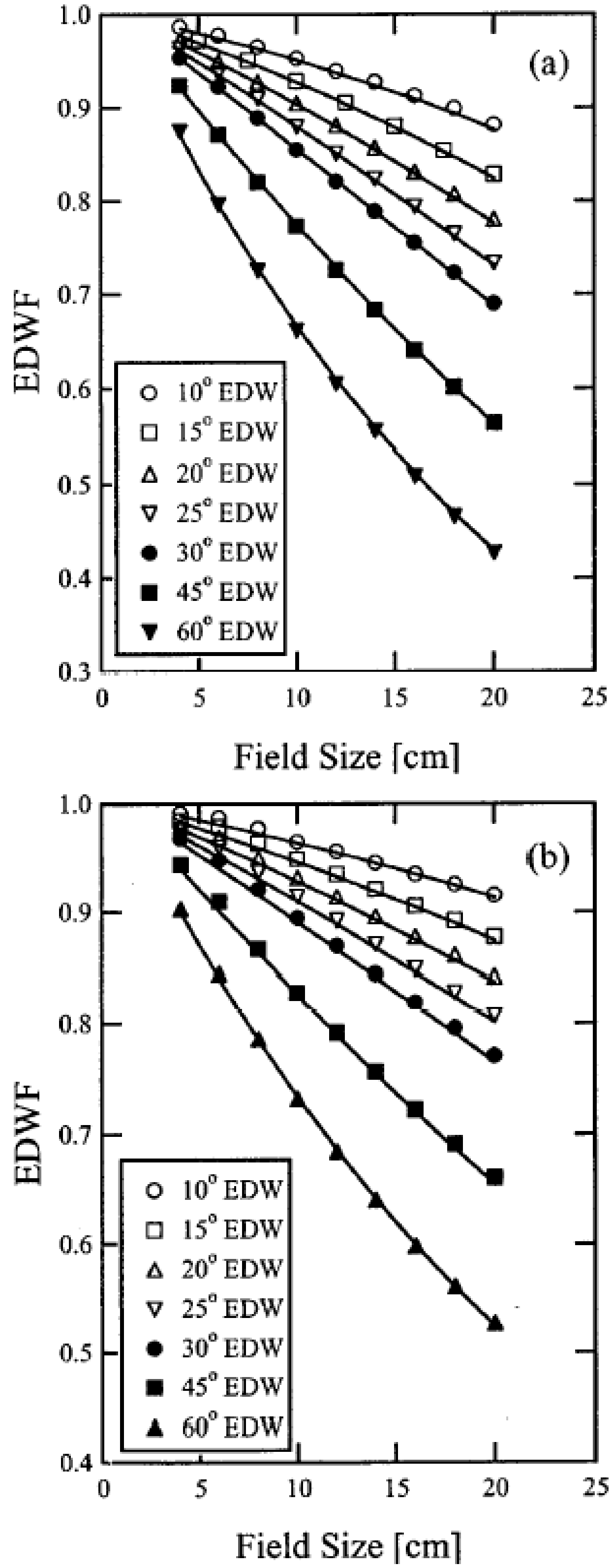


Figure 1. Agreement between diode (+) and ion chamber (O) measurements for 30cm EDW fields. Taken from Ref 18

Figure 2. EDW Wedge factors vs Field Size for 6X photon beam. Taken from Ref. 13.



