Original Article/นิพนธ์ต้นฉบับ

The Accuracy of Analytical Anisotropic Algorithm Version 8.9.17 on Wedge Factor and 2D Dose Distribution for Symmetric and Asymmetric Fields of Enhanced Dynamic Wedge

Manpuen S, M.Sc.[1], Tangboonduangjit P, Ph.D.[2], Tuntipumiamorn L, M.Sc.[3]

[1] *Radiation Oncology Unit, Department of Radiology, Faculty of Medicine Ramathibodi Hospital, Mahidol University*

[2] *Master of Science Program in Medical Physics, Faculty of Medicine Ramathibodi Hospital, Mahidol University*

[3] *Department of Therapeutic Radiology, Faculty of Medicine Siriraj Hosptal, Mahidol University*

Absract

Background: The technique of Enhanced Dynamic Wedge (EDW) was introduced to establish the wedge-shape dose distribution. Prior to the application in clinical situations was required the verification of dose calculation to reproduce the EDW in treatment planning system (TPS).

Objective: To evaluate the accuracy of Anisotropic Analytical Algorithm (AAA) version 8.9.17 for the EDW in symmetric and asymmetric fields.

Materials and Methods: Comparison between measured and calculated Enhanced Dynamic Wedge Factors (EDWFs) and 2D dose distributions were investigated for 6 MV photon beam of 10°, 30° and 60° EDW and field size 10x10 cm^2, 15x15 cm^2 and 20x20 cm^2 for symmetric and asymmetric fields in wedge and non-wedge direction. The points of evaluation for EDWF were the central and off-axis for each situation.

Results: The percentage deviation between measured and calculated EDWFs was less than 1% for all geometries, both symmetric and asymmetric of EDW field. For the off-axis points, the maximum deviation was 1.22% for asymmetric field Y2=0 (in wedge direction) of field size 10x10 cm^2 for EDW 60°. The comparison of 2D dose distributions using MapCHECK2 showed good agreement between measured and calculated with the AAA algorithm with a 100% passing rate for nearly all geometries of EDW fields. The minimum passing rate found in asymmetric field sizes 20x20 cm^2 (X1=0 and Y2=0) of EDW 10° was 94.9%.

Conclusion: The results of this study confirm the accuracy of the AAA calculations in modeling the enhanced dynamic wedge both symmetric and asymmetric fields.

Keywords: Enhanced Dynamic Wedge, Analytical Anisotropic Algorithm, 2D dose distribution, MapCheck, Wedge Factor

Corresponding author: Supamas Manpuen, Medical Physics, M.Sc.
Radiation Oncology Unit, Department of Radiology, Faculty of Medicine Ramathibodi Hospital, Mahidol University Tel 083-825-6111 E-mail: lovelyamm@hotmail.com

Introduction

Since the discovery of x-ray by Wilhelm Conrad Rontgen in 1895, the radiotherapy which is a treatment technique of using radiation to kill cancer treatment was improved of irradiation techniques and the machines to achieve the goal of treatment. The delivery must require high dose to the target volume whilst at the same time minimizing the dose to normal tissue to avoid the complication as much as possible. For this purpose, several techniques has been used to modify the beam to conform the radiation dose to the shape of the tumor such as using the physical wedged for creating wedge-shaped dose distribution. Generally the physical wedge is made from a high density material such as lead or steel and placed into the path of beam that mounted externally on the head of treatment machines. The radiation beam intensity decreases when it passes the wedge filter. The physical wedges can provide fixed four wedge angles of 15°, 30°, 45° and 60° for field size up to 20 cm width. At present, it has a treatment modality available for a Varian accelerator which reproduced wedge-shaped dose distribution by the use of computer-controlled jaw motion and dose rate in terms of Enhanced Dynamic Wedge (EDW).

