East Eur. J. Phys. **1**. 20-26 (2021)
DOI:10.26565/2312-4334-2021-1-03

PACS: 29.20.Ej; 87.50.sj; 87.55.Qr

STUDIES OF DOSIMETRY PROTOCOLS FOR ACCELERATED PHOTONS AND ELECTRONS DELIVERED FROM MEDICAL LINEAR ACCELERATOR

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Received October 22, 2020, accepted December 15, 2020

We focus on the comparative study of dosimetry protocols in radiotherapy for accelerated photon and electron delivered from medical linear accelerator (LINAC). In this study, a comparison between the protocols (TRS 398, DIN 6800-2 and TG 51) for both the electron and photon delivered from Clinac 2300CD and Clinac DHX 3186 were performed. We used photon beams with energies of 6 and 15 MV and electron beams of 4, 6, 9, 12, 15 and 18 MeV for both Medical Linac. In case of Clinac the maximum deviations for the relative dose at D_{max} for the photon beam (15 MV) among the protocols was observed to be 1.18% between TRS-398 and TG-51, 1.56% between TG-51 and DIN 6800-2; and 0.41% between TRS-398 and DIN 6800-2. Conversely, these deviations were 3.67% between TRS-398 and TG-51, 3.92% between TG-51 and DIN 6800-2 for 4 MeV and 0.95% between TRS-398 and DIN 6800-2 in the case of Clinac 2300 CD for the PTW Markus and Exradin A10. For the measurement of the maximum absorbed dose depth to water using three protocols, the maximum deviations were observed between TRS 398 and TG-51 as well as TG51 and DIN 6800-2.
KEYWORDS: TRS (Technical Report Series), TG (Task Group), DIN (Deutsches Institut für Normung).

Approximately 60% of cancer patients are referred for external beam radiotherapy, for which the most commonly used equipment is a medical LINAC that produces an electron beam and photon beam [1]. The precise planning of the treatment depends on the tumor type, size, position, stage, and health condition of patients [1, 2]. By considering various uncertainty components associated with beam calibration factors, a study of the uncertainty in determining of the absorbed dose to water had been carried out by C. Pablo *et.al.* [3] Their results showed a typical uncertainty in the determination of absorbed dose to water during beam calibration approximately 1.3% for photon beams and 1.5% for electron beams ($k = 1$ in both cases). M. S. Huq *et. al.* [4] performed a study by comparing International Atomic Energy Agency Technical Report Series No. 398 (IAEA TRS-398) and AAPM TG-51 absorbed dose to water protocols in the dosimetry of high-energy photon and electron beams. They compared the two protocols in two ways: (i) by analyzing the differences of the basic data included in the two protocols for photon and electron beam dosimetry in detail and (ii) by performing experiments in clinically accelerated photon and electron beams and determining the absorbed dose to water following the recommendations of the two protocols [4]. For electron beams, the ratios TG-51/TRS-398, of the absorbed dose to water D_w were observed to be lie between 0.994 and 1.018 depending upon the chamber and electron beam energy used, with mean values of 0.996, 1.006, and 1.017 respectively, for the cylindrical, well-guarded and not well-guarded plane-parallel chambers [4]. A dosimetric study comparing NCS report-5, IAEA TRS-381, AAPM TG-51 and IAEA TRS-398 in three clinical electron beam energies was carried out by H. Palmans *et. al.* [5]. In their work, they compared dosimetry for three clinical electron beam energies using two NE2571-type cylindrical chambers, two Markus-type plane-parallel chambers and two NACP-02-type plane-parallel chambers [5]. Another comparison of high-energy photon and electron dosimetry for various dosimetry protocols was performed by F. Araki *et. al.* [6] They calculated the absorbed dose to water calculated according to the Japanese Association of Radiological Physics, IAEA TRS-277 and IAEA TRS-398 protocols, and compared it to that calculated using the TG-51 protocol. A comparison of protocols for external beam radiotherapy beam calibrations was carried out by S S Al-Ahababi *et. al.* [7] where they used the IAEA TRS-398, AAPM TG-51 and IPEM 2003 protocols. The comparisons were carried out by delivering electron beams of nominal energies of 6, 9, 12, 16 and 20 MeV using Physikalisch-Techische Bundesanstalt (PTW) Markus and NACP-02 plane-parallel chambers.

