Proton beam dosimetry intercomparison with new Japanese protocol

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Abstract

A new protocol for dosimetry in external beam radiotherapy was published by the Japan Society of Medical Physics (JSMP) in 2002. The protocol deals with proton and heavy ion beams as well as electron and photon beams, using the absorbed-dose-to-water formalism with calculated $N_{D,w}$ factors. To establish inter-institutional uniformity in proton beam dosimetry, an intercomparison program was carried out with the new protocol. The absorbed doses were measured with different cylindrical ionization chambers in a water phantom at a position of 30-mm residual range for a proton beam, that had range of 155 mm and a spread out Bragg peak (SOBP) of 60-mm width. As a result, the intercomparison showed that the use of the new protocol would improve the ±1.0 % (one standard deviation) and 2.7 % (maximum discrepancy) differences in absorbed doses stated by the participating institutions to ±0.3% and 0.9 %, respectively. The new protocol will be adopted by all of the participants.

1. Introduction

Japan Society of Medical Physics (JSMP) has published a new code of practice for dosimetry, titled "Standard Dosimetry of Absorbed Dose in External Beam Radiotherapy" [1]. The principal purposes for the revision are to adopt the absorbed-dose-to-water based formalism, to update physical data, to harmonize with international protocols, to note narrow beam dosimetry and to deal with proton and carbon beams.

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Recently, the number of proton and carbon beam therapy facilities has increased in Japan [2]. The consistency in absorbed dose is essential to compare clinical results between the facilities. International organizations, such as ICRU, recommend periodic dosimetry intercomparison to verify inter-institutional uniformity of proton beam dosimetry [3-4]. Although the NIRS group had attended international dosimetry intercomparisons for proton and carbon beams [5-6], the domestic intercomparison involving new facilities had not been carried out in Japan. Then, using the new dosimetry protocol, the first nationwide proton dosimetry intercomparison was held at PMRC of University of Tsukuba, with the participation of NIRS, PMRC, NCC, HIBMC and WERC personnel. The aims of the intercomparison were to evaluate the differences in absorbed dose determined at different proton therapy facilities in Japan and to establish consistency in absorbed dose to water for proton beams with the new protocol.

2. Materials and Methods

2.1 . The new Japanese dosimetry protocol

The new Japanese dosimetry protocol mostly follows IAEA Technical reports series No. 398 [7], which is based on N_{D,w,Q_0}, i.e., the calibration factor in terms of absorbed dose to water for a dosimeter at a reference beam quality Q_0. According to the protocols, absorbed dose is given by

$$D_{w,Q} = M_Q N_{D,w,Q_0} k_{Q,Q_0} \qquad (1)$$

where

$D_{w,Q}$ is the absorbed dose to water at the reference depth in a water phantom irradiated by a beam of quality Q

M_Q is the reading of a dosimeter at quality Q, corrected for influence quantities other than beam quality,

and k_{Q,Q_0} is the factor to correct for the difference between the response of an ionization chamber in the reference beam quality Q_0 used for calibrating the chamber and in the actual user beam quality Q.

However, N_{D,w,Q_0} has not been supplied by the Japanese primary standard dosimetry laboratory. The new Japanese protocol alternatively gives the calculated values of $N_{D,w,Q_0}/N_{X,Q_0}$, which depend upon ionization chambers. The value of N_{X,Q_0} is the calibration factor in terms of exposure for a dosimeter at a reference beam quality Q_0, which is supplied by the Japanese standard dosimetry laboratories.

To calculate k_{QQ_0} for proton beam, the new Japanese protocol recommends to use the values of W_{air}, the mean energy expended in air per ion pair formed by proton beam, and $s_{w,air}$, the proton mass stopping power ratio of water to air, which are given in IAEA Technical reports series No. 398 [7], respectively.

2.2 Proton beam dosimetry

The proton beam used for the intercomparison had range of 155 mm and spread out Bragg peak (SOBP) of 60-mm width in water. The field size of the proton beam was 15 cm×15 cm. Each cylindrical ionization chamber was inserted in a water phantom with a 1-mm thick PMMA sleeve for waterproof. The center of the chamber was set at the middle of the SOBP and the field. Each chamber was irradiated with preset proton beam for which a given signal was recorded by the upstream beam monitor. Participants separately determined the absorbed dose to water per monitor unit (Gy/MU) from the ionization chamber measurements, using the new protocol and their respective dosimetry procedures.

Table I compares the dosimetry procedures which had been used for proton beam by each institute. NIRS had used the dosimetry procedure which was based on "Code of Practice for clinical proton dosimetry" [3]. On the other hand, other recent institutions had followed ICRU Report 59 [4]. The model protocols were independently modified for their respective dosimetry procedures with various correction factors, since the dosimetric data dependent upon ionization chambers were significantly limited in the protocols. So it should be noticed that non-uniformity in proton dosimetry procedure had existed between the participants until the intercomparison.

