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Dosimetric characterization of medical linear accelerator Photon and Electron beams for the treatment accuracy of cancer patients

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Abstract

In radiotherapy treatment planning process, quality assessment (QA) is indispensable for achieving accuracy and avoidance of treatment errors. In this perspective, present study focused on the Photon and Electron beams characterization of a medical linear accelerator (LINAC) to ascertain dosimetric QA in Absolute and Reference dosimetry. In this connection, the beam outputs were investigated in terms of D_{max} and $D_{w,max}$ (dose at depth d_{max}) in absolute dosimetry for Photon and Electron beams, respectively. In accordance with the measured D_{max} and $D_{w,max}$ parameters, Photon and Electron beam outputs were standardized to ensure standard output of 1 cGy/MU. In reference dosimetry, the parametric evaluation was performed for dosimetric QA in terms of percent depth dose (PDD), beam profile flatness and symmetry, output factors: S_{cp} , S_c , S_p with varying field size (FS) ranging from 4×4 cm² to 40×40 cm² normalized at FS 10×10 cm² for the 6 MV and 10 MV Photon beams. The measured PDDs at 10 cm depth (D_{10}) were found to be 66.8% and 73.6% for 6 MV and 10 MV Photon beams, respectively, with significantly small deviation of 1% and 0.8% in comparison with an international PDD protocol of British Journal of Radiology-25 (BJR -25). In the case of Electron beams characterization, PDD was verified with 10×10 cm² cone/applicator, beam profile flatness and symmetry were analyzed at the field sizes ranging from 6×6 cm² to 25×25 cm² normalized at 10×10 cm² cone/applicator, and Electron cone ratios were investigated for a given cone/applicator relative to the 15×15 cm² one for the 6, 9, 12, 15 MeV Electron energies. The PDDs of all the Electron beams revealed reasonable consistency with manufacturer's estimations of 90%, 80%, and 50% PDDs at various depths of ionization.

Keywords: Percent Depth Dose; Water Phantom; Ionization Chamber; Photon; Electron; Field Size

1. Introduction

Cancer is the second leading cause of death in the world after cardiovascular diseases which claims the lives of millions across the world [1]. Nevertheless, nowadays millions of cancer patients extend their life due to early identification and treatment. Generally, cancer is treated by surgery, radiotherapy or chemotherapy either separately or in combination of any of the above treatment modalities. Recently immune-therapy, photodynamic-therapy, monoclonal antibody-therapy or other methods are used as an alternative or complementary technique in the treatment of cancer. The choice of therapy depends upon the location and grade of the tumor and the stage of the disease, as well as the general state of

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the patient (performance status). However, among various cancer therapy modalities, more than 65% of patients are primarily treated with radiotherapy. The aim of radiotherapy is to cure or locally control the cancer diseases while minimizing complications in normal tissues using ionizing radiation e.g., X-rays, Gamma ray Photon beams, and Electron beams, etc. The ultimate goal of radiotherapy is to cure the patient without any damage to other organs. In radiotherapy, every cancer patient deserves to receive the best possible accuracy in prescribed dose for the malignant tumor to achieve a desired precession in curative treatment or palliation in long-term tumor control. Currently, radiotherapy performs a key role as one of the useful treatment modalities to ensure the best outcome in cancer treatment procedure.

Nowadays, external beam radiotherapy with ionizing radiation has become one of several modalities used for cancer treatment, along with chemotherapy and surgery. It is estimated as a vital part of cancer management, since around 50% of patients receiving radiotherapy in their treatment [2]. In the middle of the twentieth century, megavoltage energies became available through the use of Betatrons, Cobalt-60 gamma rays, and LINACs. Among these modalities, concurrently developed medical LINACs became the most widely used radiation source in modern radiotherapy. Almost all developed countries are using LINAC as a basic treatment machine. In a LINAC, energy is higher and charged particles are accelerated in a straight line, so it can treat deep seated tumor with better doses. In using LINAC, dose rate remains same because when the machine is on work only then radiation generates while no decay in shutdown. The conceivable minimum field size in LINAC is $0.5 \times 0.5 \text{ cm}^2$, hence, every small area can be treated by using LINAC although the accurate dosimetry of small fields in sub-centimeter range used in modern treatment techniques makes the measurement difficult due to steep dose gradient, lack of charge particle equilibrium, detector size as well as the partial occlusion of the radiation beam [3, 4, 5]. Nevertheless, a LINAC customizes high energy X-rays to conform to a tumor's shape with a view to deliver a large, uniform X-ray fields in conventional therapy to destroy cancer cells while sparing surrounding normal tissue [6]. The advancement of LINAC technology has improved the precision and efficiency of radiation therapy. Conventional LINACs are relatively safe in the sense that once machine is off there is no radiation in the room. Thus, after delivering the prescribed dose there will be no X-rays produced [7].

The purpose of applying LINACs in radiotherapy is to cure or improve the quality of life of a cancer patient through the accurate delivery of a radiation dose to a prescribed target volume [8]. However, there will always be some uncertainty in the dose to be delivered. This uncertainty in dose is due to errors and physical limitations that may occur at different steps in the radiotherapy treatment process. Since patient care is always the first priority in radiotherapy, hence corresponding quality assurance (QA) is a prerequisite that has been introduced for long been in place.

Among all treatment modalities, as the specialized LINAC machines are being used for achieving higher accuracy in radiotherapy, hence, must be properly maintained and checked to ensure quality treatment. Radiation is an invisible energy source and therefore errors are not simply detected during delivery. Therefore, regular QA of the machine through measurements and checks are a vital part of radiotherapy. The necessity of QA is mainly to ensure that radiation dose is delivered correctly. In this connection, machine's beam characteristics needs to be measured and compared to tolerance levels (unacceptable in the long term) and action levels (unacceptable at any time). Presently, in Bangladesh, most of the government and private hospitals are using LINACs for external beam radiotherapy with high energy photon and Electron beams. In such perspective, quality assessment (QA) of LINAC is prerequisite to ensure the accuracy of the prescribed dose from the Photon and Electron beams [9]. Hence, the QA of a LINAC machine needs to be performed prior to patient treatment in order to maintain the treatment accuracy as per standard protocols [9, 10]. The main purpose of QA is to ensure the consistency of quality of a machine, patient safety, deliverance of right dose to the patients, the mechanical or software errors. To fulfill this QA requirements, the process of commissioning a LINAC for clinical use includes comprehensive measurements of dosimetric parameters that are necessary to validate the treatment planning systems (TPS), to be used to select optimal radiation modality and treatment technique for individual patients [11]. Therefore, it is essential to have a minimum data set which includes Percentage Depth Dose (PDD), Dosimetric Profile, and Output characterization for a series of field sizes.

Keeping this in mind, some basic dosimetric parameters like Beam outputs, PDDs, Profile flatness and symmetry, and Output factors were measured with different FS for the Photon and Electron beams of LINAC (D-2300CD) machine. The prime objective of this study is to verify the dosimetric beam profile for the evaluation of Photon and Electron beam characteristics to ensure the treatment accuracy. In line with this objective, the measured PDD profiles were authenticated in terms of the standards of the BJR-25 [12]. The main aim of this study is to measure dosimetric parameters in order to minimize the uncertainties of the treatment process so as to avoid unnecessary exposure to critical organs.

2. Material and methods

2.1. Experimental Instrumentation

A medical LINAC machine (D-2300CD) was undertaken for radiation beam quality assessment. This type of medical LINAC is commonly used to treat malignant lesions anywhere in or on the patient's body. Thus, the radiation beam quality assessment is a prerequisite to maintain the desired treatment accuracy. In this perspective, the dosimetry profile of this medical LINAC was investigated in this study. This LINAC has dual energy mode of Photon and Electron beam facility. It has two Photon beams of 6 and 10 MV beam potential, and four Electron beams of 6, 9, 12 and 15 MeV energies. The advantage of applying the 6 and 10 megavoltage X-ray Photon beams is that they can easily penetrate the body to reach deep-seated tumors, including those of the prostate, colon, liver or ovary. On the other hand, the above-mentioned megavoltage Electron beams are less penetrating than X-rays but create a more-uniform field of radiation. These Electron beams do not irradiate the tissues which lies below the tumor; they are used for skin cancers and tumors close to the surface, as well as for head and neck tumors, where it is vital to avoid the brain or spinal cord under the cancer. A photographic view of the analyzed LINAC (D-2300CD) is shown in Fig. 1 (a), and the schematic diagram of a typical medical LINAC is shown in Fig. 1 (b).

