Wedge factor dependence on computer controlled wedge system in Siemens ONCOR linear accelerator

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Abstract: Wedge factor is the measurement which shows how much dose reduces to the target after introducing a wedge filter between the source and target. Virtual wedge factor (VWF) is purely computer controlled jaw movement dependent. The quality control of wedge factor or verification has periodically been very important because if minor changes occurs in jaw speed or motion it makes the major changes in wedge profile of virtual wedge which appears. It causes the wrong treatment to the patients.So, this study is much more important and focusing on the area where ignoring. In this work we obtained the wedge factors for both virtual wedge (VW) and Physical Wedge (PW) at different field sizes (10×10 cm^2 ,15×15 cm^2 and 20×20 cm^2) , wedge angles (15°, 30° ,45° and 60°) and energies (6 MV and 15 MV). This work has been carried out on Siemen's linear accelerator (LINAC) and IBA-blue water phantom is used for scanning purposes. The CC-13 ionization chamber is used for PW and LDA-99, Linear Detector Array, for VW. The source to surface distance (SSD) and depth in our work remain 100cm and 10 cm respectively. These detectors were connected with their respective electrometers and all the observation will be taken through Omnipro version 7, supporting software. The wedge factors were plotted against various field sizes for both energies and wedge angles.The difference between the VWF from published data and our data were calculated for 6 MV energy .The mean wedge factor for both physical and virtual wedge were analyzed by using Statistics package software, SPSS (V15) as a function of field size, wedge angle and photon energy. Analysis of Variance (ANOVA) was performed on the mean wedge factor by using an F-test. The observations show that the virtual wedge factors are almost constant, equal to unity but, physical wedge factors increase with field size and energy in both these conditions this increment is not statically significant , physical wedge factors (PWFs) decreases with wedge angle ,this effect is highly statistically significant.

Keywords*: physical wedge, significance, virtual wedge, wedge factor*

1. Introduction

Introduction of wedge filter between source and target minimize the output of the linear accelerator or produce atteneuation across the radiation beam[1], but wedges are sometime essential in the treatment planning system (TPS) in most clinical sites. As wedge filters are placed, the intensity of radiation beam weaken.[2] Wedge filters are used to alter the x-rays beam isodose distribution and also use to renovate the uniformity of dose in the target volume in radiation therapy. Wedge filters are used as missing tissue compensator and in form of pair to alter the shape of isodose curves so that two beams can be inclined with a minimum hinge angle at the volume without creating a hot spot.[3] There are two types of wedges used in radiotherapy, physical wedge (PW) and computer controlled wedge also known as Virtual Wedge (VW). Physical wedges are made up of metallic materials and designed in such a way as to produce an advanced reduction across the radiation beam. Physical (Metallic) wedges generally having (15°, 30°, 45° and 60°) angles. Physical wedges can be inserted in the treatment head in four ways in, out, left and right. The virtual wedge is a computer controlled system which allows delivery during treatment planning system (TPS), of a wedge shaped dose distribution. It produces a dose distribution in replacement of the physical wedge by varying beam intensity while moving a collimator jaw at constant speed across the field of treatment. Virtual wedge is also known as dynamic wedge for different manufacturers. The report on the implementation of computer controlled wedge was published in 1990.[4] The virtual wedge may have any range of angles between 10° to 60° and possible for in and out direction. The VW behaves like open field, i.e. VW reduces dose less than the physical wedge. Wedge factors indicates to reduce doses from wedges. Virtual wedge almost has wedge factor equal to unity for all field sizes and wedge angles.[1]

Generally the use of virtual wedges is more advantageous as compared to physical wedges because there is less number of monitor units (MU) and easily controllable with computer algorithm, i.e. virtual wedge factor always approaches to unity for all angles whereas physical wedge factor always less than one and further reduces with increasing angle.[5] Wedge profile of computer controlled wedge can be obtained by moving one of secondary jaws and varying the rate of dose during radiotherapy.

