Dosimetric Study of Enhanced Dynamic Wedges to Clinical Implementation into XiO Treatment Planning System.

C.Rodrigues[1], V. Batel[2] , S. Germano[2], I. Monteiro Grillo[2], J.L.Pinto[1]

[1]Dep. de Física, Universidade de Aveiro, 3810-193 Aveiro, Portugal.

[2]Serviço de Radioterapia, Hospital de Santa Maria, Lisboa, Portugal.

***Abstract* - This work presents the physical and dosimetric properties of the Enhanced Dynamic Wedges (EDW) including depth doses, beam profiles and effective wedge attenuatin factors (EWAF) by experimental determinations. The measurements were performed for 6 MV at a Linear accelerator Varian Clinac 2100 C/D, Varian Medical Systems. The main purpose of this work was to study the dosimetric properties of EDW in order to implement them in XiO treatment planning system (TPS) by two algorithms, Clarkson and Convolution/Superpositon under the same conditions.**

I. INTRODUCTION

The use of mechanical wedge filters is a well established method for dose inhomogeneity compensation in photon therapy.[1] By computer-controlled movement of one of the collimator jaws, it is possible to generate a wedge-shaped isodose distribution. This concept has been developed further, yelding the dynamic beam delivery option on Varian´s Clinac 2100 C.[2] Originally, this concept was introduced as the dynamic wedge (DW), wich was later improved as the enhanced-dynamic wedge (EDW) modality. [3]

The EDW provides wedge angles of 10º, 15º, 20º, 25º, 30º, 45º and 60º for both symmetric and asymmetric field sizes. The upper independent jaws, assigned as Y1 and Y2, can travel from full open position to 10 cm over the central axis, thus allowing field syzes up to 30 cm width. [1] [4] EDW is based on a segment treatment table (STT), wich contains the position (in equidistanced steps) of the jaws with respect to the cumulative number of monitor units (MUs) to be delivered.[3] One reference STT is needed per photon energy. This reference STT corresponds to the full field width of 30 cm and a wedge angle of 60º and is referred to as the “Golden” STT (GSTT) because all other field sizes and wedge angles can be derived from this STT. Two wedge orientations, Y1-IN and Y2-Out, are supported. [4]

This paper relates the physical and dosimetric properties of the EDW, i.e: determination of the effective wedge attenuatin factor (EWAF) by determination of the depth dose for open fields and for fields with EDW; determination of the dose profiles of EDW for several depths, field syzes, wedge angles and Y1-IN and Y2-Out orientations; comparison of the percentage depth dose (PDD) in open field with the PDD with EDW in several depths, determination of the experimental wedge angles and implementation of the EDW in XiO treatment planning system (TPS).

II. MATERIAS AND METHODS

Measurements were performed for 6 MV beams (Varian Clinac 2100 C/D, Varian Oncology Systems, Palo Alto, CA) with a 0º angle for the gantry and the collimator, using 100 MUs and a dose of 300 MU/min. The voltage of the electrometer was + 400 V and the unit of measurement was the nC.

A. Effective Wedge Attenuation factor

The EWAF is defined as the ratio of the measurements done with the ionization chamber with EDW by the measurments done in open field at the same reference depth and field size.[4] In both cases, for the determination of the EWAF, we used the average of the measurements done with EDW in Y1-IN and Y2-OUT orientations. In equation (1) is described the method used for the determination of the EWAF, where Y0º is the measurement done in open field and Y1-IN and Y2-OUT the mean measurements done with EDW in both directions

$$EWAF = \frac{\left(\frac{Y1_{IN} + Y2_{out}}{2}\right)}{Y_{0^0}} \qquad (1)$$

The EWAF was determined for a depth of 10 cm and a source surface distance (SSD) of 90 cm for symmetric fields of 4, 5, 10, 15 and 20 cm^2 and asymmetric fields of 20 and 30 cm^2. For the dose determination in open field and with EDW we used a MP3 system, an electrometer, UNIDOS E, a ionization chamber, *Semiflex PTW Freiburg* 31002, directly in the water phantom and a reference ionization chamber. The ionization chamber *Semiflex* has an active volume of 0.125 cm^3. For the dose measurement of the asymmetric fiels we used a deslocation from the central axis (CAX) of +5,-5 and 2.5 cm .

B.Determination of the dose profiles of EDW.

For the determination of the profiles of the EDW we used: the MP3 system, the ionization chamber *Semiflex* 31002, a reference chamber, a linear array *LA48 PTW Freiburg*, a multi-channel electrometer,*Multidos*, and a ME48 accessory.

The linear array LA48 allows measure dose profiles of both symmetric and asymmetric fields at a certain depth. This device allows the simultaneous integration of the dose in 47 points. Each ionization chamber is sealed and fluid –filled. The linear chamber array was mounted on the water phantom and the standard *MEPHYSTO* software was used for positioning and readout. The measurements with the LA48 needs a connection with *MULTIDOS*, upgranding it to a 48 channels dosimeter.