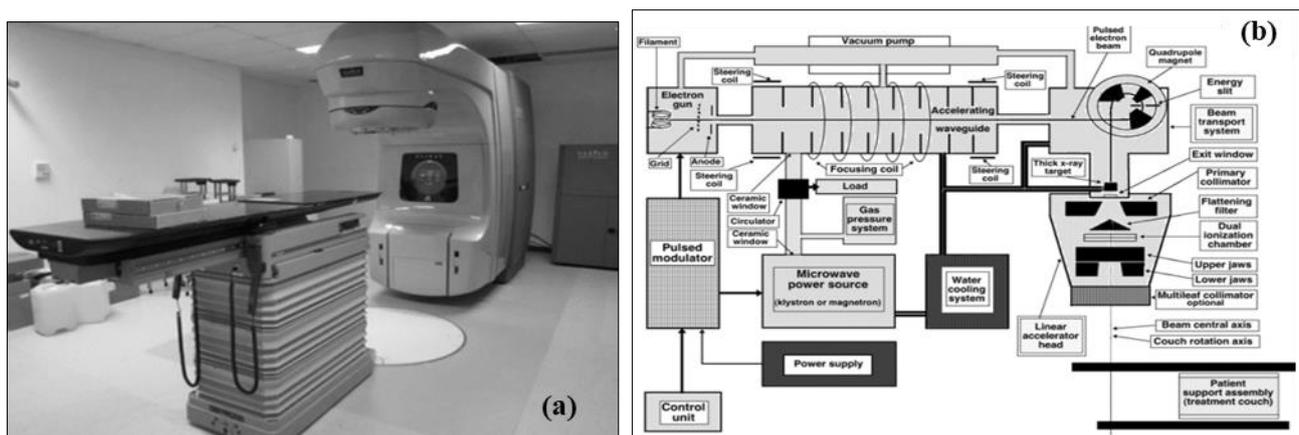


Figure 1 (a) Photographic view of the analyzed LINAC (D-2300CD) (b) Schematic diagram of a typical medical LINAC machine

The major modules of this LINAC (D-2300CD) are the Drive stand, Gantry, Modulator cabinet, Treatment couch and Control console. The multileaf collimator (MLC) of this LINAC is the tertiary collimator system which is positioned just below the level of the standard upper and lower adjustable jaws. There are 80 leaf MLC in the collimator of this LINAC and these collimators are static. For tertiary systems, the collimator jaws are used in concert with the leaves to shape the X-ray fields. The X-jaws move along the leaf direction. On the other hand, Y-jaws are strategically placed at the upper and lower borders of the field. To facilitate the Electron beam therapy, the auxiliary system of the presented LINAC consists of several basic systems that are not directly involved with Electron acceleration, rather these systems make the acceleration possible for clinical operation with Electron beam. The Electron beam transport system brings the pulsed high-energy Electron beam from the accelerating waveguide onto the target in the X-ray therapy mode and onto the scattering foil in the Electron therapy mode [13].

2.2. Experimental Technique

The dosimetry feature of the analyzed medical LINAC (D-2300 CD) was investigated in the present study to authenticate the QA profile. The dosimetric verification of the radiation beam is a prerequisite prior to commissioning the clinical trial. This is because, in commissioning of external beam radiotherapy with a LINAC, it needs to take into account of all radiation beam characteristics. The beam output statistics is required to be organized into a dosimetry data book, to be entered into a computerized treatment planning system (TPS) for dosimetric quality assurance (QA). Consequently, based on this dosimetric QA parameters, treatment plan and treatment procedures are verified. In order to acquire the radiation beam characteristics, the basic dosimetric parameters, namely, PDDs, profile flatness and symmetry, output factors, and transmission factors were experimentally measured. These basic dosimetric parameters were measured for both Photon beams (6 and 10 MV) and Electron beams (6, 9, 12 and 15MeV) with different field size(s). Experimental measurements were performed in a Three-Dimensional (3D) computer-controlled water phantom (IBA RFA300) with using the waterproof cylindrical type Farmer ionization chamber (0.65cc, IBA FC 65 P#1787) and an IBA Compact

Chamber (0.13cc IBA CC13) coupled with an IBA electrometer (DOSE1#13527). This electrometer (DOSE1#13527) provides significant precision in data acquisition as it exceeds the recommendations of the IEC 60731 [14]. Finally, these dosimetric equipment were deployed under the exposure arrangement of the LINAC machine to verify its Photon and Electron beams characteristics. The main intention of measuring these dosimetric parameters is to minimize the uncertainties in the treatment process with a view to avoid unnecessary exposure to the adjacent critical organs. The analysis of the dosimetric parameters were performed by using IBA Planning software. To verify the accuracy, measured PDD profiles were authenticated in terms of the BJR-25 protocol. The purpose of this process is to substantiate the measured dosimetric characteristics of a LINAC machine in terms of standard protocols.

2.3. Dose Assessment Instrumentation

A large size motorized 3D water phantom (IBA RFA300) was used for the Absolute and Reference dosimetry of the Photon and Electron radiation beams with vertical beam incidence. This system is based on the large-size water tank with a scanning range of $480 \times 408 \times 500$ mm. This 3D phantom has the detector moving range up to 480 mm with precise 3D stainless steel moving mechanism driven by three calibration-free, high-speed stepper motors. This device includes three stepper motors for a detector positioning speed of 50 mm/s and a positioning accuracy of ± 0.1 mm. It consists of stable 20 mm thick acrylic walls and etched lines for precise tank alignment. In dose measurement with this phantom, a cylindrical type IBA farmer ionization chamber (0.65cc, IBA FC 65 P#1787) was mounted to IBA RFA300 phantom for the absolute dosimetry and reference dosimetry as well as measuring the tray transmission factor and MLC transmission factor. In the measurement process of total output factor (S_{cp}), collimator scatter factor (S_c), and phantom scatter factor (S_p), an IBA Compact Chamber (0.13cc IBA CC13) was used as a standard chamber for clinical applications with high reproducibility in a water phantom. In the experimental dosimetric data acquisition process, a DOSE 1 (S/N 13527) electrometer was coupled with the aforesaid waterproof chambers. This electrometer is high-precision reference class device for the measurements of absorbed dose which significantly exceeds the recommendations of the IEC 60731 [14]. The present dosimetry process was performed by complying with the dosimetry protocol of American Association of Physicists in Medicine (AAPM): AAPM TG-51[15].

3. Results and discussion

The dosimetric parameters of the LINAC beam characteristics were verified to ascertain consistency with clinical applications. Measurements were performed through systematic and sequential approach. Essential procedures were followed methodically to ensure the accuracy in dose delivery as a prerequisite of a LINAC machine to be certified and commissioned for the treatment of cancer patients. This condition essentially requires to be fulfilled to satisfy the clinical data accuracy as per standard protocols' tolerance values of the beam parameters. In this connection, the breakthrough of this study demonstrated the assurance of precise dose delivery in clinical application. Therefore, the dosimetric QA breakthrough of the present LINAC beams reasonably complied with the tolerance limits of the standard dosimetry protocols [9, 10] as an imperative to ensure treatment quality with accurate dose delivery of a LINAC machine in any cancer center. The detailed dosimetric QA approach is discussed in the subsequent section:

3.1. Photon Beam Characterization

3.1.1. Maximum Depth Dose Measurement

The beam output was investigated in terms of D_{max} to characterize the Photon beams. In this process, depth doses (D_w) at 10 cm depth (D_{10}) were measured, and in accordance with this D_{10} , maximum depth doses (D_{max}) were estimated for the 6 MV and 10 MV Photon beams with reference field size 10×10 cm² and source-to-surface distance (SSD) 100 cm as per AAPM TG-51 protocol [15]. The purpose of this measurement is to standardize the Photon beam outputs. The procedural sequences of this measurement at respective Photon beams are described in the subsequent section:

