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Absorbed Dose Measurements for Teletherapy Prediction of Superficial Dose Using Halcyon Linear Accelerator

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ABSTRACT

Introduction: Measurement of entrance dose and dose at different depth is essential to avoid over dose and under dose of patients. The aim of this study is to verify the variation in the absorbed dose using a water equivalent material.

Material and Methods: The plastic phantom was arranged on the couch of the halcyon linear accelerator by Varian with the farmer ionization chamber inserted and connected to the electrometer. The image of the setup was taken using the High-Quality Single 1280x1280x16 higher on the service mode, to check the alignment with the isocenter. The beam quality $TPR_{20,10}$ (Tissue phantom ratio) was done to check the beam quality of the machine at a field size of 10 cm x 10 cm. The calibration was done using SAD type set-up at a depth of 5 cm. This process was repeated for ten consecutive weeks and the values recorded.

Results: The results of the beam output for the teletherapy machine were satisfactory and accepted in comparison with the commissioned measurement of 0.62. The beam quality $TPR_{20,10}$ (Tissue phantom ratio) was reasonable with respect to the beam quality of the machine at a field size of 10 cm x 10 cm.

Conclusion: The results of the beam quality and the absorbed dose rate showed a good consistency over the period of ten weeks with the commissioned measurement value.

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Introduction

Cancer causes around 7.9 million deaths worldwide each year (1) according to World Health Organization. The primary treatments for this disease include oncologic surgery, chemotherapy, and radiation therapy. Radiation therapy is recommended for approximately 50% of cancer patients. The predominant form of radiation therapy is teletherapy, where the radiation source is situated outside the body, and the emitted beam penetrates tissues to interact with both normal and tumor cells (2). For treating deep-seated tissues, the linear accelerator (LINAC) is commonly used. In a LINAC, electrons are accelerated and collide with a target as they pass through a linear tube, gaining energy. This interaction generates a bremsstrahlung x-ray beam, which exits the machine and interacts with the patient's tissues (2).

The Halcyon linear accelerator is primarily developed for delivering intensity-modulated radiation therapy (IMRT) and volumetric modulated arc therapy (VMAT). Its standout characteristics include rapid treatment delivery, boasting a dose rate of 800 monitor units per minute (MU/min) (3,4). The Halcyon linear accelerator also includes specialized features like a flattening filter-free (FFF) beam and an automated daily Image Guided Radiation Therapy (IGRT) workflow (5). The precision of IMRT and VMAT planning and delivery is influenced by the quality of the treatment planning system, which relies on accurate beam data acquisition and modeling. The Halcyon system comes with a preconfigured reference beam model integrated into the Eclipse treatment planning system, which cannot be altered by users (4). This pre-built beam model aids in handling the complexities associated with small fields and multi-leaf collimator (MLC) dosimetry, ensuring better alignment between planned and delivered treatments (6)

The RW3 Slab phantom is specifically designed for dosimetry in high-energy radiation therapy, capable of handling radiation from ^{60}Co sources and electron energies ranging from 4 MeV to 25 MeV. It is well-suited for high-energy photon and electron dosimetry and facilitates quality control for both absolute and relative dose measurements. Made from water-equivalent RW3 material, it mimics the properties of human tissue for accurate dosimetric evaluations (7).

The Ionization chambers are designed for absolute photon and electron dosimetry with therapy dosimeter (8). The ionization chamber is the most

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practical and most widely used type of dosimeter for accurate measurement of machine output in radiotherapy (9). It may be used as an absolute or a relative dosimeter. Its sensitive volume is usually filled with ambient air and the dose related or dose rate related measured quantities are the ionization charge Q or ionization current I, respectively, produced by radiation in the chamber sensitive air mass m_{air}. Charge Q and air mass m_{air} are related to absorbed dose in air D_{air}.(10).