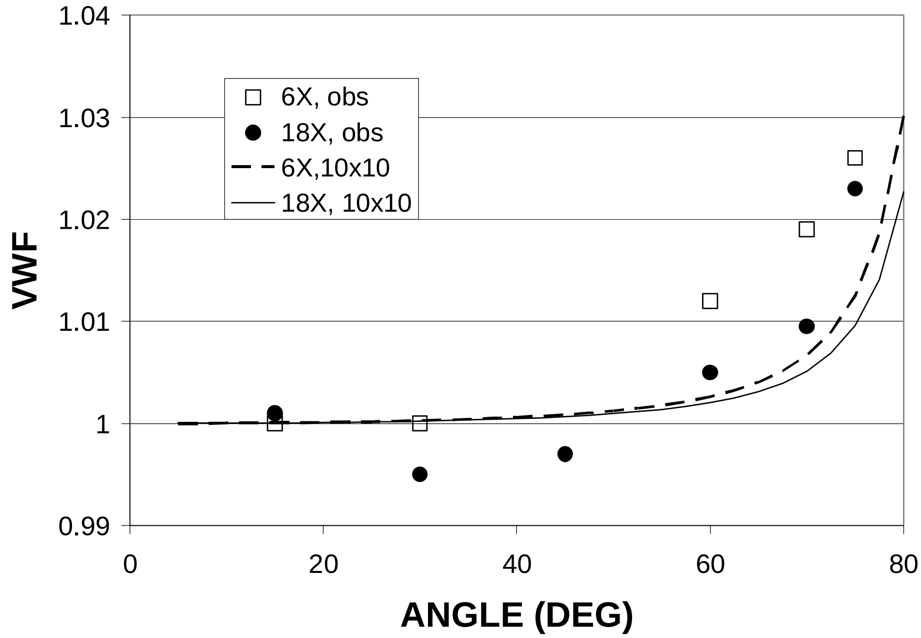


Figure 4. VW WFs versus Wedge Angle for 6X and 18X 10x10 beam. Taken from Ref. 19.

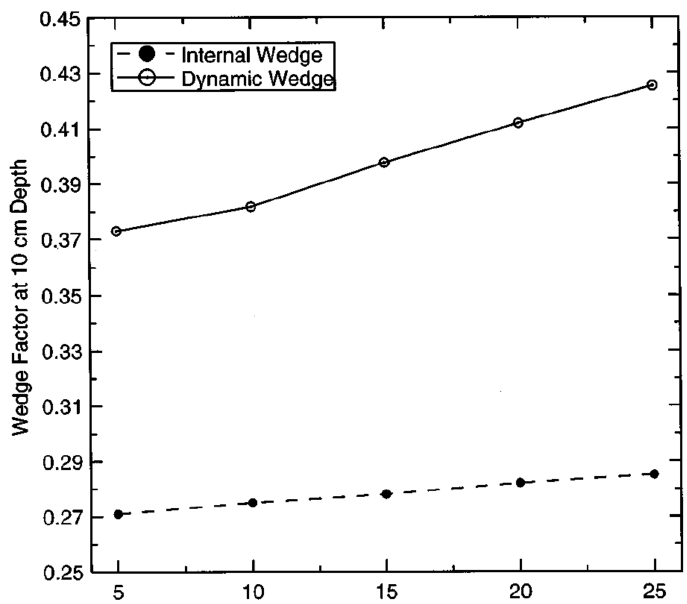


Figure 3. Wedge factor versus field size for Elekta Filterless and Internal Wedge. Taken from Ref 15.

Dosimetric Aspects Specific to Intensity Modulation with an MLC System

Each of the three major manufacturers offers solutions to what may be termed patient-specific field compensation. That is, the delivery of an intensity distribution which has been determined optimum for a particular patient's anatomical setup. Efficient delivery of intensity modulated fields is achieved through the use of MLC systems which may be used to deliver a segmented or dynamic MLC treatment. Table 2 lists some general properties of these delivery systems and how they differ between vendors. This table is by no means complete, yet highlights some of the design differences currently offered by the three major linac manufacturers.

Table 2. Comparison of MLC Delivery Systems

Description	Elekta	Seimens	Varian*
Leaf Travel	20cm to -12.5cm	20cm to -10cm	14.5 cm* relative to most retracted leaf
Max Leaf Speed	2.0 cm/sec	2.0 cm/sec	2.5 cm/sec
Interdigitization?	No	No	Yes
Minimum leaf gap	5.0 mm	0.0	0.5 mm
Rounded Leaf end?	Y	N	Y
Jaw Replacement	Upper	Lower	Tertiary
Delivery mechanism	SMLC	SMLC	DMLC or SMLC
Control System	Linac	Linac	Controller workstation
Monitoring	Video	Potentiometers	Potentiometers

*Differences exist between Mark II and Milennium MLC systems

Dosimetric requirements for MLC systems differ depending on design. Typical system tests include verification of leaf, interleaf and leaf end transmission; positional accuracy in static and/or dynamic mode; and small field dosimetry.