In addition to the proton beam dosimetry, exposure measurements in a ^{60}Co γ-ray field with all ionization chambers were also carried out at Tsukuba University Hospital for comparison.

Table I. The comparison of dosimetry procedures between the participants

Institution	Model Protocol	W_{air} (eV)	$s_{w,air}$
NIRS	Code of Practice	35.2	1.123
PMRC	ICRU59	34.8	1.132
NCC	ICRU59	35.18	1.133
HIBMC	ICRU59	34.8	1.133
WERC	ICRU59	34.8	1.134

3. Results and Discussions

Table II summarizes the results of the intercomparison. The "Old" column shows the absorbed dose to water per monitor unit (Gy/MU) which was determined with the procedure routinely used at each institute. The "New" column shows the values determined by the new Japanese protocol. In "Old" column, a maximum discrepancy of 2.7% exists and a standard deviation of 1% is shown. In this case, participants calculated the absorbed dose with different dosimetric parameters, i.e., w-value for proton beam, proton stopping power ratio etc., according to the respective dosimetry procedures. The lack of unity in dosimetry procedures between the participants resulted in the observed significant discrepancies.

On the other hand, a maximum discrepancy of 1.0% and a standard deviation of 0.3% is shown in the "New" column. The standard deviation is equal to that of exposure measurements in a ^{60}Co γ-ray field. This means that the obtained consistency of proton beam dosimetry is nearly identical to the consistency obtained in the case of ^{60}Co γ-rays. As a result, it is shown that the use of the new protocol improves the differences in absorbed doses stated by the participants.

Table II. The results from the proton dosimetry intercomparison

Institution	Ionization Chamber	Cobalt 60 Exposure(C/kg)	Proton/Absorbed Dose to Water Old (Gy/MU)	Proton/Absorbed Dose to Water New (Gy/MU)	Ratio New/Old
NIRS	PTW30001(ICT2)	0.00902	0.1121	0.1125	1.004
	PTW30001(ICS0)	0.00899	0.1119	0.1124	1.004
PMRC	C-110(0.6ml)#823	0.00898	0.1132	0.1125	0.994
NCC	C-110(0.6ml)#754	0.00895	0.1140	0.1121	0.983
	C-110(0.6ml)#967	0.00901	0.1149	0.1129	0.983
HIBMC	PTW30001	0.00895	0.1144	0.1129	0.987
	PTW31003	0.00902	0.1145	0.1133	0.989
WERC	PTW30001	0.00894	0.1131	0.1123	0.993
Mean		0.00898	0.1135	0.1126	0.992
Standard Deviation/Mean (%)		0.3	1.0	0.3	0.9

4. Conclusion

To establish inter-institutional uniformity in proton beam dosimetry, an intercomparison program was carried out using the new Japanese dosimetry protocol, which followed IAEA Technical Report Series No. 398, especially in selecting the dosimetric parameter for proton beam. The dose measurements using different cylindrical ionization chambers were carried out in a water phantom at a position of 30-mm residual range for a proton beam which had a range of 155 mm and spread out Bragg peak (SOBP) of 60 mm width. As a result, the use of the new protocol improved the ±1.0 % (one standard deviation) and 2.7 % (maximum discrepancy) differences in absorbed doses stated by the participating facilities to ±0.3% and 0.9 %, respectively. The results shows that the lack of consistency in dosimetry procedures between the institutions results in significant discrepancies and that it is neccessary to have a common dosimetry protocol. The new Japanese protocol will be adopted by the all of the participants.

REFERENCES

[1] JAPAN SOCIETY OF MEDICAL PHYSICS, Standard Dosimetry of Absorbed Dose in External Beam Radiotherapy (in Japanese), Tsuushou Sangyou Kenkyuusha, Tokyo (2002)

[2] PARTICLE THERAPY COOPERATIVE GROUP, Particle Newsletter **29**, Boston, (2002)

[3] VYNCKIER, S., et al., Supplement to the code of practice for clinical proton dosimetry, Radioth. Oncol. **32** (1994)174-9

[4] INTERNATIONAL COMMISSION ON RADIATION UNITS AND MEASUREMENTS, Clinical Proton Dosimetry – PART I: Beam Production, Beam Delivery and Measurement of Absorbed Dose, ICRU Report 59, ICRU, Bethesda, MD (1988)

[5] VATNITSKY, S., et al., Proton dosimetry intercomparison based on the ICRU Report 59 protocol, Radiotherapy and Oncology **51** (1999) 273

[6] FUKUMURA, A., et al., Carbon beam dosimetry intercomparison at HIMAC, Phys. Med. Biol. **43** (1998) 3459

[7] INTERNATIONAL ATOMIC ENERGY AGENCY, Absorbed Dose Determination in External Beam Radiotherapy, Technical Reports Series No. 398, IAEA, Vienna (2000)