6 MV Photon Beam

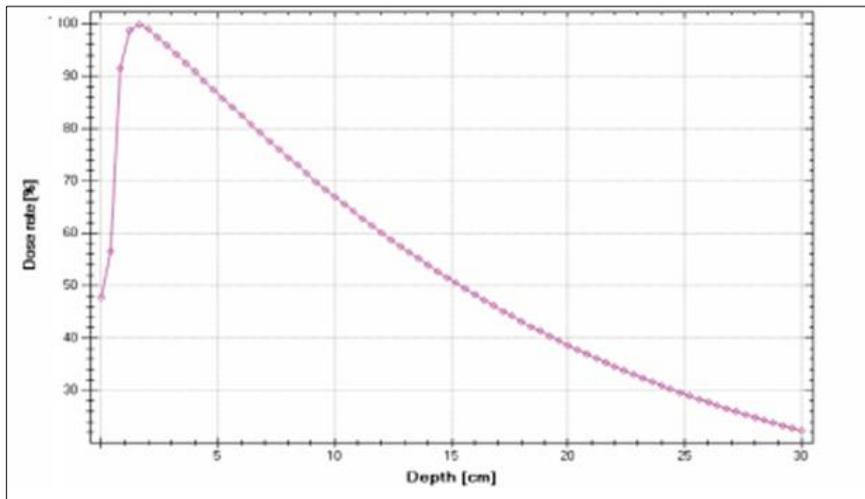
The depth dose (D_w) of 6 MV Photon beam measured at 10 cm depth of water was found to be 0.683352 cGy/MU. In accordance with this, the measured dose maximum (D_{max}) was found to be 1.02298 cGy/MU. One of the main goals of this study is to ascertain the standard dose of 1 cGy/MU, hence to ensure this, the observed data of the meter reading M_{10} was tuned at 1.3455×10^{-8} C from 1.4401×10^{-8} C; consequently, D_{max} was set to the dose of 1.0002 cGy/1MU which is significantly equal to the required standard dose of 1cGy/MU.

10 MV Photon Beam

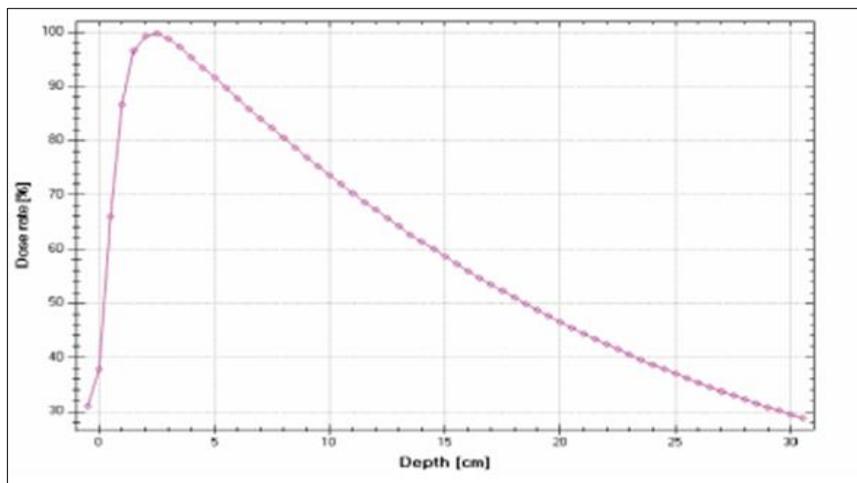
The depth dose (D_w) of 10 MV Photon beam measured at 10 cm depth of water was found to be 0.74722 cGy/MU. The measured dose maximum (D_{max}) was found to be 1.0124 cGy/MU. Like 6MV beam, in order to ascertain a standard dose of 1cGy/MU, the observed data of the meter reading M_{10} was tuned at 1.4800×10^{-8} C from 1.5961×10^{-8} C; consequently, D_{max} was set to the dose of 0.9988 cGy/MU which indicates a good agreement with the required standard dose of 1 cGy/MU.

3.1.2. Verification of Percentage Depth Dose (PDD) for 6MV and 10 MV beams

The PDD scan was performed with field sizes (FS) ranging from 4×4 cm² to 40×40 cm² using the 3D IBA RFA300 phantom. The demonstrated PDDs were measured for the FS of 10×10 cm² and SSD of 100 cm. These PDDs were acquired from the scanning data at different water depths in the 3D phantom with the mounted ionization chamber (0.65cc, IBA FC 65 P#1787) for FS of 10×10 cm². The PDD profiles scanned at 6 and 10MV Photon beams are shown in Fig. 2 (a, b).



(a) PDD profile scanned at 6 MV



(b) PDD profile scanned at 10 MV

Figure 2 The PDD profiles scanned at (a) 6 MV and (b) 10MV

The measured PDDs at 10 cm depth (D_{10}) were found to be 66.8% and 73.61% for 6 MV and 10 MV Photon beams, respectively that indicates a small deviation of 1% and 0.8% in comparison with an international standard PDD protocol of BJR-25 [12].

The corresponding depth vs measured PDDs for 6 MV and 10 MV are presented in Table 1 and Table 2 respectively.

Table 1 The depth vs measured PDDs for 6 MV

Depth(cm)	Measured PDD	Clinical %DD (From BJR-25)	%Δ
1.5	99.9	100	0.1
5	86.6	86.9	0.3
10	66.8	67.5	1.0
15	50.6	51.7	1.9
20	38.4	39.3	2.3

Table 2 The depth vs measured PDDs for 10MV

Depth(cm)	Measured PDD	Clinical PDD (From BJR-25)	%Δ
2.5	99.9	100	0.1
5	91.9	91.4	0.5
10	73.6	73.0	0.8
15	58.3	57.8	0.85
20	46.2	45.6	1.3

3.1.3. Profile Flatness and Symmetry of Photon beams

Flatness and Symmetry are main parameters in determining the quality of the Photon and Electron beams produced by linear accelerators which can be defined in accordance with IEC60976 [16]. To maintain the consistent beam profile, the flatness and symmetry accuracy needs to be within the recommended tolerance limits of $\pm 2\%$ and $\pm 3\%$ respectively [9]. Thus, the flatness and symmetry values in the central 80% field width of the measured profile, as defined during machine commissioning, should not deviate from the baseline by more than the tolerance values [9]. In the current study, the Photon beams were scanned at 6MV and 10MV to obtain the lateral profile which offers a scope to check the flatness and symmetry of the beam. The flatness and symmetry profile of the scanned Photon beams are evident in Fig. 3 (a, b). The observed variation in the verified flatness and symmetry profile of the scanned beams are presented in Table 3. The flatness was determined according to the following Equation 1.

$$Flatness(\%) = \frac{D_{max} - D_{min}}{D_{max} + D_{min}} \times 100\% \quad (1)$$

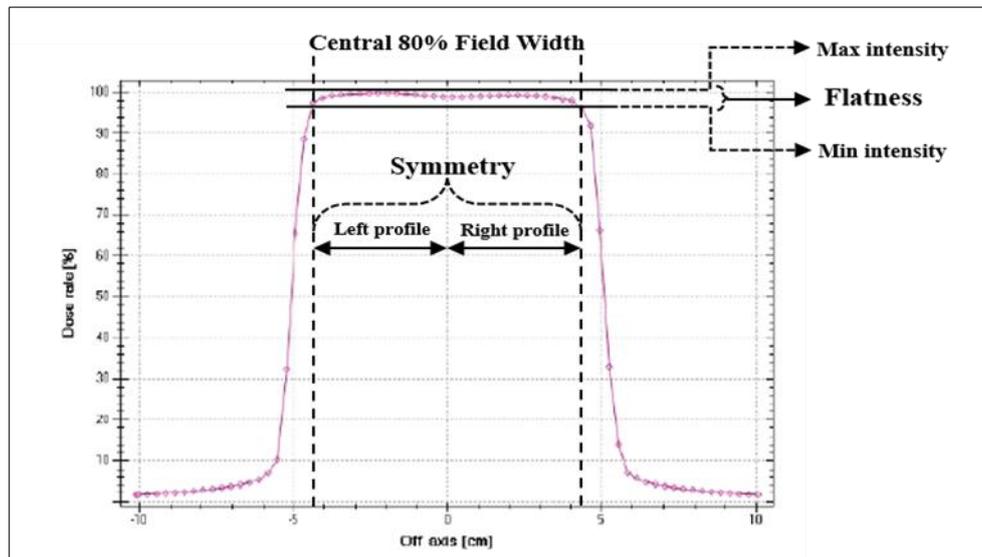
where, D_{max} and D_{min} are the maximum and minimum dose along the profile within the core 80% of the field size.

