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Dosimetric evaluation of a treatment planning system using pencil beam convolution algorithm for enhanced dynamic wedges with symmetric and asymmetric fields

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Background: The dosimetric performance of Eclipse 6.5 three dimensional treatment planning system (3DTPS) is evaluated by comparing the calculated and measured dose in two dimensions following the guide lines of American Association for Physicists in Medicine Task Group 53. ***Materials and Methods:*** The calculations were performed by the 3DTPS for symmetric as well as asymmetric fields for standard source to surface distance (SSD) at d_{max}, 5, 10 and 20cm depths in water phantom using 45° and 60° enhanced dynamic wedges (EDWs) in a field of 15 cm×15 cm size for 6 MV photon beams. Measurements were carried out for 6 MV photon beams produced by a linear accelerator, Clinac EX - 2100, equipped with EDWs using 0.125cc volume PTW ionization chamber and PTW UNIDOS electrometer for beam axis and two off axis points. ***Results:*** The deviations between the calculated dose (D_{calc}) and the measured dose (D_{meas}) at toe, centre and heel at different depths for symmetric as well as asymmetric fields for both the wedge angles is less than 2% at all the points and in all geometries. For 45° EDW the deviation was maximum at 20 cm depth and in asymmetric geometry. For 60° EDW the deviation was maximum at 20 cm depth but in symmetric geometry. ***Conclusion:*** The results indicate that the accuracy of Eclipse 6.5 (version 7.3.10) three dimensional treatment planning system used with the EDWs in symmetric as well asymmetric fields is adequate in clinical applications under the studied experimental conditions. **Iran. J. Radiat. Res., 2008; 5 (4): 169-174**

Keywords: *Enhanced dynamic wedge, dose distribution comparison, asymmetric fields, treatment planning system, calculation algorithms.*

INTRODUCTION

Radiation therapy treatment planning for many clinical situations requires wedge-shaped isodose distributions. The wedged dose distributions can be generated through the use of physical wedges (PWs), motorized wedges and the synchronization of jaw or multileaf collimator dynamic motion with accelerator dose output.

Modern medical accelerators are usually equipped with a dynamic wedge (DW) option. The DW makes use of dynamic movement of one pair of independent jaws on a linac and generates dose distributions equivalent to those produced by a PW placed in static fields. The segmented treatment tables (STTs), which are implemented on Varian linacs, are used to control the dose rate and jaw movement for producing a set of DWs. Each STT contains information on the moving collimator position versus cumulative weighting of monitor units (MUs). The enhanced dynamic wedge (EDW), the second generation of DW for Varian linac, uses a single STT to generate all the other STTs for all field sizes and wedge angles [1]. The clinical advantages of using DWs have been reported by many investigators [2-7]. EDW is preferred over PW because it is not limited in length and does not create additional low energy electron and photon scatter that increases both surface and peripheral dose [8, 9]. However use of DW requires more complex dosimetry and quality control procedures [10]. During commissioning activity, care must be exercised to ensure that dynamic wedges are

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correctly modeled in the treatment planning computer system. This includes verifying the accuracy of both the isodose distributions and the monitor units (MUs) generated by the treatment planning system [11].

Venselaar and Welleweerd [12] investigated seven treatment planning systems (TPSs) and showed that a number of algorithms for calculating MUs in wedged asymmetric fields have their limitations. They proposed the criterion for the confidence limit for the different types of test geometries as given in table 1. Other [13] investigated Theraplan-Plus treatment planning system for asymmetrically collimated open and wedged beams and found that the difference between calculation and measurement increased with increasing thickness of the wedge, and increased gradually when the asymmetry was shifted from the thin part of the wedge to the thick part of the wedge. They found that confidence limit of the points measured in fields under the thick part of the 45° wedge exceeded the criterion described in table 1 [13].

Table 1. Values of the criterion for the confidence limit for the different types of test geometries set by Venselaar and Welleweerd (2001) [12].

