TG-51 versus TG-21: A Comparison for Clinical Reference Dosimetry of High-Energy Photon and Electron Beams

Jao-Perng Lin[1, 2], Kuei-Hua Lin[1], Mu-Tai Liu[2], Tieh-Chi Chu[1]
[1]Department of Nuclear Science, National Tsing Hua University
[2]Department of Radiation Oncology, Changhua Christian Hospital

INTRODUCTION

In applications of ionizing radiation to problems related to medicine, it is important to measure the amount of radiation delivered. The need for accurate dosimetry is greatest in radiation therapy for cancer. In radiotherapy, a large dose of radiation is delivered to a tumor and the effectiveness of the treatment depends on delivering the dose with an accuracy of 5% or better in some situations. Practical clinical dosimetry today is based on the quantity absorbed dose, and accurate measurement of absorbed dose represents one of the major responsibilities of clinical medical physicist. It is also for radiation protection purposes. In general, such measurements have been based on the use of ion chambers calibrated in terms of exposure or air kerma and the application of a dosimetry protocol such as the AAPM's TG-21 protocol. The AAPM's TG-21 protocol published in 1983, there have been a large number of improvements in the understanding of radiation dosimetry in the 17 years since TG-21 was developed.

Much of the complexity of the TG-21 and similar protocols comes from the fact that they start from an ion chamber calibrated free-in-air for air kerma, and must transfer this information to obtain absorbed dose to water, based on a measurement in a phantom. These complexities themselves meant an increases potential for errors in the clinic. To overcome these complexities, primary standards have been developing standards for absorbed dose to water in photon beams from ^{60}Co and accelerator beams. The AAPM's TG-51 is a new protocol on calibrating ion chambers in terms of absorbed dose to water in a ^{60}Co beam.

The purpose of this paper is two-fold: (1) to indicate specific differences in the data and techniques between AAPM's TG-51 and TG-21 protocol; and (2) to show the magnitude of the discrepancies in results when following the TG-51 and TG-21 protocol strictly.

MATERIAL AND METHOD

The following equation was used to calculate absorbed dose in TG-21 protocol:

$$D_{water} / MU = MN_{gas} (L/\rho)_{air}^{med} P_{ion} P_{repl} P_{wall} \quad (1)$$

where D_{water} / MU is absorbed dose to water per monitor unit at reference depth; M is the temperature and pressure corrected electrometer reading in coulombs (C); N_{gas} is the cavity-gas calibration factor obtained from the National Calibration Laboratory; $(L/\rho)_{air}^{med}$ is the mean restricted collision stopping power ratio; P_{ion} accounts for ion chamber collection efficiency not be 100%; P_{repl} is the chamber replacement factor and P_{wall} is wall correction factor.

The fundamental equations of the TG-51 protocol are

$$D_W^Q = MN_{D,W}^Q$$

(2) where D_W^Q is the absorbed dose to water (in Gy) at the point of measurement of the ion chamber when it is absent, M is the fully corrected electrometer reading in coulombs which has been corrected for ion recombination, polarity and electrometer calibration effects and corrected to standard environmental conditions of temperature and pressure, and $N_{D,W}^Q$ is the absorbed-dose to water calibration factor (in Gy/C) for ion chamber when placed under reference conditions in a beam of quality Q. it is easier to start from an absorbed-dose calibration factor for a ^{60}Co beam, viz. $N_{D,W}^{^{60}Co}$, than to get an ion chamber calibration for each beam quality Q needed for a clinic and the apply eq.(2). In this case, define a quality conversion factor, k_Q, converting the absorbed-dose calibration factor for a ^{60}Co beam into a calibration factor for an arbitrary beam quality Q.

$$N_{D,W}^Q = k_Q N_{D,W}^{^{60}Co} \quad (3)$$

Using k_Q, gives

$$D_W^Q = Mk_Q N_{D,W}^{^{60}Co} \quad (4)$$

In an ideal world, values of k_Q measured using primary standards for absorbed dose would be available for all the ion chambers used for reference dosimetry. The k_Q for electron beams has two components: one, k_{R50}, which depends on the chamber but is a function of the beam quality specifier, R_{50}; and the second, P_{gr}^Q,

which extracts the gradient corrections and which, for a cylindrical chamber, depends on the shape of the particular depth-dose curve being measured, i.e.:

$$k_Q = P_{gy}^Q k_{R50} \quad (5)$$

In the above approach the final dose equation at d_{ref} is:

$$D_{D,W}^Q = MP_{gr}^Q k_{R50} N_{D,W}^{60Co} \quad (6)$$

Photon Beams (TG-51):

$$D_W^Q = Mk_Q N_{D,W}^{60Co}$$

- Ideally, measure k_Q using primary standards
- TG51 contains k_Q values for all known reference level ion chambers
- k_Q only varies by 5%