Similarly, the symmetry was determined according to the following Equation 2.

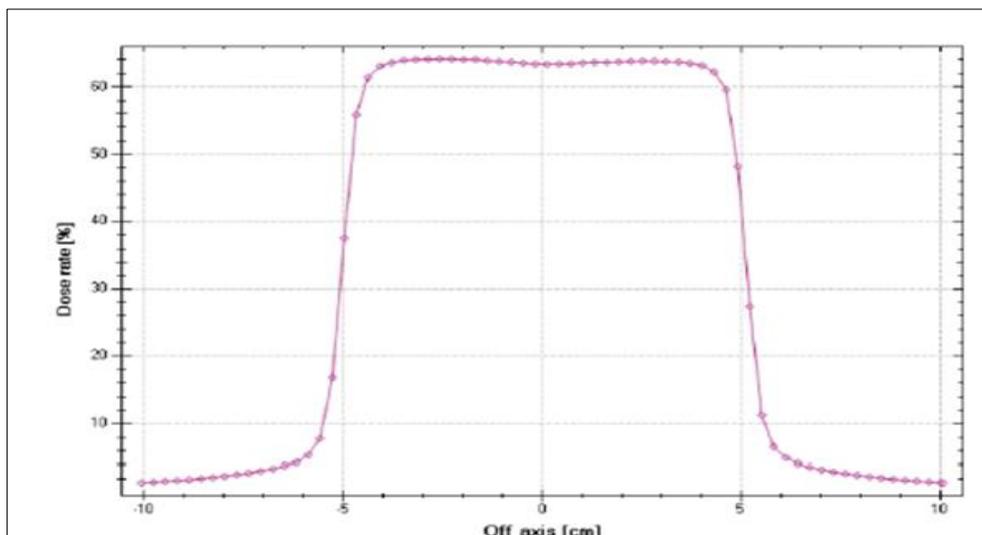
$$Symmetry (\%) = \frac{Area_{left} - Area_{right}}{Area_{left} + Area_{right}} \times 100 \quad (2)$$

where, A_{left} and A_{right} are the areas bounded by the profile on the left and right of the beam central axis.

The Profile flatness and symmetry were evaluated with FS $10 \times 10 \text{ cm}^2$ for 6MV and 10MV Photon beams. The Profile flatness with FS $10 \times 10 \text{ cm}^2$ for 6MV and 10MV Photon beams were found to be 1.1% and 1.1%. The symmetry with FS $10 \times 10 \text{ cm}^2$ for 6MV and 10MV Photon energies were found to be 1% and 0.7% as presented in Table 3. In accordance with the AAPM TG-40, the flatness and symmetry tolerances for 6MV and 10MV Photon are up to $\pm 2\%$ and $\pm 3\%$, respectively. Therefore, the flatness and symmetry of Profiles for 6MV and 10MV Photon beams with reference FS ($10 \times 10 \text{ cm}^2$) are found within the recommended range of the AAPM TG-40 scale.



(a) Beam profile scanned at 6MV



(b) Beam profile scanned at 10MV

Figure 3 Beam profile of Flatness and Symmetry of Photon beams (a) scanned at 6MV and (b) scanned at 10MV

Correspondingly, evaluated flatness and symmetry for the Photon beams of 6MV and 10 MV are presented in Table 3.

Table 3 The Flatness and Symmetry of the Photon beams

Beam voltage (MV)	Field Size	Symmetry	Flatness	Penumbra
6	10×10	1%	1.1%	0.65cm - 0.66cm
10	10×10	0.7%	1.1%	0.66cm - 0.64cm

3.1.4. Verification of various output factors

Various output factors, namely total output factor (S_{cp}), collimator scatter factor (S_c) and phantom scatter factor (S_p) were verified with different FS (s) ranging from at 4×4 cm² to 40×40 cm² normalized at 10×10cm² FS for the 6 MV and 10 MV Photon beams.

Total output factor (S_{cp})

The total output factor (S_{cp}) is defined as a ratio of the absorbed dose at the reference depth d for any field size $A \times A$ cm² to the dose at the same depth d and SSD for the reference field (10×10 cm²). The total output factors were measured at reference depth d_{max} in a large 3D water phantom at 100 cm SAD (i.e., 98.5 cm SSD) for 6 MV and 100cm SAD (i.e., 97.6 cm SSD) for 10 MV using an IBA Compact Chamber (0.13cc IBA CC13) and an IBA electrometer (DOSE1#13527). The measured data are presented in Table 4 and Table 5 for 6 MV and 10 MV Photon beams, respectively.

Table 4 Measured total output factors (S_{cp}) for 6 MV at 100MU and dose rate: 300MU/min

Field Size	$M_1 \times 10^{-8}C$	$M_2 \times 10^{-8}C$	Average	S_{cp}
4×4	2.0050	2.0060	2.0055	0.9236
6×6	2.0770	2.0760	2.0765	0.9563
8×8	2.1300	2.1310	2.1305	0.9811
10×10	2.1720	2.1710	2.1715	1.0000
12×12	2.2060	2.2060	2.2060	1.0159
15×15	2.2450	2.2450	2.2450	1.0338
20×20	2.2920	2.2920	2.2920	1.0555
25×25	2.3260	2.3270	2.3265	1.0714
30×30	2.3590	2.3590	2.3590	1.0863
35×35	2.3840	2.3840	2.3840	1.0979
40×40	2.4010	2.4010	2.4010	1.1057

Table 5 Measured total output factors (S_{cp}) for 10 MV at 100MU and dose rate: 300MU/min

Field Size	$M_1 \times 10^{-8}C$	$M_2 \times 10^{-8}C$	Average	S_{cp}
4×4	2.0260	2.0250	2.0255	0.9112
6×6	2.1160	2.1160	2.1160	0.9519
8×8	2.1770	2.1780	2.1775	0.9795
10×10	2.2230	2.2230	2.2230	1.0000
12×12	2.2620	2.2620	2.2620	1.0175
15×15	2.3000	2.3020	2.3010	1.0351
20×20	2.3470	2.3480	2.3475	1.0560
25×25	2.3810	2.3810	2.3810	1.0711
30×30	2.4140	2.4140	2.4140	1.0859
35×35	2.4390	2.4390	2.4390	1.0972
40×40	2.4590	2.4580	2.4585	1.1059

Collimator scatter factor (S_c)

The collimator scatter factor (S_c) is commonly called the output factor and can be defined as the ratio of the output in air for a given field to that for a reference field (10 × 10 cm²). This S_c was measured using an IBA Compact Chamber (0.13cc IBA CC13) with a buildup cap of size large enough to provide maximum dose buildup for the given energy

beam. The S_c was investigated by measuring the relative ionization in air for both 6 MV and 10 MV Photon beams as presented in Table 6 and Table 7, respectively.