Description	Tolerance
1- Complex geometry (wedged fields, inhomogeneities, irregular fields, asymmetrical collimator setting) Central and off-axis data	3% of local dose
2- More complex geometries, i.e. combinations of #1 Central and off-axis data	4 % of local dose

Several investigators have evaluated the accuracy of TPS by comparing the measured and calculated dose in the field axis using dynamic wedge and concluded that the TPS models the wedged dose distributions for symmetric fields, with dose variations below 2% of the normalization or 2 mm for regions with high dose gradient. However, no investigations have been reported using dynamic wedge compared measured with calculated two-dimensional dose distributions before Caprile *et al.* (2007). These authors have shown that for 60° EDW and large fields, the pencil beam convolution algorithm does not accurately model the dose distributions and could lead to inaccuracies of clinical significance [14].

Our aim was therefore to evaluate Eclipse 6.5 (version 7.3.10) three dimensional treatment planning system (3DTPS) precision in modeling dose distributions by comparing calculated with measured dose in wedged fields (symmetric as well as asymmetric) by using 45° and 60° EDWs.

MATERIALS AND METHODS

A linear accelerator, Clinac EX -2100 with Varian's EDW having wedge angles of 10°, 15°, 20°, 25°, 30°, 45°, and 60° was used to produce 6 MV photon beams. The dose distributions were calculated by Eclipse 6.5 (version 7.3.10) 3DTPS using PBC for EDWs with symmetric and asymmetric fields for 15 cm×15 cm field at depths of dmax, 5, 10, 20 cm at source to surface distance (SSD) of 100 cm. Calculations were performed in a phantom created by the 3DTPS with a homogeneous density of 1 g/cm^3. The calculation grid was 2.5×2.5 mm for the PBC calculations.

The dose was calculated for two EDW angles 45° and 60° for 6 MV photon beams at three points for each depth (one point located on the central beam axis while other two points at off-axis distances of -4.0 cm and +4.0 cm as shown in figure 1 a-d). For each beam setting, dose was calculated at 12 points. In this way dose was calculated at 48 points for each wedge angle. In total, dose was calculated at 96 points where 24 points were in symmetric field and 72 points were in asymmetric fields.

Doses were measured at predefined points in water phantom with a 0.125cc volume PTW ionization chamber and PTW UNIDOS electrometer. The chamber was mounted in a holder, placed in a 50cm × 50cm × 50cm PTW three dimensional water phantom. The water surface was leveled at SSD of 100 cm. The gantry of the treatment unit was set to 0°. The Clinac was set to deliver 300 monitor units (MUs) per minute. To reduce the

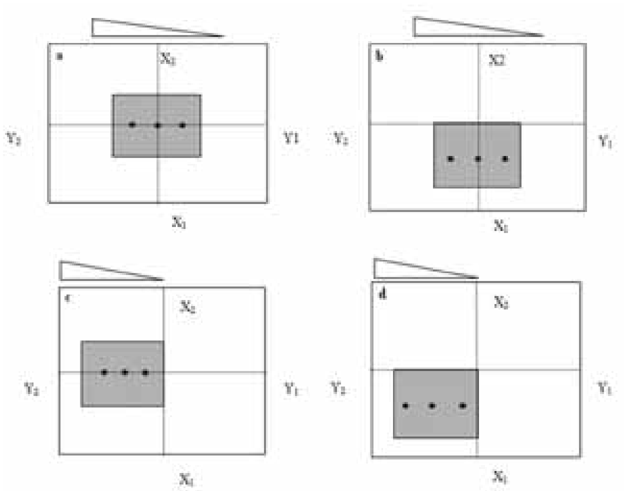

Figure 1. (a) A top view of the beam setup showing the points of measurement in the symmetrical setting (X1=7.5,X2=7.5,Y1=7.5.Y2=7.5); (b) in the asymmetrical setting (X1=15,X2=0,Y1=7.5.Y2=7.5); (c) in the asymmetrical setting (X1=7.5,X2=7.5,Y1=0.Y2=15); and (d) in the asymmetrical setting (X1=15,X2=0,Y1=0.Y2=15).

variability of working conditions, the dosimetry measurements were performed in a single session.

The position of the ionization chamber is critical in the case of wedged beams due to the dose gradient in the direction of the wedge. Therefore, measurements were repeated with a collimator rotation angle of 90° and 270°. The position of the chamber was then adapted to ensure a central position of the chamber with respect to the wedge.

