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External Auditing on Absorbed Dose Using a Solid Water Phantom for Domestic Radiotherapy Facilities

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Purpose: We report the results of an external audit on the absorbed dose of radiotherapy beams independently performed by third parties. For this effort, we developed a method to measure the absorbed dose to water in an easy and convenient setup of solid water phantom.

Materials and Methods: In 2008, 12 radiotherapy centers voluntarily participated in the external auditing program and 47 beams of X-ray and electron were independently calibrated by the third party's American Association of Physicists in Medicine (AAPM) task group (TG)-51 protocol. Even though the AAPM TG-51 protocol recommended the use of water, water as a phantom has a few disadvantages, especially in a busy clinic. Instead, we used solid water phantom due to its reproducibility and convenience in terms of setup and transport. Dose conversion factors between solid water and water were determined for photon and electron beams of various energies by using a scaling method and experimental measurements.

Results: Most of the beams (74%) were within ±2% of the deviation from the third party's protocol. However, two of 20 X-ray beams and three of 27 electron beams were out of the tolerance (±3%), including two beams with a >10% deviation. X-ray beams of higher than 6 MV had no conversion factors, while a 6 MV absorbed dose to a solid water phantom was 0.4% less than the dose to water. The electron dose conversion factors between the solid water phantom and water were determined: The higher the electron energy, the less is the conversion factor. The total uncertainty of the TG-51 protocol measurement using a solid water phantom was determined to be ±1.5%.

Conclusion: The developed method was successfully applied for the external auditing program, which could be evolved into a credential program of multi-institutional clinical trials. This dosimetry saved time for measuring doses as well as decreased the uncertainty of measurement possibly resulting from the reference setup in water.

Key Words: Quality assurance, External auditing, Solid water phantom, Dosimetry

Introduction

Radiation treatment plays an important role in the cancer management. In treating patients with radiations, the radiation oncologist prescribes a treatment regimen (including radiation dose) whose goal is to cure or control the disease while minimizing complications to normal tissue. In general, published clinical and experimental results demonstrate that the response of tumors and normal tissues to radiation is highly variable.[1] Moreover, for some tumors and normal tissues the dose response curves may be very steep in the therapeutic dose range, i.e., a small change in dose can result in a large change in clinical response. In addition, the prescribed radiation dose to the tumor is usually constrained by the tolerance dose of surrounding normal tissues. Consequently, since the window for optimal treatment can be quite narrow, the radiation dose must be delivered accurately and consistently. Quality assurance is required in all areas

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involved in the radiation treatment process in order to satisfy the therapeutic goal. Quality assurance is all those planned or systematic actions to provide the organizational structure, responsibilities, procedures, processes and resources for assuring the quality of patient management.[2,3]

An external audit for radiotherapy should be performed periodically by the third parties to maintain a uniform quality of patient care among different facilities. The third parties would be a national agency or nationally or internationally recognized bodies, depending on the purpose of the auditing. This is especially very important for multi-institutional clinical trials to improve the success rate of the trials and the reliability of trial findings.

Among many auditing items for radiotherapy, we developed a method to determine absorbed dose to water from ion-chamber measurements in solid water phantom within the context of the absorbed dose calibration protocol (i.e., The American Association of Physicists in Medicine [AAPM] task group [TG]-51). The developed method was first cross-calibrated by a secondary standard dosimetry laboratory (i.e., Korean Food and Drug Administration [KFDA]). Then we conducted dose auditing to radiation treatment facilities within the country through the method developed in this study. In 2008, 47 beams of 12 facilities were involved in the auditing program. If the discrepancies were 5% or more, we immediately notified the onsite physicist.[2)]

Materials and Methods

1. Phantom and ionization chamber

The measurement in water was performed in a water tank of which volume is 30×30×30 cm^3 (1-DTM™, ARM, St. Lucie, FL, USA). Solid water phantom slabs (VIRTUAL WATER™, Radiation Products Design Inc., Albertville, MN, USA) made of semi-water equivalent material (ρ=1.04 g/cm^3) were used for the study. The slabs had an area of 30×30 cm^2, having various thickness of 0.1∼5 cm. For back-scatter material, an another solid water phantom (White water phantom™, Civco, Kalona, Iowa, USA) was used.

