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Penumbral Dose Characteristics of Physical and Virtual Wedge Profiles

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Abstract

Purpose: Both physical and virtual wedges are used in radiotherapy to get uniform and desired dose distribution in clinical setting. All linear accelerators of different venders have computer controlled dynamic wedges called virtual wedge filters. Penumbra is one of the important photon beam characteristics needed to be understood in radiation therapy at the time of commissioning of Treatment Planning system (TPS) as well as applying various treatment planning algorithms in clinical applications. In this study we measured the dose profiles of open field, physical wedges (PW) and virtual wedges (VW) for energies (6 MV & 15 MV), various field sizes (10 × 10, 15 × 15 & 20 × 20 cm^2), depths (d_{max}, 10 cm, 20 cm) and wedge angles (15˚, 30˚, 45˚ and 60˚). From beam profile we calculated the penumbral width for open and wedged fields. The study was carried out on Siemens ONCOR IMRT Plus linear accelerator. The obtained penumbral width of PW and VW of all wedge angles was subtracted from the penumbral width of open field. The deviations in penumbral width were compared and statistically analyzed as a function of energy, depth, field size and wedge angles. ***Material and Method***: The penumbral width was measured using IBA CC13 ion chamber in IBA Blue phantom (a 3D water phantom). The source to surface distance (SSD) during our study was kept 100cm and measurement was taken for 10 × 10, 15 × 15, 20 × 20 cm^2 field sizes and for 15˚, 30˚, 45˚, 60˚ wedges. These measurements were taken for both 6 MV and 15 MV photon energies. Virtual wedge profiles were acquired using LDA-99 linear detector array (IBA, Germany). The deviations in penumbral width for both PW and VW were calculated by subtracting the penumbral width from open field penumbral width in gun direction (in-plane) and deviation in VW penumbral width, and were obtained by subtracting the open field penumbral width in left-right direction (cross-plane) direction. The measured deviations were plotted for both PW and VW. Statistics on the measured deviations was performed by using SPSS Version 15.

Results & Conclusion: The results of one way ANOVA (Analysis of Variance) show that the deviations are significant with energy and the deviations are higher in lower energy than higher energy. The deviations increase as depth increases, the deviations are also significant with depth. The deviations increase with field sizes; the deviations as a function of field size are highly significant. The deviations are higher in PW than VW but the deviations with wedge type are in-significant. As wedge angle increases, deviations also increase and the effect of wedge angle is highly significant on deviations.

Keywords

Physical Wedge, Virtual Wedge, Penumbra and Deviations

1. Introduction

According to recent data secondary breast cancer and heart toxicity has become the most significant issue in modern radiotherapy [1]. Improvement in dose distribution in the treatment of tumor and uniformity of dose in treating organs at risk, IMRT (Intensity modulated radiation therapy), VMAT (Volumetric modulated arc therapy) and wedge filters with 3DCRT (Three dimensional conformal radiotherapy) are commonly used in radiotherapy techniques. The knowledge and understanding of use of wedge filter during TPS (Treatment planning system) becomes more essential to reduce radiation toxicity. While treating thoracic, breast and pelvic tumors the use of wedge filter is very common and the steep dose gradient may produce hot spots in lungs, heart, and rectum in these cases [2] [3] [4] [5].

Penumbra is one of the important beam characteristics parameters which can be defined as the distance between 80% and 20% points of dose on a transverse beam profile. The term penumbra in a general means the region at the edge of a radiation beam, over which the rate of dose changes rapidly as a function of distance from the central axis. The physical penumbra is the sum of individual transmission penumbra and geometric penumbra and it is mostly due to the scatter in medium [6]. Transmission penumbra is the variation in the dose at the edges of the beam caused by collimator. The main reason is the different thickness of collimator blocking the beam. This occurs due to the beam energy from the edges or the blocks. Geometric penumbra is width of the penumbra at any depth due to geometry of setup. This occurs due to the size of source, and large sources have large geometric penumbra. Scatter penumbra is created under collimator jaws into the region of penumbral tail; there is a small component of dose produced by the jaws of collimator [6].

The physical penumbra is affected by the beam energy, finite source size, source to surface distance (SSD), source to collimator distance (SCD) and depth in the water phantom [7].

