Volume 13. Number 2. 175-189 DECEMBER 2024

Jurnal ilmiah pendidikan fisika Al-Biruni
https://ejournal.radenintan.ac.id/index.php/al-biruni/index
DOI: 10.24042/jipfalbiruni.v13i2.24016

P-ISSN: 2303-1832
e-ISSN: 2503-023X

Dosimetric Analysis of 6 MV Energy Photon Radiation Beam on Flatness and Symmetry on Linac in Radiotherapy Installation of UNAND Hospital

Rika Analia[1], Ramacos Fardela[*1], Ridwan[2], Fiqi Diyona[3], Afdhal Muttaqin[1]

[1]Departement of Physics, Universitas Andalas, Indonesia
[2]Siemens Healthineers, Indonesia
[3]Medical Physics, Radiotherapy Installation, Unand Hospital, Indonesia

Corresponding Address: ramacosfardela@sci.unand.ac.id

Article Info

Article history:

Received: September 2, 2024
Accepted: December 24, 2024
Published: December 30, 2024

Keywords:

LINAC;
Dosimetry;
Photon Beam;
Flatness and Symmetry.

ABSTRACT

A dosimetric analysis of a 6 MV photon energy radiation beam on flatness and symmetry in LINAC radiotherapy at UNAND Hospital has been conducted. The aim was to measure the quality of the photon beam using an ion chamber cc 13 detector by observing the beam profile and analyzing the effect of field size and irradiation depth. This study used a blue phantom as the object of irradiation with 6 MV photon energy and variations in irradiation field size. The results showed that the PDD curve at 6 MV energy was by the international standard recommended by BJR-25. Then, the average values of flatness and symmetry in the field area of 10×10 cm^2 and 15×15 cm^2 are 1.6% and 2.4% for flatness and 2.3% and 1.9% for symmetry. Thus, the dose distribution is more uniform, and both the left and right sides of the profile on the center axis appear balanced, which will help deliver the dose to the patient better. Thus, these values are suitable for clinical use. This study found that the beam profile was larger on the left side of the main axis. This must be considered to ensure the dose distribution complies with the established safety standards. The results also show that variations in the field area and irradiation depth can affect the beam profile, and the resulting flatness and symmetry values follow the IAEA TRUS-381 and AAPM TG-142 recommendation standards, which are ±2% flatness and ±3% symmetry.

INTRODUCTION

Radiotherapy is a very important medical tool in the medical world because it can cure cancer patients without damaging normal tissue (Fauziah & Abdullah, 2018). To produce quality treatment, the Linac radiation beam, including its flatness and symmetry file profile, must be maintained in good condition under those set by international organizations such as the International Atomic Energy Agency (IAEA) or American Association of Physicists in Medicine (AAPM). Linac has the advantage of generating photon beams because it has a wide energy spectrum that can be customized according to clinical needs. This lets the photon beam penetrate cancerous tissue at a certain depth (Mayles et al., 2007).

Radiation therapy is basically related to radiobiological effects, especially the radiosensitivity of cancer cells. In giving radiation doses, a tolerance of ± 5% of the total dose given to the intended target is given (IAEA, 2000). This principle aligns with the International Commission on Radiation Units and Measurement (ICRU) guidelines recommended by the IAEA and TRS-381, stipulating that any uncertainty in all radiotherapy treatments should be limited to less than ±5%. The radiation dose given to

How to cite Analia, R., Fardela, R., Ridwan, R., Diyona, F., & Muttaqin, A. (2024). Dosimetric analysis of 6 MV energy photon radiation beam on flatness and symmetry on linac in radiotherapy installation of UNAND Hospital. *Jurnal ilmiah pendidikan fisika Al-Biruni, 13*(2), 175-189.

patients and used during medical operations can be regulated and adhered to properly through radiation dose monitoring (Fardela et al., 2023). According to the TG 224 report, it is also recommended to perform radiation beam measurements (such as output, symmetry, flatness, range, and focal spot) monthly at the gantry angle to ensure the quality and accuracy of radiotherapy procedures (Mirandola, 2015).

Quality Assurance (QA) is designed to ensure accuracy in dose calculations performed by medical physicists using the Treatment Planning System aircraft with measurements of the dose received by the patient, including dosing of the patient in the Linac aircraft, data transmission, and proper positioning. However, inaccuracies can be caused by faulty equipment, operational errors, and human error (Jenkins et al., 2015). In addition, daily dosimetry measurements taken before treatment, including symmetry consistency, photon, and electron output flatness, are usually taken by the Radiotherapist (Radiotherapy Technician) to warm up the aircraft in the morning. This is done to ensure that the Linac aircraft is in a condition suitable for clinical use. The role of medical physicists is very important in performing dose calculations, measuring the quality of radiation beams, and maintaining beam output variables within established tolerance limits (Sidabutar & Setiawati, 2014).

The LINAC quality control process ensures that patient dose adjustments during radiotherapy follow the guidelines and standards established by Varian Medical Systems. Quality control is carried out by measuring the Percentage Depth Dose (PDD) and the dose profile (Sumitra et al., 2020). Two parameters, flatness and symmetry, can be used to determine the stability of the LINAC profile (Qomariyah et al., 2019).

Symmetry and flatness are two important factors that affect the uniform dose distribution at the target volume point (Bayatiani et al., 2021). Beam uniformity (flatness and symmetry) is a dose variation above 80% over an irradiation field area of 10×10 cm² on the main axis or perpendicular to the beam uniformity tolerance of ±3%(Kutcher et al., 1994). Beam uniformity plays an important role in ensuring that radiation beams have the right impact on patients, both of which are indicators in determining the success of cancer therapy (Laili et al., 2014). Flatness is the percentage of maximum permissible dose variation within a single radiation beam field. Symmetry measures the maximum permissible deviation between the radiation dose on the left side and the radiation dose on the right side of the radiation beam field. These two parameters are part of the quality evaluation of the Linac machine and ensure uniform and symmetrical dose distribution at the intended target (Podgorsak, 2005).

