



Scientific Inquiry and Review (SIR)

Volume 5, Issue 3, September 2021

ISSN (P): 2521-2427, ISSN (E): 2521-2435

Journal DOI: <https://doi.org/10.32350/sir>

Issue DOI: <https://doi.org/10.32350/sir/52>

Homepage: <https://journals.umt.edu.pk/index.php/SIR/Home>

Journal QR Code:



Article: **Improving Clinical Dosimetric Accuracy of Cancer Treatment Using a Special Quality of Electron and Photon Beams**

Author(s): Ayesha Ikhlaq¹, Saeed Ahmad Buzdar¹, Mamoona Aslam¹, Muhammad Usman Mustafa¹, Sana Salahuddin¹, Mehrun Nisa²

Affiliation: ¹ Institute of Physics, The Islamia University of Bahawalpur, Bahawalpur, Pakistan
² Government Sadiq College Women University, Bahawalpur, Pakistan

Article DOI: <https://doi.org/10.32350/sir/53.02>

QR Code:



Citation:

Ikhlaq A, Buzdar SA, Aslam M, et al. Improving clinical dosimetric accuracy of cancer treatment using a special quality of electron and photon beams. *Sci Inquiry Rev.* 2021;5(3):12–26.

Copyright Information:



This article is open access and is distributed under the terms of [Creative Commons Attribution 4.0 International License](https://creativecommons.org/licenses/by/4.0/)

Indexing



A publication of the
School of Science, University of Management and Technology
Lahore, Pakistan

Improving Clinical Dosimetric Accuracy of Cancer Treatment Using a Special Quality of Electron and Photon Beams

Ayesha Ikhlaiq¹, Saeed Ahmad Buzdar¹, Mamoon Aslam¹,
Muhammad Usman Mustafa¹, Sana Salahuddin¹, Mehrun Nisa²

¹Institute of Physics,

The Islamia University of Bahawalpur, Bahawalpur, Pakistan

²Government Sadiq College Women University, Bahawalpur, Pakistan

*ayesha.ikhlaq@iub.edu.pk

Abstract

Electron and photon beams demonstrate extraordinary characteristics useful for the treatment of cancer. These characteristics are essential to analyze before the calibration of the linear accelerator with dual energies. This study focused on the dosimetric characteristics of the different energies of electron beam for different field sizes. The basic objective of this work was to calculate the dosimetric parameters and characteristics of the electron beam, especially depth dose characteristics along the central axis. In this work, 6 MeV, 9 MeV, 12 MeV, 15 MeV and 18 MeV of electron beam and 6 MV and 15 MV of photon beam with different field sizes were used. The characteristics of the depth dose of electron and photon beams in water were analyzed to optimize the radiation quality for radiation treatment planning. The different beam characteristics are due to different interactions that occur between electron beams giving them a definite range, whereas photon beams are attenuated leading to dose deposition and a much larger range with no definite end. Depth dose characteristics of electron and photon beams are not similar since the interaction of these beams with matter depends on their quality. Attenuation and penetration factors change with changing dosimetric parameters. A complete analysis of the dosimetric characteristics of electron and photon beams helps to choose the more accurate beam for the treatment of cancer. This work helps to increase accuracy in the treatment of cancer with radiotherapy.

Keywords: absorbed dose, electron beam, percentage depth dose, photon beam, radiation therapy, treatment planning

1. Introduction

Radiation therapy is among the most basic and important treatments of cancer, other than surgery and chemotherapy. High energy radiations are used to damage the DNA of the cell and consequently, further growth of the cell stops. Radiotherapy treatment needs special care in its implementation and also a good judgment in preparing the treatment plan for cancer [1, 2]. The basic purpose of radiation therapy is to damage cancer cells. Errors and uncertainty in radiation therapy decrease the degree of its accuracy. Many factors such as the type of tumor, its positioning, imaging, diagnosis and uncertainty in normal tissue response are responsible for the administration of an accurate dose in radiotherapy [3].