The PTW Unidose universal electrometer, identified by reference number T1008 and serial number 010583, is capable of measuring integrated dose (or charge) and dose rate (or current) simultaneously. It operates within a high voltage range from 0 to ±400 volts, adjustable in increments of ±50V. Charge and current values are displayed in Coulombs (C) or Amperes (A). This device includes a comprehensive detector library that encompasses detector data and calibration factors.

The OPUS 20 THIP logging barometer is a standalone instrument designed for measuring and recording atmospheric pressure, temperature, and humidity. It measures air pressure ranging from 300 to 1300 hPa (hectopascals), temperatures between -20°C to 50°C, and humidity levels from 0% to 100% relative humidity (RH), all with a resolution of 0.1.

The absorbed dose protocols established by the American Association of Physicists in Medicine (AAPM) TG-51 and the International Atomic Energy Agency (IAEA) TRS-398 mandate the use of liquid water as the phantom material for reference dosimetry (11). This study introduces a structured approach for measuring the absorbed dose to water using ionization chambers that are calibrated in terms of absorbed dose to water, but irradiated within solid phantoms. This framework is essential for accurately converting dose measurements obtained with solid phantoms to an absolute basis. Applying this approach offers significant benefits in terms of verification measurements and quality assurance (12–14). Putting solid phantom measurements on an absolute basis has distinct advantages in verification measurements and quality assurance. To facilitate this conversion, a phantom dose conversion factor is used. This factor translates measurements made in solid phantoms, analyzed according to an absorbed dose calibration protocol, into an absorbed dose to water under reference conditions (11).

Materials and Methods

An integrated self-check tool called Machine Performance Check (MPC) is used to verify if the critical functions of the system are operating within specifications. The application is designed for reliable and fast system testing on a daily basis before routine treatment starts.

The drum phantom was securely fastened to the couch in order to perform MPC Beam and Geometry Check. MPC then automatically acquires a series of MV and kV images, capturing beam properties as well as mechanical characteristics for different collimator rotations, gantry rotations, and couch settings. The acquired series of images is immediately processed.

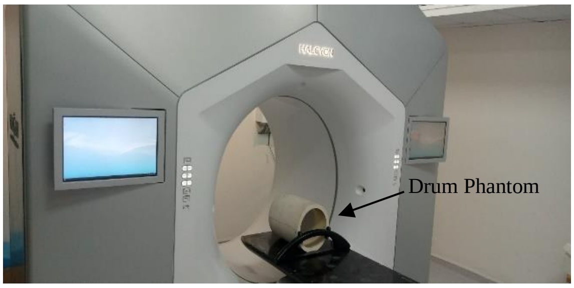

Figure 1. Drum Phantom attached to the couch

The farmer ionization chamber was inserted into the plastic phantom that was set up on the couch of the Halcyon linear accelerator and connected to the electrometer. The type of phantom used in this study was the RW3 Slab Phantom, which is specifically designed for dosimetry in high-energy radiation therapy. It is compatible with photon energies ranging from ^{60}Co to 25 MV and electron energies from 4 MeV to 25 MeV. This phantom is ideal for high-energy photon and electron dosimetry and allows users to conduct quality control for both absolute and relative dose measurements. Constructed from water-equivalent RW3 material, also known as Goettingen White Water, it accurately simulates the properties of human tissue for precise dosimetric analysis (15).

