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Validation of Motorized Wedge Effective Isodose Angle with a 2D Array Detector

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ABSTRACT

Introduction: Elekta Versa HD linear accelerator is equipped with a universal wedge filter which is a single large physical wedge driven by motors; in other words, motorized wedge. It provides a nominal wedge isodose angle of 60° for the field size of 30×40 sq. cm. Motorized wedge isodose distribution generated is a combination of open and wedged beam segments. With this background in mind, the present study aimed to validate the planned wedge effective isodose angle.

Material and Methods: The current study validated the planned wedge effective isodose angle for 15°, 30°, 45°, and 60° with 6MV and 15MV for 10x10 sq. cm and 20x20 sq. cm field size. To this end, an analytical formula was applied against a 2D array detector using PTW MultiCheck software.

Results: As illustrated by the obtained results, the calculated, measured, and planned wedge effective isodose angle in this work represented a maximum deviation from its pre-set angle (a nominal wedge angle) of 9° for a 6MV photon energy and 5° for 15MV for field sizes of 10×10 sq. cm and 20×20 sq. cm.

Conclusion: In the present study, we validated the planned wedge effective isodose angle for field sizes of 10x10sq. cm and 20x20sq. cm for 6MV and 15MV photon energies using an analytical method and 2D array detector with a reasonable agreement.

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Introduction

Wedge filters are used in radiotherapy to change the characteristics of photon beams and enhance dose uniformity in the target volume. Various options exist for the generation of wedge isodose distribution. Elekta compact linear accelerators generate an isodose wedge distribution using a mounted remote-controlled motorized wedge (MW) inside the Linac head [1].

Wedge filters are categorized into physical and non-physical types. A physical wedge filter is a wedge-shaped material which absorbs and reduces the photon fluence of the beam. It results in the slope of isodose lines from their actual positions [2]. On the other hand, the non-physical wedge is a method for achieving the desired wedge angle using the unidirectional movement of collimator jaws. Differential blocking of beams or a combination of radiation dose from the open field and physical wedge in the beam direction (e.g., motorized wedge) is a non-physical technique to create a wedge effect [3]. This motorized wedge filter enjoys a number of substantial advantages, such as the reduced risk of physical harm to radiotherapy technologists and patients and the improvement of patient throughput. It also reduces operator fatigue and enhances the availability of needed wedge angles, instead of fixed wedge angles [4]. In addition, a motorized wedge filter provides the flexibility to select from 1°-60° instead of limited standard angles [5]. Due to computer-based control systems, wedge fields can be delivered by moving a single universal wedge in and out of the radiation field. Elekta Precise Linear Accelerator goes along with a motorized wedge of a nominal wedge angle of 60° [6]. The use of a spectrum of wedge angles gives a uniform dose to the treatment volume [7, 8]. Unlike the physical wedge, the wedge distribution which uses a motorized wedge is a combination of wedged and open beam segments. The

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choice of weighting factors results in the desired wedge angle. An effective wedge angle formula is used to calculate the wedge angle [9, 10].

Therefore, motorized wedges extend the ability to change radiation beam characteristics as a universal wedge. Nonetheless, to gain a considerable clinical advantage, the efficiency of the treatment planning with this wedge system should be verified for accurate dose calculation and constraints [11].

Quality assurance processes are required to support this technology which relies on computer control to move the fixed internal 60° wedges in and out of the radiation field to yield an effective wedge angle [12]. Wedge filters are used in Teletherapy to affect the doses relevant to the external patient contour and obtain an acceptable dose distribution in the target. Since the dose calculation accuracy needs to be within ±5%, as multiple algorithm support in the treatment planning system is necessary [13]. To estimate wedged beam dose using diode sensors surface dose correction to be applied for different angles and field size. [14]. Radiotherapy is used to give adequate and uniform dose distribution to tumor cells as much as possible to minimize side effects and reduce damage to healthy cells. The patient's body surface has curvatures; accordingly, the dose at different points of interest will not be uniform. Various beam modification devices were used in the beam's direction to achieve the uniformity of the dose delivery [15].

The present study suggested a novel method for the detection of wedge effective isodose to measure the delivered dose angle. To this end, 2D array detector was applied. PTW MultiCheck software was used against the analytical formula for which inputs were taken from a treatment planning system (TPS) for a wedge effective isodose angle of 15°,30°,45°, and 60° for 6MV and 15MV for 10x10 sq. cm and 20x20 sq. cm field size.