According to the recommendations of AAPM and IAEA, the flatness and symmetry values on the beam must meet the tolerance limits of ±2% and ±3% to be used clinically (IAEA, 2014; Smith et al., 2017). If the measurement results follow the specifications, the data will be used as a reference in the quality assurance program on the radiotherapy aircraft. Percentage Depth Dose (PDD) can provide information about beam quality so that the dose delivered can be optimized in the irradiation field and depth. Meanwhile, the radiation beam profile can provide beam quality information for dose distribution in the lateral direction (Qomariyah et al., 2019). Several studies have shown that flatness and symmetry are necessary to verify the radiation output beam on the Linac aircraft. Hasanah et al. (2020) analyzed the PDD curve and electron radiation beam profile of the CLINAC CX variant Linac aircraft. The analysis results show that the electron beam is standardized based on PDD and dose profile, which is ±2 mm. According to the lateral dose distribution measurements, the larger irradiation field (25×25 cm²) produced a more uniform and symmetrical dose profile than the smaller irradiation field (10×10 cm²). The dose profile in the beam direction is by standardization, namely ±4.5%, ±7% Flatness, and ±2% for symmetry (Hasanah et al., 2020). Deccaboter et al. (2022) analyzed 9 different beam parameters at gantry angles. Where the throughput, symmetry, and flatness are within ±2%. Whereas, Full width at half maximum (FWHM), spot position, and penumbra width on the center axis plane are within ±1 mm where the differences are all ½ of the 6 MeV energy distance relative to the baseline, which shows an agreement score higher than 90% (Decabooter et al., 2022). Dutta et al. (2023) analyzed the performance and evaluated the variation of the true beam on the Linac where the isocenter shift occurred due to the gantry, collimator, and table. For the rotation, it was within a circle with a diameter of ± 2 mm. Then, the conformity of the optical field and the measured radiation were symmetrical for all available energies within ± 2 mm. Results for important metrics like output, flatness, symmetry, and spot size stayed within predetermined tolerances (±1% for output and ±1 mm for positional accuracy) during the 12-month testing. This demonstrates the procedure's dependability and accuracy (Dutta et al., 2023). Based on the above studies, conducting further studies on the dose profile generated at Linac is important. The cc 13 ion chamber detector was used in the study due to its high ability to detect dose exposure from a wide field.

The study aims to measure the quality of a 6 MV photon beam using an ion chamber cc13 detector by observing the beam profile, focusing on symmetry and flatness. Photon energy will be used to test several dosimetric parameters, including radiation beam output, PDD, beam profile, flatness, symmetry, and the effect of field size. The field size will vary, allowing us to observe the impact of field size on the width of the radiation beam produced by the photons. The depth is determined by the position detected by the detector in each irradiation field.

In addition, this study will analyze the effect of field size and irradiation depth. The benefit of the study is that photon beam testing is expected to guide clinical personnel in identifying the impact of beam asymmetry and flatness when performing measurements. Thus, this study is expected to improve the monitoring and performance of Linac devices in radiotherapy.

METHODS

Research Materials and Tools

The equipment used in this study is LINAC aircraft, Blue Phantom, ion chamber cc13 with (reference detector (R) and field detector (F), computer common unit (CCU), connector cable, and computer for MyQA software access.

Measurement Plan Setup

Radiation beam measurement using photon energy on the Linac therapy plane is carried out to verify and measure the flatness and symmetry values of the beam, as well as the condition of the Linac therapy plane using external light. The treatment and verification plan uses a 6 MV photon beam with field area variations. The basic parameters of PDD, Profile, beam flatness, and beam symmetry were measured experimentally using a blue phantom connected to an ion chamber detector to obtain the characteristics of radiation exposure. PDD curves and dose profiles were analyzed through the MyQA computer program located in the control room for Linac radiotherapy, while Microsoft Excel was used for data analysis.

Object Position Settings

The object consists of a blue phantom filled with distilled water with a position right in the field or under the gantry beam. Connect the ion chamber Field detector (F) and Reference detector (R) with a connector cable, then connect to the CCU. The reference detector (R) is positioned directly above the Field detector (F), as shown in Figure 1. Then, the position of the detector was set with an SSD of 100 cm and an isocenter starting with 0 cm. Furthermore, a LAN cable is attached to the CCU and then forwarded to the controlling computer. Setting the size of the photon irradiation field is controlled through MyQA software with an irradiation area of 5×5 cm^2, 10×10 cm^2, 15×15 cm^2, 20×20 cm2, and 25×25 cm^2, and an irradiation angle of 0°. PDD measurements are made with the detector moving to the Z-axis. At the same time, the dose profile is measured in the inplane and cross-plane directions to observe the distribution of radiation dose on the phantom and obtain a dose profile curve. Measurements are made 3 times directly.