Electron Beams (TG-51):

$$D_{D,W}^Q = MP_{gr}^Q k_{R50} N_{D,W}^{60Co}$$

- k_Q has 2 components
- P_{gr}^Q measured in clinic
- k_{R50} presented in protocol vs R_{50}

The measurements and calculations in this study were based on an NE 2581 farmer-type cylindrical ion chamber with Shonka A-150 wall material with an inner diameter of 0.63 cm or a Wellhöfer IC 15 cylindrical ion chamber (with C552 wall material and an inner diameter of 0.6 cm). Clinical reference dosimetry is performed in Wellhöfer water phantom (blue phantom 48×48×40 cm^3) with WP700 software. Measurements were made for 6, 15 MV photon beams and 6, 9, 12, 15, 18, 21 MeV electron beams on a Siemens PRIMUS3008 linear accelerator. The AAPM's TG-21 protocol assigns an absorbed dose to water starting with an air-kerma calibration of an ion chamber. The TG-51 protocol uses ion chamber with absorbed-dose-to-water calibration factors. The discrepancies between TG-51 and TG-21 protocols for clinical reference dosimetry of high-energy photon and electron beams are compared for various beam energies and ion chambers.

RESULTS

The implementation of TG-51 protocol doesn't change the results of clinical reference dosimetry in photon beams by more than roughly 1% compared to those assigned following TG-21 for measure in water. Slightly larger change can be found at d_{max} in electron beam. Comparison shows discrepancies somewhat larger than expected, 1% or more difference for all beams for some chambers. The results are consistent with the current understanding on the discrepancies of water-to-air stopping power ratios between values calculated by using monoenergetic and realistic electron incident beams at d_{max}.

Table I. Dose TG-51/Dose TG-21 at d_{max} (photon)

Photon beam energy	TG51/TG21	
	NE 2581	IC 15
6 MeV	0.996	0.997
15 MeV	1.009	1.011

Table II. Dose TG-51/Dose TG-21 at d_{max} (electron)

Electron beam energy	TG51/TG21	
	NE 2581	IC 15
6 MeV	0.9704	0.9604
9 MeV	0.9977	1.0088
12 MeV	1.0030	1.0237
15 MeV	1.0117	1.0416
18 MeV	1.0251	1.0507
21 MeV	1.0175	1.0475

CONCLUSIONS

The major advantage of using Eq. (4) as the basis of a dosimetry protocol is the simplicity of using it. Furthermore, the concept of k_Q is very straightforward which should make it much easier to teach and to learn. At the same time, this approach should reduce the uncertainties in dosimetry protocols for photon beams. This fact alone should reduce the number of errors involved in clinical dosimetry. For both electron and photon beams, the use of absorbed-dose calibration factors as the starting point in the dosimetry chain means that there is no

need to determine N_{gas} from an exposure or air-kerma calibration factor and hence there is no need to know the many factors required to determine it.

One practical but real problem in applying dosimetry protocol is the need to use waterproofing sleeves which can have a non-negligible effect on the chamber response. It is need to use a waterproofing sleeve which minimizes air gaps near the chamber wall (≦0.2 mm) and it should be made of polymethylmethacrylate (PMMA) ≦1 mm thick.

REFERENCES

1. AAPM TG-21, *A protocol for the determination of absorbed dose from high-energy photon and electron beams.* Med. Phys. 10, 741-771 (1983).
2. D.T. Burns, G.X. Ding, D.W.O. Rogers, *R_{50} as a beam quality specifier for selecting stoppimg-power ratios and reference depths for electron dosimetry*. Med. Phys. 23, 383-388 (1996).
3. G.X Ding, D.W.O. Rogers, T.R. Mackie, *Calculation of stopping-power ratios using realistic clinical electron beams*. Med. Phys. 22, 485-501 (1995).
4. G.H. Fletcher, Textbook of radiotherapy. 3rd ed. Lea and Febiger, Philadelphia(1981).
5. T.G. Michael, W.K. Robert, N.R. Azam et al., *The effect of thickness of the waterproofing sheath on the calibration of photon and electron beams*. Med. Phys. 12 (2), 234-236 (1985).
6. R.A. Peter, J.B. Peter, B.M. Coursey et al., *AAPM's TG-51 protocol for clinical reference dosimetry of high-energy beams*. Med. Phys. 26 (9), 1847-1870 (1999).
7. D.W.O. Rogers, A.F. Bielajew, *Differences in electron depth dose curves calculated with EGS and ETRAN and improved energy range relationships*. Med. Phys. 13, 687-694 (1986).
8. F.H. William, *Effects of plastic protective caps on the calibration of therapy beams in water*. Med. Phys. 12 (2), 243-248 (1985).