Different group of dosimetrists did experiments several times to ensure lower uncertainty, best suited protocols and improvement of protocols for the commissioning of medical Linac and more precisely healthcare purposes. The aims of our work is to analyze the dosimetry applying three different most preferable protocols maintaining the QA parameters for high energy photon and electron beams delivered from the medical linear accelerator (Clinac). Different ionization chambers were used to calculate the absorbed dose to water and a comparison among chambers was investigated. For each chamber the absorbed dose to water was calculated using three different protocols. Sometimes in same reference conditions absorbed dose differs from Clinac to Clinac because of wall material of jaws. To confirm that dose variations we use two different medical LINAC and same chamber response with LINAC in this research work. This study will be helpful for defining more accurate dosimetry and developing more general protocol for ensuring patient safety during treatment planning.

METHODS AND MATERIALS

Absorbed dose to water calibration in ^{60}Co

The calibrations in terms of absorbed dose to water are available only for ^{60}Co gamma radiation [8]. The reference point of the chamber was at 5g/cm² water depth. The size of the radiation field (50% isodose level) at the reference plane was 10 cm×10 cm [9 – 12]. The PTW Markus chamber was set up for determining the calibration factor in a water phantom, and then the Physikalisch-Techische Bundesanstalt (PTW) UNIDOSE electrometer was used to obtain the dose rate. From these dose rates the calibration factor was measured using the IAEA TRS-398 protocol. The same procedure was used to calibrate the Exradin A10 and IBA FC65-G (2009) chambers. The descriptions of different protocols are presented in Table 1.

Table 1. Description of different protocols [**10, 13, 14**]

Criteria	**Chamber Type**	**TRS 398**		**AAPM TG-51**		**DIN 6800-2**	
		Electron	Photon	Electron	Photon	Electron	Photon
Chamber position	Cylindrical	At $Z_{ref} + r/2$	At Z_{ref}	At Z_{ref}	At Z_{ref}	At $Z_{ref} + r/2$	At $Z_{ref} + r/2$
	Plane parallel	At Z_{ref}		At Z_{ref}		At Z_{ref}	
Beam quality	Cylindrical / Plane parallel	specified by the half-value of the depth dose in water R_{50}	specified by the tissue phantom ratio $TPR_{20,10}$	specified by the half-value of the depth dose in water R_{50}	specified by $\%dd(10)_X$	specified by the half-value of the depth dose in water R_{50}	specified by $Q = 1.2661\frac{M_{20}}{M_{10}} - 0.0595$
Value of T_o	Cylindrical / Plane parallel	20 °C		22 °C		20 °C	
Ion recombination correction factor	Cylindrical / Plane parallel	$K_s = a_0 + a_1\left(\frac{M_1}{M_2}\right) + a_2\left(\frac{M_1}{M_2}\right)^2$		$P_{ion} = \frac{1 - \frac{V_H}{V_L}}{\frac{M^H_{raw}}{M^L_{raw}} - \frac{V_H}{V_L}}$		$K_s = \frac{\frac{U_1}{U_2} - 1}{\frac{U_1}{U_2} - \frac{Mu_1}{Mu_2}}$	
Chamber positioning correction	Cylindrical	none		none		$K_r = 1 + \lvert\delta\rvert .\ r/2$	

RESULTS

Calibration of Ionization Chambers

The calibration factors of Markus, A10 and FC65-G are listed in Table 2.

Table 2. Calibration factors of Markus, A10 and FC65-G

Chamber Model	**Chamber Serial No.**	**Calibration factor in Gy/nc**		**Variation (%)**
		Certified by (Physikalisch-Techische Bundesanstalt) PTB	**Experimentally found**	
PTW23343 Markus	3941	0.5448	0.5349	1.8200
Exradin A10	XC110304	0.6087	0.6047	0.6600
IBA FC65-G	2009	0.0476	0.0477	0.1900

Absorbed dose to water for Photon beam
Absorbed dose to water according to different protocols

TRS 398	$M_Q = M_{raw} \times K_{TP} \times K_{elec} \times K_{pol} \times K_s$ $D_{w,Q} = M_Q \times N_{D,w,Q_0} \times K_Q$
TG 51	$M = M_{raw} \times P_{TP} \times P_{elec} \times P_{pol} \times P_{ion}$ $K_Q = P_{gr}^Q \times K_{R_{50}}$ $K_{R_{50}} = K'_{R_{50}} \times K_{ecal}$ $D_{w,Q} = M \times N_{D,w,Q_0} \times K_Q$
DIN 6800-2	$M_Q = M \times K_\rho \times K_p \times K_r \times K_s$ $k_E = k'_E \times k''_E$ $k'_E = 1.106 - 0.1312\,(R_{50})^{0.214}$ $k''_E = 0.982\,(P_{cav})_{R_{50}}$ $(P_{cav})_{R_{50}} = 1 - 0.037e^{-0.27R_{50}}$ $D_{w,Q} = M_Q \times N_{D,w,Q_0} \times K_Q$

a. Beam quality.