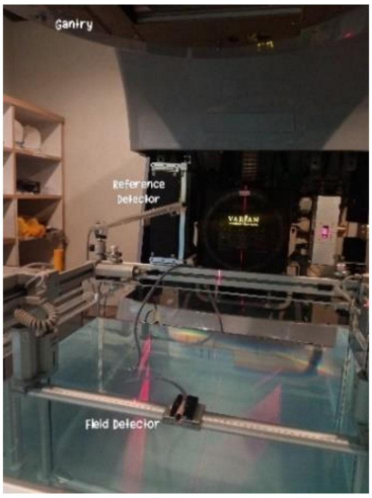


Figure 1. Position of the detector (Source: UNAND Hospital)

Data Analysis

Photon Beam PDD Measurement

Percentage of depth dose (PDD) is the quotient of the absorbed dose at a certain depth (D_d) with the absorbed dose at the maximum depth (D_{max}) expressed as a percentage with the formula:

$$PDD = \frac{Dd}{D_{max}} \, x \, 100 \quad (1)$$

Flatness and Symmetry

The stability of the beam profile on the Linac aircraft can be observed through two parameters, namely flatness and symmetry. Symmetry and flatness are obtained from the beam profile obtained during measurement. Flatness and symmetry measurements can use the equation below:

$$F = \frac{D_{max} - D_{min}}{D_{max} + D_{min}} \, x \, 100 \, \% \quad (2)$$

Meanwhile, the equation below can be used to determine the symmetry:

$$S = \frac{A_{left} - A_{right}}{A_{left} + A_{right}} \, x \, 100\% \quad (3)$$

Research Flow

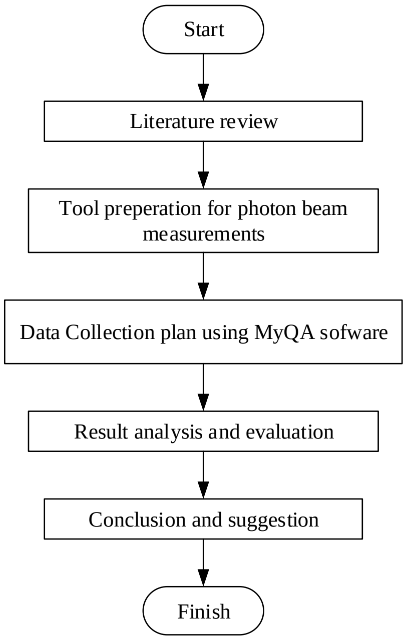


Figure 2. Flowchart

This section explains the initial preparation stage, starting with collecting and studying relevant literature to understand the theoretical foundations and research methods. Then, preparations were made for the measurement of the photon beam, including the calibration of the LINAC machine, connecting the reference detector and field to the phantom and CCU, as well as setting up the irradiation at various field sizes with three repetitions using MyQA software. The radiation data collection was organized and calibrated according to the established protocols. The results were analyzed and evaluated using Microsoft Excel to determine the flatness and symmetry of the photon beam. The conclusion and suggestions are based on the analysis results and their implications for clinical use, with recommendations for further development. After the analysis and conclusions are complete, the research ends.

RESULTS AND DISCUSSION

Radiation Dose Measurement Results at 6 MV Photon Beam

PDD measurements were performed before dose profile measurements for LINAC calibration and to ensure that the resulting dose followed the standard. The results of PDD measurements on a 6 MV photon beam are based on the depth of the target and the detector used. The detector was ion chamber cc13 with a blue phantom as the measurement medium. PDD was obtained to verify the irradiation depth at 30 cm with a field area of 10×10 cm^2 and SSD of 100 cm. The curve of PDD measurement results can be presented in Figure 3.

From the reference values shown in Table 1, it is known that the 6 MV photon beam reaches the maximum dose (D_{max}) at a depth of 1.5 cm with a clinical depth percentage of 100%. PDD measurements have also been carried out by Sruti et al., which shows that Dmax on a 6 MV photon beam is at a depth of 15.99 mm or 1.6 cm with PDD at D10 at 66.87%(Sruti et al., 2015). BJR-25 provides information that the Dmax value at 6 MV energy is at a depth of 1.5 cm with a clinical depth percentage of 100%, and the D_{10} depth dose is 67.5%. The D_{10} depth dose determines the beam quality after reaching the maximum dose (BJR Supplement 25, 1996).

BJR-25 provides information that the Dmax value at 6 MV energy is at a depth of 1.5 cm with a clinical depth percentage of 100%, and the D10 depth dose is 67.5%. The D10 depth dose determines the beam quality after reaching the maximum dose. However, the D10 value obtained in this study is 68.2%, which is only a slight difference of 0.7% from the recommendation by BJR-25. Nonetheless, this difference is acceptable because, according to the BJR-25 international standard PDD protocol, it shows a small deviation of ±1% (Rahman, 2021).

Before reaching a maximum, the low surface dose pattern precedes the exponentially decreasing PDD curve. The attenuation of X-rays causes a low dose at the surface of the water phantom. As the depth of interaction of X-rays with the water phantom increases, the ionization process via the photoelectric effect, Compton effect, and pair production mechanisms increases. As a result, the dose increases and reaches a maximum in the stacking area (Bilalodin et al., 2022).

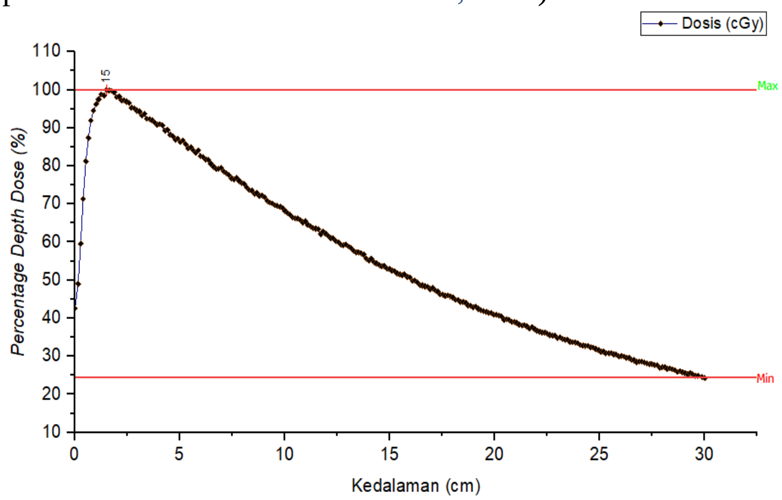


Figure 3. PDD Graph of a 6 MV Photon Beam

Table 1. Depth Dose of 6 MV Photon Beam

Energy	Depth Dose D_{max} (cm)	PDD (%)						
		$D_{1,5}$	D_5	D_{10}	D_{15}	D_{20}	D_{25}	D_{30}
6 MV	1,5	100	86,3	68,2	52,9	40,9	31,2	24,3