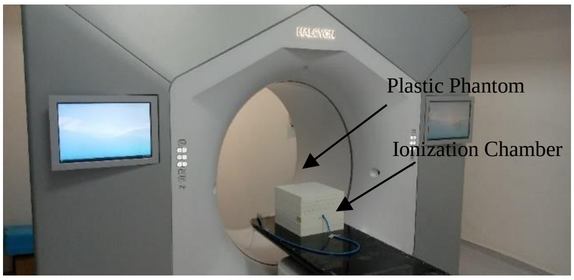

Figure 2. Ionization Chamber placed inside the Plastic Phantom

The image of the setup was taken using the High-Quality Single 1280×1280×16 high resolution on the service mode, to check the alignment with the isocenter. The beam quality $TPR_{20,10}$ (Tissue phantom ratio) was done to check the beam quality of the machine at a field size of 10 cm x 10 cm. The calibration was done using SAD type set-up at the depth of 5 cm. This process was repeated for ten consecutive weeks and the values recorded. The charges were computed using the TRS 398 work sheet to calculate the corresponding absorbed-dose rate at the depth of 5 cm. PTW Farmer Ionization chamber was used. The 30010 Farmer chamber are designed for absolute photon and electron dosimetry with therapy dosimeter

The PTW Unidose universal electrometer, referenced as T1008 and bearing serial number 010583, was utilized in this study. This device is capable of measuring both integrated dose (or charge) and dose rate (or current) simultaneously. It operates within a high voltage range from 0 to ±400 volts, with adjustments available in ±50V increments. The measured electrical values of charge and current are displayed in Coulombs (C) or Amperes (A). Additionally, the electrometer features a comprehensive detector library, complete with detector data and calibration factors.

The paper tape was used to hold the ionization chamber firmly on the couch and the measuring ruler was used to measure the difference between the chamber insert and the centre of the phantom.

The OPUS 20 THIP logging barometer is a self-contained instrument for the measurement and logging of atmospheric pressure, temperature and humidity. It measures air pressure within the range of (300 to 1300) hPa, temperature range (20 to 50) ºC and humidity of (0 to 100%) RH, all with a resolution of 0.1.

Adopted Design (Technical Reports Series (TRS 398))

To provide practical guidelines for implementing TRS 398 for hospital users in Member States, the coordinated research project (CRP E2.40.09) was expanded. Its scientific scope now includes analyzing and quantifying potential differences with other dosimetry protocols. This study revealed that the primary objective of the extended project was to test the procedures recommended in TRS 398 across various types of radiation beams and ionization chambers, and to compare these results with those from other major protocols used worldwide. The recommendations in the TRS 398 Code of Practice have replaced those of TRS 277 and TRS 381, (12), which are still commonly used by most Member States, demonstrating an improvement in practical dosimetry (16).

Results

To avoid errors and provide high confidence that patients will receive the prescribed therapy accurately, each step in the integrated RT process requires quality control and quality assurance (QA) as has been demonstrated in Table 1 over 10 weeks. The recorded values of TPR 20/10 against the ten weeks of the study is shown in Figure 1. The calibrated values at 400 V, 200 V and the negative polarity of 400 V is shown in Figure 2. The Table 2 shows the comparison between the dose and the absorbed dose over 10 weeks. The absorbed dose plotted against the weeks of study is shown in Figure 3.

Table 1. Tissue Phantom Ratios (TPR) values against commissioned values at various depths

Week	TPR at 20 cm	TPR at 10 cm	TPR at 20/10	Commissioning value	% Deviation value
1	8.39	13.48	0.62	0.62	0.00
2	8.47	13.50	0.63	0.62	0.80
3	8.47	13.50	0.63	0.62	0.80
4	8.51	13.50	0.63	0.62	1.13
5	8.39	13.47	0.62	0.62	0.00
6	8.49	13.48	0.63	0.62	1.13
7	8.48	13.52	0.63	0.62	0.80
8	8.47	13.50	0.63	0.62	0.80
9	8.39	13.46	0.62	0.62	0.00
10	8.39	13.48	0.62	0.62	0.00

