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Development and Evaluation of Multipurpose Phantom for Delivery Quality Assurance of Intensity-modulated Radiation Therapy

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Treatments demanding high accuracy, such as intensity-modulated radiation therapy (IMRT), should provide the optimal dose distribution and correct intervention. Otherwise, they may become unsafe and cause adverse effects to patients. Delivery quality assurance (DQA) for treatment verification can be performed considering the absolute dose using an ionization chamber and relative dose using a film. However, a film imposes a long waiting time for measurement and is sensitive to temperature and humidity, development conditions, and noise. We aim to evaluate the usefulness of a multipurpose phantom for fast and simple IMRT DQA. The multipurpose phantom is made of poly (methyl methacrylate)-based resin. The phantom allows the insertion of a 2D array detector and an ionization chamber. Therefore, the relative and absolute doses can be measured simultaneously. The IMRT DQA evaluation provided absolute dose of 0.35 ± 1.74% and relative dose of 99.03 ± 0.6 % in 3 mm/3% gamma evaluation for a linear accelerator. In addition, the absolute and relative doses were 1.37 ± 1.05% and 98.7 ± 0.78% in helical tomotherapy, respectively. Therefore, the dose measurements were within acceptable error limits of 3%. The results demonstrate the multipurpose capabilities of the proposed phantom for evaluating dose distribution and absolute dosimetry.

Keywords : electromagnetic radiation, multipurpose phantom, relative dose, absolute dose, intensity-modulated radiation therapy, delivery quality assurance

1. Introduction

Electromagnetic radiation therapy is aimed at delivering radiation dose to a tumor area while sparing surrounding normal tissue [1, 2]. Recently, this type of therapy has been directed to precise interventions such as intensity-modulated radiation therapy (IMRT). IMRT can produce dose distributions with improved conformity to the target while sparing critical organs [3, 4]. In addition, it improves the dose distribution compared with conventional electromagnetic radiation therapy [5].

Accurate IMRT requires the optimal dose distribution and correct intervention for providing safety and preventing adverse effects to patients. Thus, thorough dosimetry is necessary during implementation and treatment verification before application to patients [6, 7]. Delivery quality assurance (DQA) for treatment verification can be performed by measuring the absolute dose using an ionization chamber and the relative dosimetry using a film or 2D array detector (2DAD) [8, 9]. However, a film has a long waiting time for measurement and is sensitive to temperature and humidity, development conditions, and noise. Moreover, as periodic dose/pixel calibration should be performed, handling is complicated and time consuming [10, 11]. On the other hand, 2DADs provide instantaneous measurements after irradiation, but they have a lower resolution compared with films, lower accuracy compared with ionization chambers in absolute dosimetry, and specific directionality [12-14].

If the relative and absolute doses can be measured

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simultaneously, quickly, accurately, and conveniently, fast DQA may be achieved, thereby shortening the time required for treatment planning and enabling timely radiation therapy to patients. In this study, we aimed to achieve fast and accurate DQA by developing a multipurpose phantom to simultaneously measure relative and absolute doses.

2. Materials and Methods

2.1. Materials

MapCHECK 2 (Sun Nuclear, Melbourne, FL, USA) was used as the 2DAD. Its specifications are listed in the Table 1. We also used the A1SL thimble ionization chamber (Standard Imaging, Middleton, WI, USA) with effective volume of 0.053 cm^3, which is suitable for IMRT DQA. Computed tomography (CT) was performed using the SOMATOM Definition AS Open system (Siemens Healthineers, Erlangen, Germany) for the treatment plans. The Pinnacle treatment planning system version 16.0 (Philips Radiation Oncology Solutions, Philips Healthcare, Andover, MA, USA) and tomotherapy planning station version 5.1.3 (Accuray, Sunnyvale, CA, USA) were also used. A linear accelerator (linac, ONCOR impression+ 160MLC, Germany) for radiation therapy and the tomotherapy HiArt system (Accuray, Sunnyvale, CA, USA) were used for evaluation. The designed multipurpose phantom was made of poly (methyl methacrylate) (PMMA)-based resin. The PMMA is colorless and transparent, and it can be dyed with various colors. In addition, it is widely used because it hardly absorbs visible light and has excellent weather resistance, color-ability, moldability, and strength.

2.2. Methods

2.2.1. Multipurpose phantom design

The multipurpose phantom was configured to simultaneously measure relative and absolute doses to verify a treatment plan of IMRT. The ionization chamber can be inserted above the phantom for absolute dose measurement, and the 2DAD can be inserted for relative dose measurement. The density of PMMA measured by CT was 1.19 g/cm^3.

The phantom was configured as shown in Fig. 1 with the layout of the ionization chamber and 2DAD shown as areas (a) and (b). Point (c) in Fig. 1 indicates the center of the phantom and the measurement point of the ionization chamber. The phantom thickness was 3.35 cm.