Radiation field leaf positional accuracy is more complex for rounded leaf end systems, where light field and radiation field discrepancies occur. For Varian systems, standard light field correction tables require an offset ranging from 0.4 – 1.2mm (depending on leaf position). Graves *et al.*,[20] described a procedure for accurately calibrating leaf position for a Varian MLC. Their results, displayed in Figure 5, demonstrate consistency between several different Varian MLCs. Within error bars, a linear offset (with respect to programmed MLC leaf position) is sufficient.

A number of other presentations have detailed QA procedures specific to each manufacturers MLC system.

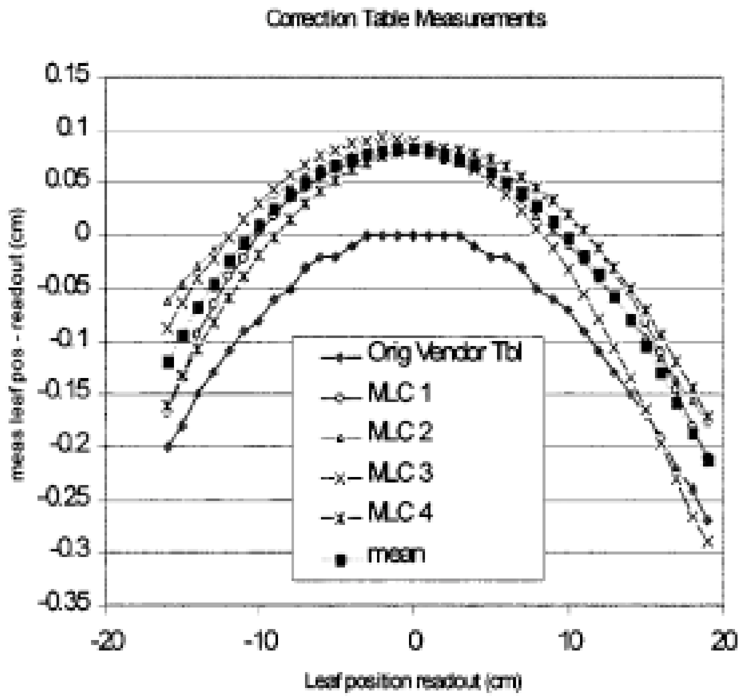


Figure 5. Results of MLC offset versus position for 4 MLCs of the same type. Also displayed is default Varian MLC table. Taken from Ref. 20

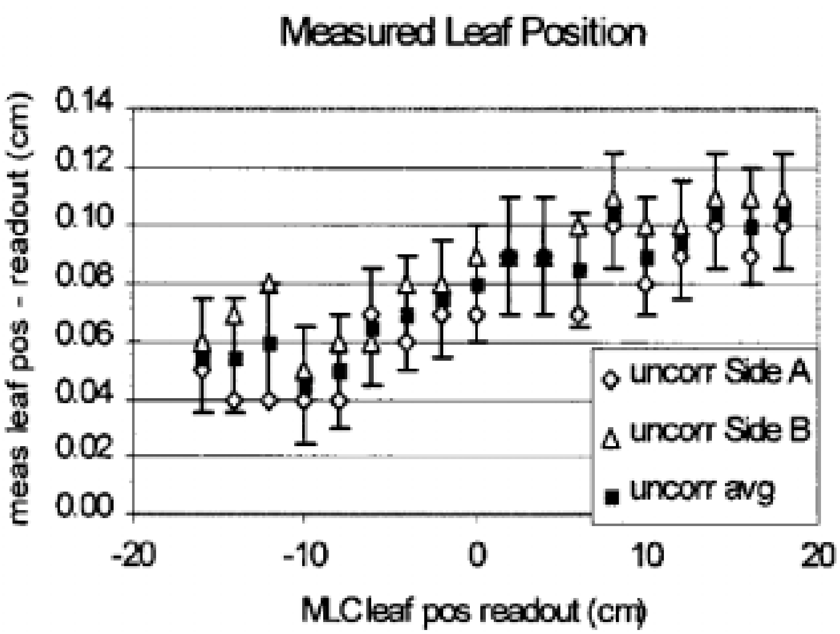


Figure 6. Leaf position offsets required when using Light field table for Varian Rounded Leaf ends. Taken from Ref. 20

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