The measurement of K_Q using three different protocols are presented in Table 3.

Table 3. Measurement of K_Q

Energy (MV)	K_Q		
	IAEA TRS-398	**AAPM TG-51**	**DIN 6800-2**
6	0.996	0.992	0.993
15	0.981	0.976	0.977

b. Comparison among protocols.

To make a comparison among protocols, we considered three main correction factors: pressure temperature correction, ion recombination correction and polarity correction factors. The values of these parameters are listed in Table 4.

Table 4. Values of pressure temperature, ion recombination and polarity correction factor

K_{tp}			
Chamber	**IAEA TRS 398**	**AAPM TG 51**	**DIN6800-2**
FC65-G (2005)*	1.0078	1.0013	1.0081
FC65-G (2009)*	1.0080	1.0015	1.0082

k_s				
Chamber	**Energy (MV)**	**IAEA TRS 398**	**AAPM TG-51**	**DIN 6800-2**
FC65-G (2005)*	6	1.0048	1.0050	1.0054
	15	1.0063	1.0065	1.0078
FC65-G (2009)*	6	1.0027	1.0028	1.0027
	15	1.0061	1.0064	1.0065

k_{pol}				
Chamber	**Energy (MV)**	**IAEA TRS-398**	**AAPM TG-51**	**DIN 6800-2**
FC65-G (2005)*	6	1.0018	1.0018	1.0011
	15	1.0009	1.0009	0.9993
FC65-G (2009)*	6	1.0017	1.0017	1.0011
	15	1.0009	1.0009	1.0006

*Here FC65-G (2005) and (2009) represents serial number.

A comparison of the maximum dose depths (D_{max}) measured with three different protocols is presented in Table 5.

Table 5. Comparison of maximum dose depth (D_{max}) measured with three different protocols

Chamber	Energy (MV)	D_{max}			Deviation (%) in between		
		IAEA TRS-398	AAPM TG51	DIN 6800-2	TRS-398 & AAPM TG51	AAPM TG51 & DIN6800-2	DIN 6800-2 & TRS-398
FC65-G (2005)	6	9.962×10^{-03}	9.859×10^{-03}	9.940×10^{-03}	1.03	0.82	0.22
	15	9.882×10^{-03}	9.765×10^{-03}	9.917×10^{-03}	1.18	1.56	0.36
FC65-G (2009)	6	9.847×10^{-03}	9.745×10^{-03}	9.872×10^{-03}	1.03	1.29	0.26
	15	9.816×10^{-03}	9.700×10^{-03}	9.856×10^{-03}	1.18	1.56	0.41

We found that the percentage of the depth dose increases with increasing of energy, and the maximum dose D_{max} decreases. This is because the main influencing correction factor K_Q decreases with increasing energy. The variation of the maximum dose depth at D_{max} for FC65G (2005) and FC65G (2009) according to IAEA TRS 398 and AAPM TG 51 was found to be 1.18% and 1.03% in 15 and 6 MV photon energies respectively. However, in DIN 6800-2 the variation of dose at D_{max} for FC65G (2005) and FC65G (2009) was found to be less than 0.5% in both 6 and 15 MV photon energies.

Absorbed dose to water for Electron beam

a. PDD Curves.

The PDD curves were observed at energies of 4, 6, 9, 12 and 15 MeV for Clinac 2300CD, and at energies of 6, 9, 12 and 15 MeV for DHX-3186. All comparative curves for limited length are shown in Figures 1 and 2. Since the electron beam has significantly low penetration power the reference depth for an electron is close to the phantom water surface.