Table 6 Measured collimator scatter factors (S_c) for 6MV at SSD=100 and 100MU

Field Size (cm ²)	$M_1 \times 10^{-8}C$	$M_2 \times 10^{-8}C$	Average	S_{cp}
4×4	0.3820	0.3820	0.3820	0.9550
6×6	0.3900	0.3900	0.3900	0.9750
8×8	0.3960	0.3960	0.3960	0.9900
10×10	0.4000	0.4000	0.4000	1.0000
12×12	0.4040	0.4040	0.4040	1.0100
15×15	0.4070	0.4070	0.4070	1.0175
20×20	0.4110	0.4110	0.4110	1.0275
25×25	0.4130	0.4130	0.4130	1.0325
30×30	0.4150	0.4150	0.4150	1.0375
35×35	0.4170	0.4170	0.4170	1.0425
40×40	0.4190	0.4190	0.4190	1.0475

Table 7 Measured collimator scatter factors (S_c) for 10MV at SSD=100 and 100MU

Field Size (cm ²)	$M_1 \times 10^{-8}C$	$M_2 \times 10^{-8}C$	Average	S_c
4×4	0.4500	0.4570	0.4505	0.9514
6×6	0.4590	0.4610	0.4600	0.9715
8×8	0.4680	0.4690	0.4685	0.9894
10×10	0.4730	0.4740	0.4735	1.0000
12×12	0.4780	0.4780	0.4780	1.0095
15×15	0.4820	0.4820	0.4820	1.0180
20×20	0.4860	0.4860	0.4860	1.0264
25×25	0.4900	0.4900	0.4900	1.0348
30×30	0.4920	0.4920	0.4920	1.0391
35×35	0.4960	0.4960	0.4960	1.0475

Phantom Scatter Factor (S_p)

The phantom scatter describes the influence of the scatter originating in the phantom only, which can be quantified by the phantom scatter factor (S_p). The S_p is defined as the phantom scatter dose contribution for a specified collimator defined field size and a specified field size at the phantom surface, normalized to unity for the reference irradiation set-up. It is derived from the total scatter correction factor (S_{cp}), divided by the collimator scatter correction factor (S_c) for the same collimator defined field size. Thus, S_p is the ratio of total output factor (S_{cp}) to collimator scatter factor (S_c), denoted as $S_p = \frac{S_{cp}}{S_c}$. The measured phantom scatter factors (S_p) for 6 MV and 10 MV Photons beams are presented in Table 8 and Table 9 respectively.

Table 8 Measured phantom scatter factors (S_p) for 6MV at SSD = 100 cm and 100 MU

Field Size (cm ²)	S_{cp}	S_c	$S_p = S_{cp}/S_c$
4×4	0.9236	0.9550	0.9671
6×6	0.9563	0.9750	0.9808
8×8	0.9811	0.9900	0.9910
10×10	1.0000	1.0000	1.0000
12×12	1.0159	1.0100	1.0058
15×15	1.0338	1.0175	1.0161
20×20	1.0555	1.0275	1.0272
25×25	1.0714	1.0325	1.0377
30×30	1.0863	1.0375	1.0471
35×35	1.0979	1.0425	1.0531
40×40	1.1057	1.0475	1.0555

Table 9 Measured phantom scatter factors (S_p) for 10MV at SSD = 100 cm and 100MU

Field Size (cm ²)	S_{cp}	S_c	$S_p = S_{cp}/S_c$
4×4	0.9112	0.9514	0.9577
6×6	0.9519	0.9715	0.9798
8×8	0.9795	0.9894	0.9900
10×10	1.0000	1.0000	1.0000
12×12	1.0175	1.0095	1.0080
15×15	1.0351	1.0180	1.0168
20×20	1.0560	1.0264	1.0288
25×25	1.0711	1.0348	1.0350
30×30	1.0859	1.0391	1.0451
35×35	1.0972	1.0475	1.0474
40×40	1.1059	1.0475	1.0558

3.1.5. Tray Transmission Factor

The tray transmission factor (TTF) is defined as a ratio of the dose in a phantom with and without a tray in the beam for the same number of monitor units delivered at a fixed SSD and depth in phantom. In this study, tray transmission factor was measured at 10 cm depth in water for 100 cm SSD and 10×10 cm² FS using IBA farmer type ionization chamber (0.65cc IBA FC 65 P#1787) and IBA electrometer Dose 1(S/N: 13527). The measured transmission factor was found within ±2% of the manufacturer's tolerance value. The verified tray transmission factors for 6MV and 10MV Photon beams are presented in Table 10.

Table 10 Verified tray transmission factors (TF) for 6 MV and 10 MV Photon beams

Beam voltage (MV)	Output: without tray	Output: with Tray		Average	TTF
		$M_1 \times 10^{-8}C$	$M_2 \times 10^{-8}C$		
6	1.408	1.364	1.364	1.364	0.97
10	1.563	1.526	1.526	1.526	0.98

3.1.6. Multileaf Collimator Transmission Factor

Multileaf collimator (MLC) transmission factor (TF) was measured at 10 cm depth in water with 100 cm SSD and 10×10 cm² FS coupling an IBA Farmer type ionization chamber (0.65cc IBA FC65P#1787) and IBA electrometer Dose1 (S/N: 13527). The MLC transmission factor was found to be within $\pm 2\%$ of the manufacturer's tolerance value. The verified MLC transmission factors for 6MV and 10 MV Photon beams are presented in Table 11.

Table 11 Verified Multileaf Collimator (MLC) Transmission Factor (TF)

Beam voltage (MV)	Output without MLC	Output with MLC		Average	MLCTF
		$M_1 \times 10^{-8}C$	$M_2 \times 10^{-8}C$		
6	1.3925	0.019	0.019	0.019	0.0136
10	1.5325	0.025	0.024	0.0245	0.0160

3.1.7. Wedge Transmission Factor

Wedge transmission factor (WTF) was measured at 10 cm depth in water with 100 cm SSD and 10×10 cm² FS for the 6MV and 10MV beam quality. In both cases, a Farmer type IBA chamber and was used in the measurement process. The monitor unit (MU) was set at 100 MU in both beam qualities, and the open field readings were recorded as $1.4016 \times 10^{-8}C$ and $1.556 \times 10^{-8}C$ for 6MV and 10MV Photon beams respectively. The measured WTFs for M V and 10M V are presented in Table 12 and Table 13, respectively.

Table 12 Measured wedge transmission factors for 6MV

Angle (degree)	Wedge Position	$M_1 \times 10^{-8}C$	$M_2 \times 10^{-8}C$	Average	Average (In & Out)	WTF
15	In	1.072	1.072	1.072	1.074	0.767
15	out	1.077	1.077	1.077		
15	Left	1.074	1.074	1.074		
15	Right	1.075	1.075	1.075		
30	In	0.863	0.863	0.863	0.867	0.619
30	Out	0.871	0.871	0.871		
45	In	0.684	0.684	0.684	0.689	0.492
45	Out	0.694	0.694	0.694		
60	In	0.562	0.563	0.563	0.571	0.407
60	Out	0.578	0.579	0.579		

Table 13 Measured wedge transmission factors for 10MV

Angle (degree)	Wedge Position	$M_1 \times 10^{-8}C$	$M_2 \times 10^{-8}C$	Average	Average (In & Out)	WTF
15	In	1.247	1.246	1.2465	1.249	0.803
15	Out	1.252	1.252	1.252		
30	In	1.039	1.039	1.039	1.043	0.670
30	Out	1.046	1.046	1.046		
45	In	0.812	0.813	0.813	0.818	0.526
45	Out	0.823	0.823	0.823		
60	In	0.675	0.675	0.675	0.683	0.439
60	Out	0.691	0.691	0.691		

3.2. Electron Beam Characterization

3.2.1. Depth Dose Measurement

The Electron beam output was investigated in terms of maximum depth dose ($D_{w,max}$). In this regard, depth doses ($D_{w,dref}$) were measured at reference depth d_{ref} for the all the Electron energies of 6, 9, 12, 15 MeV with 10×10 cm² cone and 100 cm SSD according to TG-51 protocol [15]. Then, $D_{w,max}$ was determined in accordance with the measured $D_{w,dref}$. The purpose of this measurement is to standardize the Electron beam outputs. The stepwise process of this measurement technique for respective Electron energies are described in the subsequent section:

6 MeV Electron Beam

The depth dose per monitor unit ($D_{w,dref}/MU$) of 6 MeV Electron beam measured at d_{ref} in water was found to be 0.9792 cGy/MU. In accordance with this, the measured Dose/MU at d_{max} ($D_{w,max}$) was found to be 0.9008 cGy/MU. The main focus of this study is to ensure a standard dose ($D_{w,max}$) of 1 cGy/ MU as beam output, hence to ensure this, the observed data of the meter reading M_{dref} was tuned to 2.241×10^{-8} C from 2.189×10^{-8} C, consequently $D_{w,max}$ was set to the dose of 1.0031cGy/ MU, which is perfectly meet the required standard dose of 1 cGy/MU.