Profiles were taken at several depths, 1.5, 5 and 10 cm, for wedge angles of 15º, 30º, 45º and 60º and for symmetric fields of 5x5, 10x10 and 20x20 cm^2 at a SSD of 100 cm. For asymmetric setups, the 30 cm^2 field was subsenquently blocked to a 20x10, 10x20 cm^2 and the 20 cm^2 field to 5x10 cm^2 by changing the inicial postion of the Y1 collimator jaw while keeping the other one at a fixed position. For this dosimetrics measurements was used a displacement respect to the CAX.

C. Comparison of the percentage depth dose (PDD) in open field with the PDD with EDW in several depths

The PDD were adquired by single point measurements using PTW ionization chamber connected to a PTW Unidos Dosemeter. The chamber readings for the open field of 10x10 cm^2 was recorded for a fixed number of MUs at depths of 1.5 cm (dmax), 5 cm and 10 cm, in order to appreciate if the PDD for open field is the same as for EDW field. For the PDD at depths of 1,5 cm (dmax), 5 cm and 10 cm the proceeding was the same as without EDW: dividing the reading done with EDW in the depths of 1,5, 5 and 10 cm by the reading done with EDW in maximum energy doses, 1,5 cm.

C.Determination of the experimental wedge angles.

The determination of the experimental angle has the finality of verifying if the measured angle correspond to the used in the TPS. For the calculation we used a numeric estimation where the angle is defined by the line that connect two points in a quarter size of the field in each sides of the central axis of the isodose curve at a 10 cm depth. [6]

For the calculation of the experimental angle of the EDW we used the profiles of the 60º,45º, 30º and 15º EDW with orientations Y1-IN and Y2-OUT in an SAD setup (depth 10 cm).

II. RESULTS

A. Effective Wedge Attenuation factor (EWAF)

In Table 1 is demonstrated the calculated EWAF for symmetric and asymmetric field syzes, different EDW angles and wedge fields for 6 MV.

Wedge Angle (º)	Wedge Field (cm^2)	EWAF	Wedge Angle (º)	Wedge Field (cm^2)	EWAF
60	4	0,865	60 (asymmetric field)	30 (20x10)	0,133
	5	0,827			
	10	0,654			
	15	0,523		30 (10x20)	0,133
	20	0,420			
10	10	0,946			
	20	0,872			
15	10	0,920			
	20	0,818			
30	10	0,846	30 (asymmetric field)	20 (5x10)	0,758
	20	0,679			
45	10	0,762			
	20	0,552			

Table 1- Calculated EWAF for symetric and asymetric field syzes.

We observe that the EWAF obtained experimentally decrease with the increase of the field size and also decrease with the increase of the nominal angle of the EDW. The decrease of the EWAF with the increase of the field size is due the decreasing on the relative quantity of MUs administrated in the central axis, this verifys the prescrited in the STTs calculated. This observation in the decreasing of the EWAF with the increasing of the field size is according with results previsouly published. [2][3]

B. Dose profiles of EDW.

Figure 1 and Figure 2 show the measured dose profiles for 6 MV photons at a field size of 10x10cm^2 at depths of dmax (=1.5cm), 5 cm and 10 cm, for the 60º EDW.

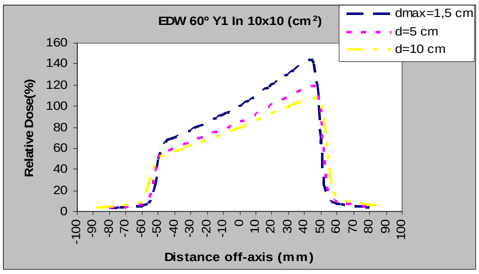

Figure 1- Dose Profiles of the 10x10 cm^2 field with EDW 60º Y1-IN at depths of 1,5 (dmax), 5 and 10 cm.

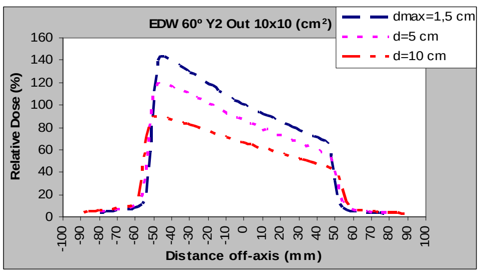

Figure 2- Dose Profiles of the 10x10 cm2 field with EDW 60º Y2-OUT at depths of 1,5 (dmax), 5 and 10 cm.

C. Comparison of PDD in open field with the PDD with EDW in several depths.

The folow figure and table are comparasions of the PDD values obtained experimentally for the open fiel 10x10 cm^2 and the values obtained for the same field with EDW for different angles and two orientations, Y1-IN and Y2-OUT.