Although mass density and composition are specified by the manufacturer, electron density was invalid. To acquire the electron density of solid water phantom, Computed Tomography (Big Bore Brilliance, Philips, Malvern, PA, USA) images were taken to compare Hounsfield unit (HU) between water and solid water phantom. Electron density of each material was evaluated using the HU.[4)] Hole for insertion of cylindrical ionization chambers was drilled into phantom at appropriate depth. Both of water and solid water phantom were irradiated with beam at a source to surface distance (SSD) of 100 cm.

Farmer type chamber (PTW Farmer Chamber TN30013, PTW, Freiburg, Germany) and electrometer (UNIDOS, PTW) which were certified from KFDA were used for measurement.

Since calibration factors are given for standard environmental condition of temperature at 22°C and pressure at 101.33 kPa, one corrects charge or meter reading to standard environmental conditions using temperature-pressure correction equation.[5)]

Temperature and pressure was measured at each dosimetry using thermometer (SK-1100, Sato, Japan) and barometer (Pocket Line Testo 511, Testo, Frankfurt, Germany).

2. Cross calibration between water and solid water phantom

The AAPM TG-51 protocol uses ion chambers as the basis for measurement and requires absorbed dose to water calibration factors. An important point in this protocol is that clinical reference dosimetry must be performed in a water phantom. Reference dosimetry measurements in plastics, including water equivalent plastics, are not allowed.[5)] Nevertheless, a solid water phantom can be used to measure the absorbed dose. To measure absorbed dose using solid water phantom, we used the conversion factor. First, we measured absorbed dose in water according to TG-51 protocol for both photon and electron. Next, we repeated the measurements in a solid water phantom using the same method. The conversion factor is equal to the ratio of absorbed dose in water to that in solid water (Tables 1 and 2). The beam quality must be specified in order to determine the correct value of the quality conversion factor, k_Q, or k'_{R50}. It is essential to use SSD=100 cm and 10×10 cm^2 field size.[5)]

Table 1. Dose Conversion Factors between Solid Water and Water for Photon Energy

Energy (MV)	6	10	15
Conversion factor	1.004	1.00	1.00

To do this, $\%dd(10)_x$ were measured. k_Q was taken from TG-51 report. The difference between %dd(10) of beam data and that of measurement was about 2% thus the error of k_Q is 0.3%. To calculate k'_{R50}., we tried to measure R_{50}. For cylindrical chambers the following expression can be used for $2 \leqq R_{50} \leqq 9$ cm with maximum error of 0.2%.[5]

$$k'_{R_{50}}(cyl) = 0.9905 + 0.0710e^{(-R_{50}/3.67)} \quad (1)$$

Set-up with an exact depth is not possible because of the slab thickness. The minimum slab thickness is 0.1 cm while the unit for R_{50} is in sub millimeter. The difference had an effect by about 0.1% error of k_{R50}. Thus the uncertainty of k'_{R50} is 0.3%. To measure setup error, measurements were repeated 20 times. The uncertainty was taken from deviation of each reading. The total uncertainty of measurement was 1.22%. This total uncertainty includes the uncertainty of measuring device that provided by the manufacturer and k_Q (Table 3).

Table 2. Dose Conversion Factors between Solid Water and Water for Electron Energy

Energy (MeV)	6	9	12	16	20
Conversion factor	1.021	1.016	1.01	1.005	1.001

Table 3. The Uncertainty of Measurement (Provided by the Manufacturer)

Type	Uncertainty (%)
Chamber	1.1
Thermometer	0.3
Barometer	0.3
Measurement set-up	0.14
K_Q	0.3

Table 4. 6 MV Photon Percent Depth Dose (PDD) Data (Depth, 10 cm)

	PDD data from beamdata (%)	Measured PDD (%)	Difference (%)	K_Q (from measurement)
Hospital 1	66.70	66.70	0	0.991
Hospital 2	67.10	65.97	1.13	0.992
Hospital 3	65.90	66.29	−0.39	0.992
Hospital 4	66.30	66.91	−0.61	0.990
Hospital 5	−	−	−	−
Hospital 6	66.40	66.07	0.33	0.992
Hospital 7	65.90	67.03	−1.13	0.990
Hospital 8	66.70	66.16	0.54	0.992
Hospital 9	66.90	66.37	0.53	0.991
Hospital 10	67.80	66.06	1.74	0.992
Hospital 11	67.31	66.98	0.33	0.990
Hospital 12	68.25	67.40	0.85	0.990

Table 5. 10 MV or 15 MV Photon Percent Depth Dose (PDD) Data (Depth, 10 cm)