9 MeV Electron Beam

The depth dose per monitor unit ($D_{w,dref}/MU$) of 9 MeV Electron beam measured at d_{ref} in water was found to be 1.0268 cGy/MU. In accordance with this, the measured Dose/MU at d_{max} ($D_{w,max}$) was found to be 1.0339 cGy/MU. To achieve the standard dose ($D_{w,max}$) of 1 cGy/MU as beam output, the observed data of the meter reading M_{dref} was tuned to 2.2096×10^{-8} C from 2.2733×10^{-8} C, consequently $D_{w,max}$ was set to the dose of 1.0049/MU cGy, which indicates a good agreement with the required standard dose of 1 cGy/MU.

12 MeV Electron Beam

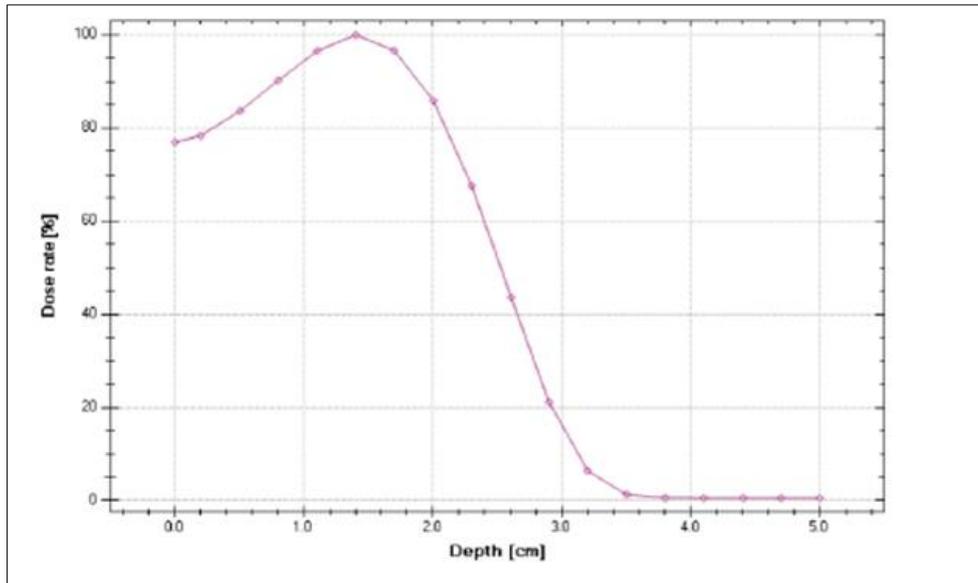
The depth dose per monitor unit ($D_{w,dref}/MU$) of 12 MeV Electron beam measured at d_{ref} in water was found to be 1.0595 cGy/MU. In accordance with this, the measured Dose/MU at d_{max} ($D_{w,max}$) was found to be 1.0599 cGy/MU. To achieve the standard dose ($D_{w,max}$) of 1 cGy/MU as beam output, the observed data of the meter reading M_{dref} was tuned to 2.207×10^{-8} C from 2.336×10^{-8} C, consequently $D_{w,max}$ was set to the dose of 1.0014 cGy/MU, which perfectly satisfies the required standard dose of 1 cGy/MU.

15 MeV Electron Beam

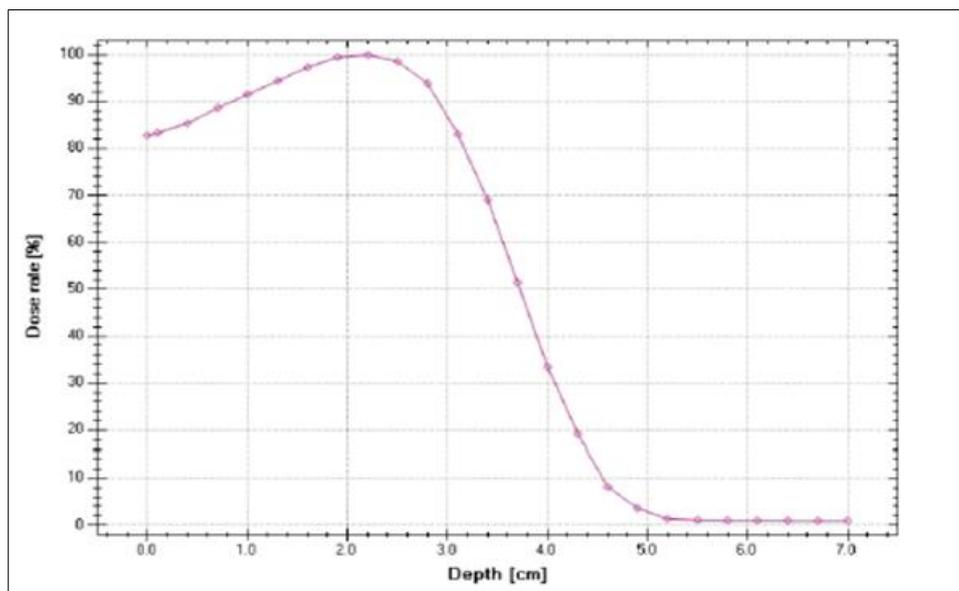
The depth dose per monitor unit ($D_{w,dref}/MU$) of 15 MeV Electron beam measured at d_{ref} in water was found to be 1.0588 cGy/MU. In accordance with this, the measured Dose/MU at d_{max} ($D_{w,max}$) was found to be 1.0604 cGy/MU. To achieve the standard dose ($D_{w,max}$) of 1 cGy/MU as beam output, the observed data of the meter reading M_{dref} was tuned to 2.2193×10^{-8} C from 2.357×10^{-8} C, consequently $D_{w,max}$ was set to the dose of 0.9985 cGy/MU, which ensures a good agreement with the required standard dose of 1cGy/MU.

3.2.2. Percent Depth Dose (PDD)

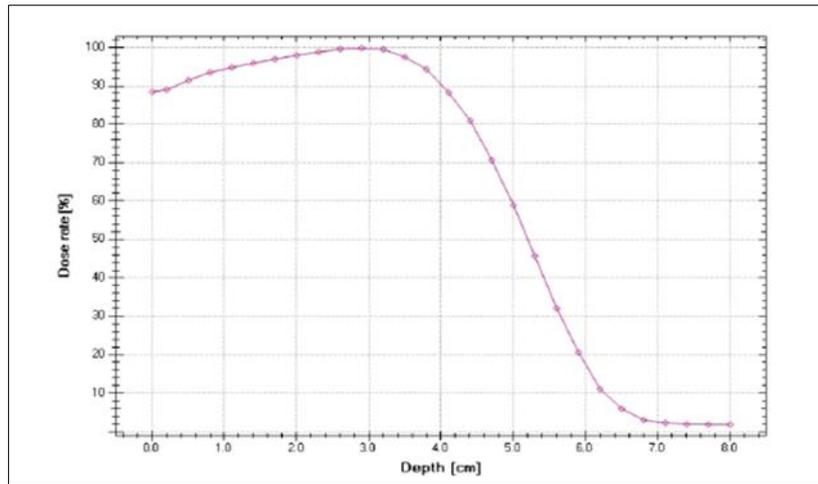
The percent depth doses were scanned with 10×10 cm² cones for all Electron energies with the Scanditronix scanning system. In this process an IBA Compact Chamber (0.13cc IBA CC13) was used for PDD scanning process as per AAMP TG-25 protocol to produce depth dose curves [17]. The experimental observations were consistent with the manufacturer’s specifications. The PDD curves of Electron beams scanned at 6, 9, 12, 15 MeV are shown in Fig. 4 (a, b, c, d).



