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Original Research

Comparative Study of Electron Beam Dosimetry Protocols: IAEA TRS-398 vs. AAPM TG-51

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Abstract

Purpose: *To compare electron beam output measurements under reference conditions using the IAEA TRS-398 and AAPM TG-51 dosimetry protocols, and to determine the most suitable protocol for absolute dose calibration in a country without a defined national standard.*

Materials and Methodology: *The study was conducted using a Varian 2300 CD linear accelerator with electron beam energies of 9 MeV and 15 MeV. Absolute dose measurements were performed under reference conditions (10×10 cm² field size, 100 cm SSD) using two ionization chambers: the PTW TM34045 Advanced Markus (plane-parallel) chamber for absolute dosimetry and the PTW TM31021 Semiflex 3D (cylindrical) chamber for depth dose distribution. A total of 200 monitor units (MU) were used for each measurement. Comparisons between the TRS-398 and TG-51 protocols were made by altering reference values of depth and field size.*

Results: *For 9 MeV, the measured absolute dose values were 1.0155 cGy/MU (TRS-398) and 0.993 cGy/MU (TG-51), showing a discrepancy of 1.6%. For 15 MeV, the values were 1.032 cGy/MU (TRS-398) and 1.003 cGy/MU (TG-51), resulting in a 0.67% discrepancy. These differences are within clinically acceptable limits.*

Discussion: *Both protocols provided consistent and reliable results for electron beam dosimetry under reference conditions. However, the IAEA TRS-398 protocol demonstrated greater ease of implementation and adaptability, particularly in contexts without established national dosimetry standards. Given its international recognition and practical advantages, the TRS-398 protocol is recommended for high-energy electron beam calibration in such settings.*

Keywords: *Electron Beam Dosimetry, IAEA TRS-398, AAPM TG-51, Absolute Dose Calibration, Linear Accelerator, Ionization Chamber, Reference Conditions*

Introduction

High-energy electrons have been used in radiation therapy since 1947, following the successful extraction of beams from betatrons, and became more widely adopted in the 1970s with the commercial availability of linear accelerators [11,12]. These megavoltage electron beams are particularly effective for treating superficial tumors (<5 cm deep). The ICRU (1984) report provided comprehensive guidance on electron-beam dosimetry, though it lacked clinical practicality. The AAPM TG-21 protocol (1983) improved dose calibration accuracy but involved complex calculations, increasing the potential for clinical errors. To address these issues, the AAPM TG-51 protocol was introduced, offering simplified implementation using absorbed dose to water calibration factors (ND,W) [5]. Similarly, the IAEA TRS-398 protocol provides a Code of Practice for reference dosimetry, covering electron energies from (~4 to 50 MeV), and is widely used internationally. When selecting a clinical dosimetry protocol, it's essential to ensure traceability to a standard dosimetry lab and practicality for routine clinical use [3,11]. Accurate dose delivery within ±5% uncertainty is critical for treatment success, especially with modern imaging guiding precise target delineation. Both TG-51 and TRS-398 are based on the absorbed dose to water standard, but differ in stopping power data, correction factors, and calibration procedures, potentially leading to variations in clinical dose measurements [16,19]. This study conducted a systematic comparison of TG-51 and TRS-398, measuring electron outputs under identical conditions, to evaluate differences in absorbed dose and beam quality, and to estimate the expected discrepancies when switching protocols [1,2,9].