In 1991, Varian Medical System introduced the Dynamic Wedge (DW) which based on the foundation of D. Leavitt's work[2]. In 1996, Varian improved the capabilities of Dynamic Wedge called Enhanced Dynamic Wedge (EDW). The EDW can be delivered by both symmetric and asymmetric fields for seven wedge angles of 10°, 15°, 20°, 25° 30°, 45° and 60°, field sizes up to 30 cm wide in wedge direction which allows larger wedge fields and provide a linear dependence of wedge factors (WFs) on field sizes. EDW has many advantages over physical wedges. They are easy to use, allow for more wedge angles, no additional scatter, do not require the therapist to enter the treatment room, and absence of beam hardening effect due to no absorbing materials in the beam. Nevertheless EDW also have some disadvantages and limitation, such as the rotation of collimator to provide sloping in any direction and it would take a long time in the process of implementation and commissioning for the treatment planning system (TPS). The EDW parameters in the treatment planning system that used to determine the accuracy in beam modeling and dose calculation namely percent difference between calculation and measurement for wedge factors (WFs), percentage depth dose (PDDs) and beam profiles. In order to verify the accuracy of monitor units (MUs) and dose distribution necessary to deliver a correct dose at a valid point, Enhanced Dynamic Wedge factors (EDWFs) need to be determined. These appear to be depend on the field size especially the field dimension in the wedge direction and wedge angle, and also dependent on the off-axis distance in the wedge direction for asymmetric EDW fields.

In this study, the aim was to evaluate the accuracy of Anisotropic Analytical Algorithm (AAA) version 8.9.17 (the last version of photon dose calculation algorithm to be implemented in the Eclipse treatment planning system at Ramathibodi Hospital) for calculating the EDW fields both symmetric and asymmetric in wedge and non-wedge direction. And also comparing measured 2D dose distribution in the plane perpendicular to the beam axis by using MapCHECK2 and calculated those by the ECLIPSE treatment planning system AAA algorithm for different field sizes and wedge angles.

Material and Method

1. Measurements of enhanced dynamic wedge factor using cylindrical waterproof ionization chamber 0.13 cm^3

In this study, Enhanced Dynamic Wedge Factors (EDWFs) were measured by 0.13 cm^3 waterproof ionization chamber with DOSE-1 electrometer in Blue

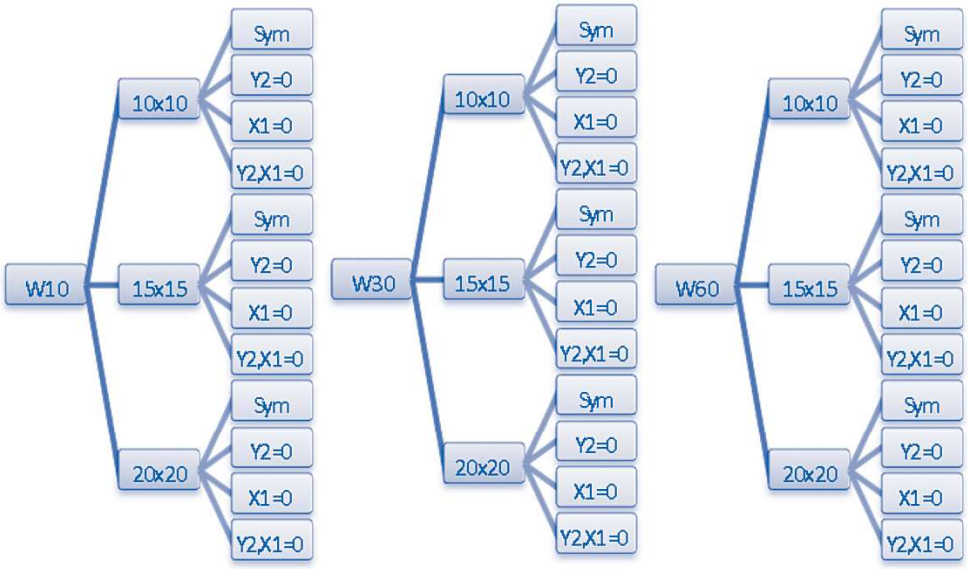


Figure 1. *The layout of the experimental divided into EDW 10, 30 and 60 degree for symmetric and 3 conditions of asymmetric fields (Y2=0, X1=0, and Y2=X1=0)*

water phantom. The chamber was mounted in the holder and connected to a Common Control Unit (CCU) for controlling the position of chamber. Doses were measured for specified points namely, the first point at the central beam axis and the last two points at the off-axis distance (heel side and toe side of wedge fields) at depth 10 cm and source to surface distance (SSD) of 90 cm for EDW symmetric field sizes of 10x10 cm^2, 15x15 cm^2 and 20x20 cm^2 with the photon energy 6 MV for EDW angles of 10, 30 and 60 degree. There were 3 designed conditions for asymmetric fields namely Y2=0, X1=0, and Y2=X1=0. The outline of the experiment is shown in Figure 1.