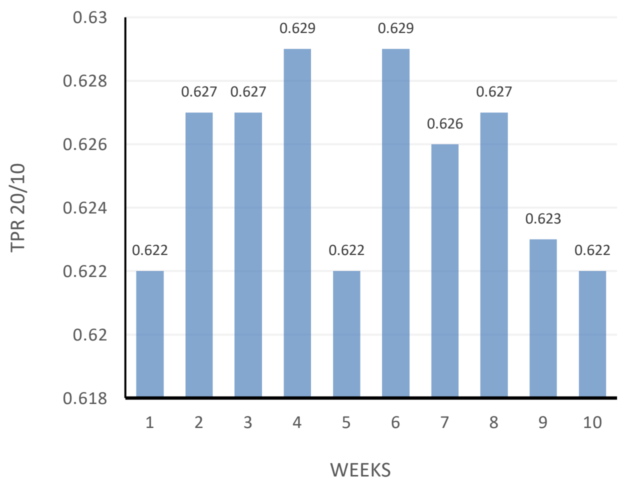

Figure 3. Graphical representative of TPR 20/10

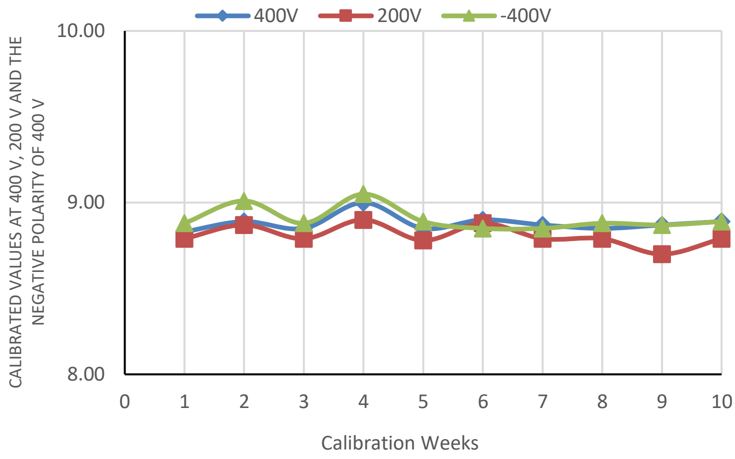

Figure 4. Calibration values over 10 weeks

Table 2. Absorbed dose rates within 10 weeks

WEEKS	Absorbed Dose Rate (Gy)	K_{TP}
1	0.990	1.010
2	1.090	1.010
3	1.000	1.010
4	1.000	1.000
5	0.980	1.000
6	0.990	1.000
7	0.990	1.000
8	0.990	1.000
9	0.980	0.990
10	0.980	0.990

K_{TP} = Pressure corrector factor

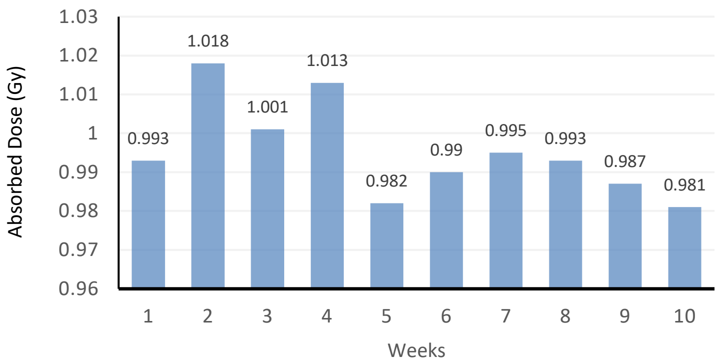

Figure 5. Graphical representative of absorbed dose

Discussion

The energy deposited per unit mass locally in an absorbing media by ionizing radiation is referred to as the absorbed dose. Absorbed dosage and kerma are identical for the energies commonly used in diagnostic X-ray techniques. Modern radiotherapy relies heavily on precise delivery of radiation dose to the intended target volume. The International Commission on Radiation Units and Measurements (ICRU) has advised that the overall accuracy in delivering the prescribed tumor dose should ideally be within ±5%. This recommendation is based on thorough analysis of dose response data and assessment of potential errors in clinical dose delivery. Achieving this level of accuracy is challenging due to various uncertainties inherent in dose delivery to patients.