	PDD data from beamdata (%)	Measured PDD (%)	Difference (%)	K_Q (from Measurement)
Hospital 1	77.30 (15 MV)	77.3 (15 MV)	0	0.973
Hospital 2	77.60 (15 MV)	76.56 (15 MV)	1.04	0.975
Hospital 3	−	−	−	−
Hospital 4	−	−	−	−
Hospital 5	77.00 (15 MV)	76.86 (15 MV)	0.14	0.974
Hospital 6	74.00 (10 MV)	73.19 (10 MV)	0.81	0.980
Hospital 7	75.60 (10 MV)	76.81 (10 MV)	−1.21	0.974
Hospital 8	73.87 (10 MV)	73.44 (10 MV)	0.44	0.980
Hospital 9	73.93 (10 MV)	73.48 (10 MV)	0.44	0.980
Hospital 10	73.67 (10 MV)	73.14 (10 MV)	0.53	0.980
Hospital 11	−	−	−	−
Hospital 12	77.30 (15 MV)	76.41 (15 MV)	0.89	0.975

3. Absorbed dosimetry in the domestic radiotherapy center

When performing on-site dosimetry, the beam quality should be measured because it varies with machine type (Tables 4 and 5). So the %dd(10) was measured. Comparing %dd(10) measured at the site and %dd(10) from beam data of that facility, the maximum difference was 2%. We used k_Q with measured %dd(10) (Table 6). We performed dosimerty with applied AAPM TG-51 protocol using solid water phantom. The dosimetry setup was SSD=100 cm, field size= 10×10 cm^2 (Fig. 1). Using custom-made AAPM TG-51 worksheet, the output of beam was calculated (Fig. 2).

When performing measurement, ionization chamber was inserted in the hole of solid water phantom. Since the temperature in the hole and room temperature is slightly different, temperature should be measured in the hole not at the treatment room. The difference was about 2°C before measurement and decreased during measurement. But the difference before and after measurement was below 0.1°C.

Results

CT number and electron density differences between water and solid water phantom is shown in Table 7. According to AAPM TG-51 protocol, the reference depth in water for photon beam is 10 cm, resulting in an equivalent depth of 9.92 cm for solid water phantom. The equivalent depth was calculated by Eq.(10) of Ref.6.[6] Difference of electron density between two material also affect the reference field size and SSD. The scaled dimension of between two material introduced the conversion factor.[7] Only for lower energy photon (6 MV), dose to the solid water phantom was determined to be 0.4% less than dose to water. The other photon beams of higher energy had no conversion factor. The dose conversion factor for each electron energy was determined. The higher the electron energy, the less the conversion factor as shown Table 2.

Table 6 summarizes the results of the absorbed dose of 47 beams for 12 domestic radiotherapy center (Figs. 3 and 4). The standard deviation of the total 47 beams was 3.0%. Five