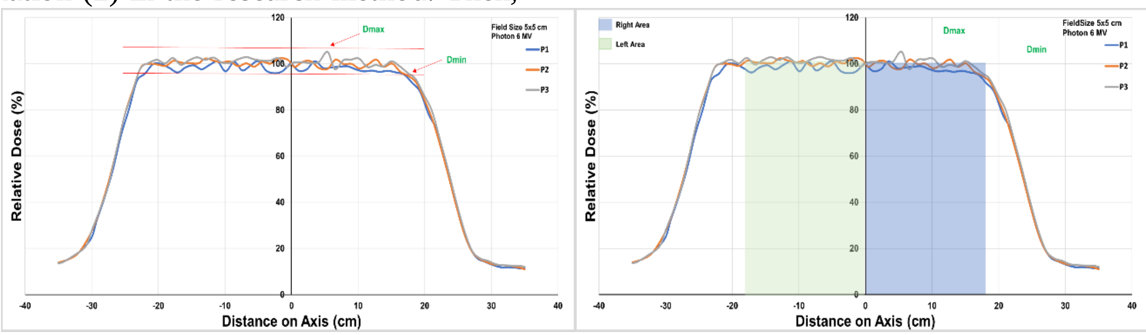
Dose Profile Measurement Results at 6 MV Photon Beam

To ensure beam profile consistency, flatness, and symmetry, accuracy must be within the recommended tolerance limits of ±2% and 3%, respectively (Gerald J Kutcher et al., 1994). To find significant differences in the duration of irradiation in real time, measurements were taken three times on each field area, consisting of the 1st (P1), 2nd (P2), and 3rd (P3) measurements.

Flatness measurement starts by finding the depth value at the maximum dose (D_{max}) and the depth value at the minimum dose (D_{min}), which will then be calculated using equation (2) in the research method. Then, symmetry is determined by determining the left and right areas as in equation (3).

Flatness and Symmetry Measurement of 6 MV Photon Energy Beam Profile on 5×5 cm^2 Field Area

Figure 4 presents the results of beam profile measurements on flatness and symmetry with a field area of 5×5 cm^2 using the cc13 ion chamber detector. Based on Figure 4 (a and b) and Table 2, D_{max} in P1, P2, and P3 showed an increase in dose at the time of the last measurement, namely 100.5 cGy, 102.3 cGy, and 105.2 cGy with an average maximum dose of 102.7 cGy.



(a) (b)

Figure 4. Dose Profiles Flatness (a) and Symmetry (b) Field Area 5×5 cm^2

The increase in D_{max} at each measurement affects the flatness, with flatness values P1, P2, and P3 of 4.4%, 5.3%, and 5.8%, respectively, and an average of 5.2%. The resulting flatness value is quite high, which causes the beam profile to be non-uniform at the top of the main axis. The non-uniformity of the beam also affects the symmetry value of the dose profile, where P1, P2, and P3 are relatively high, namely 6.9%, 6.1%, and 8.5%.

Table 2. Flatness and Symmetry Measurement of 5×5 cm^2 Irradiation Field Area

Measurements	**D_{max} (cGy)**	**D_{min} (cGy)**	**Flatness (%)**	**Symmetry (%)**	**FieldWidth (cm)**	**Center (cm)**
P1	100,5	92	4,4	6,9	5	-0,19
P2	102,3	91,9	5,3	6,1	5,1	-0,19
P3	105,2	93,5	5,8	8,5	5	-0,18
Average	**102,7**	**92,5**	**5,2**	**7,1**	**5,1**	**-0,2**

This shows that the higher the flatness, the higher the symmetry value. The left and right areas experience a high symmetry difference with an average of 7.1% in the width of the beam profile area, which is quite a large shift in the left area, as shown in Figure 4b.

The flatness and symmetry measurements on a 5×5 cm^2 field area show that P1, P2, and P3 are in an unfitness and unsymmetric beam condition, where the relative dose distribution in the beam profile is not evenly spread or uniform. This unevenness occurs due to significant variations in the measured dose at various points along the beam width, which causes the profile to be uneven and unflatness. Positioning errors of the reference detector (R) and detector field (F) are also possible. The small field size also causes the detector to run very fast so that the water in the phantom experiences slight shocks that cause the dose to be piled up at a certain place (Edi Guritna et al., 2017).