Materials and Methods

The equipment, instruments, and software used in the current study are as follows:

Treatment Planning System (Monaco 5.11, Elekta, 2016), Linear Accelerator (Versa HD, Elekta, 2013), RW3 phantom, 2D detector array (Seven29, PTW, 2009), and MultiCheck software (PTW, 2013).

Linear Accelerator (Versa HD, Elekta, 2016) is a treatment delivery system housing a motorized wedge which can generate a range of effective wedge isodose angles with higher-energy X-rays, such as 6, 10, and 15MV.

RW3 phantom (PTW, RW3, 2007): These slab phantoms have density equivalent to water with sensor adopter plates required for dosimetry.

The seven 2D array seven29 detector (PTW, Seven29, and 2009): Detector matrix with a 729-ionization chamber for quality control and dosimetry in radiation therapy.

MultCheck (PTW, Multicheck, 2013): This software performs consistency tests of photons and electrons. This can be used to verify the beam central axis and transverse profile parameters, including wedge isodose angle. In the present study, this software was used with 2D array sensors to find the wedge angle.

The following steps were taken for the estimation and calculation of effective wedge angle using an analytical formula

- Computed tomography (CT) images of 30x30x20 cm^3 RW3 plastic plates already available in the treatment planning system was used to place beams.
- Treatment plans were generated for various wedge isodose angles, namely 15°,30°,45°, and 60°, for energies 6MV and 15MV for field size 10×10 sq. cm, 20×20 sq. cm with gantry, couch, collimator angle 0°, and source-to-surface distance setup (i.e., SSD=100cm).
- Dose at 10cm depth at one-fourth of the field size at the surface from the central axis on either side, such as D_1 and D_2 values (D_1 and D_2 are the dose value on wedge isodose lines at–FS/4 and +FS/4 at 10cm depth), were recorded.
- Absorption coefficient values were calculated using the formula $\mu=0.1\times\ln(D_{10}/D_{20})$ where D_{10} and D_{20} are the radiation-absorbed dose values at the depths of 10 and 20cm.
- The recorded D_1, D_2, $D_{10,}$ and D20 values for each plan to calculate the wedge angle, $\Theta_{E,}$ using the following formula:

We used an analytical formula to calculate the wedge angle [4]

$\Theta_E=\arctan[\ln(D_1/D_2)/0.5\times FS\times\mu]$, (1)

where μ is the absorption coefficient and FS is field size at the surface.

The following procedure was implemented for the estimation of the wedge angle using a 2D array detector

Figure 1 shows Experimental setup for motorized wedge profile/angle measurement

- After setting the Linear Accelerator Gantry, Couch, and Collimator angle to 0 degrees, 15cm RW3 plates were placed on the couch and aligned using an adapter plate.
- The 2D array detector was then placed on the slabs and its crosshair was matched to the central axis.
- A 9.3cm of RW3 plastic plates were placed above the detector so that the active volume of the sensor was at 10 cm depth with a source-to-surface distance of 100cm.
- The set-up was exposed to a radiation dose with Monitor Units (MUs) calculated by TPS for various wedge angles (wedged field and open field), namely 15°,30°,45°, and 60°, for

energies 6MV and 15MV for field size 10×10 sq. cm, 20×20 sq. cm was delivered.

– The measured wedge angles were noted for each plan using the absorption coefficient (μ) obtained from TPS and the beam profile obtained from the PTW multiCheck software connected to the 2D array detector.

Figure 1. Experimental setup for motorized wedge profile/angle measurement

Results

The following values were obtained for the effective isodose wedge angle (Tables 1 and 2) using two different methods. They are presented in terms of percentage differences regarding the analytical formula technique in the present study. Moreover, for each of the planned wedge angles, a 2D array detector demonstrated a better agreement, as compared to the analytical formula method. In addition, a concordance was detected between the analytical formula and the 2D array detector method to be within ±2σ (i.e., with two standard deviations). Nevertheless, the difference between the planned wedge effective isodose angle and calculated and measured wedge was reported as 9° for 6MV and 5° for 15MV (Tables 1 and 2).