VWF is purely computer controlled jaw movement dependent. The quality control of wedge factor or verification has periodically been very important because if minor changes occurs in jaw speed or motion it makes the major changes in wedge profile of virtual wedge which appears. So ultimately the patient treating may get an unwanted dose.This study is much more important and focusing on the area where ignoring. As an example of AAPM TG40 report regarding quality control program for LINAC in which the annual performance of wedge transmission factor constancy is recommended. So this study is strongly support the proposed frequency of weekly or monthly checking of VW factor as Ogata et al suggested.[6]

When treatment started from the console of LINAC, the screen displays a curve, which specifies the final positions of stationary and moving jaws as well as the dose to be delivered at each and every point across the target volume with respect to recommended MUs on a central axis. The position of stationary jaws indicates by the highest monitor unit shown on this curve.[7]

As treatment set-up parameters recognized, the active jaw moves to its initial position close to the opposing static jaw without touching it. During radiotherapy, the moving jaw travels at a constant speed to its final position, but the variation in dose rate occurred. This movement produces the necessary wedge profile by distributing higher dose at the “toe” of the wedge field as compare to the “heel” during the active phase of treatment.

Our study will be helpful in finding out the statistical significance of physical wedge factor with beam energy, field size, and wedge angle. There are so many advantages of VW over PW and so many studies have been done which shown the advantage of virtual wedge over physical wedges. The online portal is required at the start of irradiation of treatment set-up, physical wedges do not produce online portal imaging but however in virtual wedge. McGhee at al gives the solution to the 60° VW field and open field.[8] Treatment automation delivery is one of the most common advantage in VW over PW.VW reduces peripheral doses which are clinically significant in tangential breast irradiation of young ladies.

In this study we proved statistically the significance of wegde factor on VW. Most studies show that the dependence of PWF on depth and field size is significant.[9, 10] Attala et al calculated the wedge factors for field size 20 × 20 cm^2, energies (6 MV and 10 MV) and from source to surface distance 90cm for both physical and virtual wedges on the same machine (ONCOR Linac) by using PTW 30013 farmer type ion chamber.[1] He also found the dependence of field size. The same work was done by Zhu et al on Siemens primus Linear accelerator for 6 MV and 23 MV energy.[3]

2. Materials and methods

This experiment was performed on the Siemens ONCOR linear accelerator for both x-ray beam energy using 3 dimensional 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 pointing accuracy of water phantom in 0.1 mm having 500 mm/s scanning speed. Standard relative dosimetry setup was arranged for measurement. For physical wedge factor (PWF), we use CC13 ion chambers, (IBA, Germany) along with portable IBA electrometer CU500E and for virtual wedge factors (VWF), LDA 99 with emxx electrometer. Both electrometers for wedge factors dosimetry were connected through computer having Omnipro-accept software to obtain observations. We used the ion chamber for dose profile and wedge factor acquisition in case of physical wedge, whereas LDA array is specially designed for profile of the virtual wedge because we cannot move the ion chamber relative to the motion of y-jaw which forms the virtual wedge profile. Both detectors contains their own electrometers. 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.The wedge angles for both physical wedge and virtual wedges on which the wedge factors were calculated are 15°, 30°, 45° and 60°.The depth remains 10 cm during our experiment. This work was performed for three different field sizes (10 × 10 cm^2, 15 × 15 cm^2 and 20 × 20 cm^2) and for 15 MV and 6 MV energies.

2.1. Theory

According to the definition of wedge factor by ICRU report 24[11], wedge factor for any wedge angle w is defined as

$$WF(a,b,w) = \frac{D(a,b,w)}{D(a,b,o)} \tag{1}$$

Where D (a, b, w) is the dose at a certain point along the central axis in a given field with dimensions "a" and "b" with the wedge in place, and D (a, b, o) is the dose to the similar point in an open field of defined dimensions of the same monitor units (MUs). In case of manual insertion of the wedge and the accelerator is allowed to move in more than one direction of wedge insertion, the wedge factor also depends on the orientation of the wedge with respect to the collimator jaws "ot", so the equation (3) can be written

$$WF(a,b,ot) = \frac{D(a,b,ot)}{D(a,b,o)} \tag{2}$$

Wedge direction can be used as pointing vector directed from thick to thin edge of physical wedge.[11] The dose after the introduction of wedge, D (a, b, w) is the sum of dose from primary beam ,phantom scattering and collimator scattering. If it is assumed that the beam profile is linear in the presence of the wedge and divergence is ignored, so the irradiated wedge volume is proportional to the field area and independent of wedge orientation. Then wedge factor may be written as

$$WF(a,b,ot) = WF(A,w) \tag{3}$$

where A is the area of field and multiple of a and b[12],"ot" shows the dimension,"o" shows the open field and "w" shows the wedged field.