Penumbra creates greater doses than normal at the edges of tissues which is undesirable. For a steep dose gradient between the target volume and healthy tissues, the penumbral width should be as small as possible. In order to reduce penumbral width the diameter of source should be small. The diameter of source should be 2 - 3 mm for modern LINACS. Penumbra is reduced by increasing the source to collimator distance (SCD) and by using secondary blocks placed near to the patients for shaping the field [7] [8]. Penumbra may also be weakened by strengthening the clearance between irradiation head to surface/skin in order to using wedges. It shows that penumbra also upon the direction of collimator edges. The leaves of collimator always are directed towards the source and independent position of leaf. This property is called the focusing. Focusing can be obtained by the movement of leaves in circular path or by the rotations of the edges of leaf [9]. For this reason MLCs (Multileaf collimators) curved edges are used in modern LINACS. But in case of curved leaves penumbra is not completely independent of leaf position [10].

As far as the clinical importance or disadvantage is concern the penumbral region needs precise attention during treatment planning. Penumbra of the beam is not considered when delineating the PTV (Planning Target Volume), however when selecting the beam sizes, the width of the penumbra has to be taken into account. The variation in the penumbra has to implement during TPS especially it creates problem in delivering small off-center segments. Tissues near to the edges of field have greatest dose uncertainties and accurate measurement is required of the spatial dose variation with the limitation of computer controlled algorithm. Mega volt photon beams produce a high increase in dose in a few mm of tissues and organs [11]. For IMRT which delivered through MLCs, beamlet dose intensities can be changed by moving the MLC leaves with in the irradiated field; therefore, accurately modeling penumbra and transmission for the MLC leaves is very important [12] [13].

In this study the comparison of penumbral dose for open field, physical and virtual wedge filter is carried out. The main purpose of this study to observe the behavior penumbra of open filed and wedge fields at various wedge angles, depth, energy and field size.

2. Method and Material

All the measurements were taken on Siemen's ONCOR linear accelerator having 82 Leaves MLC as X-collimator, while VW produces by collimator jaws in Y-direction. In the commissioning of TPS, the beam data for wedge field (physical and virtual) needs to be more accurate and reproducible because minor fluctuation can cause greater impact in clinical setting due to dose gradient profile. Because of different techniques use to generate wedged dose distribution and their positions with respect to the target of linear accelerator, the physical wedge (PW) and virtual wedge (VW) are expected to have some different dosimetric characteristics [14]. The LINAC is installed at Atomic energy medical center (AEMC), Karachi for both 6 MV and 15 MV X-ray beams using 3D water phantom (Blue phantom, IBA Germany). The dimension of water tank is 480 mm × 480 mm × 400 mm and walls are made of acrylic. The point accuracy of water phantom in 0.1 mm has 500 mm/s scanning speed. We align the water phantom with the laser such that the horizontal axis (x-axis/cross-plane direction) is the left right position. For in-plane direction which is along the y-axis (gun target) direction. The scanning the orientation in gun target and left -right direction can compromise the TPS of wedged field but in open field orientation does matter.

For accurate scanning process, the phantom must be positioned so that it is adjusted with transverse (cross-plane) and radial (in-plane) directions. This can be done by aligning probe holders with the edge of fields. Standard relative dosimetry setup was arranged for measurement, using CC13 ion chambers, (IBA, Germany), portable IBA electrometer/control unit, CU500E and dosimetry computer having Omnipro-accept software. CC13 Ion chamber was kept at beam's central axis, with chamber center at water surface, such that the distance from source to surface (SSD) was 100cm. Cross plane beam profiles were measured at three different depths (D_{max}, 10 cm, 20 cm) for various field sizes (10 × 10 cm^2, 15 × 15 cm^2, 20 × 20 cm^2) for open field (cross-plane and in-plane).

All the profiles then converted into tabular data using option in the Omnipro accept software. Penumbral width for all cases (open field and wedge field) was calculated by beam profiles. Penumbral width deviations for PW were obtained by subtracting the penumbral width in PW field from open field (cross-plane) direction and penumbral width deviations for VW were obtained by subtracting the penumbral width in VW field from open field (in-plane) direction, All the deviations were finally analyzed as a function of wedge type (physical and virtual), wedge angle, field size, energy and depth by using statistical software package SPSS15. If deviations are positive means penumbral width in open filed are greater than penumbral width in wedge field and negative deviations shows vice versa.