In the present study, Microsoft excel was applied to create a Bland-Altman plot using the basic definition of the graphical method as the difference between two techniques on the Y-axis against averages of two on the X-axis. This plot is constructed by drawing lines at the mean difference of values of two methods and upper and lower limits of agreement on the Y-axis. The upper limits of the agreement are mean difference plus 1.96 times the standard deviation of the differences and. On the other hand, the lower limits of agreement are the mean difference minus 1.96 times the standard deviation of the differences [16]. Bland-Altman plot displays an agreement within ±2σ (Figures 2, 3, 4, 5).

Table 1. Comparison of analytical formula and 2D array detector methods to find wedge angle for 6MV

Planned wedge angle	Field Size(sq. cm)					
	Wedge angle -10x10		Percentage Deviation %	Wedge angle- 20x20		Percentage Deviation %
	Analytical Formula Method 1	2D array detector Method 2		Analytical Formula Method 1	2D array detector Method 2	
15°	10.56°	13.08°	- 23.86	12.83°	12.57°	2.03
30°	23.32°	24.20°	-3.77	25.54°	25.42°	0.47
45°	35.63°	37.07°	-4.04	39.08°	39.15°	-0.18
60°	51.31°	52.75°	-2.81	55.06°	55.23°	-0.31

Table 2. Comparison of Analytical Formula and 2D array detector methods to find wedge angle for 15MV

Planned wedge angle	Field Size(sq. cm)					
	Wedge angle-10x10		Percentage Deviation %	Wedge angle- 20x20		Percentage deviation%
	Analytical Formula Method 1	2D array detector Method 2		Analytical Formula Method 1	2D array detector Method 2	
15°	13.56°	14.69°	-8.33	15.02°	15.12°	-0.67
30°	27.38°	28.18°	-2.92	29.77°	29.51°	0.87
45°	41.11°	41.98°	-2.12	44.53°	44.14°	0.88
60°	56.54°	57.36°	-1.45	58.88°	58.69°	0.32

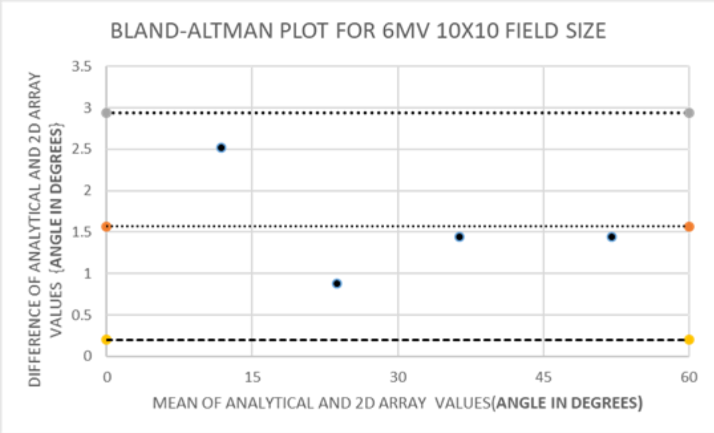

Figure 2. Bland-Altman plot for 6MV 10x10 field size- wedge angle agreement between the two methods

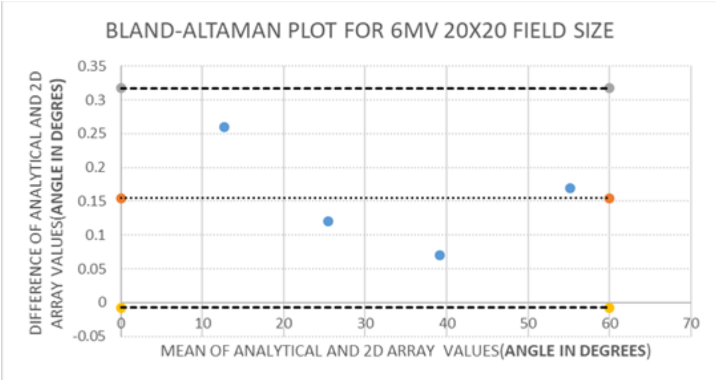

Figure 3. Bland-Altman plot for 6MV 20x20 field size-wedge angle agreement between the two methods