3. Results and discussion

Figure 1-2 shows that physical wedge factor increases slightly with the field size. Most studies have been done and shows that PWF increases with field size.2,4 As field size increases photon scatting from irradiated wedge volume. The negligble increase in virtual wedge factor in greater field size is possibly due to the transmission through dynamic collimator jaws and extra focal radiation beneath the jaws.13 The virtual wedge factor (VWF) rises to field size, especially for large angles. In case of VWF, the no. of additional MU in the toe side of wedge filters has considerably rises with higher fields .It means VWF are directly relative with field size especially for large angles.14 VWF has a quadratic dependence on field size for high attenuation coefficient, that is lesser energy beam and greater wedge angle. Variation in the treatment delivery time and MUs between physical and virtual wedges are not as huge as that of absolute value of WF since the variation in the values of WF between VW and PW is may be due to the fact that the MUs for VW is redefined.

The wedge factors decrease as wedge angles increase the similar observation have been made by Attala et al.[4] This is due to the attenuation of radiations with wedge angle or beam hardening. This effect seems to be more effective in physical wedges .Ogata et al[6] calculated the mean wedge factors for 6 MV energy using 2D linear diode array MAPCHECK using 10 × 10 cm^2 field size. If we compare it with our measured data in Table 2.

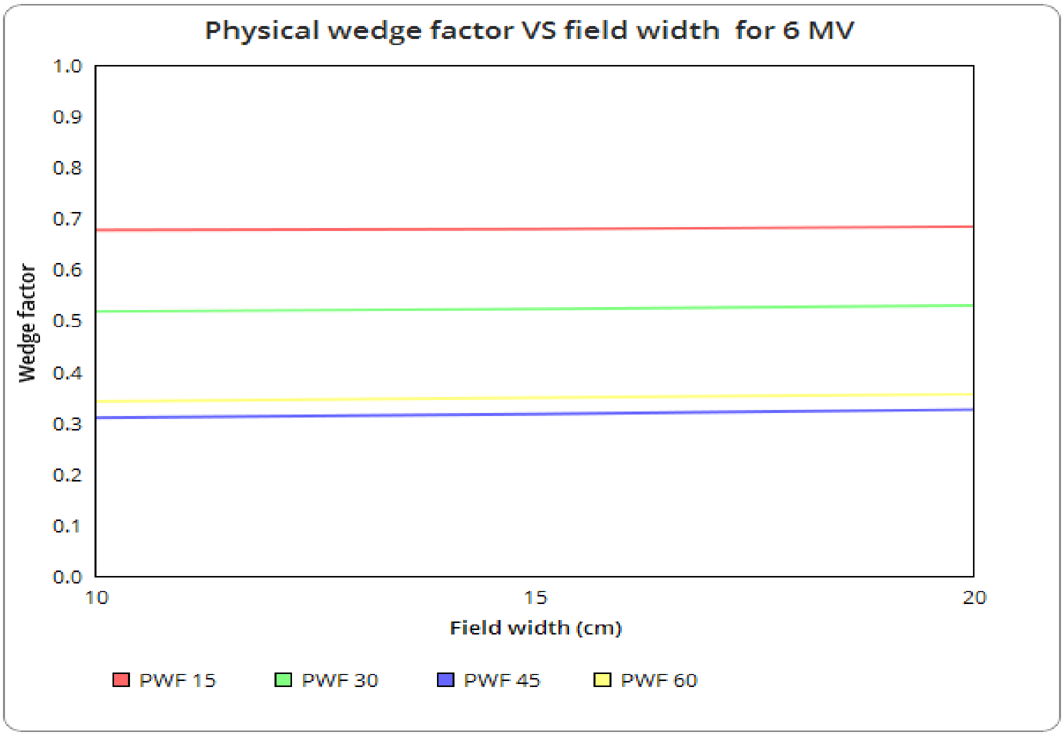

Figure 1. Physical wedge factors for all selected wedge angles against field sizes for 6 MV.