Materials and Methodology

In this study, dosimetric measurements were carried out using an Advanced Markus electron ionization chamber (PTW TM34045, S/N 001978), which is a waterproof, plane-parallel chamber recommended by IAEA TRS-398 and AAPM TG-51 protocols for high-energy electron beam calibration [1,2]. It was calibrated in a Co-60 gamma unit with a calibration factor ND,W = 1.513 × 10^9 Gy/C. For percentage depth dose (PDD) measurements, a Semiflex 3D cylindrical ionization chamber (PTW TM31021, S/N 142147) was used [3,6]. A PTW UNIDOS electrometer (S/N 002171), calibrated with the chamber as a single unit, was used to record dosimetric data. Measurements were conducted in a motorized IBA water phantom system, utilizing distilled water as the medium, with all necessary components such as a controller unit, water reservoir, and lifting table. Environmental conditions were monitored using a thermometer and a high-precision GTD 1100 barometer (measuring range: 225.0–825.0 mmHg, resolution: 0.1 mmHg), while humidity was maintained between 20–80% using a dehumidifier, negating the need for humidity corrections. The chambers were precisely positioned using PTW 31013 and IBA CC13 holders, with high-quality cables and connectors ensuring reliable signal transmission [13]. Dosimetric calculations were performed following both IAEA TRS-398 and AAPM TG-51 protocols, with absorbed dose to water determined at the reference depth Zref. Both protocols incorporate correction factors for temperature, pressure, polarity effect, and ion recombination, all of which were carefully applied using standardized formulas. The polarity effect was evaluated by measuring ion chamber readings at ±300V for 9 MeV and 15 MeV beams, and the ion recombination correction was determined using the two-voltage method (300 V and 100 V) [1,2,5]. The beam quality was specified using R_{50}, the depth at which the absorbed dose falls to 50% of its maximum, with R_{50} calculated from percentage depth ionization (PDI) curves. For cylindrical chambers, gradient corrections were applied where necessary, and the reference depth was adjusted based on R_{50} values. All procedures adhered strictly to the guidelines established in the respective protocols to ensure accurate and standardized dosimetry [1,2,6].

Result and Discussions

The dosimetric measurements were performed with a source-to-surface distance (SSD) of 100 cm and a field size of 20 cm × 20 cm. A 10 cm × 10 cm electron applicator was used for beam collimation [1,2,12].The environmental conditions during the measurements included a temperature of 22°C and an atmospheric pressure of 100.1 kPa. A total of 200 monitor units (MU) were delivered for each irradiation setup, ensuring consistency across all dosimetric evaluations [11,18].

According to TRS-398: According to IAEA TRS-398, for the 9 MeV electron beam, the reference depth (Zref) was determined as 0.6 × R_{50} – 0.1 cm = 2 cm, with R_{50} = 3.5 cm. The applied correction factors were: pressure and temperature (kT,P = 1.019), polarity (K_{pol} = 1.006), ion recombination (K_s = 1.0018), and electrometer (Kelec = 1.00). The uncorrected meter readings were M_1 = 1.434 nC (+V) and M_2 = 1.428 nC at reduced voltage. The corrected meter reading (MQ) was calculated as 1.4726 nC. With a chamber calibration factor (ND,W) of 1.513 × 10^9 Gy/C and beam quality factor (kQ) = 0.912, the absorbed dose to water (DW,Q) was 2.031 Gy for 200 MU, corresponding to 1.0155 cGy/MU. The output at Zmax was calculated as 1.015 cGy/MU, assuming 100% PDD at Zref [1,5,9].

For the 15 MeV electron beam, Zref = 0.6 × R_{50} – 0.1 cm = 3.62 cm, with R_{50} = 6.2 cm. The correction factors were kT,P = 1.019, K_{pol} = 1.0135, K_s = 1.0016, and Kelec = 1.00. The uncorrected readings were M_1 = 1.414 nC (+V) and M_2 = 1.409 nC, giving a corrected meter reading (MQ) = 1.463 nC. Using ND,W = 1.513 × 10^9 Gy/C and kQ = 0.897, the absorbed dose to water (DW,Q) was 1.986 Gy for 200 MU, or 0.993 cGy/MU. The output at Zmax was 1.003 cGy/MU, assuming a 99% PDD at Zref.