The American association of physicists in medicine task group NO. 71(AAPM TG-71) protocol establishes a measurement depth of 5-10 cm for absolute dosimetry to minimize the effect of scattered light and achieve electron equilibrium. However, in difficult cases, it is recommended to measure the maximum dose at deeper positions [15, 16]. Therefore, considering the maximum energy (15 MV, D_{max} = 3.0 cm) of the linac photon beam for treatment, we set the depth to 3.35 cm, corresponding to water equivalent density of 4.0 g/cm^2. Distance (d) in Fig. 1 indicates the distance to the measurement point of the 2DAD, and distance (e) (4.8 cm) is set considering the inherent 2DAD buildup of 1.2 cm.

2.2.2. DQA procedure

To evaluate IMRT using a linac in the developed multipurpose phantom, a treatment plan for DQA was established by obtaining a CT image with the 2DAD inserted. The thickness from the 2DAD to the upper

Table 1. Specifications of Sun Nuclear MapCHECK 2.

	MapCHECK2
Detector type	SunPoint™ Diode detectors
Detector quantity	1527
Field size	26.0 × 32.0 cm
Array geometry	-Detector spacing parallel to X and Y axes: 1.0 cm -Row spacing offset: 0.5 cm
Detector spacing	0.707 cm (Uniform throughout array)
Active detector area	0.64 mm^2
Active detector volume	0.019 mm^3
Detector sensitivity	32 nC/Gy
Radiation measured	Photon: ^{60}Co to 25 MV, Electron: 6 MeV to 25 MeV
Dose rate dependence	±1% over the range, 50-1400 cGy/min
Inherent buildup	1.1 ± 0.1 g/cm^2, 1.2 cm (2 cm water equivalence)

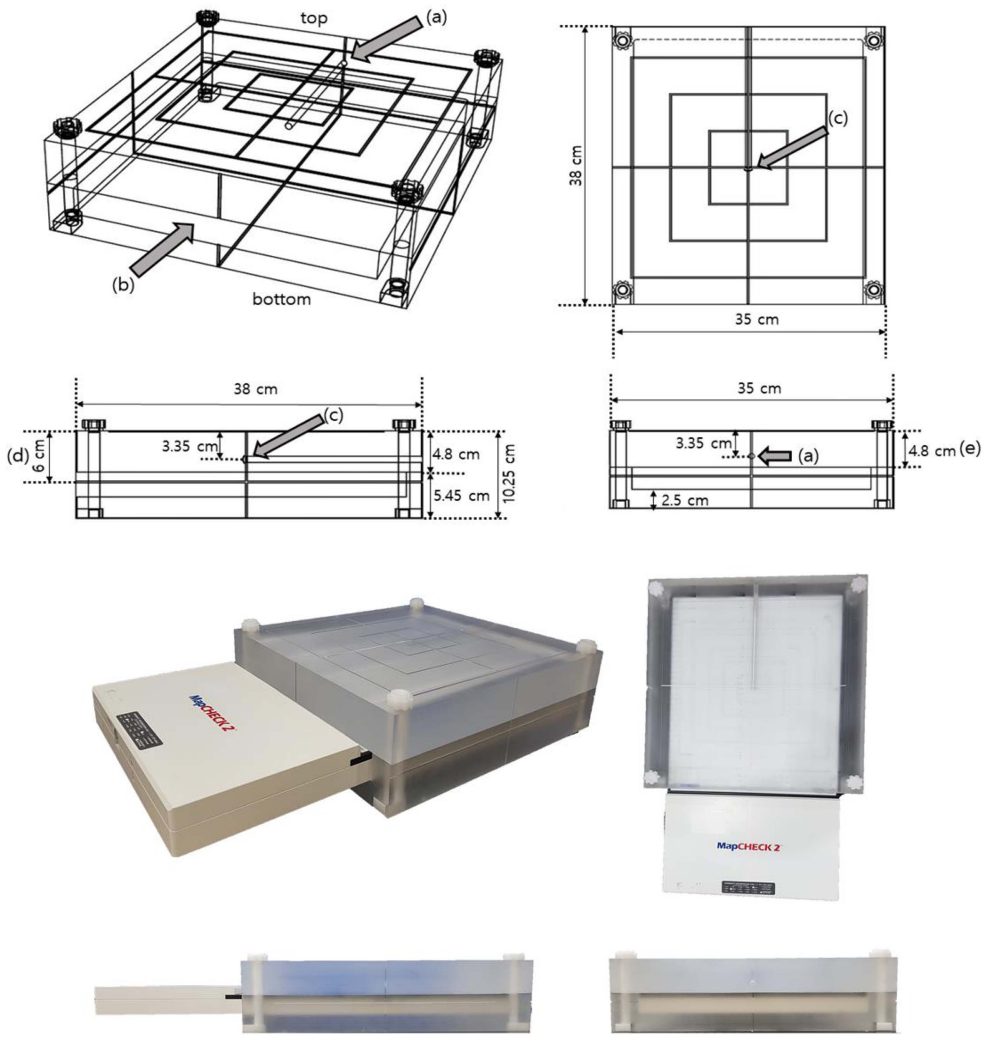

Fig. 1. (Color online) Schematic of proposed multipurpose phantom.