In radiation therapy, efforts have been made to reduce the spatial noise and to determine a more accurate dose for the treatment of cancer. The outcome attained by different advanced techniques and multi-leaf collimators bolus for better positioning. Accuracy can be achieved by minimizing the time and increasing the energy of the delivered dose [4].

The basic priority in radiation therapy is to damage the cancerous cells, while sparing normal tissues from radiation. This can be achieved by using advanced techniques and modalities during treatment, such as the use of multiple beams to damage cancerous cells from different directions.

Photon and electron beams are the most widely used beams in the treatment of cancer. Linear accelerator is the most advance and common machine used to deliver radiation [5]. In the past, electron beams of energy up to 22 MeV were used, while photon beam was regarded as the most suitable for the treatment of cancer. Recently, a very high energy electron beam with energy more than 150 MeV was introduced in theoretical studies using PENELOPE code. This high energy beam can be used to treat 40 cm deep tumor [6]. Very high energy electron beams of 100-250 MeV have the ability to treat superficial tumor as well as deep-seated tumor due to their advanced dosimetric characteristics [7]. Total skin electron beam therapy is another effective and minimum toxic radiation therapy delivered with a low energy electron beam. This therapy is mostly used in the treatment of mycosis fungoides [8].

The surface of human body is not uniform. It is challenging to deliver the maximum dose needed to treat deep-seated tumor through an electron beam. Thermo-luminescent dosimetry is the best technique for dose optimization in total skin electron irradiation and partial skin electron irradiation with the adjustment of monitor units. In this way, the prescribed dose can be delivered [9]. Intraoperative radiation therapy is another good technique in the treatment of head and neck, breast, prostate and gastrointestinal cancers. This technique is beneficial in delivering more dose to the target area while sparing normal tissues [10].

Dosimetric characteristics of electron and photon beams are among the most significant features of radiation therapy before radiation treatment planning to cure cancer. In radiation therapy, the treatment of cancer depends on the dosimetry of the beam; many modalities in dosimetry cause a better change in the treatment of cancer with radiation therapy. Accuracy in dosimetry assures that the maximum dose is delivered to the malignant area, while sparing normal tissues [11]. For high energy electron beams, advances in dosimetric calculation are investigated using alanine pellets irradiated in a water equivalent-plastic phantom [12]. Chambers are used for the dosimetry of electron and photon beams. Plane-parallel chambers are good for reference electron dosimetry, whereas cylindrical chambers are better for the dosimetry of photon beams [13].

For the last few years, electron beam therapy has been the most used technique for treating superficial tumor, due to the characteristics of rapid dose fall-off and uniform distribution of the dose at the surface. In the case of electron beam, it is beneficial to treat skin tumor over a small treatment area, as maximum dose is deposited near the surface of the target area [14].

Electron beam is mostly used for the treatment of skin cancer. The dose delivered using electron beam can be determined with the help of the target medium. In the same way, for photon beam therapy, dosimetric parameters can be measured. Depth dose curve can be measured with the help of ionizing chambers. Different chambers are currently used to calculate the depth dose curve.

Once depth dose curve is obtained, other typical parameters can be explored on its basis. As water is the main constituent of human tissue,

therefore water phantom is used for dose calibration [15]. Dosimetry is the most fundamental part of radiation therapy. The entire treatment planning depends on data collection during dosimetry. The patient's treatment completely depends on the treatment plan and the prescribed dose depends on the depth, field size, energy of the selected beam, and source to surface distance (SSD) [16]. Dosimetric calculations provide complete information about treatment planning parameters [17].

The shape of depth dose curve is the most interesting and observable characteristic in electron and photon beam dosimetry. On striking the target material, an electron beam results in a plain curve. It transfers energy on multiple scattering and the resultant portion is known as a build-up region [18]. Afterwards, electron dose is reduced and this region is called the fall-off region because electron's multiple scattering becomes the major reason to stop the further movement of electron. This is the reason that the depth of electron dose remains minimum. On the other hand, photon beam delivers energy by ionizing other particles and an exponentially decreasing depth dose curve is obtained [19, 20].