The measurement in EDW Y1-IN collimator (coll 270°) was assigned. The delivery of fixed 300 monitor units (MUs) was used for each field that divided into 4 groups. Group A is Symmetric fields. Group B is Asymmetric field of Y2=0. Group C is Asymmetric field of X1=0. Group D is Asymmetric field of X1 and Y2=0. Figure 2 illustrates the locations of measured points. The detail of the points of measurement in each field can be defined as the followings:

1. Point 1 located at negative off-axis direction -3 cm for field size 10x10 cm^2, at -4 cm for F.S. 15x15 cm^2, and at -5 cm for field size 20x20 cm^2. This point is under the heel of wedge fields.
2. Point 2 located at center of beam
3. Point 3 located at positive off-axis direction 3 cm for field size 10x10 cm^2, at 4 cm for field size 15x15 cm^2, and at 5 cm for field size 20x20 cm^2. This point is under the toe of wedge fields.

By the definition, the EDWFs for a symmetric field size are determined as the ratio of a dose with EDW on the central axis to the open field dose in the same field size and depth. For the EDWFs for asymmetric fields, the center of beam is away from the central axis therefore the position of measured point will change to the center of EDW beam[5].

$$EDWFs_{(FS,\ d=10)} = \frac{IC\ Reading\ EDW_{(FS,\ d=10,\ center\ of\ beam)}}{IC\ Reading\ OPEN_{(FS,\ d=10,)}}$$

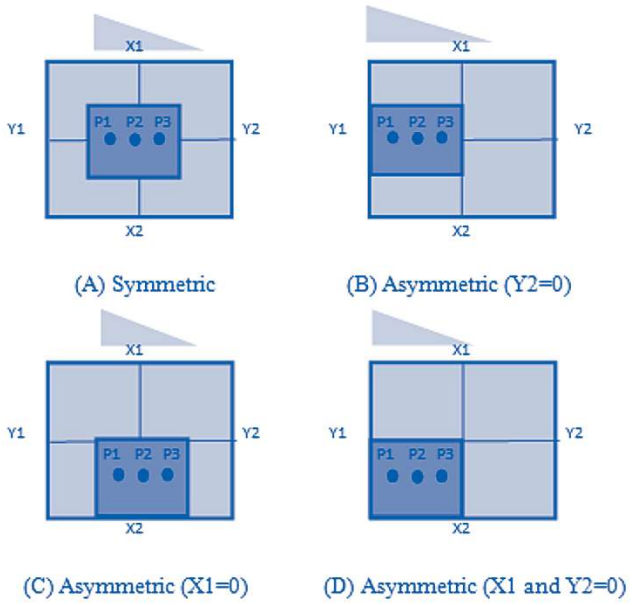


Figure 2. *The beam setups and the points of measurement are divided into 4 groups*

2. Measurements of 2D dose distribution using MapCHECK2

Begin the measurement by placing the Map CHECK2 on the treatment couch with the electronic part of MapCHECK2 away from the radiation beams and align the center of beam to MapCHECK2 by using cross hairs. Adjust the couch height until the laser superimposed to the detector plane marked on the side of the MapCHECK2. Also the surface of MapCHECK2 should be 98.80 cm SSD since the detector are 1.2 cm below the surface. Add additional buildup 3 cm by using solid water phantom to create total buildup equal to dose at depth 5 cm because MapCHECK2 already has 2 cm of water-equivalent buildup and the surface of MapCHECK2 were at 95.8 cm. Performs the measurement of EDW fields same as designed in EDWFs but changed the depth of measurement to 5 cm water equivalent and delivered fixed monitor unit of 300 MU in each field.