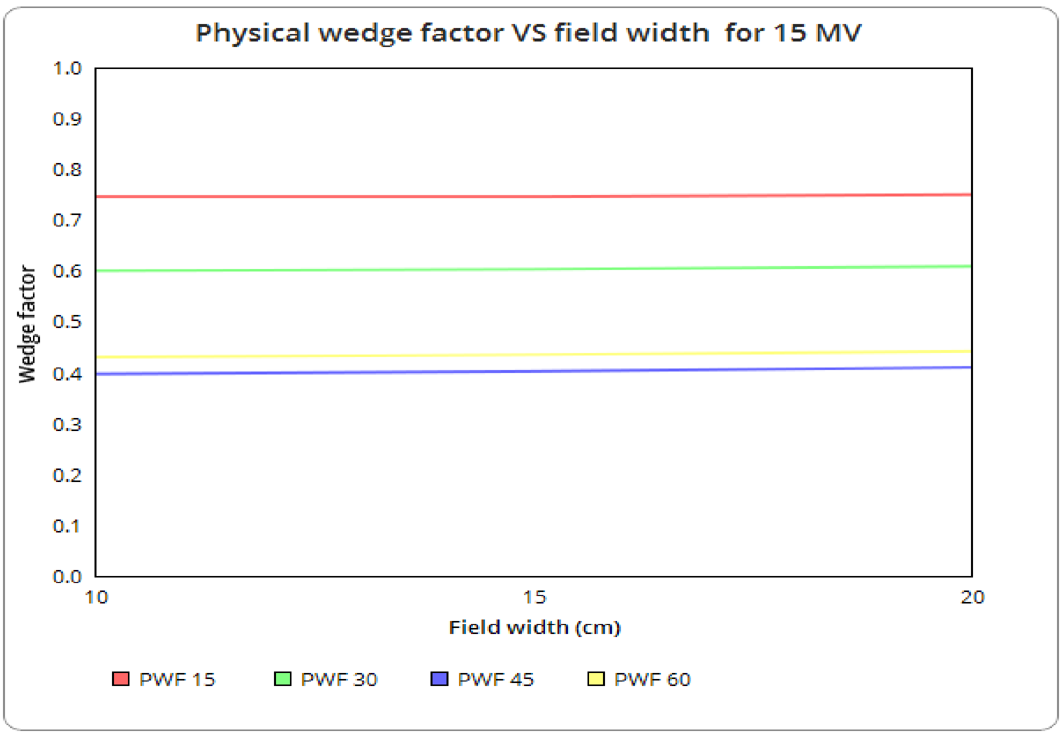

Figure 2. Physical wedge factors for all selected wedge angles against field sizes for 15 MV.

Table 1. Wedge factors for 6 MV and 15 MV energies including all wedge angles and selected field sizes.

Energy (MV)	Field Sizes (cm²)	PWF				VWF			
		15°	30°	45°	60°	15°	30°	45°	60°
6	10 × 10	0.677	0.518	0.31	0.342	0.998	0.992	0.994	0.994
	15 × 15	0.679	0.523	0.317	0.349	0.996	0.991	0.995	0.995
	20 × 20	0.684	0.53	0.326	0.356	0.996	0.99	0.995	0.995
15	10 × 10	0.746	0.6	0.397	0.43	0.998	0.996	0.988	0.988
	15 × 15	0.746	0.603	0.402	0.435	0.998	0.996	0.987	0.987
	20 × 20	0.75	0.609	0.41	0.442	1	0.995	0.988	0.988

Table 2. Comparison of VWF for 6 MV energy and 10 × 10 cm² field with published data.

Virtual wedge angles	Our Study	Ogata et al	Difference
15	0.998	0.991	0.007
30	0.992	0.986	0.006
45	0.994	0.989	0.005
60	0.994	0.990	0.004

Table 3. Statistical significance of different parameters on wedge factors.