2. Methodology

The purpose of this work was to study the characteristics of electron and photon beams as these two are the most widely used beams in the treatment of cancer. Linear accelerator used in this work was from Varian, also known as VitalBeam, with dual energy mode (both photon and electron beams' availability). Multiple electron beams including 6 MeV, 9 MeV, 12 MeV, 15 MeV and 18 MeV beams with the field size of $6\times 6\text{ cm}^2$, $10\times 10\text{ cm}^2$, $15\times 15\text{ cm}^2$, $20\times 20\text{ cm}^2$ and $25\times 25\text{ cm}^2$ were used. Whereas, photon beams of 6 MV and 15 MV with the field size of $6\times 6\text{ cm}^2$, $10\times 10\text{ cm}^2$ and $20\times 20\text{ cm}^2$ were used. The entire data was measured in a water phantom filled with distilled water. The source to surface distance was 100 cm. Depth dose curves were measured in central axis in such a way that the isocenter of the machine and phantom remained the same. Dose build-up region and fall-off regions were discussed. These regions are different for both electron and photon beams. Using electron beam, the maximum dose is delivered at the surface and rapid dose fall-off is observed afterwards. Whereas, in the case of photon beam, dose decays exponentially due to a different attenuation property.

Many basic parameters were calculated after analyzing the depth dose curve. For example, surface dose, dose at 0 cm, and dose at the depth of 20 cm. These values vary with different energies of photon and electron beams and for different field sizes. Depth dose curve also depends on the source to surface distance. Moreover, with the further study of depth dose curve, more parameters can be explored including d_{50} , d_{80} , average decrease dose, surface dose, maximum dose and the ratio of surface dose to maximum dose. Beam spectrum can be studied with the help of surface dose. In the case of photon beam, dose distribution varies due to the low energy of the beam. For electron beam, surface dose increases with an increase in energy. This is the reason that electron beam is preferable in the treatment of skin tumor. Whereas, in the case of photon beam, surface dose decreases with an increase in energy. However, for both electron and photon beams, surface dose increases with an increase in field size. Different parameters of electron and photon beams were examined such as beam energies, field sizes, and source to surface distance cause attenuation, penetration and scattering of the beams. All measurements were taken in the MP3 water tank invented by the IBA dosimetry CC13 ionization chamber.

3. Results and Discussion

Dosimetric characteristics of electron and photon beams can be evaluated through the study of different constraints. The exposure of radiation to the target material was determined by the amount of radiation absorbed and it was calculated along the central axis of the beam. Different constraints such as the percentage depth dose, field size, energy, and source to surface distance were calculated for the electron beam energies of MeV (6, 9, 12, 15, 18) and for the photon beam energies of MV (21, 6 and 15). Rapid dose fall-off regions and the decrease in depth dose per cm (50% dose, 80% and 90% doses) were investigated.

Typical values of d_{\max} , d_{50} and d_{80} were analyzed. The difference between $d_{50} - d_{\max}$, $d_{80} - d_{\max}$ and $d_{50} - d_{80}$ is described in Table 1. It illustrates that dose difference is increased with the increase in energy. However, different modes of variation exist. The maximum dose does not show a linear relationship with energy and d_{\max} shows a non-homogeneous behavior with the change in energy, as shown in Figure 1 and Figure 2.