3. Comparison between measurement by Map CHECK2 and calculation with AAA algorithm version 8.9.17.

First step is to create the water equivalent phantom and design the number of image planes and plan separation. In this study, the phantom size was 60x60x60 cm^3 and CT value of 0 HU was assigned for water material. Next step was to create the new plan and new fields. In dialog box of field properties filled the geometries with parameters that used in this experiment such as the collimator setting, gantry rotation, collimator rotation and EDW angle by following the MapCHECK2 measurement. In total, the number of fields set up that calculated with AAA algorithms was 39 fields include the symmetric and asymmetric fields of EDW 10, 30 and 60 degree and open field with field sizes of 10x10 cm^2, 15x15 cm^2 and 20x20 cm^2. The depth of isocenter was located at 5 cm TSD 95 cm the same as MapCHECK2 2D

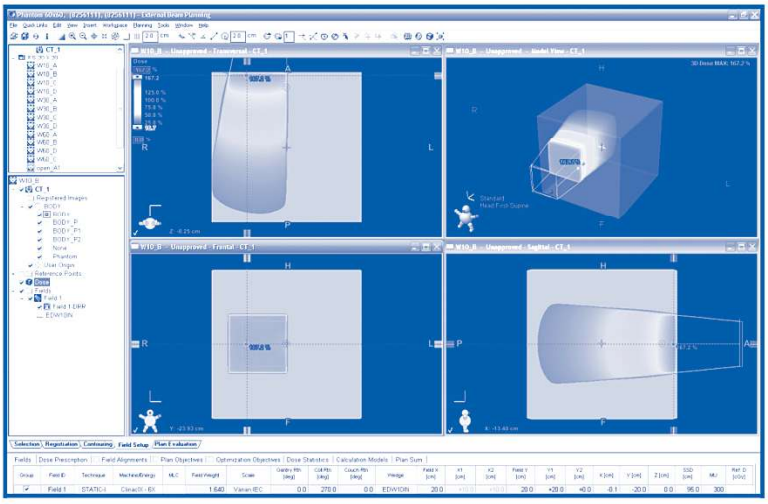


Figure 3. *The window of field setup in Eclipse TPS*

dose distribution measurement and at 10 cm TSD 90 cm for EDWFs calculation. The prescription was set to deliver 300 MU for all geometries.

3.1 Comparison of EDWFs

After the set up field process and calculation using the AAA, the dose at each points were recorded for open and EDW fields. The detail of the points of measurement in each field is shown in Figure 4.10. Also the calculation of EDWFs was then derived by taking the ratio of the dose at each point with the EDW fields to the dose at center of beam for open fields.

The deviations of EDWFs between measurement and calculation are expressed as the equation below

$$\% \text{ difference} = (EDWF_{cal} - EDWF_{meas}) * 100\% / EDWF_{meas}$$

3.2 Comparison of dose distributions

For comparison of 2D dose distribution, dose plan will be exported to the MapCHECK2 software. Initially, the verification plan will be created by using MapCHECK2 phantom as shown in Figure 4. and then export dose map in coronal plane which was used for the dose comparison and loaded into the MapCHECK software. The criteria for comparison dose distribution between two dose maps can be evaluated by determining the dose difference tolerance and a distance to agreement set by user.

3.3 Dosimetric evaluation using Gamma Index

In this study, the analysis of dose distribution used the Gamma Index evaluation method that consists of the comparison of dose differences and the comparison of Distance to Agreement (DTA). This idea was first presented by Low et al. (1998). Acceptance criteria for evaluating the accuracy of dose calculation of a TPS for complex geometry i.e. wedge, inhomogeneity, asymmetry, block or MLC fields used dose variation of 3% and DTA of 3 mm for high dose gradient that recommended by Venselaar et al (2001)

Results

1. Comparison of Enhanced Dynamic Wedge Factor (EDWFs)

The results of Enhanced Dynamic Wedge Factor (EDWFs) and the percent deviation between measurement and calculation for EDW 10°, 30° and 60° for symmetric and asymmetric fields of 10x10 cm^2, 15x15 cm^2 and 20x20 cm^2 at collimator of 270° (Y1-IN direction) at depth 10 cm for 6 MV photon beam.