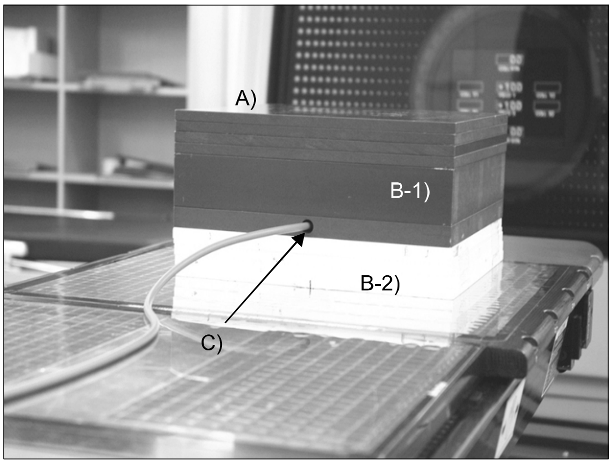
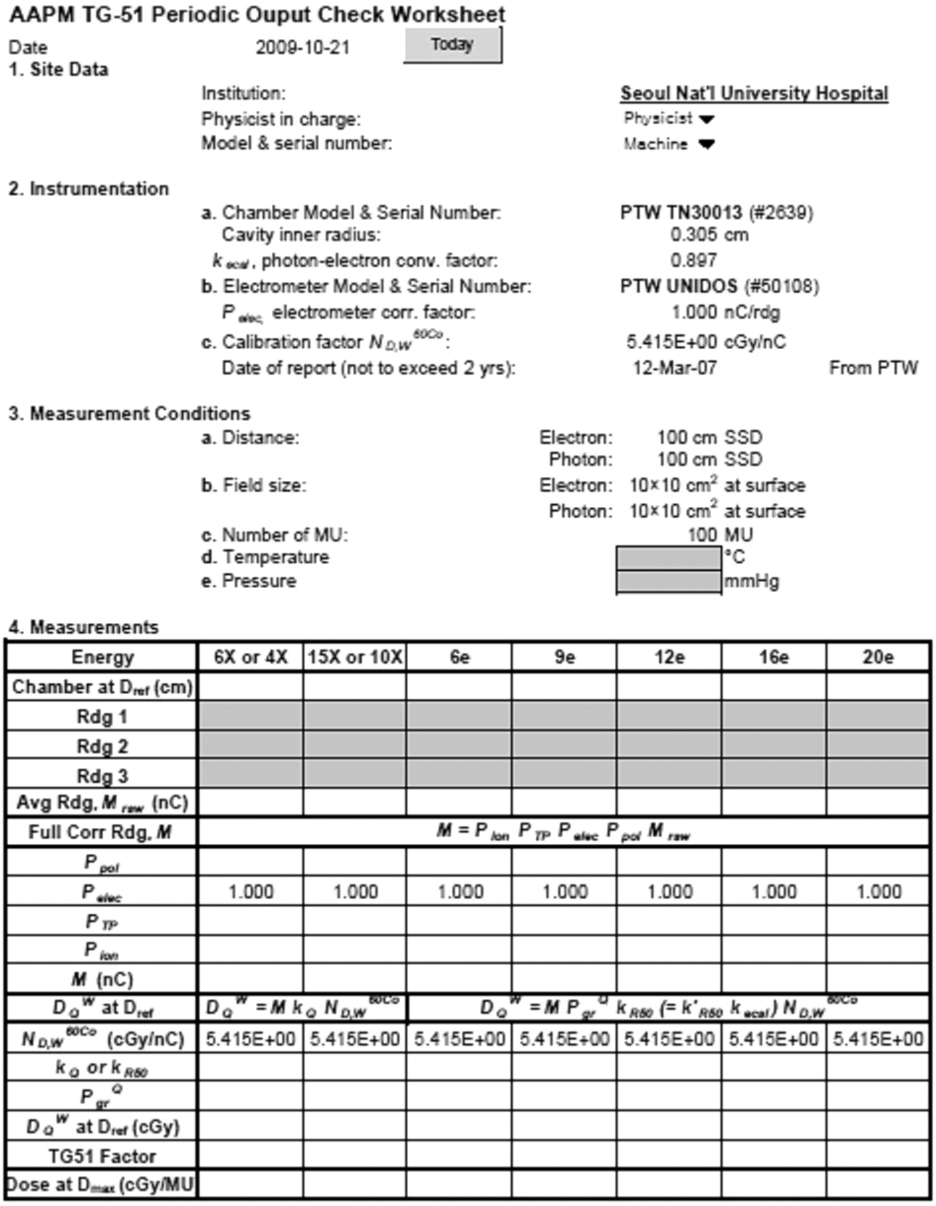


Fig. 1. Measurement geometry and equipments. (A) Source to surface distance is 100 cm. Field size is 10×10 cm^2. (B-1) Solid water phantom is used for measurement. (B-2) White solid water phantom is used as back scatter material. (C) Farmer type ion-chamber is inserted in holl.

Table 6. Ratio of Absorbed Dose Measured in Domestic Radiotherapy Centers to the Those of Host Center

	Photon output		Electron output				
	6 MV or 4 MV	15 MV or 10 MV	6 MeV	9 MeV	12 MeV	16 MeV	20 MeV
Hospital 1	0.998	0.989	1.005	1.000	0.994	0.989	0.985
Hospital 2	0.994	1.008	1.019	1.005	1.007	1.001	1.008
Hospital 3	1.006	–	–	1.011	–	–	–
Hospital 4	0.996	–	–	–	0.990	–	–
Hospital 5	–	1.037	–	1.004	1.008	–	–
Hospital 6	0.996	0.997	0.975	0.973	0.971	–	–
Hospital 7	0.989	0.986	–	0.992	–	–	–
Hospital 8	1.004	1.029	1.024	0.994	0.988	–	–
Hospital 9	1.021	1.045	1.020	1.044	–	–	–
Hospital 10	1.008	1.014	1.129	1.127	–	–	–
Hospital 11	1.006	–	–	–	–	–	–
Hospital 12	0.989	0.996	0.992	–	0.999	–	–