Before being used clinically, the output of photon and electron beams from external beam radiotherapy machines must undergo calibration. This calibration of basic beam output is just one critical aspect within a broader chain of processes necessary for ensuring accurate dose delivery to the patient. These processes include measuring relative dose data, equipment commissioning and quality assurance, treatment planning, and precise patient positioning on the treatment machine.

To avoid errors and provide high confidence that patients will receive the same prescribed dose, each step in the integrated RT process requires quality control and quality assurance (QA) as has been demonstrated in Table 1 over 10 weeks. This work offers QA data for verifying dose variations in absorbed dose measurements using a water-equivalent material, which is crucial for ensuring high confidence that patients will receive the prescribed therapy accurately. Each step in the integrated radiotherapy process requires quality control and quality assurance. Recent advancements in RT, such as intensity-modulated and image-guided RT, have highlighted the necessity for a systematic RTQA program that strikes a balance between patient safety and quality and available resources.

As seen in Table 1, the following results shows Tissue Phantom Ratio (TPR) for 10 weeks. The fourth week recorded the highest value which of 8.50 and the lowest value was obtained in the first week, ninth week and the tenth week. The average value of 8.45 was obtained for TPR at 20 cm while 13.48 was obtained for TPR at 10cm. The highest deviation values of 1.13 % & 1.16 % were observed at weeks 4, 6 and 9 respectively while weeks 1, 5 and 10 observed zero percent deviation.

As seen in Figure 3, the recorded values of TPR 20/10 against the ten weeks of this study shows that week 4 and 6 have the highest of 0.629 while week1, 5 and 10 had the exact commissioned value of 0. 622. As shown in Table 1, the commissioned value of TPR at 20/10 is 0.62 and it compared well with the obtained value of this study (Table 1) at depth 20 cm, 10 cm.

Calibration values over 10 weeks

The calibrated values at 400 V, 200 V and the negative polarity of 400 V (Figure 4) revealed the highest value of 9.00 at 400 V of the fourth week, while the lowest value of 8.83 was obtained in the 1^{st} week. The highest value at 200 V was 8.900 (at week 4) while the lowest value of 8.700 was obtained at week 9. The highest value for the negative polarity of 400 V was 9.050 at week 4 and the lowest value of 8.85 was observed at the 6^{th} and 7^{th} weeks.

Absorbed dose rates within 10 weeks

As shown in Table 2, the temperature, pressure corrector factor (K_{TP}) oscillates around 1.0 except weeks 9 and 10 which recorded 0.99. The absorbed dose plotted against the weeks of study (Figure 5) showed that the second week had the highest on the graph at 1.09 and weeks 5, 9 and 10 had the lowest values of 0.98. The ionization chamber is the most practical and frequently used dosimeter for precise measurement of machine output in radiotherapy. It can function as either a relative or absolute dosimeter. Typically, its sensitive volume is filled with ambient air, and the measured quantities related to dose or dose rate are the ionization charge (Q) or ionization current (I), respectively, produced by radiation in the chamber's sensitive air mass (Mair). The charge (Q) and air mass (Mair) are related to the absorbed dose in air (Dair) (17).

The sensitive air volume or mass in an ionization chamber can be determined either by direct measurement, making the chamber an absolute dosimeter under specific conditions, or indirectly by calibrating the chamber's response in a known radiation field, thereby using it as a relative dosimeter, as done in this study.

The procedures for calibrating a clinical photon or electron beam are outlined in international or national radiation dosimetry protocols or codes of practice. The choice of which protocol to use is typically left to individual radiotherapy departments. Dosimetry protocols are generally issued by national or regional organizations, such as the American Association of Physicists in Medicine (AAPM) in North America (18).

The LINAC can be used for therapy (treatment) after successfully completing certain scientific methods known as pre-commissioning testing, as demonstrated in this study (Figure 4). Commissioning a LINAC for clinical use involves comprehensive measurements of dosimetric parameters needed to validate the Treatment Planning System (TPS) used to choose the optimal radiation modality and treatment technique for individual patients. Thus, it is crucial to have a minimum dataset, which includes percentage depth dose (PDD), profile, and output characterization for various field sizes (FSs) (19).