Table 1. Depth of Maximum Dose, Depth of 50% Dose and Depth of 80% Dose of Different Energies at 100 SSD for the Field Size of 20×20cm²

Energy (MeV)	d _{max} (cm)	d ₅₀ (cm)	d ₈₀ (cm)	d ₅₀ -d _{max} (cm)	d ₈₀ -d _{max} (cm)	d ₅₀ -d ₈₀ (cm)
6	1.35	2.32	1.97	0.97	0.6	0.35
9	2.05	3.45	3.11	1.4	1.06	0.34
12	2.75	4.85	4.27	2.1	1.52	0.58
15	3.15	6.15	5.41	3	2.26	0.74
18	2.75	7.54	6.36	4.79	3.61	1.18

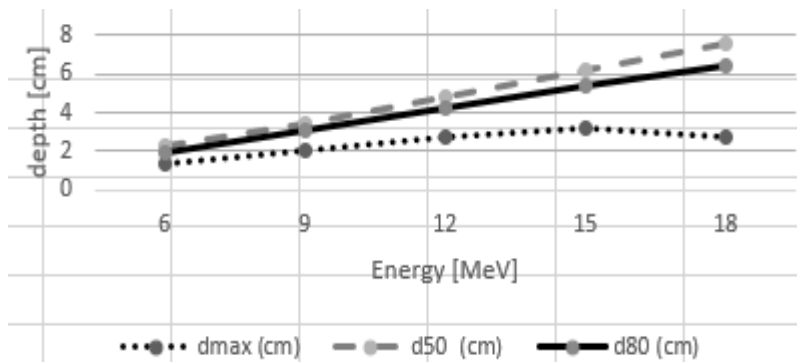


Figure 1. Depth Dose of Max Dose, 50% Dose and 80% Dose

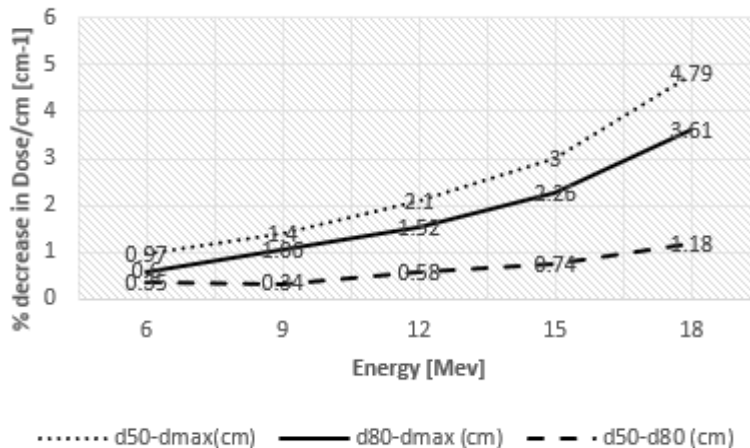


Figure 2. Percent Decrease in Dose for Electron Beams of Different Energies at 100 SSD for Field

Depth dose fall-off was calculated by measuring average decrease in dose/cm. Dose fall-off in between d_{\max} and d_{50} , d_{\max} and d_{80} , and d_{50} and d_{80} was estimated with the average decrease in dose per cm, as shown in Table 2.

Table 2. Average Decrease in Percent Dose per cm for Electron Beams of Different Energies at 100 SSD for the Field Size of 20x20cm²

Energy (MeV)	Average Decrease b/w d_{50} and d_{\max}	Average Decrease b/w d_{80} and d_{\max}	Average Decrease b/w d_{50} and d_{80}
6	51.55	33.33	85.71
9	35.71	18.87	88.24
12	23.80	13.16	51.72
15	16.67	8.85	40.54
18	10.44	5.54	25.42

The calculated data for percentage depth dose at different depths was used to determine the average decrease in dose for different electron energies. It was noted that the average decrease in dose was linear between all doses except d_{50} and d_{80} . For example, 6 MeV average decrease was calculated as 85.7 and it increased for the energy of 9 MeV, that is, 88.2. The analysis showed that average decrease between two depths decreases with the increase in energy and the decrease rate of dose is not linear. This change is due to the mode of interaction with matter. High energy beams interact differently as compared to low energy beams. Hence, the attenuation factor and movement of the former differ from that of the latter. Beam energy is plotted against average decrease in energy in Figure 3.