The deviations between the calculated dose (D_{calc}) and the measured dose (D_{meas}) are expressed as a percentage of the locally measured dose by using the equation (1) (11, 15):

$$\text{Relative Error } (\delta)=(D_{calc}-D_{meas})\times 100\%/D_{meas} \qquad (1)$$

In addition to the graphical representation the concept of the confidence limit, Δ, is used which is based on the calculation of the average deviation between calculated and measured dose values for a group of data points in comparable situations, and the standard deviation (1 SD of the average) of the differences. The confidence limit is defined as follows in Equation (2) (11, 15).

$$\Delta=|\text{average deviation}|+1.5\times SD \qquad (2)$$

In order to compare calculated and measured doses, sample criteria of acceptability set by Venselaar and Welleweered (2001) shown in table 1 [12] as well as of the American Association for Physicists in Medicine Task group-53 (AAPM TG-53) for external dose calculations in the inner region shown in table 2 is followed [16].

Table 2. Sample criteria of acceptability for external dose calculations by AAPM TG-53 [16].

Situation	Absolute dose at normalization point (%)	Central ray (%)	Inner beam (%)
Wedged fields	2	2	5

RESULTS AND DISCUSSION

Table 3 describes the deviations between the calculated dose (D_{calc}) and the measured dose (D_{meas}) at toe, centre and heel at different depths for symmetric as well as asymmetric fields for both the wedge angles. The deviation is less than 2% at all the points and in all geometries. For 45° EDW the deviation was maximum at 20 cm depth and in asymmetric geometry. For 60° EDW the deviation was maximum at 20 cm depth but in symmetric geometry. The confidence limit is calculated by using equation (2) for both EDWs and is shown in table 4 for symmetric geometry and in table 5 for asymmetric geometry.

Published criteria for the acceptability of TPS dose calculations present significant variation. The first criteria published by Van Dyk *et al.* in 1993 [17] are characterized by increased tolerance limits due to the fact that most of the TPS were using two-dimensional algorithms at the time. The recommendations of AAPM TG53 report in 1998 by Fraass *et al.* [16], report 7 of the Swiss Society for Radiobiology and Medical Physics (SSRMP) in 1997 [18] and Venselaar and Welleweerd in 2001 [13] are generally more strict, but realistic for a properly functioning dose calculation algorithm. When the complexity of the geometry increases, however, tolerance limits may have to be less strict relative to beam modeling geometry. In this work the set of tolerance limits proposed

Table 3. The deviations between the calculated dose (Dcalc) and the measured dose (Dmeas) by the equation (1)

Depth	EDW 450			EDW 600		
	Deviations for Symmetrical setting (X1=7.5,X2=7.5,Y1=7.5.Y2=7.5)					
	Toe	Centre	Heel	Toe	Centre	Heel
d_{max}	0.68	0	-0.19	0.22	0	0.63
5cm	0.86	0.5	0.48	0.44	0.58	1.22
10cm	0.65	0.28	0.41	0.09	0.25	0.83
20cm	0.98	0.54	1.05	0.26	0.74	1.61
	Deviations for Asymmetrical setting (X1=15,X2=0,Y1=7.5.Y2=7.5)					
d_{max}	0.13	0	0.44	-0.41	0	1.1
5cm	0.35	0.25	0.71	-0.16	0.5	1.28
10cm	0.34	0.2	0.62	-0.31	0.14	1.3
20cm	1.14	0.96	1.54	0.43	0.9	1.85
	Deviations for Asymmetrical setting (X1=7.5,X2=7.5,Y1=0.Y2=15)					
d_{max}	0.83	0	0.02	0.59	0	0.67
5cm	1.06	0.28	0.41	0.72	0.34	1.11
10cm	0.87	0.1	0.26	0.4	0.31	0.71
20cm	1.17	0.71	0.95	0.96	0.81	1.27
	Deviations for Asymmetrical setting (X1=15,X2=0,Y1=0.Y2=15)					
d_{max}	0.97	0	0.17	0.48	0	0.36
5cm	1.19	0.35	0.2	0.56	0.05	0.66
10cm	1.02	0.4	0.07	0.43	0.36	0.53
20cm	1.56	0.79	0.54	0.92	0.47	1.13

Table 4. Summary of the results of the comparison between calculated and measured dose values for 15cm × 15 cm symmetric field separated into toe, the central part, and the heel.