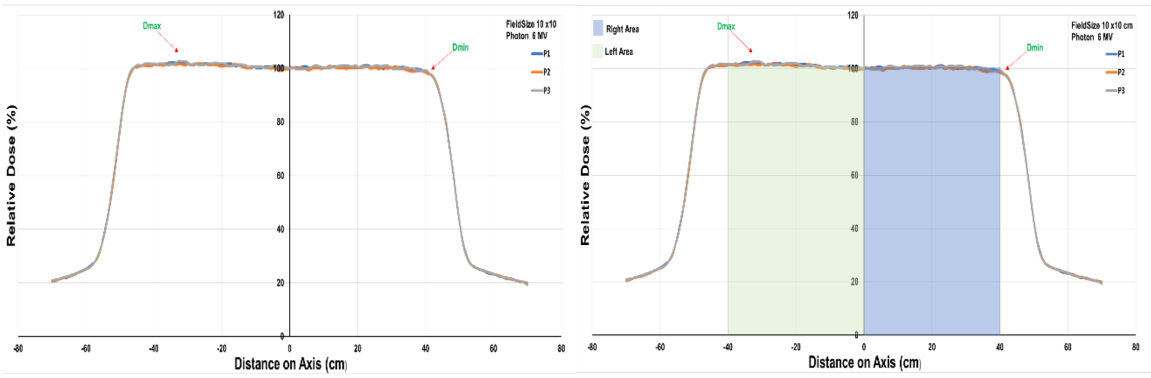
Dosimetry for these small radiation fields is a new challenge for medical researchers or physicists compared to dosimetry for standard radiation fields. Interference effects caused by materials and detector design also affect the measurement. To date, no detector is suitable for measuring photon and electron beams relative to a small field area (Andreo, 2018).

Flatness and Symmetry Measurement of 6 MV Photon Energy Beam Profile on 10×10 cm^2 Field Area

Figure 4 presents the results of beam profile measurements on flatness and symmetry with a field area of 10×10 cm^2 using the cc13 ion chamber detector.

Figure 5 (a) and (b) and Table 3 show the dose profile graphs for a field area of 10×10 cm^2, where the average value of Dmax in the three measurements is 102.3 cGy and D_{min} is 99 cGy. The maximum dose (D_{max}) and minimum dose (D_{min}) values in the dose profile are close to each other, which indicates the dose distribution in the center area of the radiation beam field is uniform and evenly distributed, as shown in Figure 4(a). The average flatness in measurements P1, P2, and P3 are 1.5%, 1.5%, and 1.8%, with an overall average of 1.6%. It can be seen that measurements made many times will cause the flatness value to get higher in each measurement.

Nevertheless, the dose distribution in the radiation field is quite uniform and within the recommended limits. In addition, Mariatul et al. also analyzed the dose profile with a photon energy of 6 MV on an irradiation field area of 10×10 cm2; it was found that the flatness was good, which was 1.78% (Mariatul et al., 2014).



(a) (b)

Figure 5. Dose Profiles Flatness (a) and Symmetry (b) Field Area 10×10 cm^2

Table 3. Flatness and Symmetry Measurement of 10×10 cm^2 Irradiation Field Area

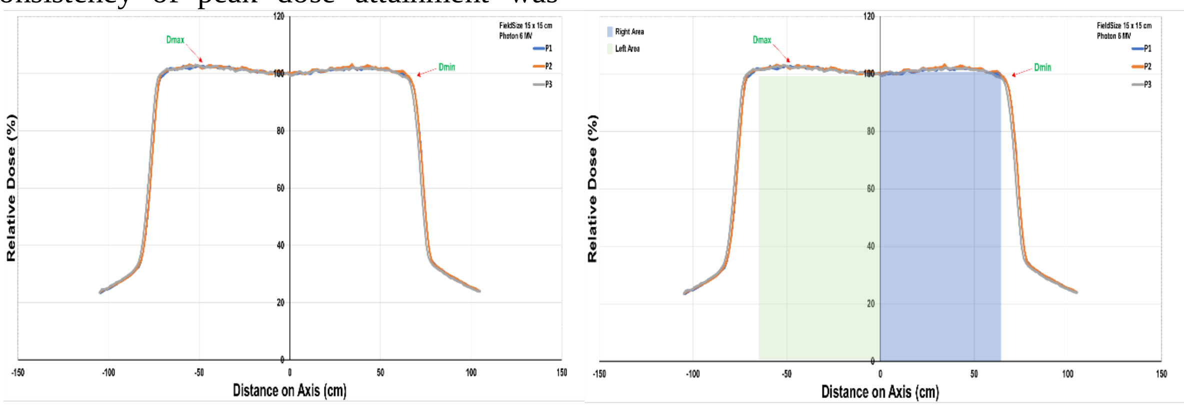
Measurement	D_{max} (cGy)	D_{min} (cGy)	Flatness (%)	Symmetry (%)	FieldWidth (cm)	Center (cm)
P1	102,3	99,2	1,5	2,8	10,22	-0,19
P2	101,8	98,7	1,5	2,4	10,21	-0,18
P3	102,7	99	1,8	1,6	10,22	-0,19
Average	**102,3**	**99**	**1,6**	**2,3**	**10,2**	**-0,2**

This means that a 10×10 cm^2 field is recommended for clinical practice because it produces an even dose distribution on the surface. Figure 5(b) shows that the beam's axis and left side areas are fairly symmetrical, with an average symmetry value of 2.3%. In addition, the measured field width is approximately 10.2 cm, closer to the initial expected size of 10×10 cm^{2,} so the beam center is slightly shifted to the left side. Overall, the measurements with three repetitions showed that the flatness and symmetry parameters for the 10×10 cm^2 irradiation field were in good condition and line with the expected clinical standards.

Flatness and Symmetry Measurement of 6 MV Photon Energy Beam Profile on 15×15 cm^2 Field Area

Based on Figure 6 (a and b) and Table 4, the dose profile measurements of the 15×15 cm^2 field area at 6 MV energy showed a maximum dose at each measurement with an average of 102.3 cGy. The maximum dose (D_{max}) produced in the 15×15 cm^2 field area irradiation is almost the same as the 10×10 cm^2 irradiation area, with a minimum dose (D_{min}) of 99 cGy. This indicates that the consistency of peak dose attainment was quite stable and did not decrease significantly compared to the previous irradiation. If the maximum and minimum dose values are good enough, the flatness and symmetry values of the irradiation will also be good enough. Table 4 shows the flatness value varies from 1.5% to 1.8%, with an average of 1.6%, indicating a small variation in the dose distribution on the irradiation plane.