The data acquired during the initial commissioning of the LINAC serves as the standard reference for clinical purposes (Table 1). The scientific methods employed for commissioning modern Linear Accelerators are rigorous and time-intensive, requiring considerable dedication. This study also involves weekly measurements of the machine's output, comparing them to the parameters established during commissioning (Figures 4 & 5). These measurements serve as reference data for clinical use, ensuring that the parameters obtained experimentally remain consistent throughout normal operation of the LINAC system.

Finally, this study clarifies that the procedures described are not advocating for the use of plastic phantoms in clinical reference dosimetry; these procedures should follow the IAEA TRS-398 recommendations, which specify using liquid water. The study outlines conditions under which absorbed dose to water can be measured using solid phantoms combined with a methodology similar to IAEA TRS-398, corrected using an experimentally determined phantom dose conversion factor. By experimentally determining this conversion factor, the study accounts for potential variability in materials of the same type of plastic phantom. This allows for interpreting the results of solid phantom measurements in a physically meaningful way. Additionally, by comparing measured and calculated phantom conversion factors, the suitability of a given plastic for clinical reference dosimetry can be assessed.

The technology behind particle accelerators has been advancing for over a century, starting with the initial experiments at the Cavendish Laboratory in Cambridge. Over time, accelerators have found numerous applications beyond basic research, including medical and industrial uses. Today, more than 40,000 accelerators are in operation, ranging from the MeV to the TeV energy scale, from meters to kilometers in length, and from thousands to billions of Euros in cost. While new giant machines based on existing technology are being studied, various competing ideas for advanced accelerators are also being explored. It remains uncertain when and which of these new technologies will become available. However, any such technological breakthrough would likely feature radical innovation, often leading to widespread impact across different fields of application (20).

The growth of accelerators in science follows a pattern that is well represented by a linear function. In contrast, the growth dynamics of accelerators in industry and medicine are highly nonlinear. Additionally, we propose that the worldwide growth in the total number of accelerators follows an "S-shaped" time trend. This curve, with a long-standing tradition in statistics, is widely used in biology, demography, and economics. In innovation studies, S-shaped curves depict the adoption of new technology over time: diffusion rates initially increase rapidly and then decline, leading to a period of rapid diffusion (20). This model has been applied in recent studies evaluating the social benefits of accelerators in science and medicine, specifically the Large Hadron Collider (LHC) at CERN and the National Centre of Oncological Hadrontherapy (CNAO) in Pavia, Italy.

Conclusion

The variation in the absorbed dose using a water equivalent material have been verified and found to be consistent over several weeks. The results of the beam output for the teletherapy machine were satisfactory and accepted in comparison with the commissioned measurement of 0.62. The beam quality $TPR_{20,10}$ (Tissue phantom ratio) was reasonable with respect to the beam quality of the machine at a field size of 10 cm x 10 cm. The calibration performed using SAD type set-up at the depth of 5 cm was good as the process were repeated in ten consecutive weeks. The results of the beam quality and the absorbed dose rate showed a very good consistency over the period of ten weeks.

The socio-economic impacts of this study are: - short term goal achievements of this work is to check the output of the machine if is still maintain the output value as when it was been commissioned for use and to ensure the dose prescribe by the oncologist is the same as the dose delivered to the patients. The Long-term goal achievement of this study has been to reduce the machine down time thereby reducing the cancer burden in Nigeria.