AAPM TG-51 Periodic Ouput Check Worksheet

Date 2009-10-21 Today

1. Site Data

Institution: Seoul Nat'l University Hospital

Physicist in charge: Physicist

Model & serial number: Machine

2. Instrumentation

a. Chamber Model & Serial Number: PTW TN30013 (#2639)

Cavity inner radius: 0.305 cm

k_{ecal}, photon-electron conv. factor: 0.897

b. Electrometer Model & Serial Number: PTW UNIDOS (#50108)

P_{elec} electrometer corr. factor: 1.000 nC/rdg

c. Calibration factor $N_{D,W}^{60Co}$: 5.415E+00 cGy/nC

Date of report (not to exceed 2 yrs): 12-Mar-07 From PTW

3. Measurement Conditions

a. Distance: Electron: 100 cm SSD; Photon: 100 cm SSD

b. Field size: Electron: 10×10 cm^2 at surface; Photon: 10×10 cm^2 at surface

c. Number of MU: 100 MU

d. Temperature °C

e. Pressure mmHg

4. Measurements

Energy	6X or 4X	15X or 10X	6e	9e	12e	16e	20e
Chamber at D_{ref} (cm)							
Rdg 1							
Rdg 2							
Rdg 3							
Avg Rdg, M_{raw} (nC)							
Full Corr Rdg, M	$M = P_{ion} P_{TP} P_{elec} P_{pol} M_{raw}$						
P_{pol}							
P_{elec}	1.000	1.000	1.000	1.000	1.000	1.000	1.000
P_{TP}							
P_{ion}							
M (nC)							
D_Q^W at D_{ref}	$D_Q^W = M k_Q N_{D,W}^{60Co}$		$D_Q^W = M P_{gr}^Q k_{R50} (= k'_{R50} k_{ecal}) N_{D,W}^{60Co}$				
$N_{D,W}^{60Co}$ (cGy/nC)	5.415E+00	5.415E+00	5.415E+00	5.415E+00	5.415E+00	5.415E+00	5.415E+00
k_Q or k_{R50}							
P_{gr}^Q							
D_Q^W at D_{ref} (cGy)							
TG51 Factor							
Dose at D_{max} (cGy/MU)							

Fig. 2. The worksheet is used to calculate output according to task group (TG)-51.

Table 7. CT* Number Differences between Water and Solid Water Phantom

	Water	Solid water phantom
CT no. of ROI†1 (HU‡)	−8.03 (±19.7)	6 (±49)
CT no. of ROI 2 (HU)	−8.00 (±19.3)	5.6 (±43.9)
CT no. of ROI 3 (HU)	−8.60 (±15.7)	5.1 (±45.2)
CT no. of ROI 4 (HU)	−9.30 (±21.6)	4.5 (±50.9)
Average (HU)	−8.48	5.3
Electron density	1.0077	1.0163
Difference (%)	−0.85	
Equilibrium range (cm)	10	9.92

*computed tomography, †region of interest, ‡hounsfield unit.

beams exceeded the tolerance levels, which is over 3%. Three facilities among 12 had beams exceeded the tolerance levels. The total uncertainty of applied AAPM TG-51 protocol measurement using a solid water phantom was determined ±1.22%.

Discussion and Conclusion

Measurement was performed by two skilled physicists and It takes about 20 minutes to measure the output of 2 photon and 5 electron beams. Measurement time was significantly

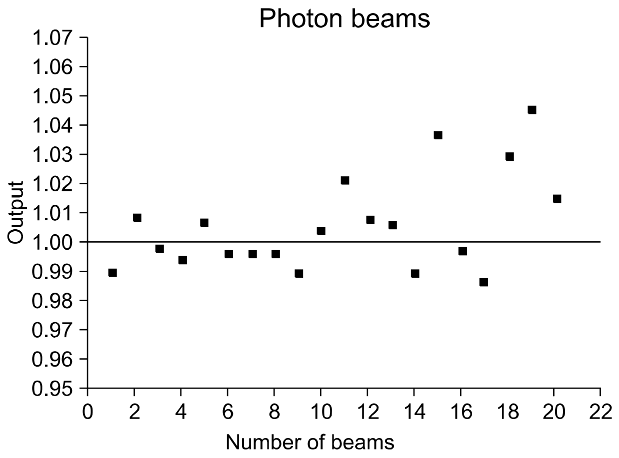


Fig. 3. Absorbed dose distribution of photon beam. The two of 20 X-ray beams were out of the tolerance (±3%).