EDW 45°			
	toe	centre	heel
Standard deviation	0.16	0.25	0.51
Average deviation	0.79	0.33	0.15
Confidence limit	1.03	0.62	0.91
Minimum relative error	0.65	0.00	-0.19
Maximum relative error	0.98	0.54	1.05
EDW 60°			
Standard deviation	0.14	0.33	0.43
Average deviation	0.25	0.29	0.93
Confidence limit	0.47	0.79	1.58
Minimum relative error	0.09	0.00	0.63
Maximum relative error	0.44	0.74	1.61

Table 5. Summary of the results of the comparison between calculated and measured dose values for 15cm × 15 cm asymmetric field separated into toe, the central part, and the heel.

EDW 45°			
	toe	centre	heel
Standard deviation	0.42	0.33	0.43
Average deviation	0.89	0.34	0.49
Confidence limit	1.51	0.82	1.14
Minimum relative error	0.13	0.00	0.02
Maximum relative error	1.56	0.96	1.54
EDW 60°			
Standard deviation	0.45	0.31	0.42
Average deviation	0.38	0.32	1.00
Confidence limit	1.13	0.79	1.63
Minimum relative error	-0.16	0.00	0.36
Maximum relative error	0.96	0.90	1.85

by Venselaar and Welleweerd [13] (within 4%) and Fraass *et al.* (1998) [16] (within 5%) was followed. In addition, results of this work are limited to the linac in our department.

The accuracy of the dose calculation algorithm has been investigated for 45° EDW and 60° EDW for one symmetric and three asymmetric geometries. The points of measurement are divided into three groups. In the first group the points of measurement are along the central axis. In the second group the points of measurement are under the toe (+4 cm off axis). In the third group the points of measurement are under the heel (-4 cm off axis). Caprile *et al.* [14] have studied the mentioned groups only in symmetric geometry using films. Comparing results of the previous study with those of the present work it is evident that TPS is modeling the dose distribution well within tolerance limit.

In the first group of points in symmetric setting, the maximum deviation is 0.54% for 45° EDW and 0.74% for 60° EDW and in asymmetric setting the maximum deviation was 0.96% for 45° EDW and 0.90% for 60° EDW.

In the second group of points in symmetric setting the maximum deviation was 0.98% for 45° EDW and 0.44% for 60° EDW and in asymmetric setting the maximum deviation was 1.56% for 45° EDW and 0.96% for 60° EDW.

In the third group of points in symmetric setting the maximum deviation was 1.05% for 45° EDW and 1.61 for 60° EDW and in asymmetric setting the maximum deviation was 1.54% for 45° EDW and 1.85% for 60° EDW.

Ion chamber measurements indicate that the calculated dose was slightly low only at one point for 45° EDW & at three points for 60° EDW but on the rest of the points the dose was high. The deviation between calculated and measured dose along the central axis was the least as compared to toe and heel. The deviation in symmetric setting was less than that of asymmetric setting. The maximum deviation was found at 20 cm depth for both the wedges. In the symmetric setting the maximum value of confidence limit was 1.03 for 45° EDW and 1.58 for 60° EDW. In the asymmetric setting the maximum value of confidence limit was 1.51 for 45° EDW and 1.63 for 60° EDW.

In summary, observed deviations between TPS calculated doses and measured dose by ion chamber from shallow to large depths, for symmetric as well as asymmetric wedged fields and for both EDWs are well within acceptability criteria and tolerances set by TRS 430 (15), Fraass *et al.* (1998) (16), Venselaar and Welleweerd (13), Van Dyk *et al.* (17) and Mijnheer *et al.* (19).

CONCLUSION

The observed deviations were well within tolerance levels set by AAPM TG-53 reported by Fraass *et al.* (1998) (16) as well as the report by Venselaar and Welleweerd (2001) (12). The results indicate that the accuracy of Eclipse 6.5 (version 7.3.10) three-dimensional treatment planning system used with the enhanced dynamic wedges in symmetric as well asymmetric fields is adequate in clinical applications under the studied experimental conditions.

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