Wedge	Parameters		N	Mean WF	S.D	F-Value	P-Value
Physical	Energy (MV)	6	12	0.467	0.152	1.740	0.201^NS^
		15	12	0.547	0.144		
	Field Size (cm²)	10 × 10	08	0.502	0.159	0.001	0.998^NS^
		15 × 15	08	0.506	0.157		
		20 × 20	08	0.513	0.155		
	Wedge angle (°)	15	06	0.713	0.036	82.230	0.000**
		30	06	0.563	0.044		
		45	06	0.360	0.047		
		60	06	0.392	0.048		
Virtual	Energy (MV)	6	12	0.994	0.003	0.649	0.429^NS^
		15	12	0.993	0.004		
	Field Size (cm²)	10 × 10	08	0.993	0.004	0.216	0.808^NS^
		15 × 15	08	0.994	0.003		
		20 × 20	08	0.995	0.004		
	Wedge angle (°)	15	06	0.997	0.001	4.716	0.012^NS^
		30	06	0.993	0.002		
		45	06	0.991	0.003		
		60	06	0.995	0.003		

NS = Not significant, ** = Highly significant and * = Significant

It is obvious that the beam energy increases the wedge factor. If we analyse our work statistically by using SPSS 15, through F-statistics. Table 1 will give the statistical significance of all parameters on wedge factors.The mean wedge factor for all wedge angles,field sizes and beam energy were calculated and standard deviation among these wedge factors separately for both physical and virtual wedges through SPSS.

3.1. Energy dependence

Table 3 shows that mean wedge factor in 15 MV is greater than 6 MV and S.D (standard deviations) within the values of PWF and VWF, 15 MV has higher variations due to scattering. The variety among the mean values of wedge factor is 5.3% .It is obvious, high energies produces more doses in open field as well as in wedge fields. The effect within PW seems to be significant, but in the combination of both wedges it becomes insignificant. The p value is greater than 0.05, it is not clinically significant as VWF has approximate identical values. So, no need of correcting wedge factors.

3.2. Field size dependence

A linear relation is found between wedge factors and field sizes with less variations among the values with higher fields. Saffar et al[15] suggested no correction of wedge factor, because only 1.72% variation per 10 cm variation in field size, this study was performed on Neptun 10PC, Linac 9MV X-ray machine. In this study, the mean wedge factor varies 0.8% with field size. Attala et al[1] also obtained the linear effect of wedge factor with field size on the same machine. Zhu et al[3] concluded that WF increases slightly with field size on Siemens Primus linear accelerator. Photons scattering is greater in greater fields and stability in higher fields reduces standard deviations.

As $p > 0.05$, which makes this effect in-significant on wedge factors, but within PWF this effect is clinical significant.

3.3. Wedge angle dependence

Increase in wedge angle reduces wedge factors but variations increases due to scattering. The angle of wedge reduces the dose as thickness of wedge increases. This effect also in-significant here but only in PW it is significant. The beam hardening effect with increasing wedge angle reduces the dose as well as wedge factor.[16]

3.4. Wedge filter dependence

The PWF has lesser mean as compare to VWF with greater variations. This effect is highly statistically significant as p value is zero. Most of studies have been done on different machines with different ion chambers and VWF almost equal to unity in all cases.[1,3]

4. Conclusion

The study shows that VW has high wedge factor than PW for all field sizes, wedge angles and both energy used in our work. Mean wedge factor for VW is nearly equal to unity in all cases which shows how similar is the VW as an open field. The Mean physical wedge factor increases with field size, this dependence is not statistically significant. Mean physical wedge factor decreases with wedge angle, but the higher decrement shown in 45° wedge, this dependence is also insignificant. As far as the energy is concerned 15 MV has higher mean physical wedge factor than 6 MV shows insignificant dependence.

The open field PDDs and VW PDDs are almost similar, the wedge factors of VW are almost constant with field size, depth, SSD, Wedge factors and energies. All the variations in wedge factors are due to PW due to their geometry. The large difference in the value of PWF and VWF can create a problem in delivering dose to the patients. Wrong selection of wedge filter during radiotherapy may create excessive number of monitor units (MU). In the report of ICRP, Educational prevention with radiotherapy in new technologies, 23 patients overdosed due to wrong selection of wedge, four of them died in first year of treatment.[17] Our work provides the right selection of wedge during treatment to avoid radiation damages.

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