3. Results and Discussions

Table 1 shows the deviations in penumbral width for both types of wedges from open field. These observations are for all wedge angles, field sizes, depth and energy as discusses in above sections.

Figure 1 and Figure 2 shows that in higher wedge angles (45˚ and 60˚) and in higher field width, the deviations is getting more negative *i.e.* here in wedge field the penumbral width is greater as compare to open field. This variation or difference in higher field size is due to the fact that collimator edge scatter and transmission penumbra increases with field size. Similarly, as depth increases the deviations in negative side increases more because the scattering is more prominent in lower energy component of beam. If we analyze the deviations statistically, as a function of different parameters shows in Table 2.

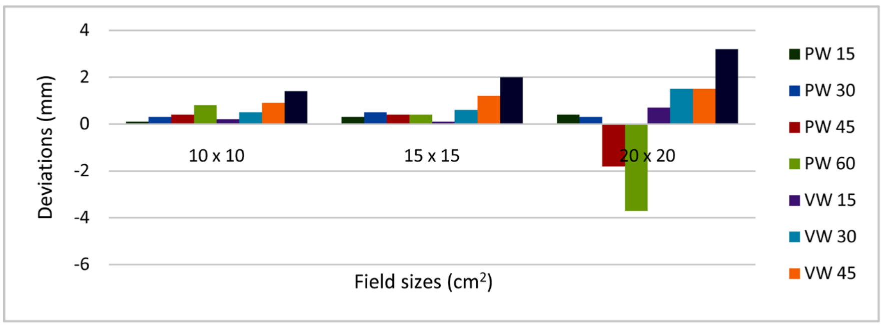
Table 2 shows the dependence or significance of some factors like energy, depth, field sizes, wedge type and wedge angles on deviations.

3.1. Energy Significance

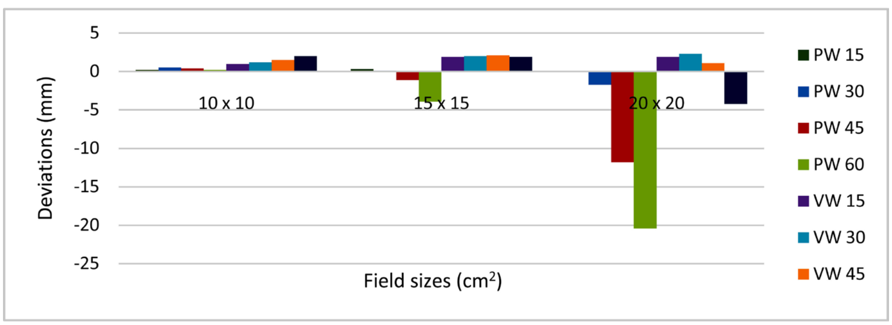
As energy increases the deviations decreases and variation among the deviations

Table 1. Deviations in wedged and open penumbral width.