The resulting flatness values are within clinical tolerance limits, indicating consistency and uniform and even beam quality, as shown in Figure 6a. If the beam quality is even or uniform, the axis will be symmetrical with an average symmetry value of 1.9%. The symmetry value, which varies between 1.6% and 2.2%, shows that there is a slight difference between the two sides when repeating the measurement. However, the value is within the clinical tolerance limit for symmetry, ±3%. FieldWidth was also fairly consistent with an average of 15.4 cm, although there was a slight leftward shift, as shown in Figure 6b. Overall, the radiation beam output measurements on the 15×15 cm^2 irradiation field were in good condition and accordance with the expected clinical standards.



(a) (b)

Figure 6. Dose Profile of Flatness (a) and Symmetry (b) of Field Area 15×15 cm^2

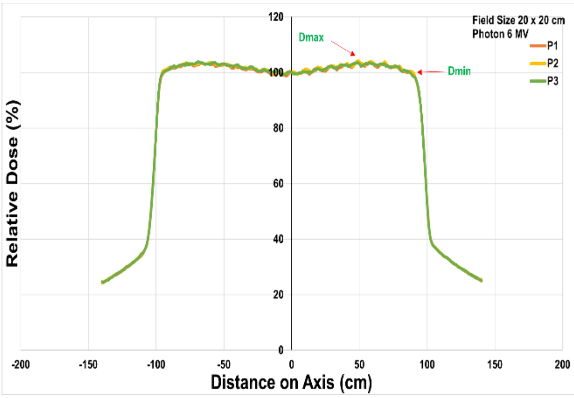
Table 4. Flatness and Symmetry Measurement of 15×15 cm² Irradiation Field Area

Measurements	D_{max} (cGy)	D_{min} (cGy)	Flatness (%)	Symmetry (%)	FieldWidth (cm)	Center (cm)
P1	102,7	99,6	1,5	2	15,35	-0,17
P2	103,2	99,9	1,6	2,2	15,35	-0,17
P3	102,8	99	1,8	1,6	15,35	-0,17
Average	**102,3**	**99**	**1,6**	**1,9**	**15,4**	**-0,2**

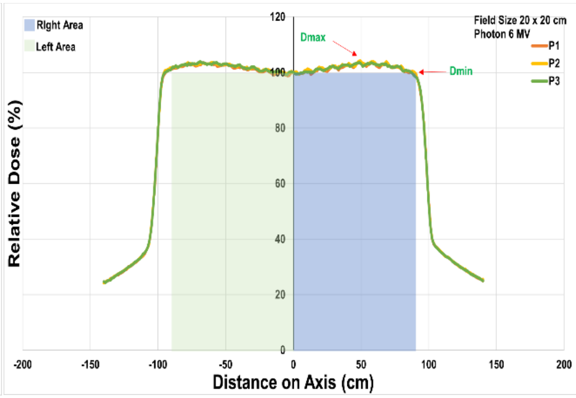
Flatness and Symmetry Measurement of 6 MV Photon Energy Beam Profile on 20×20 cm^2 Field Area

Based on Figure 7 (a and b) and Table 5, the dose profile measurement for a 20×20 cm2 field at 6 MV energy showed an average maximum dose of 103.9 cGy. This shows an increase in the maximum dose produced in the previous measurement, possibly due to the difference in field area. The minimum dose value was 99.1 cGy, close to the maximum. Figure 6a displays the Flatness graph, which shows that the relative dose at each measurement was fairly uniform, with an average flatness of 2.4%. Although this value slightly exceeds the clinical standard, the beam profile generated at 20×20 cm2 irradiation is still tolerable at ±2%. Figure 7b shows the symmetry area on each right and left axe with an average symmetry value of 1.7%.

The symmetrical area between the left and right is quite good from the previous irradiation, but there is an imbalance on the left side, which gets a larger dose than the other side. FieldWidth shows the width of the irradiation.



(a)



(b)

Figure 7. Dose Profile of Flatness (a) and Symmetry (b) of Field Area 20×20 cm^2

Table 5. Flatness and Symmetry Measurement of 20×20 cm² Irradiation Field Area

Measurements	D_{max} (cGy)	D_{min} (cGy)	Flatness (%)	Symmetry (%)	FieldWidth (cm)	Center (cm)
P1	103,6	98,7	2,4	1,5	20,43	-0,17
P2	104,2	99,5	2,3	1,8	20,43	-0,17
P3	103,9	99	2,4	1,7	20,44	-0,17
Average	**103,9**	**99,1**	**2,4**	**1,7**	**20,4**	**-0,2**

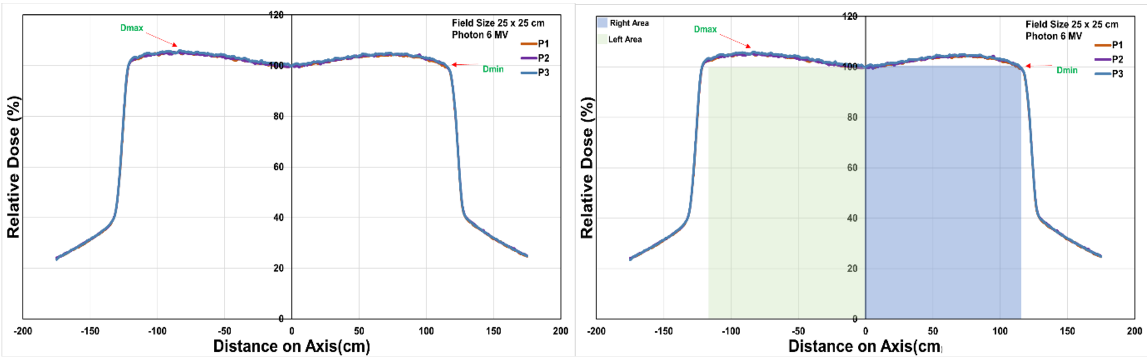
The field is about 20.44 cm, which shows that the irradiation field is in accordance with the initial measurement planning.