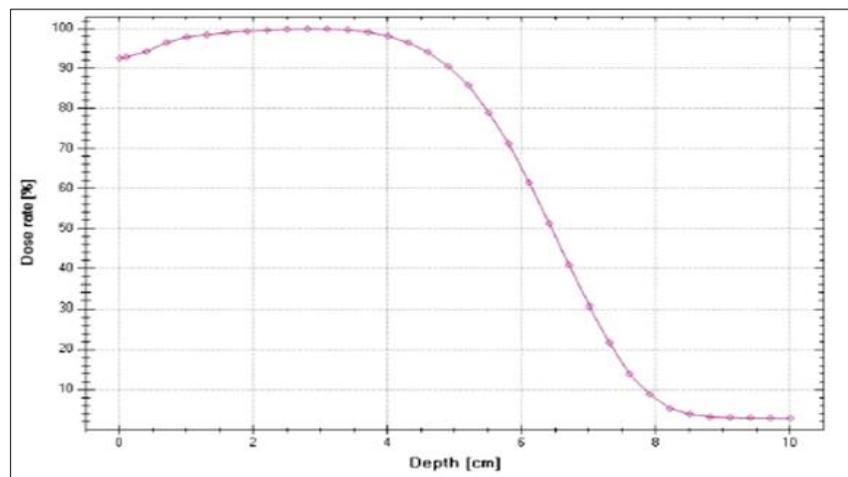
(a) PDD profile scanned at 6MeV



(b) PDD profile scanned at 9MeV



(c) PDD profile scanned at 12MeV



(d) PDD profile scanned at 15MeV

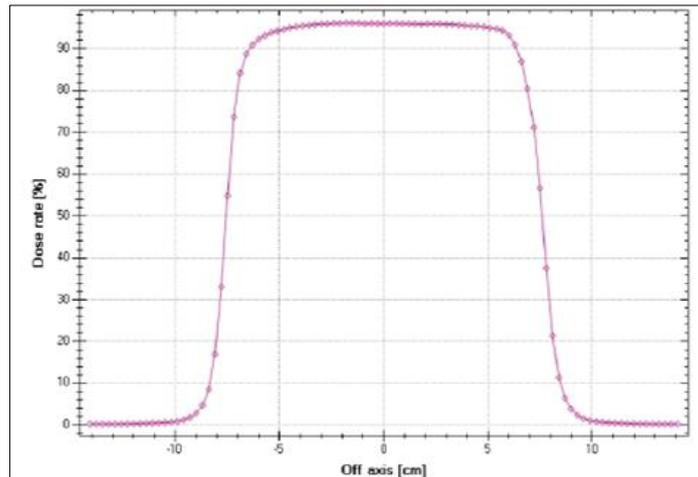
Figure 4 The PDD curves of Electron beams scanned at: (a) 6 MeV, (b) 9 MeV, (c) 12 MeV, (d)15 MeV

The corresponding measured data of the PDDs for the Electron beams of 6, 9, 12 and 15 MeV are presented in Table 18. In the measured PDDs, consistency was observed with manufacturer’s estimations on the measured 90%, 80%, and 50% PDDs at various depths of ionization of the 6, 9, 12 and 15 MeV Electron energies.

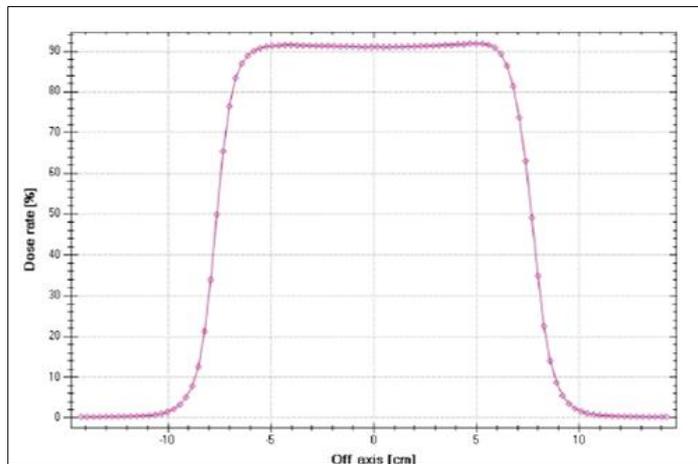
Table 18 The PDDs at various Electron energies

Beam energy (MeV)	Percent of depth dose		
	90%	80%	50%
	Depth of ionization (cm)		
6	1.87	2.09	2.52
9	2.91	3.17	3.72
12	4.02	4.43	5.20
15	4.95	5.47	6.44

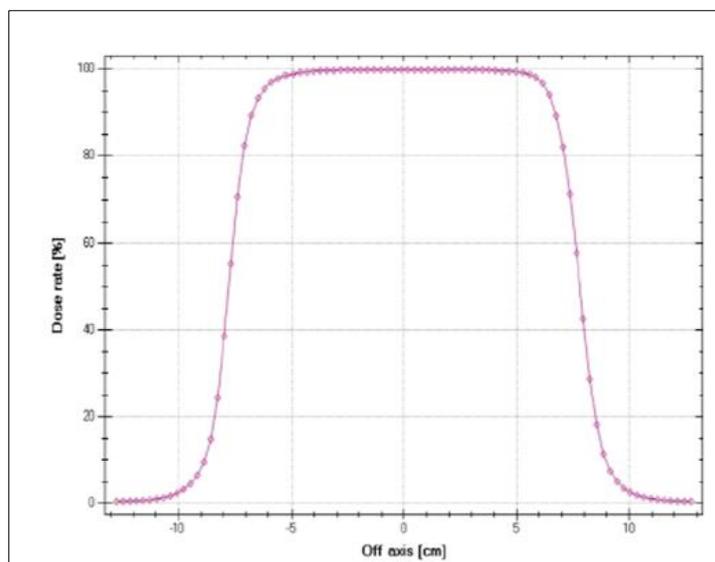
3.2.3. Profile Flatness and Symmetry of Electron beams



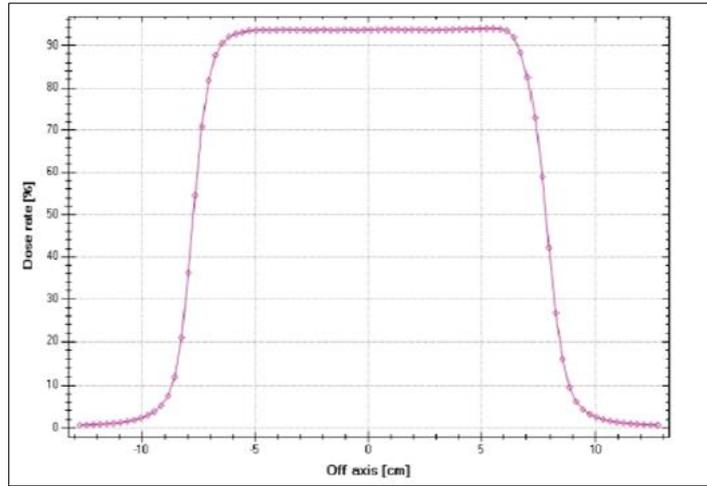
(a) Flatness and Symmetry Profile scanned at 6MeV



(b) Flatness and Symmetry Profile scanned at 9MeV



(c) Flatness and Symmetry Profile scanned at 12MeV



(d) Flatness and Symmetry Profile scanned at 15MeV

Figure 5 The Flatness and Symmetry curves of the Electron beams scanned at (a) 6 MeV, (b) 9 MeV, (c) 12 MeV, (d) 15 MeV energies

The Flatness and Symmetry of Electron beams at various energies were verified at 100cm SSD and 200MU using an IBA Compact Chamber (0.13cc IBA CC13). The Flatness and Symmetry curves of the Electron beams scanned at 6, 9, 12, 15 MeV energies are shown in Fig. 5 (a, b, c, d). The Profile flatness for 6 MeV, 9MeV, 12MeV and 15 MeV Electron energies were found to be 2.2%,1.8%, 2.4% and 1.40% respectively. The Profile Symmetry for the 6 MeV, 9MeV, 12MeV and 15MeV energies were found to be 1.2%, 1.1%, 1.2% and 1.40% respectively. The AAPM TG-40 recommended tolerances of the Profile Flatness and Symmetry are up to $\pm 3\%$ and $\pm 3\%$ for 6MeV, 9MeV, 12MeV and 15MeV Electron energy. Therefore, the investigated Profile flatness and symmetry were found within the tolerant range of the AAPM TG-40 scale.

The corresponding verified parameters of flatness and symmetry evaluations for the Electron beams of 6 MeV, 9 MeV, 12 MeV and 15 MeV energies are presented in Table 19.

Table 19 The Flatness and Symmetry evaluation at various Electron energies

Beam Energy (MeV)	Cone / Applicator (cm ²)	Symmetry	Flatness	Penumbra
6	10×10	1.20%	2.20%	0.95cm - 1.15cm
9	10×10	1.10%	1.80%	1.21cm - 1.31cm
12	10×10	1.20%	2.40%	1.27cm - 1.40cm
15	10×10	1.40%	1.20%	1.08cm - 1.18cm

3.2.4. Electron Cone Ratios

Electron Cone ratios at a given Electron energy were determined by comparing the relative ionization at the depth of maximum dose for a given cone relative to that for the 15×15 cm² cone. All Measurement were performed at 100cm SSD and 200MU using an IBA Compact Chamber (0.13cc IBA CC13). The measured Electron Cone ratios for various energies and Applicators are presented in Table 20.