According to AAPM TG-51: Under AAPM TG-51, for the 9 MeV beam, the reference depth (dref) was similarly determined as 0.6 × 3.5 – 0.1 = 2 cm. Correction factors applied were pressure and temperature (PT,P = 1.012), polarity (Ppol = 1.006), ion recombination (Pion = 1.002), electrometer (Pelec = 1.00), and photon-electron conversion (Kecal = 0.905). The electron quality conversion factor ($K'_{R_{50}}$) = 1.0343. The corrected chamber reading (M) was 1.459 nC, yielding an absorbed dose to water (Dw,Q) = 2.06 Gy for 200 MU, or 1.032 cGy/MU. The output at Zmax was 1.032 cGy/MU, consistent with 100% PDD at Zref.

For the 15 MeV beam, dref = 0.6 × 6.2 – 0.1 = 3.62 cm, with correction factors PT,P = 1.012, Ppol = 1.013, Pion = 1.002, Pelec = 1.00, and Kecal = 0.905. The electron quality conversion factor ($K'R_{50}$) = 1.009. The corrected chamber reading (M) = 1.452 nC gave an absorbed dose to water (Dw,Q) = 2.006 Gy for 200 MU, or 1.003 cGy/MU. The output at Zmax was 1.013 cGy/MU, assuming 99% PDD at Zref [2,9,17].

The close agreement between TRS-398 and TG-51 results—differing by less than 1.6% for 9 MeV and 0.67% for 15 MeV—demonstrates strong consistency and validates the reliability of both protocols in clinical electron beam dosimetry under reference conditions.

Table 1: Difference of absorbed dose to water for electron beam between under reference conditions.

9 MeV			**15 MeV**		
Absorbed dose to water at 2 cm			Absorbed dose to water at 3.62 cm		
TRS-398	TG-51	% Deviation	TRS-398	TG-51	% Deviation
1.0155	1.032	1.6%	0.993	1.003	0.67%

Measurement of Output Factors: Meter readings were recorded for different applicator sizes at energies of 9 MeV and 15 MeV, with a reference applicator (10×10) value for comparison. For the 6×6 applicator, the readings were consistent across both energies (1.433 or 1.434 nC). for 10×10 applicator, the meter reading 1.459 nC for 9 MeV and 1.466 nC for 15 MeV . For 15×15 applicator, the meter reading 1.446 nC for 9 MeV and 1.442 nC for 15 MeV. For the 20×20 applicator, the meter reading 1.428 nC for 9 MeV and 1.414 nC for 15 MeV. For 25×25 applicator, the meter reading 1.388 nC for 9 MeV and 1.368 nC for 15 MeV [9,17,18].

Table 2: Output factor.

Energy	**Applicator**				
	6X6	10X10	15X15	20X20	25X25
9 MeV	0.982	1	0.991	0.978	0.951
15 MeV	0.978	1	0.983	0.974	0.933

Table 3: Measurement of output at Zmax& Zref.

Energy	**TRS-398**		**TG-51**	
	Zmax (cm)	Zref (cm)	Zmax (cm)	Zref (cm)
9 MeV	1.015	2.00	1.032	2.00
15 MeV	1.003	3.62	1.013	3.62

Table 4: Output variation between two protocols for Zmax and Zref.

Energy		**Zmax (cm)**	**Difference**	**Zref (cm)**	**Difference**
9 MeV	TRS-398	1.015	-1.67%	2.00	00%
	TG-51	1.032		2.00	
15 MeV	TRS-398	1.003	-0.99%	3.62	00%
	TG-51	1.013		3.62	

Conclusion

In this experiment, the absorbed dose to water at reference depths (2 cm for 9 MeV and 3.62 cm for 15 MeV) was found to be nearly identical using both TRS-398 and TG-51 protocols. While both are similar for dosimetric measurements, slight differences in absolute dose arise due to varying parameter considerations. TRS-398 is recommended for high-energy electron beam calibration as it offers greater uniformity across all radiation beam types, provides comprehensive data for various ion chambers, and includes procedures better suited for clinical environments.

Authors Contributions

The main research title selection, research design, and writing were conducted by Sujan Mahamud and Umma Habiba Nasrin, while data collection and data analysis were carried out with the assistance of Abu Kausar and Nazrul Islam.

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Conflict of interest

The authors declare that they do not have any conflict of interest.

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