Figure 3 describes the average decrease in depth dose corresponding with the increase in beam energy. The percentage depth dose decreased almost in the same way from d_{\max} to d_{50} or d_{80} ; these two curves don't show any significant difference in the average decrease. However, when the decrease in PDD in the middle region is analyzed, that is, between d_{50} and d_{80} , the average decrease isn't linear. Rather, it slightly increases from 6 MeV to 9 MeV, then suddenly decreases from 9 MeV to 12 MeV, and finally it decreases linearly corresponding with the further increase in beam energy.

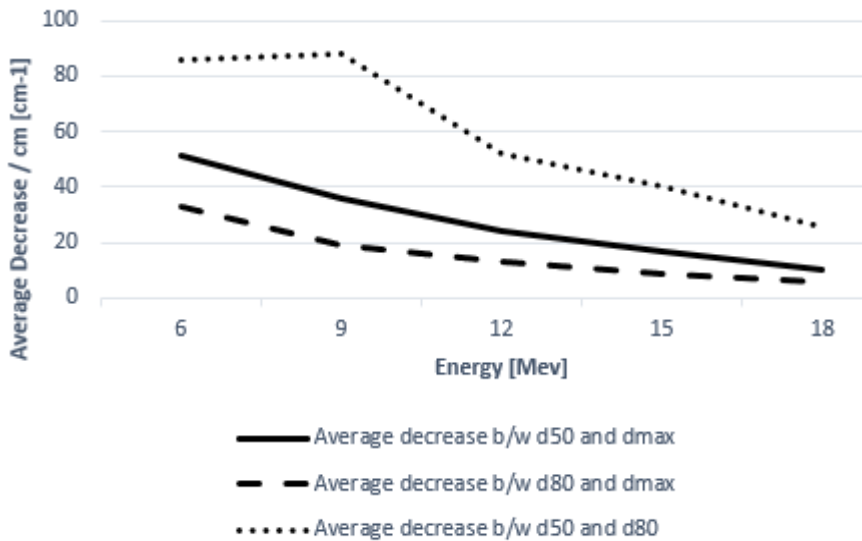


Figure 3. Average Decrease in Dose between d_{50} and d_{max} , d_{80} and d_{max} and d_{50} and d_{80}

Table 3. Ratio of Surface Dose to Maximum Dose for Different Electron Beam Energies for the Field Size of 20x20cm²

Energy (MeV)	Surface Dose (%)	Maximum Dose (%)	Ratio of Surface Dose to Maximum Dose
6	79.5	100	0.795
9	82	100	0.82
12	87.5	100	0.875
15	91	100	0.91
18	93	100	0.93

Table 3 shows that the ratio of surface dose to maximum dose is low for low energy electron beams as compared to high energy electron beams. This ratio increases with the increase in energy, as can be seen in Fig 4.

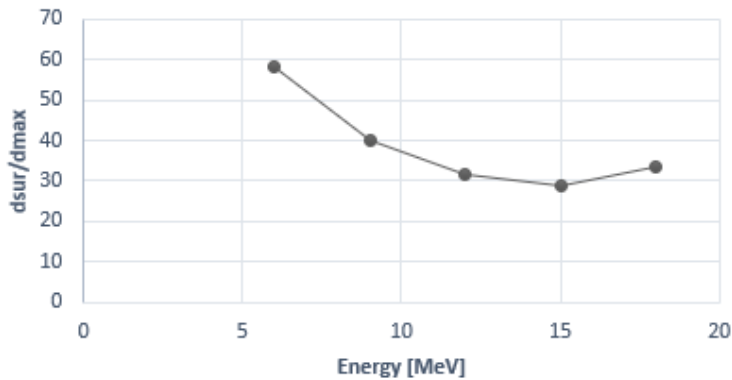


Figure 4. Ratio of Surface Dose to Maximum Dose of Different Energies of Electron Beam

Table 4. Surface Dose of 6 and 15 MV Energies of Photon and Electron Beam

Field Size cm ²	6 (MeV)	15 (Mev)	6 (MV)	15 (MV)
6×6	77.4	91.1	49.8	28.7
10×10	77.7	90.4	53.6	34.4
20×20	78.8	90.7	62.2	48