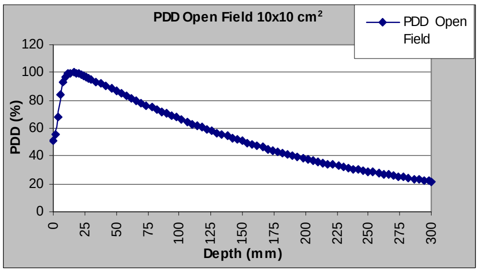

Figure 3- PDD obtained experimentally for the open field 10x10 cm^2.

EDW	Depth (cm)	1,5	5,0	10,0
EDW	Angle (º)	PDD (%)		
	open field	99,844	86,521	66,670
Y1-In	15	100,000	85,898	66,047
	30	100,000	85,510	79,906
	45	100,000	85,804	79,477
	60	100,000	85,423	79,914
Y2-Out	15	100,000	86,029	67,182
	30	100,000	84,864	65,717
	45	100,000	85,770	66,667
	60	100,000	86,187	66,122

Table 2- Comparative values of the PDD values obtained experimentally for the open field 10x10 cm2 and the values obtained for the same field with EDW for several angles and two different orientations, Y1-IN and Y2-OUT.

The values of the PDD with EDW show good agreement with the values of the PDD in open field. A exception values are found in the EDW Y1-IN 30º,45º and 60º at 10 cm depth where differents values PDD relatively to open field are found. This difference was probably due an error in the calibration of the electrometer, because all the others values show agreement.

D. Determination of the experimental wedge angles

Angle	
Nominal	**Experimental**
15º-*Y1* IN	15,0
15º-*Y2* Out	13,0
30º-*Y1* IN	28,5
30º-*Y2* Out	28,0
45º-*Y1* IN	42,5
45º-*Y2* Out	40,0
60º-*Y1* IN	57,5
60º-*Y1* Out	56,0

Table 3- Values of the angles of the EDW obtained experimentally.

In Table 3 is presented the values of the angles obtained experimentally for 6 MV.

Throught the table is possible to observe that the experimental angles differ from the expected angles in maximum value of 5º for the EDW 45º, Y2-OUT. In the literature was not found recommendations for the maximum values differences accepted between experimental angles and the angles used in calculations. Is important to enhance that a difference in the angle degree doesn´t deflect linearily a difference in doses.

III. IMPLENTATION OF THE EDW INTO XIO TPS.

Computacional calculation dose is done using a modulation algorithm and requires a "transmission matrix" derived from an STT (segment treatment table) to model the modified fluence from the source. The dose calculation is then performed using either the Clarkson or Convolution/Superposition algorithms.[7]

For the implementation of EDW into XIO the only required data are the measured of the effective attenuation factors (EWAF's) for 60 degree EDW for five square field sizes (4, 10, 15, 20, 30 cm^2) and ionometric measurements in a SAD setup at reference depth in the center of the open field. [7]

The taken profiles for a sufficient number of wedge angles (15, 30, 45, 60 degrees) and field sizes (5, 10, 20 cm^2) were in order to optimize the STT table for production of the best results through the range of clinical setups. [7]

In the end of the introduction of EDW into XIO there was no pathway by which EDW profile data may be analysed directly in Source File Maintenance. To following validation, was necessary to compare measured and calculated dose profiles generated in Teletherapy (Isodose Planning mode), Figure 4. [7]

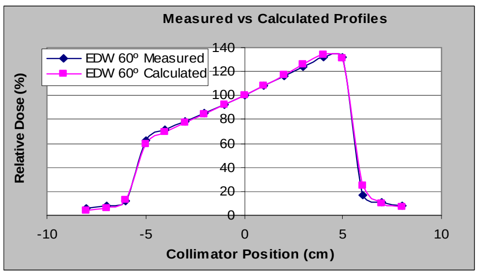

Figure 4- Measured vs Calculated Profiles by Convo/Superposition Algorithm for the 60º EDW Y1-In,10x10cm^2, before modelation.