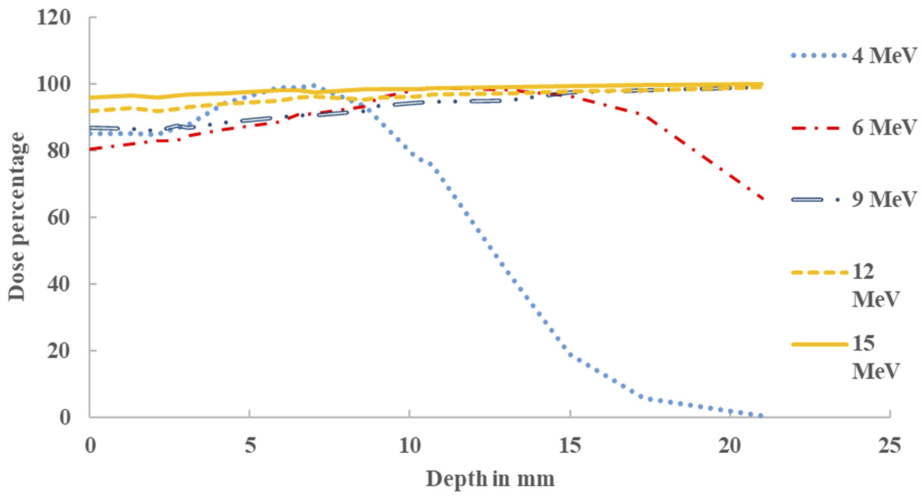

Figure 1. PDD curves for 4, 6, 9, 12 and 15 MeV electron beams delivered from 2300CD Clinac

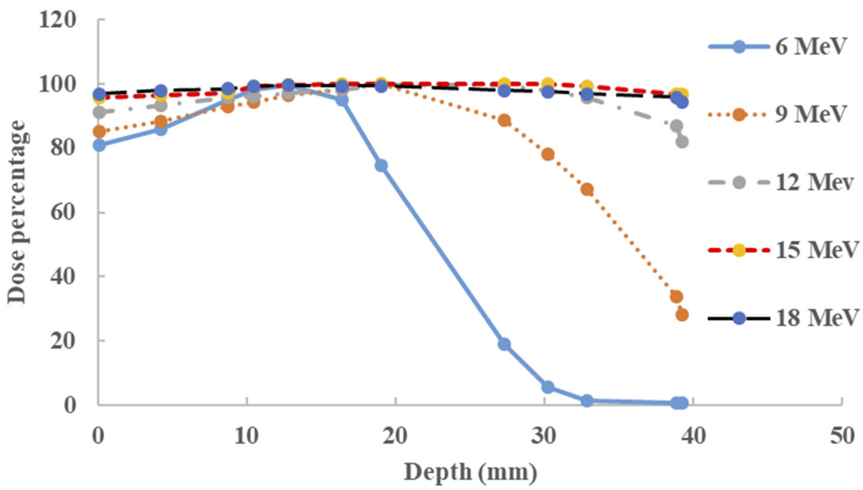

Figure 2. PDD curves for 6, 9, 12, 15 and 18 MeV electron beams delivered from DHX-3186 Clinac

The dose percentage with respect to the energy and depth is presented in Table 6.

Table 6. Dose percentage with respect to energy and depth

Clinac	Energy (MV)	Z_{ref} (cm)	Dose (%)
2300CD	4	0.64	99.60
	6	1.29	99.70
	9	2.02	100.00
	12	2.89	99.30
	15	3.69	97.80
DHX-3186	6	1.29	99.80
	9	2.02	100.00
	12	2.89	99.50
	15	3.69	98.70

Comparison among protocols

The PTW TM23343 Markus chamber was used to compare three protocols IAEA TRS 398, AAPM TG51 and DIN 6800-2. The correction factors for the electron beam are listed in table 7.

Table 7. Measurement of the correction factors for the electron beam

k_s			
Clinac	**Energy (MV)**	**IAEA TRS 398**	**AAPM TG-51**
2300CD	4	1.0088	1.0084
	6	1.0086	1.0089
	9	1.0089	1.0092
	12	1.0081	1.0083
	15	1.0078	1.0080
DHX-3186	6	1.0099	1.0102
	9	1.0110	1.0113
	12	1.0082	1.0086
	15	1.0123	1.0126
	18	1.0073	1.0075

K_Q				
Clinac	**Energy (MeV)**	***K_Q***		
		IAEA TRS-398	**AAPM TG-51**	**DIN 6800-2**
2300CD	4	0.930	0.9705	0.9262
	6	0.922	0.9507	0.9135
	9	0.913	0.9356	0.9042
	12	0.904	0.9226	0.8957
	15	0.897	0.9129	0.8889
DHX-3186	6	0.922	0.9507	0.9135
	9	0.913	0.9356	0.9042
	12	0.904	0.9226	0.8957
	15	0.897	0.9129	0.8889
	18	0.892	0.9061	0.8838