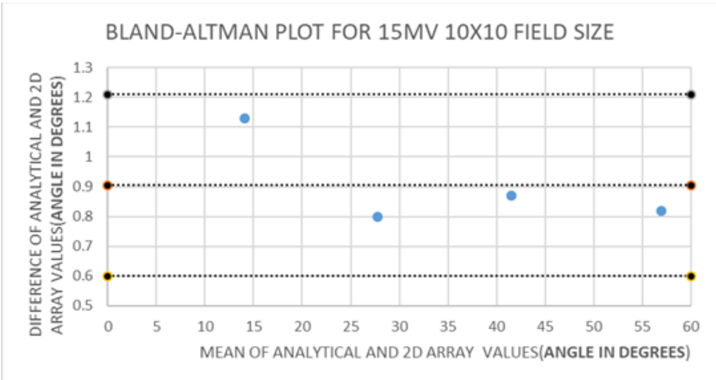

Figure 4. Bland-Altman plot for 15MV 10x10 field size-wedge angle agreement between the two methods

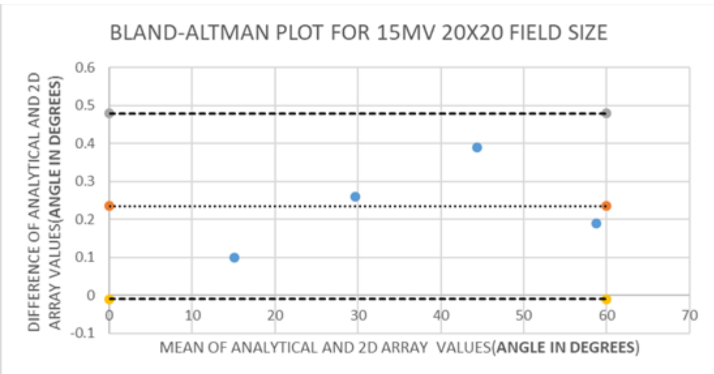

Figure 5. Bland-Altman plot for 15MV 20-x20 field size- wedge angle agreement between the two methods

Discussion

Wedge filters are needed in radiotherapy to obtain dose uniformity in the tumor area. In the present study, an effective wedge angle of 15°, 30°, 45°, and 60° for 10x10 sq. cm and 20x20 sq. cm was measured which varies with photon beam energy. Moreover, the results of the current study demonstrated a good agreement between two methods of finding a motorized/effective wedge angle. We found the maximum deviation of 9° with a planned wedge angle for 6MV 10x10 sq. cm field size and a maximum of 5° for 15MV 10x10 sq. cm field size. The maximum influence of field size on the wedge angle was observed at a 60° wedge angle. It was due to the considerable time of the present wedge filter in treatment as a result of increasing scatter radiation. The maximum difference between the planned and measured wedge angles for two field sizes was obtained at about 9°. It is worthy to note that this difference is higher, as compared to the published data [4, 9].

Every effective wedge angle was found to be less than the planned wedge angle owing to the neglect of beam hardening in the Thatcher equation [17]. The beam hardening effect was more significant for 6MV Linac relative to the cobalt unit due to its energy [18]. A recent study conducted by Mardié Behjati et al. revealed that the maximum difference between the planned and measured wedge angle was 10°. In the mentioned study, they concluded that the effect of the field size on the effective wedge angle differs from the proposed uncertainly ±2° [1].

The results of a study carried out by Rajesh Kumar et al. indicated that a motorized wedge filter is not a universal wedge, rather it depends on field size and deviates from a wedge angle of 60°. Especially at smaller field sizes (e.g., pre-set 60°), wedges isodose angles were measured at 52.8°, 59.4°, and 59.8° for field size 5×5 sq. cm, 10×10 sq. cm, and 15×15 sq. cm, respectively [3]. The results of a study performed by B. Ramya et al. suggested that motorized wedge is field size and energy-dependent. Moreover, they reported that the motorized wedge represented a deviation from its pre-set angle. In this regard, the highest difference was detected for 6MV photon energy with field size 5×5 sq. cm (within 9°), whereas the lowest difference was observed for 15MV energy with field size 20×20 sq. cm (within 2°) [19].

Conclusion

We validated the effective wedge angle for a field size of 10x10sq. cm, 20x20sq. cm for 6MV and 15MV photon energies using a 2D Array detector. The findings were in agreement with the results obtained from isodose curves generated from the treatment planning system using an analytical formula. As evidenced by the obtained results, although motorized wedge is considered a universal wedge, it represented a major deviation from pre-set wedge angle for 10x10 sq. cm and 20x20 sq. cm field size and energy 6MV and 15MV. The highest difference was reported as 9° for 6MV and 5° for the 15MV photon energy. Nonetheless, it is suggested that further investigations be conducted on a range of field sizes with the same method to confirm the already published results.

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