In Table 4, surface doses of 6 and 15 MV energies of the photon beam and 6 and 15 MeV energies of the electron beam for the field sizes of 6×6 cm², 10×10 cm² and 20×20 cm² respectively are compared. The comparison shows that the surface doses of electron beam are higher than that of the photon beam. For 6 MeV surface dose of electron beam for the field size of 6×6 cm², it is 77.4%. Whereas, it is 49.8% for 6 MV energy of the photon beam. For both 6 MeV energy of electron and 6 MV energy of photon beam, surface dose increases with an increase in field size. However, this variation is greater for the photon beam as compared to the electron beam. For 6 MeV surface dose electron beam for the field size of 10×10 cm², it is 77.7%. Whereas, it remains 78.8% for the field size of 20×20 cm². Only, a 1.1% increase is noticeable. Whereas, for 6 MV energy of the photon beam with the field size of 10×10 cm², surface dose is 49.8%. However, with an increase in the field size of 20×20 cm², surface dose becomes 62.2%. In the

case of electron beam, surface dose increases with the increase in energy. Whereas, in the case of photon beam, surface dose decreases with the increase in energy. For 6 MV energy photon beam, surface dose is 49.8%. Moreover, for 15 MV photon beam surface, dose is 28.7 %. Graphical representation of the above description is given in Figure 5.

In Figure 5, bars represent different energies of electron and photon beams, whereas the height of bars is modified with respect to different surface doses. The figure depicts that surface dose is maximum for 15 MeV electron beam, whereas surface dose is minimum for 15 MV photon beam and it increases with the corresponding increase in field size. In the case of electron beam, an increase in field size shows minor variation in surface dose. In Figure 6, different colors show different field sizes. Notable variation can be seen in the case of photon beam, whereas variation is minor in the case of electron beam energies.

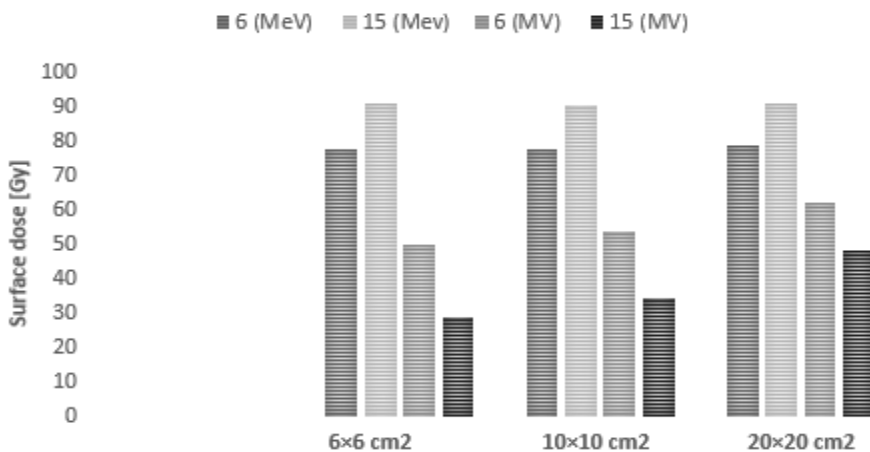


Figure 5. Surface Dose Comparison (Electron Beam of Energies 6 MeV and 15 MeV and Photon Beam of Energies 6 MV and 15 MV) for Different Field Sizes

Attenuation and penetration factors change with the changing dosimetric parameters as reported previously [18]. Variations in attenuation and penetration parameters corresponding with dosimetric parameters such as field size are reportedly caused by scattering and distance between source

and surface. This happens because of the difference in interaction energy [21].