Uncertainty in Dose Measurement

For the photon beam the total uncertainty in the measurement of absorbed dose to water was approximately similar for FC65-G (2005) and (2009) which was ± 0.57% (k = 1) for both 6 and 15 MV. Our work provides better result than that of Castro P *et al* [3]. For electron beam using the PTW TM23343 chamber, the total uncertainty in the absorbed dose to water in Clinac 2300CD were ± 1.74%, ± 1.09%, ± 0.92%, ± 0.85% and ± 0.82% for 4, 6, 9, 12 and 15 MeV respectively and that in Clinac DHX-3186 were ± 1.09%, ± 0.94%, ± 0.86%, ± 0.84% and ± 0.80% for 6, 9, 12, 15 and 18 MeV respectively (k = 1). In contrast using the Exradin A10 chamber for electron dosimetry, the total uncertainty in the absorbed dose to water in Clinac 2300CD were ± 1.67%, ± 0.97%, ± 0.78%, ± 0.69% and ± 0.65% for 4, 6, 9, 12 and 15 MeV respectively and that in Clinac DHX-3186 were ± 0.96%, ± 0.78%, ± 0.76%, ± 0.68% and ± 0.69% for 6, 9, 12, 15 and 18 MeV respectively (k = 1).

DISCUSSIONS

In general, the discrepancies in the values of beam quality, K_Q and D_{max} for various protocols exhibited in a deceasing trend for the electron beam with the increase of energy. In contrast, for the comparative study with various chambers, the variation in D_{max} also exhibited in a decreasing trend with energy for both the accelerated photon and electron. The vital influencing factor for deviations among the protocols as well as between the chambers was the beam quality conversion factor K_Q. The deviation can be resolved if the chambers can be calibrated at their respective electron or photon beam quality rather than at ^{60}Co. Our measured correction factors, according to the TG-51, TRS-398 and DIN 6800-2 protocols were in good agreement with previous published works [4, 6, 14, 15, 16].

CONCLUSIONS

In this study, it was experimentally observed that the TRS 398 protocol is in good agreement with DIN 6800-2 rather than TG51 because of the measurement technique and correction factors included with the protocol. The experimental uncertainty (Type A and B) included in the measurement is below that of the previously published and recommended works [6, 17]. In this work we found that, some uncertainties would be minimized if the chambers calibrated with the photon beam delivered from the medical LINAC rather than the ^{60}Co beam.

Compliance with Ethical Standards: This article does not contain any studies with human participants performed by any of the authors.

Funding: None

Conflict of Interest: All authors declare that they have no conflict of interest

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ДОСЛІДЖЕННЯ ПРОТОКОЛІВ ДОЗИМЕТРІЇ ДЛЯ ПРИСКОРЕНИХ ФОТОНІВ І ЕЛЕКТРОНІВ ВІД МЕДИЧНОГО ЛІНІЙНОГО ПРИСКОРЮВАЧА

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Особливу увагу в цій статті зосереджено на порівняльному дослідженні дозиметричних протоколів променевої терапії для прискорених фотонів та електронів, що надходять з лінійного медичного прискорювача (LINAC). У цьому дослідженні було проведено порівняння між протоколами (TRS 398, DIN 6800-2 і TG 51) як для електрона, так і для фотона, що надійшли з Clinac 2300CD і Clinac DHX 3186. Ми використовували пучки фотонів з енергіями 6 та 15 МВ та електронні пучки з енергіями 4, 6, 9, 12, 15 та 18 МеВ для обох медичних лінійних прискорювачів. У випадку з Clinac максимальні відхилення відносної дози при D_{max} для пучка фотонів (15 МВ) серед протоколів становило 1,18% між TRS-398 і TG-51, 1,56% між TG-51 і DIN 6800-2, та 0,41% між TRS-398 та DIN 6800-2. І навпаки, ці відхилення становили 3,67% між TRS-398 і TG-51, 3,92% між TG-51 і DIN 6800-2 для 4 МеВ, і 0,95% між TRS-398 і DIN 6800-2 у випадку Clinac 2300 CD для PTW Markus та Exradin A10. При вимірюванні максимальної глибини поглинутої дози у воді за допомогою трьох протоколів спостерігались максимальні відхилення між TRS 398 та TG-51, а також TG51 та DIN 6800-2.
КЛЮЧОВІ СЛОВА: TRS (Серія технічних звітів), TG (Цільова група), DIN (Німецький інститут стандартизації).