The deviation is less than 1% for all geometries both symmetric and asymmetric fields with the maximum deviation of -0.7% for symmetric field of 15x15 cm^2 for EDW 10°. In asymmetric fields, the maximum deviation of EDWFs is 0.56% for asymmetric field 10x10 cm^2 (X1=0) of EDW 60°.

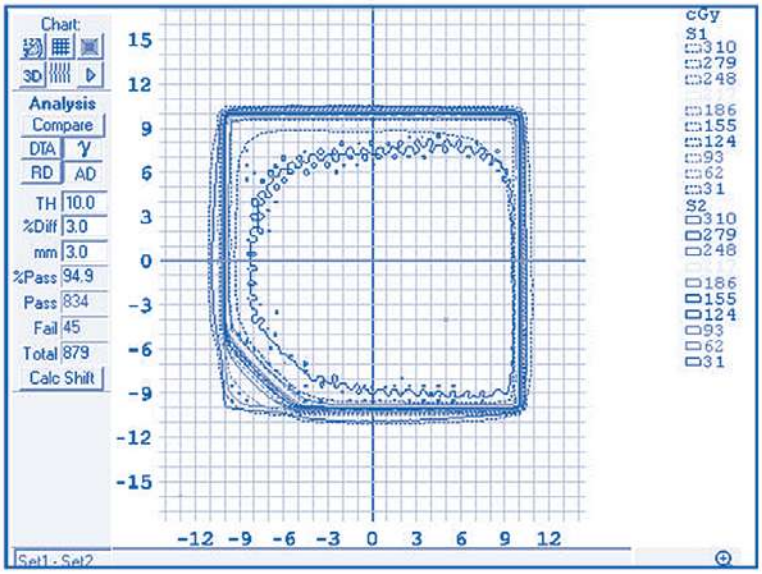
This study divided the point of measurement into three points in each field. The first point was under the heel of wedge fields, the second point was at the center of fields and the third point was under the toe of wedge fields hence the first and the third point were at the off-axis enhanced dynamic wedge position. For the off-axis point in heel position, the maximum deviation is 1.16% is found in asymmetric field Y2=0 at field size of 20x20 cm^2 for EDW 60°. And the off-axis point in toe position, the maximum deviation is 1.22% in asymmetric field Y2=0 at field size of 10x10 cm^2 for EDW 60°. As shown in the Table 1. Obviously the deviation on off-axis position is larger than the center of fields with more than 1% but still within the acceptance criteria dose variation 3% for asymmetric fields with wedge beam.

2. Comparison of 2D dose distributions between the MapCHECK2 measurement and AAA algorithm calculation.

The field sizes that used in 2D dose distribution measurement were the same as used in the earlier experiments for EDWFs. The MapCHECK2 measurements (dotted lines) and plan calculation (solid lines) were be overlapped each other to compare the 2D dose distribution by using MapCHECK2 built-in software and the acceptance criteria of 3% absolute dose and 3mm distance-to-agreement (DTA). Almost all of the conditions show that AAA algorithm tend to predict lower dose than MapCHECK2 measurement. However all of measurements test has a percent of passing rate more than 95% for both symmetric and asymmetric fields of all EDW angles. The minimum passing rate was found in asymmetric field sizes 20x20

Table 1. Fields B: Summary of percent difference of Asymmetric fields (Y2=0 wedge direction) between measurement and calculation.

Points	EDW (degree)	Percent Deviation for Asymmetric fields (%) Y2=0		
		10x10 (X1=5,X2=5, Y1=10,Y2=0)	15x15 (X1=7.5,X2=7.5, Y1=15,Y2=0)	20x20 (X1=10,X2=10, Y1=20,Y2=0)
Heel	10°	0.28	-0.52	-0.65
	30°	0.36	-0.40	-0.52
	60°	0.34	-0.64	-1.16
Center	10°	-0.26	-0.08	-0.13
	30°	-0.06	-0.02	0.07
	60°	0.31	0.09	0.17
Toe	10°	0.98	0.59	-0.07
	30°	1.03	0.75	0.11
	60°	1.22	1.13	0.65



(A)

Figure 5. *The comparison between MapCHECK2 measurement (dotted lines) and AAA calculation (solid lines) of planned dose distribution of asymmetric field 20x20 cm^2 X1 and Y2=0 (A) EDW 10°*

cm^2 (X1=0 and Y2=0) of EDW 10° as shown in the figure 5. that obtained 94.9% which in this fields the radiation beam were exposed through the trimmers at the corner. All results show good agreement of 2D dose distribution with the % passing rate more than 95% between measurement and calculation when 3% and 3mm criteria are used.