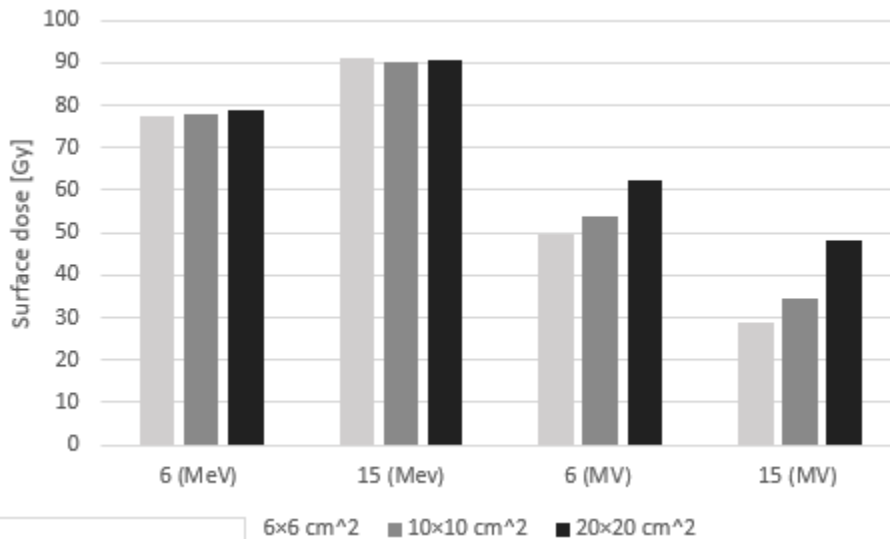


Figure 6. Surface Dose Comparison (Electron Beam of Energies 6 MeV and 15 MeV and Photon Beam of Energies 6 MeV and 15 MeV) for Different Field Sizes

4. Conclusion

In radiation treatment planning, the characteristic analysis of the depth dose curves of electron and photon beams is very beneficial in achieving a better degree of accuracy. For the calculation of the absorbed dose, it is essential to acquire the knowledge of the energy and the geometrical effect of different dosimetric parameters. Doses can be different at certain locations due to different dosimetric parameters, such as field size and source to surface distance. However, their distribution completely depends on beam energy.

Attenuation factors between two depths explain briefly the dose decrease or increase for the specific energy level. The choice of energy should be efficient in order to target the tumor, while sparing normal tissues. Electron beam is better for the treatment of superficial lesions and for treating tumors near to the skin. Whereas, photon beam is not the better option for the treatment of skin cancer, although it is better for the treatment

of deep-seated tumor. Changing field size is not a good option to increase the surface dose of electron. This analysis helps to select the more suitable beam for the treatment of cancer.

Conflict of Interest

The author's declare no conflict of interest.

References

- [1] Ikhlaq A, Buzdar SA, Mustafa MU, Salahuddin S, Aslam M. Improving Clinical dosimetric Accuracy of cancer treatment using a special quality of Electron and Photon Beam. *Sci Inquiry Rev.* 2021;5(3):1-12. <https://doi.org/10.32350/sir.53.02>
- [2] Afzal M. *Some aspects of the application of Fricke and other Gels with NMR Detection to image and plot radiation beams for tumor therapy* [Doctoral dissertation, PhD thesis]. University of Dundee.
- [3] Buzdar SA, Afzal M, Todd-Pokropek A. Comparison of pencil beam and collapsed cone algorithms, in radiotherapy treatment planning for 6 and 10 MV photon. *J Ayub Med Coll Abbottabad.* 2010;22(3):152-4.
- [4] Khan FM, Gibbons JP, Sperduto PW. *Khan's treatment planning in radiation oncology.* Lippincott Williams & Wilkins; 2016.
- [5] Donmez Kesen N, Cakir A, Okutan M, Bilge H. Research of dosimetry parameters in small electron beams. *Sci Tech Nucl Instal.* 2014;2014: 585219. <https://doi.org/10.1155/2014/585219>
- [6] Moskvin V, Salvat F, Stewart DK, DesRosiers CM. PENELOPE Monte Carlo engine for treatment planning in radiation therapy with very high energy electrons (VHEE) of 150–250 MeV. In *IEEE Nuclear Science Symposium & Medical Imaging Conference 2010* (pp. 1961-1966). IEEE. <https://doi.org/10.1109/NSSMIC.2010.5874117>
- [7] Subiel A, Moskvin V, Welsh GH, et al. Dosimetry of very high energy electrons (VHEE) for radiotherapy applications: using radiochromic film measurements and Monte Carlo simulations. *Phy Med Bio.* 2014;59(19):5811-5829.