Flatness and Symmetry Measurement of 6 MV Photon Energy Beam Profile on 25×25 cm^2 Field Area

Figure 8 (a and b) and Table 6 show the radiation dose profile measurements measured on a 25×25 cm^2 irradiation field at 6 MV energy. The measurements show an average maximum dose value of 105.5 cGy and an average drinking dose of 99.4%. The difference between D_{min} and D_{max} indicates a variation in the dose distribution in the beam. Still, this variation is relatively small, indicating that the detector's stability is working well in each measurement. Figure 7a shows the consistency of flatness across measurements with an average value of 2.9%. This value indicates that the dose distribution in the field is fairly even, with little from the center of the field to the other side. Figure 8b shows the balance between the two sides of the peak center axis of the field. The symmetry values range from 1.9% to 2.2%, averaging 2%. The right and left side areas show the balance of the dose received from both sides of the field is almost the same, indicating that the symmetry in the 25×25 cm^2 field area is very good compared to the previous field area. Then, there was a shift in the center area in all three measurements by an average of -0.2 cm, with FieldWidth showing a consistent value of about 25.5 cm. The field area of 25×25 cm^2 is still within the tolerance limit, so it is good enough for clinical use.

Effect of Field Area and Depth of Irradiation on Dose Distribution

The irradiation field area, also known as field width, is an important component in dose profile analysis, which affects the dose distribution received by the target or surrounding healthy tissues. The irradiation depth is important in dose distribution, especially for photon beams. When penetrating the target, the dose distribution pattern of photon beams usually shows a maximum dose (D_{max}) at a certain depth and



(a) (b)

Figure 8. Dose Profile of Flatness (a) and Symmetry (b) of Field Area 25×25 cm^2

Table 5. Flatness and Symmetry Measurement of 25×25 cm² Irradiation Field Area

Measurements	Dmax (cGy)	Dmin (cGy)	Flatness (%)	Symmetry (%)	FieldWidth (cm)	Center (cm)
P1	105,3	99,3	2,9	1,9	25,5	-0,18
P2	105,4	99,3	2,9	2	25,51	-0,18
P3	105,7	99,5	3	2,2	25,51	-0,18
Average	**105,5**	**99,4**	**2,9**	**2**	**25,5**	**-0,2**

Then, it decreases at deeper depths, known as the build-up effect. The following dose profile curve shows the relationship between dose distribution and field area at 6 MV energy.

Based on Figure 9, the larger the area of the irradiation field, the wider the dose profile. This can be seen from the widening of the flat area at the peak of the dose profile, indicating the uniformity of the beam produced during irradiation. The following table shows the total average value of flatness and symmetry in the dose profile in each irradiation field.

Table 6 shows how the variation of the irradiation field area can affect the characteristics of the dose profile, especially on the flatness and symmetry. The maximum dose values produced in each field area, including the minimum dose values, tend to increase as the field area increases, and the dose profile tends to become more uniform as the field area increases.

In addition, inaccuracies in determining the initial focus point and detector placement before irradiation also affect flatness and symmetry (Bayatiani et al., 2021b).

Fields with dimensions of 10×10 cm^2 and 15×15 cm^2 are effective solutions used in clinical practice because they produce flatness and symmetry within tolerance limits, with values of 1.6%, 2.4%, 2.3%, and 1.9%, respectively. This is good to use because the dose in the field becomes more uniform, and both sides of the central axis remain balanced so that the dose will be delivered well to the target. Overall, the radiation field width setting significantly impacts radiation therapy planning. FieldWidth also shows that the larger the field area, the wider the beam profile width. The following table shows the differences in depth and the number of measured doses in the 6 MV dose profile.