Discussion

According to the characteristic of EDWFs, the measured data showed that the wedge factors of the EDW are strongly dependent with field sizes which contributed a smooth and continuous decrease in the EDWFs, as shown in Figure 6. For the groups of asymmetric field that the center of beam not located on the beam axis, the EDWFs were changed the location at the off-axis position. The values of EDWFs of asymmetric fields on X axis (non-wedge direction) were similar to the symmetric fields that do not change significantly. On the other hand, the groups of asymmetric fields on Y axis and both X and Y axis (wedge direction) change significantly for all field sizes and wedge angles. The study found that EDWFs do not only depend on field size but also the position of center of beams for asymmetric fields especially in the wedge direction.

The percent deviation of EDWFs between measurement with 0.13cc ionization chamber and calculation with AAA algorithm version 8.9.17 of Eclipse TPS in both symmetric and asymmetric fields was less than 1% for all geometries and wedge angles. The results data show that the AAA version 8.9.17 can be well generated the EDWFs and ensured that the better accuracy for clinical applications can be obtained.

Previously, however, in case of the complex geometries such as the half beam of EDW reported by Christopher M. Bragg et al.[10] verified the AAA version 7.5.18 for radiotherapy treatment planning. They found the disagreement with a large discrepancy approximately 5% and distance to agreement in the steep dose gradients were less than 2 mm that greater than for symmetric EDW fields. Off-axis enhanced dynamic wedge factor that further away from the center of wedged fields has been determined and the results shown that a large variation over than

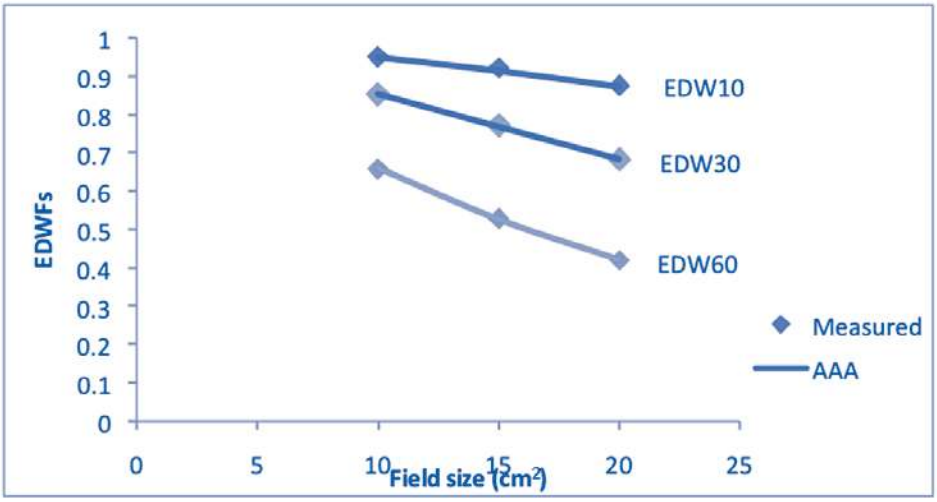
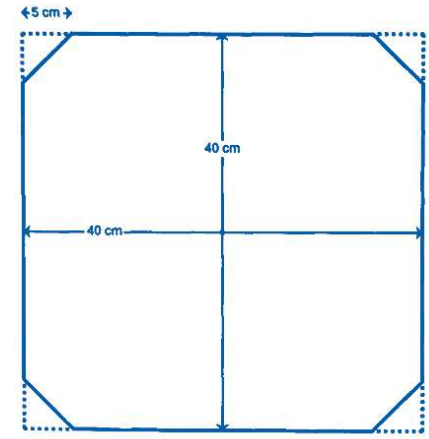


Figure 6. *Comparison of the measured (symbols) and AAA calculation (lines) for EDWFs of 6 MV photons of EDW angle 10°, 30° and 60°. The results were shown the EDWFs continuous decrease while increased field size.*



Schematic diagram of a 40×40-cm treatment field on a Clinac 2100 C at 100 cm SSD. The solid lines define the treatment beam edge. The dotted lines at the four diagonal corners are blocked areas by a set of beam edge corner trimmers which is a part of the fixed collimator assembly.