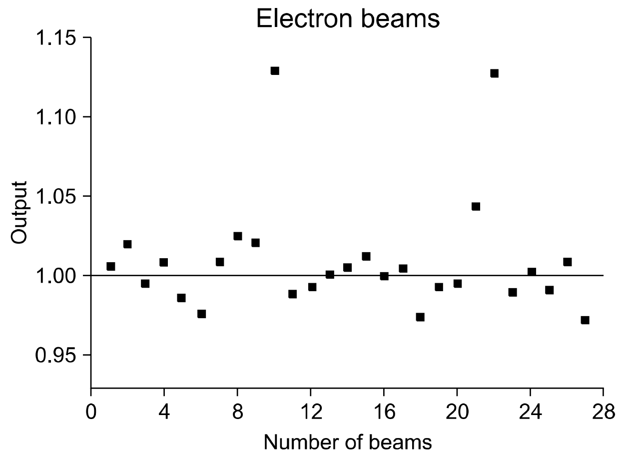


Fig. 4. Absorbed dose distribution of electron beam. The three of 27 electron beams were out of the tolerance (±3%), including two beams of >10% deviation.

reduced by using applied AAPM TG-51 protocol with solid water phantom. We presented an external dosimetry auditing method under the reference condition, but using solid water phantom for the convenience in a busy clinical environment. The dosimetry method saved time for measuring absolute dose and reduced the uncertainty of measurement possibly resulting from the reference setup in water. From the result of the external dosimetry auditing of 2008, we conclude that a nation-wide auditing program of dosimetry is necessary for the patient safety and the quality control of national clinical trials. A comprehensive method to audit the whole procedure of radiation treatment, including the treatment planning system (TPS) is under development.

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국문초록

고체팬텀을 이용한 국내 방사선 치료시설의 흡수선량에 대한 조사

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목 적: 제 3기관에 의해 독립적으로 수행된 방사선 치료 빔의 흡수 선량을 외부 감사의 결과로 보고 한다. 이를 위해 쉽고 편리하게 설치 가능 한 고체 팬텀을 이용하여 흡수 선량을 측정하는 방법을 개발했다.
대상 및 방법: 2008년 12개 방사선 치료 시설에서 외부 감사 프로그램에 참여하였고 47개의 광자선과 전자선의 제 3기관에 의해 American Association of Physicists in Medicine (AAPM) task group (TG)-51 프로토콜을 사용하여 독립적으로 교정되었다. AAPM TG-51 프로토콜은 물에서의 측정을 권고 하고 있지만 팬텀으로 물은 바쁜 병원 상황에선 몇 가지 단점이 있다. 설치와 수송이 편리하고 재현성이 있는 고체 팬텀을 사용하였다. 광자선과 전자선에 대한 물과 고체 팬텀 사이의 선량 보정인자는 스케일링 방법과 실험적 측정에 의해 결정되었다.
결 과: 대부분의 빔은(74%) 제3기관의 프로토콜로 측정한 결과 2%의 편차 이내였다. 그러나 20개 중 2개의 광자선과 27개 중 3개의 전자선은 허용범위(3%)를 초과 하였다. 특히 그중 2개의 빔은 10% 이상의 편차를 보여주고 있다. 6 MV 초과의 고에너지 광자선은 보정인자가 없었다. 6 MV 광자선의 경우 고체 팬텀에서의 흡수선량은 물에서의 흡수 선량보다 0.4% 작게 나타났다. 전자선에 대한 보정인자도 결정되었는데 전자선의 에너지가 증가함에 따라 보정인자는 작아지는 경향을 보여준다. 고체팬텀을 사용한 TG-51 프로토콜의 측정 오차는 ±1.22%로 나타났다.
결 론: 개발된 방법은 다기관 임상 연구의 인증 프로그램에 참여할 수 있는 외부 감사 기관 프로그램에 성공적으로 적용되었다. 이 선량측정은 선량을 측정하기 위한 시간을 줄이고 물을 설치할 때의 생길 수 있는 측정오차를 감소시킨다.

핵심용어: 정도관리, 외부 검증, 고체팬텀, 선량측정