- [8] Elsayad K, Susek KH, Eich HT. Total skin electron beam therapy as part of multimodal treatment strategies for primary cutaneous T-cell lymphoma. *Oncol Res Treatment*. 2017;40(5):244-52. <https://doi.org/10.1159/000475634>
- [9] Schüttrumpf L, Neumaier K, Maihoefer C, et al. Dose optimization of total or partial skin electron irradiation by thermoluminescent dosimetry. *Strahlentherapie und Onkologie*. 2018;194(5):444-53. <https://doi.org/10.1007/s00066-018-1263-9>
- [10] Avanzo M, Dassie A, Acharya PC, et al. Electron radiotherapy (IOERT) for applications outside of the breast: Dosimetry and influence of tissue inhomogeneities. *Physica Medica*. 2020;69:82-9. <https://doi.org/10.1016/j.ejmp.2019.12.003>
- [11] Kron T, Lehmann J, Greer PB. Dosimetry of ionising radiation in modern radiation oncology. *Phy Med Bio*. 2016;61(14):R167.
- [12] McEwen M, Sharpe P, Vörös S. Evaluation of alanine as a reference dosimeter for therapy level dose comparisons in megavoltage electron beams. *Metrologia*. 2015;52(2):272.
- [13] Muir BR, McEwen MR, Rogers DW. Beam quality conversion factors for parallel-plate ionization chambers in MV photon beams. *Med Phy*. 2012;39(3):1618-31. <https://doi.org/10.1118/1.3687864>
- [14] Ikhlaq A, Buzdar SA, Mustafa MU, Salahuddin S, Aslam M. Improving Clinical dosimetric Accuracy of cancer treatment using a special quality of Electron and Photon Beam. *Sci Inquiry Rev*. 2018;45(2):863-74. <https://doi.org/10.32350/sir.53.02>
- [15] Khan FM, Doppke KP, Hogstrom KR, et al. Clinical electron-beam dosimetry: report of AAPM radiation therapy committee task group No. 25. *Med Phy*. 1991;18(1):73-109. <https://doi.org/10.1118/1.596695>
- [16] Wambersie A, G. Menzel H, A. Gahbauer R, TL Jones D, D. Michael B, Paretzke H. Biological weighting of absorbed dose in radiation therapy. *Radiation Protection Dosimetry*. 2002;99(1-4):445-52. <https://doi.org/10.1093/oxfordjournals.rpd.a006829>

- [17] Buzdar SA, Afzal M, Todd-Pokropek A. Comparison of pencil beam and collapsed cone algorithms, in radiotherapy treatment planning for 6 and 10 MV photon. *J Ayub Med Coll Abbottabad*. 2010;22(3):152-4.
- [18] Buzdar SA, Rao MA, Nazir A. An analysis of depth dose characteristics of photon in water. *J Ayub Med Coll Abbottabad*. 2009;21(4):41-5.
- [19] The International Commission on Radiation Units and Measurements. *Radiation Dosimetry: Electron Beams with Energies Between 1 and 50 MeV*. 1984;35.
- [20] Klevenhagen SC. *Physics and dosimetry of therapy electron beams*. Medical Physics Publishing Corporation; 1993.
- [21] Rahman MA, Alam MJ, Akhtaruzzaman M. Characteristic's analysis of high energy external radiotherapy beams in water. *Malaysian J Med Bio Res*. 2018;5(1):51-60. <https://doi.org/10.18034/mjmbr.v5i1.450>