Figure 7. *The schematic diagram of truncate corner of treatment field size 40x40 cm^2*

the points at the center of beam but remained within the criteria of dose variation 3% and were not different significantly between heel and toe points. The maximum deviation 1.22% were found at asymmetric field in wedge direction (Y2=0) and large wedge 60 degree in heel position for field size of 10x10 cm2. However M.N. Anjum et al. (7) analyzed the off-axis point of EDW fields in a TPS using PBC algorithms and found that the variation at off-axis point was greater than at the center of beam. They concluded that it should be regarded when normalized the treatment dose of EDW fields in TPS on the off-axis point.

According to 2D dose distribution for different field sizes and wedge angles between MapCHECK2 and AAA version 8.9.17, the results show good agreement with percent passing rate more than 95% of all geometries except the asymmetric field size of 20x20 cm^2 X1=0 and Y2=0 with 94.9% passing rate when the acceptance criteria of 3% dose difference and 3 mm distance-to-agreement (DTA) were used. How-

ever when using the acceptance criteria of 2% dose difference and 2 mm DTA, the minimum passing rate was 65.5% found in asymmetric field size of 20x20 cm^2 (X1=0 and Y2=0) for EDW 10°. That is the worst condition in the clinic. The percent passing rate of EDW fields trends to decrease when increasing field size and reducing wedge angles for asymmetric EDW fields especially when asymmetric for both X and Y jaws.

When field size exceeds 35x35 cm^2, the radiation beam will expose through the trimmers which located at the corners of the beam as shown in Figure 7. The information about the dose under the trimmers was reported by Satish C. et al.[11] They pointed out that there is a higher significant transmission at the corners of large fields than the edge of field attenuated by a primary collimator jaw which could cause the varying amounts of increased leakage at the corners. Thus clinical situations that require the large asymmetric EDW fields should be aware of these results even though the EDW can be generated wedge fields of 4 to 30 cm in wedge direction.

Conclusion

In this study, the accuracy of AAA algorithm version 8.9.17 for calculating EDWFs and EDW 2D dose distributions was evaluated for symmetric and asymmetric EDW fields. The situations were chosen for fairly complex geometries that are the half beam block EDW fields from the smallest EDW angle (EDW 10°) to the largest EDW angle (EDW 60°).

The comparison of EDWFs between measurement and calculation found good agreement within 1% of all geometries and wedge angle. There is no significant difference observed between symmetric and asymmetric fields. The percent deviation at off-axis points both heel and toe side has a greater variation more than at the center of beam but still remained within the acceptance criteria of 3% dose difference. The variations at off axis point have a tendency to increase with large wedge angles but cannot be concluded that it depends on field sizes.

The results of 2D dose distribution measured by MapCHECK2 also agree with AAA algorithm which obtained the least passing rate of 95% for the criteria of 3% and 3 mm and the least passing rate of 66% for the criteria of 2% and 2 mm. The least passing rate occurs in a group of asymmetric field X1 and Y2=0 for field size 20x20 cm^2. It might because of that the radiation beam were exposed through the trimmer corner, the percent passing rate were changed significantly when compared with other fields.

The AAA algorithm versions 8.9.17 represents the accuracy for calculating EDW fields even though quite complex geometries were selected such as half beam block EDW fields both X and Y jaws which is rare to apply in clinical treatment. Nevertheless, it was indicated the confirmation to use in various situations.