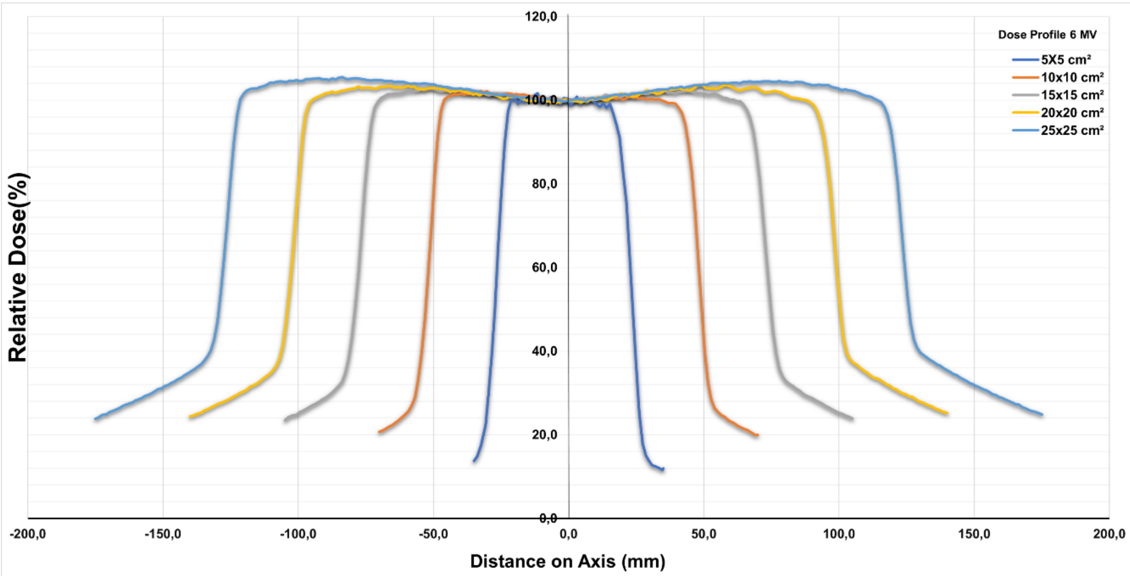


Figure 9. Energy Dose Profile of 6 MV with Variation in the Field Area

Table 6. Average Flatness and Symmetry Values of the Dose Profile

FieldSize	Maximum Dose (D_{max})	Minimum Dose (D_{min})	Flatness	Symmetry	FieldWidth	Center
5×5 cm^2	102,7 cGy	92,5 cGy	5,2 %	7,1 %	5,1 cm	-0,2 cm
10×10 cm^2	102,3 cGy	99 cGy	1,6 %	2,3 %	10,2 cm	-0,2 cm
15×15 cm^2	102,3 cGy	99 cGy	1,6 %	1,9 %	15,4 cm	-0,2 cm
20×20 cm^2	103,9 cGy	99,2 cGy	2,4 %	1,7 %	20,4 cm	-0,2 cm
25×25 cm^2	105,5 cGy	99,4 cGy	2,9 %	2 %	25,5 cm	-0,2 cm

Table 7 shows the measured radiation dose for each irradiation field area at a certain irradiation depth. The doses are divided into left and right to see the difference in depth between the measured doses. The irradiation depth starts from 1,5 cm to 17,5 cm to determine the dose distribution at various tissue depths. The effect of depth on the measured dose tends to be higher at shallower depths and decreases with increasing depth.

Table 7. Average Measured Dose at Irradiation Depth

FieldSize	Irradiation Depth	Average Total Dose	
		Dose Left Area (cGy)	Dose Right Area (cGy)
5×5	1,5 cm	100,3	99,4
	3,5 cm	63,6	42,6
10×10	3,5 cm	101,1	100,4
	7 cm	59,1	48,7
15×15	3,5 cm	100,8	101,1
	7 cm	102	99,4
	10,5 cm	41	32,9
20×20	3,5 cm	100,5	100,8
	7 cm	102,7	102,9
	10,5 cm	92,8	86,3
	14 cm	29,8	30,4
25×25	3,5 cm	101,2	101,6
	7 cm	103,5	103,6
	10,5 cm	105	103,7
	14 cm	75,1	68,4
	17,5 cm	28,8	29,6
Total Dose		**1307,2**	**1251,8**

The increase occurs at successive depths from 3 to 10 cm and decreases with increasing depth. The total dose measured for all depths and field areas is 1307,2 cGy on the left and 1251,8 cGy on the right side. The measured dose occurs more in the dose profile on the left side, which causes a slight asymmetry in the delivery of radiation doses; this needs to be considered to ensure that the dose distribution follows the specified safety standards. The absorbed dose will decrease as the distance between the source and the reference point increases because the closest organ will first absorb the irradiation process. Other factors that cause variations in absorbed dose to depth include source energy, depth, radiation field size, and source distance (Wihantoro et al., 2022).

The measured dose distribution at various depths and field widths is important to ensure that patients receive the right dose in the target area during radiation therapy. Although small asymmetry was detected, further analysis is needed to reduce potential side effects and ineffectiveness of therapy. Higher doses in shallow areas indicate that the tissue surface absorbs more radiation. Overall measurements to determine the flatness and symmetry of the 6 MV energy photon beam on the Linac machine at the Radiotherapy Installation of Andalas University Hospital are still in good condition because the beam output meets the established standards, so the machine is suitable for clinical use.

CONCLUSION AND SUGGESTION

The results of the PDD measurement of the 6 MV photon radiation beam showed that the radiation dose reached a maximum at a depth of 1,5 cm with a value of 100%. This is following international standards as recommended by BJR-25. Furthermore, the 10×10 cm^2 and 15×15 cm^2 field areas produced good flatness and symmetry during the measurement. Both met the tolerance limits set by AAPM and IAEA, which were ±2% flatness and ±3% symmetry, making them ideal choices for clinical practice. There is a slight asymmetry in radiation dose delivery. The measured dose is greater on the left than on the right. However, this asymmetry is still within acceptable limits, and therapy needs to be considered to maintain its effectiveness.

The suggestion in this study is that adjustments are needed in detector placement and irradiation settings, or perhaps mechanical component checks are also needed by Linac aircraft technicians, especially for small fields such as 5×5 cm^2. Field areas of 10×10 cm^2 and 15×15 cm^2 can be further optimized in clinical radiation therapy planning, considering that the study results show that these two sizes provide more uniform dose profile results and are by safety standards.

ACKNOWLEDGMENTS

The authors would like to thank the Directorate of Research, Technology, and Community Service, the Directorate General of Higher Education, Research, and Technology, and the Ministry of Education, Culture, Research, and Technology for funding this research under research contract Number 041/E5/PG.02.00.PL/2024.

AUTHOR CONTRIBUTIONS

RK, RF, AM, and R discuss research ideas and concepts together. Furthermore, FD is a medical physicist tasked with guiding RK in conducting research. RK is tasked with making research reports, compiling research methods, collecting research data, processing research data, evaluating research results, and compiling research report results.

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