Table 20 The Electron Cone ratios for various energies and Cone/Applicators

Beam energy (MeV)	Cone / Applicator (cm ²)	Depth	M ₁ ×10 ⁻⁸ C	M ₂ ×10 ⁻⁸ C	Average	Cone Factor
6	6×6	1.33	0.772	0.77	0.771	0.965
	10×10	1.33	0.797	0.797	0.797	0.997
	15×15	1.33	0.799	0.798	0.799	1.000
	20×20	1.33	0.808	0.807	0.808	1.011
	25×25	1.33	0.805	0.805	0.805	1.008
9	6×6	2.09	0.804	0.804	0.804	0.985
	10×10	2.09	0.817	0.817	0.817	1.001
	15×15	2.09	0.816	0.816	0.816	1.000
	20×20	2.09	0.806	0.806	0.806	0.988
	25×25	2.09	0.791	0.791	0.791	0.969
12	6×6	2.89	0.819	0.82	0.82	0.986
	10×10	2.89	0.838	0.836	0.837	1.007
	15×15	2.89	0.832	0.831	0.832	1.000
	20×20	2.89	0.82	0.818	0.819	0.985
	25×25	2.89	0.798	0.796	0.797	0.959
15	6×6	3.52	0.827	0.828	0.828	0.991
	10×10	3.52	0.845	0.844	0.845	1.011
	15×15	3.52	0.835	0.835	0.835	1.000
	20×20	3.52	0.822	0.822	0.822	0.984
	25×25	3.52	0.798	0.798	0.798	0.956

4. Conclusion

The dosimetric characteristics is verified for the megavoltage Photon and Electron beams of a medical LINAC to be useful for treatment planning in a wide range of conditions. Some key parameters, namely PDDs, Profiles, beam Output, and Output Factors are determined with a series of Field Sizes (FSs). The measured parameters of the QA process are authenticated in reference to the BJR-25 [12] and The Task Group-51 (AAPM TG-51) [15]. Therefore, accurately measured PDDs, Profiles, beam Output, and Output Factors of Photon and Electron beams indicate its efficacy for the treatment purpose of a LINAC system.

The Photon beam outputs (D_{max}/MU) are standardized to the tuned doses of 1.0002 and 0.9988 cGy/MU for 6 MV and 10 MV Photon beams, respectively; which significantly satisfies the beam output standardization criteria of 1 cGy/MU standard output dose.

The measured PDDs with different field sizes for both 6MV and 10MV Photon beams are authenticated in reference to the BJR-25 that indicates reasonably a good agreement. In addition, these measured PDDs and Profiles with different field sizes for both 6MV and 10MV Photon beams are verified in terms of the TPS calculated PDDs and Profile, and the variation is found to be less than ± 2 mm.

The Profile Flatness and Symmetry are investigated with FS (10 ×10) cm² for 6MV and 10MV Photon beams. The Flatness and Symmetry are found to be within the AAPM TG-40 tolerance ranges of up to ±3% and ±2% for 6MV and 10MV Photon beams, respectively [9]. Therefore, Flatness and Symmetry of Photon beams satisfies the required accuracy of clinical applications.

The Electron beam outputs ($D_{w,max}/MU$) are standardized to the tuned doses of 1.0031, 1.0049, 1.0014, 0.9985 cGy/MU for 6MeV, 9MeV, 12MeV and 15MeV, respectively; which reasonably satisfies the standardization criteria of 1 cGy/MU standard output dose.

The Profile Flatness and Symmetry are found to be within the AAPM TG-40 tolerance ranges of up to ±3% and ±3% for 6 MeV, 9 MeV, 12 MeV and 15 MeV Electron beams, respectively; hence reasonable accuracy is observed to be useful in clinical applications with LINAC Electron beams.

The Electron Cone ratios at various Electron energies are determined. The Cone Factors are found to be in the range of 0.965 – 1.011, 0.985 – 1.001, 0.985 – 1.007, and 0.984 – 1.011 at energies 6 MeV, 9 MeV, 12 MeV and 15MeV respectively with FS ranging from 6×6 cm² to 25×25 cm².

Compliance with ethical standards

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Disclosure of conflict of interest

There is no conflict of interest declared on this research article.

References

- [1] Akulapalli Sudhakar. History of Cancer, Ancient and Modern Treatment Methods. J Cancer Sci Ther. 2009; 1(2): 1–4.
- [2] Baskar R, Lee KA, Yeo R, Yeoh K-W. Cancer and Radiation Therapy: Current Advances and Future Directions. Int J Med Sci. 2012; 9(3): 193–9.
- [3] Das IJ, Ding GX, Ahnesjö A. Small fields: Nonequilibrium radiation dosimetry. Med Phys. 2008; 35: 206-15.
- [4] Scott AJ, Nahum AE, Fenwick JD. Using a Monte Carlo model to predict dosimetric properties of small radiotherapy photon fields. Med Phys. 2008; 35: 4671-84.
- [5] Henry FG, Ravikumar M, Sathiyam S, Ganesh KM, Retna YP, Varatharaj C. Analysis of small field percent depth dose and profiles: Comparison of measurements with various detectors and effects of detector orientation with different jaw settings. Journal of Medical Physics. 2016; 41(1).
- [6] Tiru S Subramanian, JP Gibbons, J William RH. Moderator Linear accelerators used for IMRT should be designed as small field, high intensity, intermediate energy unit. Med. Phys. 2002; 29(11).
- [7] Jing Hao, Anthony Magnelli, Andrew Godley, Jennifer S Yu. Use of a Linear Accelerator for Conducting In Vitro Radiobiology experiments. J Vis Exp. Author manuscript. 2020.
- [8] Bethesda MD. International Commission on radiation Units and Measurements (ICRU), Determination of Absorbed Dose in a Patient Irradiated by Beams of X or Gamma rays in Radiotherapy Procedures. 1976; 24.
- [9] Gerald J Kutcher, Lawrence Coia, Michael Gillin, William F Hanson, et al. Comprehensive QA for radiation oncology: Report of AAMP radiation therapy committee. Task Group-40 (TG-40) protocol of American Association of Physicists in Medicine (AAPM). Med. Phys. 1994; 21(4).
- [10] Eric E Klein, Joseph Hanley, John Bayouth, fabg-Fang Yin, et. al. Quality assurance of medical accelerators. Task Group-142 (TG-142) protocol of American Association of Physicists in Medicine (AAPM). Med. Phys. 2009; 36(9).
- [11] Sahoo SK, Rath AK, Mukharjee RN, Mallick B. Commissioning of a Modern LINAC for Clinical Treatment and Material Research. International Journal of Trends in Interdisciplinary Studies. 2012; 10.

- [12] BJR Supplement 25 “British Journal of Radiotherapy (BJR-25)”. Central Axis Depth Dose Data for Use in Radiotherapy. British Journal of Radiology. 1996; Suppl. 25.
- [13] Podgorsak EB. Radiation Physics for Medical Physicists. 2010; 110-112.
- [14] IEC (International Electrical Commission). Medical electrical equipment-Dosimeters with ionization chambers as used in radiotherapy. 2016; 3.1.
- [15] Peter R Almond, Peter J Biggs, BM Coursey, WF Hanson, et. al. Clinical reference dosimetry of energy photon and electron beams. Task Group-51 (TG-51) protocol of American Association of Physicists in Medicine (AAPM). Med. Phys. 1999; 26(9).
- [16] IEC (International Electrical Commission). Medical electrical equipment-Medical electron accelerators-Functional performance characteristics. 2007; 2.0.
- [17] Bruce J Gerbi, Jhon A Antolak, F Christopher Deibel, David S Followill, et al. Recommendations for clinical electron beam dosimetry: Supplement to the recommendations of Task Group-25. Task Group-25 (TG-25) protocol of American Association of Physicists in Medicine (AAPM). Med. Phys. 2009; 36(7).