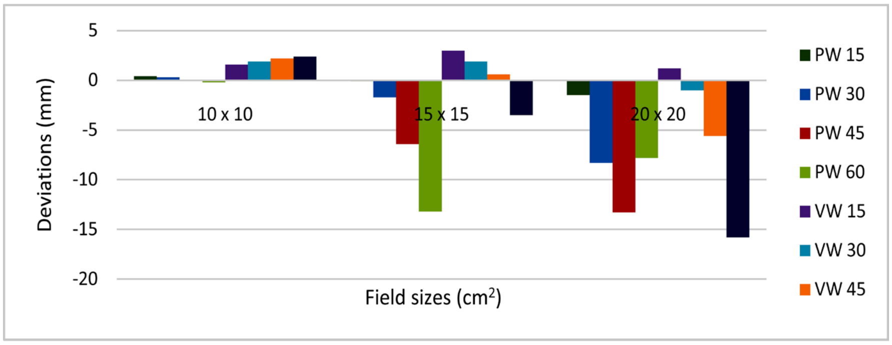
Energy (MV)	Depth (cm)	Field sizes (cm^2)	Deviations physical wedge				Deviations virtual wedge			
			15˚	30˚	45˚	60˚	15˚	30˚	45˚	60˚
6	D_{max}	10 × 10	0.1	0.3	0.4	0.8	0.2	0.5	0.9	1.4
		15 × 15	0.3	0.5	0.4	0.4	0.1	0.6	1.2	2
		20 × 20	0.4	0.3	−1.8	−3.7	0.7	1.5	1.5	3.2
	10	10 × 10	0.2	0.5	0.4	0.2	1	1.2	1.5	2
		15 × 15	0.3	0.1	−1.1	−3.9	1.9	2	2.1	1.9
		20 × 20	0	−1.7	−11.8	−20.4	1.9	2.3	1.1	−4.2
	20	10 × 10	0.4	0.3	0	−0.2	1.6	1.9	2.2	2.4
		15 × 15	−0.1	−1.7	−6.4	−13.2	3	1.9	0.6	−3.5
		20 × 20	−1.5	−8.3	−13.3	−7.8	1.2	−1	−5.6	−15.8
15	D_{max}	10 × 10	0.1	0.3	0.3	0.5	0.4	0.9	1.6	2.7
		15 × 15	−0.1	0.1	−0.5	−0.7	1.7	2.3	2.5	2.2
		20 × 20	0	−0.2	−2.2	−3.4	2.6	1.9	1.8	1.8
	10	10 × 10	0.1	0.4	0.4	0.9	0.9	1.1	1.5	2
		15 × 15	0.2	0.4	−0.7	−1.3	1.5	2.2	2.3	2.2
		20 × 20	0.1	−0.6	−3.5	−5.1	1.5	2	1.9	0.4
	20	10 × 10	0	0.2	−0.1	−0.1	1.4	1.7	2.1	2.6
		15 × 15	0.3	0.1	−1.3	−2.4	2.2	2.7	2.3	1.2
		20 × 20	−0.1	−1.3	−6.7	−9.7	2.6	1.9	1	−2.7



(a)

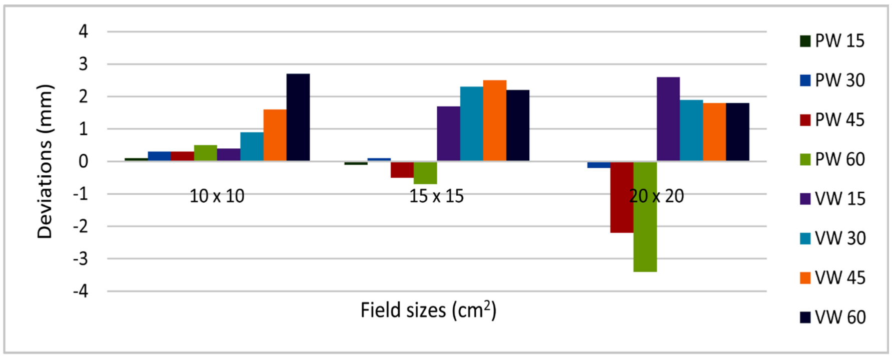


(b)

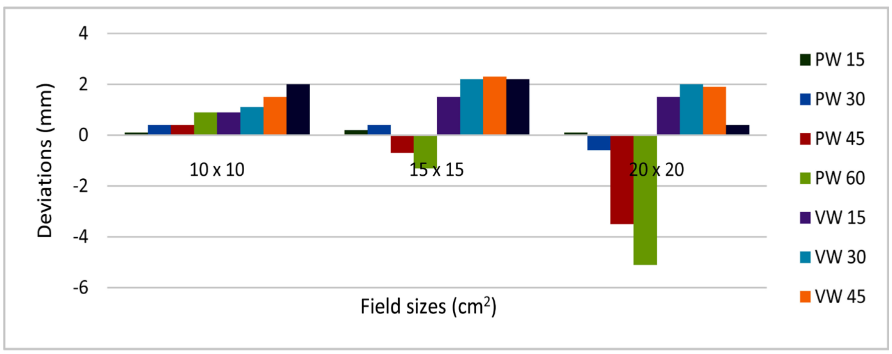


(c)