References

1. Sung H, Ferlay J, Siegel RL, Laversanne M, Soerjomataram I, Jemal A, et al. Global cancer statistics 2020: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries. CA Cancer J Clin. 2021;71(3):209–49.
2. Sousa R V, Sousa R V. Dose Rate Influence on Deep Dose Deposition Using a 6 MV X-Ray Beam From a Linear Accelerator. 2009;292–6.
3. Pokhrel D, Webster A, Stephen J, St Clair W. SBRT treatment of abdominal and pelvic oligometastatic lymph nodes using ring-mounted Halcyon Linac. J Appl Clin Med Phys. 2021;22(6):162–71.
4. Sun T, Lin X, Zhang G, Qiu Q, Li C, Yin Y. Treatment planning comparison of volumetric modulated arc therapy with the trilogy and the Halcyon for bilateral breast cancer. Radiat Oncol. 2021;16(1):1–10.
5. Georg D, Knöös T, McClean B. Current status and future perspective of flattening filter free photon beams. Med Phys. 2011;38(3):1280–93.
6. Kim H, Huq MS, Lalonde R, Houser CJ, Beriwal S, Heron DE. Early clinical experience with Varian halcyon V2 linear accelerator: dual-isocenter IMRT planning and delivery with portal dosimetry for gynecological cancer treatments. J Appl Clin Med Phys. 2019;20(11):111–20.
7. Ardekani MA, Haghparast M, Nourollahi S, Refahi S. Design of a slab phantom for breast dosimetry applications. J Cancer Res Ther. 2018;14(5):1126–9.
8. Wickman G, Johansson B, Bahar-gogani J, Holmström T, Grindborg JE, Johansson B, et al. Liquid ionization chambers for absorbed dose measurements in water at low dose rates and intermediate photon energies Liquid ionization chambers for absorbed dose measurements in water at low dose rates and intermediate photon energies. 2013;900(1998).
9. Andreo P, Seuntjens JP, Podgorsak EB. Chapter 9 Calibration of Photon and Electron Beams. Radiation Oncology. 2006. 1–95 p.
10. Andreo P. Calibration of Photon and Electron Beams. Rev Radiat Oncol Phys a Handb Teach students. 2005;301–54.
11. Seuntjens J, Olivares M, Evans M, Podgorsak E. Absorbed dose to water reference dosimetry using solid phantoms in the context of absorbed-dose protocols. Med Phys. 2005;32(9):2945–53.
12. Andreo P, Huq MS, Westermark M, Song H, Tilikidis A, DeWerd L, et al. Protocols for the dosimetry of high-energy photon and electron beams: a comparison of the IAEA TRS-398 and previous international Codes of Practice. Phys Med Biol. 2002;47(17):3033.
13. Organization WH. Absorbed dose determination in external beam radiotherapy. An international code of practice for dosimetry based on standards of absorbed dose to water. 2004;
14. Huq MS, Andreo P, Song H. Comparison of the IAEA TRS-398 and AAPM TG-51 absorbed dose to water protocols in the dosimetry of high-energy photon and electron beams. Phys Med Biol. 2001;46(11):2985.
15. Slab Phantom. 2011;4182011.
16. Niamatullah SN. Predictors of Outcome and Survival In Prostate Cancer – Data From Tertiary

Care Urology Institute In Pakistan. Hematol Transfus Cell Ther. 2021;43.

17. Stancu E, Vancea C, Valenta J, Zeman J, Badita E, Scarisoreanu A. Absorbed dose to water measurements in high energy electron beams using different plane parallel chambers. Rom Reports Phys. 2015;67(3):1152–8.
18. Beir VII. Health risks from exposure to low levels of ionizing radiation. Natl Acad Rep Br. 2005;
19. Sruti RN, Islam MM, Rana MM, Bhuiyan MMH, Khan KA, Newaz MK, et al. Measurement of percentage depth dose of a linear accelerator for 6 MV and 10 MV photon energies. Nucl Sci Appl. 2015;24(1).
20. Florio M, Bastianin A, Castelnovo P. The socio-economic impact of a breakthrough in the particle accelerators′ technology: a research agenda. Nucl Instruments Methods Phys Res Sect A Accel Spectrometers, Detect Assoc Equip. 2018;909:21–6.