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Original Article/นิพนธ์ต้นฉบับ

การตรวจสอบความถูกต้องของ Analytical Anisotropic Algorithm รุ่น 8.9.17 สำหรับ Wedge Factor และ 2D Dose Distributionในลำรังสีทั้งแบบสมมาตรและไม่สมมาตรของลำรังสี Enhanced Dynamic Wedge

ศุภมาส แม่นปืน วท.ม. (ฟิสิกส์การแพทย์)[1], ดร.พวงเพ็ญ ตั้งบุญดวงจิตร[2], รศ.ลลิดา ตันติภูมิ วท.ม. (ฟิสิกส์รังสี)[3]

[1] ภาควิชารังสีวิทยา คณะแพทยศาสตร์โรงพยาบาลรามาธิบดี มหาวิทยาลัยมหิดล
[2] สาขาฟิสิกส์การแพทย์ คณะแพทยศาสตร์โรงพยาบาลรามาธิบดี มหาวิทยาลัยมหิดล
[3] ภาควิชารังสีวิทยา คณะแพทยศาสตร์ศิริราชพยาบาล มหาวิทยาลัยมหิดล

บทคัดย่อ

บทนำ: Enhanced Dynamic Wedge (EDW) เป็นเทคนิคอย่างหนึ่งในการสร้างการกระจายตัวของลำรังสีให้มีลักษณะเป็นwedge-shape โดยการนำมาใช้งานทางคลินิกจำเป็นต้องมีการพิจารณาความถูกต้องของเครื่องวางแผนการรักษาในการคำนวณปริมาณรังสีของลำรังสี EDW ด้วย

วัตถุประสงค์: เพื่อตรวจสอบความถูกต้องในการคำนวณปริมาณรังสีของ Anisotropic Analytical Algorithm (AAA) รุ่น 8.9.17 จากการใช้ EDW ในลำรังสีสมมาตรและไม่สมมาตร โดยการทดสอบเปรียบเทียบระหว่างการคำนวณและการวัด EDW Factors (EDWFs) และ 2D dose distributions สำหรับโฟตอนพลังงาน 6 เมกะโวลต์ใน EDW ขนาดมุม 10°, 30° และ 60° องศาของลำรังสีขนาด 10x10 ซม^2, 15x15 ซม^2 และ 20x20 ซม^2 ทั้งแบบสมมาตรและไม่สมมาตรและพิจารณาที่ตำแหน่ง off-axis ของแต่ละลำรังสีด้วย

ผลการศึกษา: พบว่ามีเปอร์เซ็นต์ความแตกต่างกันอย่างไม่มีนัยสำคัญระหว่างการวัดและการคำนวณ โดยค่าที่ได้น้อยกว่า 1% สำหรับทุกๆลำรังสีทั้งแบบสมมาตรและไม่สมมาตร และค่าความแตกต่างมากสุดเพียง 0.7% พบในลำรังสีแบบสมมาตรขนาด 15x15 ซม^2 ขนาดมุม 10 องศา และที่ตำแหน่ง off-axis พบว่ามีค่าความแตกต่างมากสุดคือ 1.22% ในลำรังสีแบบที่ไม่สมมาตรในทิศทางแนวเดียวกับ wedge (Y2=0) ขนาดลำรังสี 10x10 ซม^2 ของ EDW ขนาดมุม 60° ผลการเปรียบเทียบ 2D dose distributions จากการวัดด้วย MapCHECK2 และการคำนวณด้วย AAA algorithm พบว่าให้ผลการทดลองที่มีความสอดคล้องกันโดยทุกๆลำรังสีมีเปอร์เซ็นต์ passing rate มากกว่า 95% โดยที่ส่วนใหญ่มีเปอร์เซ็นต์ passing rate เท่ากับ 100% และลำรังสีที่มีเปอร์เซ็นต์ passing rate ต่ำสุดคือ ลำรังสีแบบไม่สมมาตร (X1=0 and Y2=0) ขนาด 20x20 cm^2 ของ EDW ขนาดมุม 10° มีค่าเท่ากับ 94.9%

สรุปผลการศึกษา: จากการทดลองนี้สามารถสร้างความเชื่อมั่นในความถูกต้องของการคำนวณด้วย AAA algorithm ในการสร้างลำรังสี EDW ทั้งแบบที่สมมาตรและไม่สมมาตรได้

Corresponding Author: ศุภมาส แม่นปืน วท.ม. (ฟิสิกส์การแพทย์)
ภาควิชารังสีวิทยา คณะแพทยศาสตร์โรงพยาบาลรามาธิบดี มหาวิทยาลัยมหิดล
โทร 083-825-6111 E-mail: lovelyamm@hotmail.com