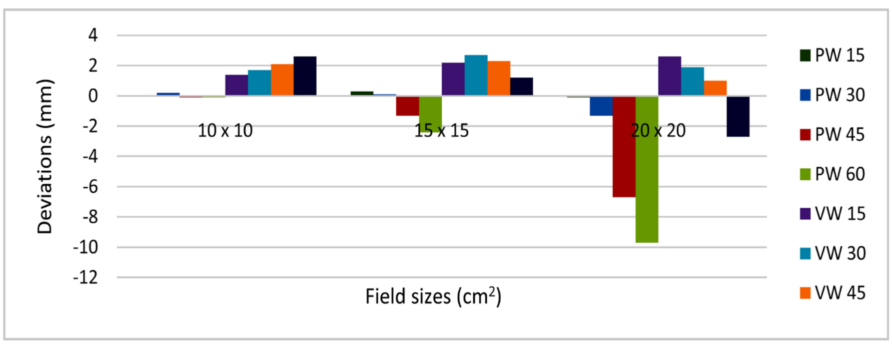
Figure 1. Represents deviations in penumbral width in presence of physical and virtual wedge for 6 MV energy. (a) D_{max} (b) 10 cm (c) 20 cm.



(a)



(b)



(c)

Figure 2. Represents deviations in penumbral width in presence of physical and virtual wedge for 15 MV energy. (a) D_{max} (b) 10 cm (c) 20 cm.

Table 2. Statistical significance of parameters on penumbral deviations.

Parameters	Categories	N	Mean	Standard deviations	F-value	P-value
Energy (MV)	6	72	2.5111	3.88005	3.889*	0.05
	15	72	1.5375	1.56488		
Depth (cm)	D_{max}	48	1.125	0.99648	4.594*	0.012
	10	48	2.0188	3.2922		
	20	48	2.9292	3.69784		
Field sizes (cm^2)	10 × 10	48	0.8938	0.78018	10.424**	0
	15 × 15	48	1.7208	2.09274		
	20 × 20	48	3.4583	4.32203		
Wedge type	Physical	72	2.05	3.80289	0.011^{NS}	0.918
	Virtual	72	1.9986	1.87643		
Wedge angle (˚)	15	36	0.8528	0.88236	6.658**	0
	30	36	1.3028	1.43696		
	45	36	2.3611	2.97045		
	60	36	3.5806	4.50116		

NS = Not significant,* = significant, ** = highly significant.

also reduces with the increase in energy. Low energy has higher scattering which increases the mean penumbral deviations which shows that in higher energy the penumbral factor lesser than lower energy. As p-value is equal to 0.05 this effect is statistically significant.

3.2. Depth Significance

The increase in depth also increases the mean penumbral deviations and variation among the deviation. This is due to beam hardening effect with depth which increases the deviations, depth losses the energy of photons. The p value is less than 0.05 which makes the depth dependence statistically significant.

3.3. Field Sizes Significance

The mean penumbral deviations are direct effect on field sizes and variation among deviations. This is due to the fact that lateral configuration set by the jaws of collimator; it increases the field size, higher field sizes have higher scattering. This effect is highly statistically significant as p value is zero.

3.4. Wedge Type Significance

The mean penumbral deviations are almost same in both PW and VW but variations among the deviations in VW are quit lesser than PW which make the use of it more convenient. As p value are greater than 0.05 it is statistically in-significant.

3.5. Wedge Angle Significance

The choice of wedge angle has been very important during TPS. The statistics shows that as wedge angle increases the mean penumbral deviations increases and the variations among deviations also increases. The higher the angles, the higher the scattering which increases the mean penumbral deviations. This is highly statistical significant as p value is zero.

4. Conclusions

Penumbra creates greater doses than normal at the edges of tissues which are undesirable. For a steep dose gradient between the target volume and healthy tissues, the penumbral width should be as small as possible. As far as the clinical importance or disadvantage is concerned, the penumbral region needs precise attention during treatment planning. Penumbra of the beam is not considered when delineating the PTV, however when selecting the beam sizes, the width of the penumbra has to be taken into account. The variation in the penumbra has to be implemented during TPS especially it creates problem in delivering small off-center segments. This study is very helpful to understand the penumbral dose variation of open field, physical and virtual wedges and hence implementation in accurate commissioning and clinical use.

It is a well known fact that due to increased use of advance radiotherapy techniques like IMRT, VMAT, SRT etc, and where the experts are debating that hard wedges in radiotherapy should be discontinued [15]. There are still lots of radiotherapy centers in the world having lack of resources, and they are using hard wedges and EDW/Virtual wedges so it is important to check periodical wedge profile reproducibility [16]. The concept and understanding of this study will also be useful in case of IMRT delivery where the leakage penumbra effect of MLCs should be taken into account for accurate dose calculation [13].

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