The STT's of the each wedge/field size are created from a Golden STT. To proceed validation was necessary the change of than GSTT for both algorithms. In Table 4 is presented the table used for Modified the Fractional Cumulative Dose. [7]

Where the Modified Frac. Cum. Dose = Default Frac. Cum. Dose Calculated by the Algorithm x (Relative Dose Measured ⁄ Relative Dose Calculated by the Algorithm). [7]

Segment	Collimator Position	Default Frac. Cum. Dose	Relative Dose Measured	Relative Dose Calculated	Modified Frac. Cum. Dose
13	-8	0,526050	5,9281116	4,00	0,779621
14	-7	0,580964	7,6448498	5,60	0,793104
15	-6	0,641210	11,802575	12,60	0,600629
16	-5	0,707274	62,875536	59,10	0,752457
17	-4	0,779690	71,351931	69,70	0,798169
18	-3	0,859035	78,353004	77,10	0,872996
19	-2	0,945937	85,032189	84,60	0,950769
20	-1	1,041080	92,167382	92,10	1,041842
21	0	1,145206	100	100,00	1,145206
22	1	1,259122	108,04721	108,50	1,253867
23	2	1,383704	116,6309	117,40	1,374639
24	3	1,519904	124,38305	126,00	1,500399
25	4	1,668756	132,34979	134,00	1,648205
26	5	1,831381	131,65236	130,90	1,841907
27	6	2,008999	16,738197	25,30	1,329131
28	7	2,202931	11,10515	10,00	2,446388
29	8	2,414611	8,3154506	7,40	2,713321

Table 4- Excel Worksheet - Convo/Superpositon

In Figure 5 is showned the distribution of the Default Fractional Cumulative Dose calculated by the algorithm Convo/Superposition vs the Modified Fractional Cumulative Dose for the EDW 60º Y1-IN, 10x10 cm^2.

The values of the new cumulative dose of the GSTT, for each algorithm, were modified then in the Source File Maintenance, changing the values of the Fractional Cumulative dose for segments from 16 to 26, obtaining then a new GSTT for each algorithm. [7]

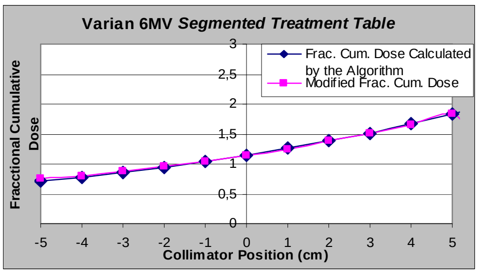

Figure 5- Default Fractional Cumulative Dose Calculated by the Algorithm vs Modified Fractional Cumulative Dose for the 60º EDW Y1-In, 10x10 cm^2.

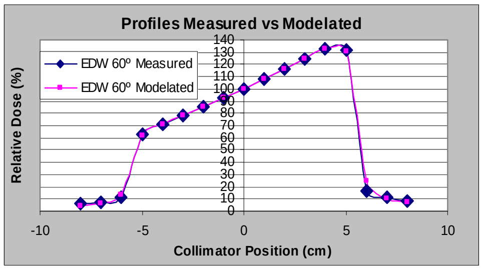

Figure 6-Measured vs Modelated Profiles by Convo/Superposition Algorithm for the 60º EDW.

In Figure 6 is possible to verify visualy the agreement between the profiles obtained experimentally and the modelated profiles by Convo/Superposition Algorithm for the 60º EDW, Y1-IN, 10x10 cm^2.

IV. CONCLUSIONS

The results obtained experimentally are according with results previsouly published. [1][2][3][5]

The implementation of EDW in XIO Treatment Planning System provides clinics with an additional effective tool for conformal radiotherapy treatment planning.

REFERENCES

[1] J.Salk, P.Blank, U.Machold, E.Rau, E.Schneider, E.Röttinger, "Physical aspects in the clinical implementation of Enhanced Dynamic Wedge (EDW)", 8th Varian Europe Users Meeting, Vilamoura, Algarve-Portugal, 27-30 April 1997.

[2] Leavitt, D. D., Martin, M., Moeller, J. H., Lee, W. L., "Dynamic Wedge Field Techniques through Computer-Controlled Collimator Motion", Medical Physics, Vol. 17, Nº 1, pp. 87-91, Jan. 1990.

[3] Koken, P. W., Heukelom, S., Cuijpers, J. P., "On the Practice of the Clinical Implementation of Enhanced Dynamic Wedges", Medical Dosimetry, Vol. 28, Nº 1, pp. 13-19, 2003.

[4] C-Series Clinac – Enhanced Dynamic Wedge Implementation Guide, 1 ed., USA, Varian Associates Inc., Oncology Systems, 1996.

[5] Leavitt D. D., PH.D., Klein, Eric, S., M., "Dosimetry Measurement Tools For Commissioning Enhanced Dynamic Wedge", Medical Dosimetry, Vol.22, Nº3, pp. 171-176, 1997.

[6] INTERNATIONAL ELECTROTECHNICAL COMISSION, Medical Electron Accelerators – Functional Performance Characteristics, IEC Performance Standard 976, Geneva, IEC, 1989

[7] C. Rodrigues, V.Batel, S.Germano, I.Grillo, J.Pinto, "Implementation of Enhanced Dynamic Wedges into XiO Treatment Planning System", Radiotherapy & Oncology, Journal of the European for Therapeutic Radiology and Oncoly, Vol. 81, Supl. 1, October 2006.