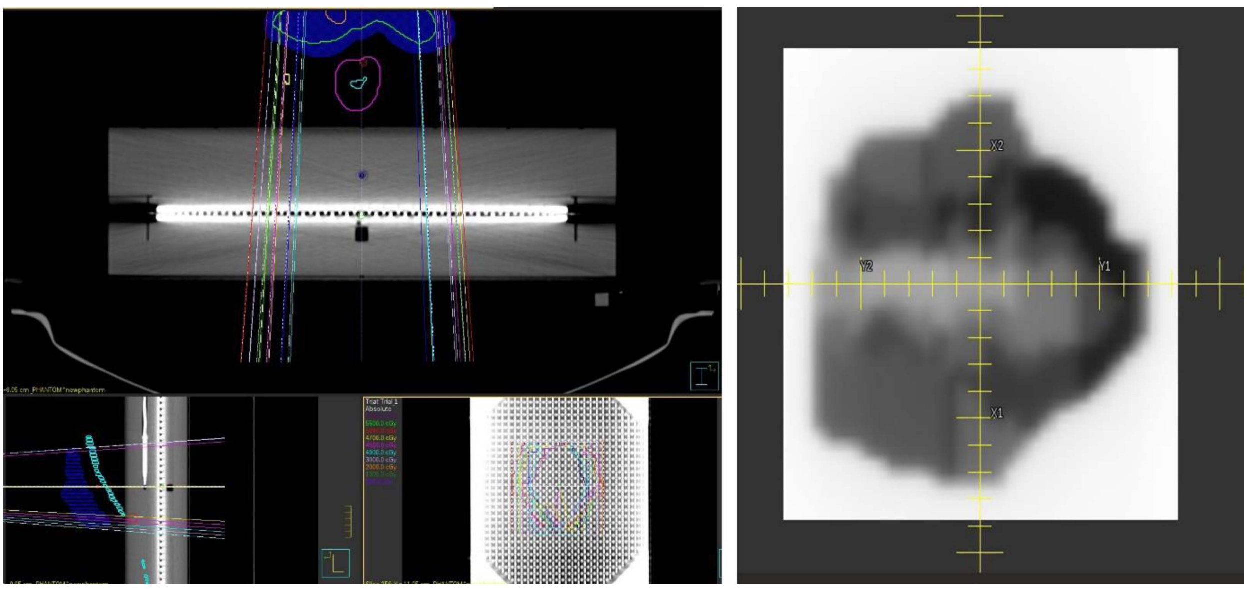

Fig. 2. (Color online) IMRT DQA set up (left) and generated dose profile (right) in Pinnacle system.

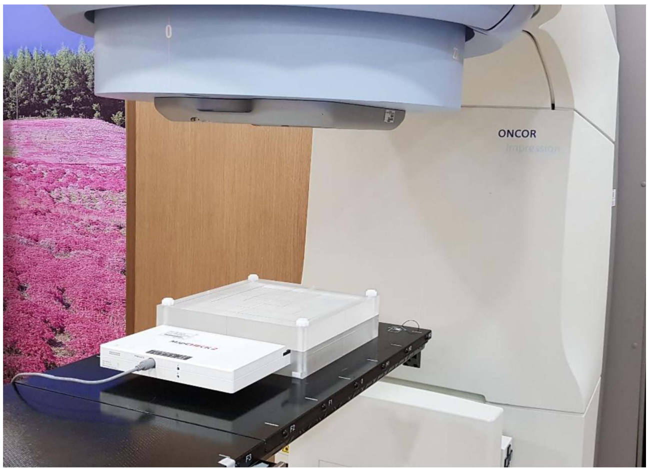

Fig. 3. (Color online) Experimental setup of multipurpose phantom in linac.

surface of the phantom was 6 cm (source-to-surface distance of 94 cm) (Fig. 2). The dose calculation algorithm used collapsed cone convolution and assumed the dose to be 100% at the center of the ionization chamber inserted into the multipurpose phantom. The phantom with the 2DAD and ionization chamber inserted was installed on a linac table (Fig. 3). The center of the multipurpose phantom was accurately positioned using megavoltage cone-beam CT images. After installing the multipurpose phantom, the dose distribution was measured with the 2DAD, and the absolute dose was measured with the ionization chamber. The two-dimensional dose distribution was analyzed by 3 mm/3% gamma evaluation in accordance with the AAPM TG-119 instructions [17]. Up to 10% of the maximum dose was set as the threshold dose, and less than that was discarded from the calculations (Fig. 4).

A treatment plan for DQA measurement was also implemented using the multipurpose phantom in tomotherapy. With the 2DAD and ionization chamber inserted into the phantom, CT scans were performed for the sagittal section, as shown in Fig. 5. We selected this

Fig. 5. (Color online) Experimental setup of multipurpose phantom in tomotherapy system.

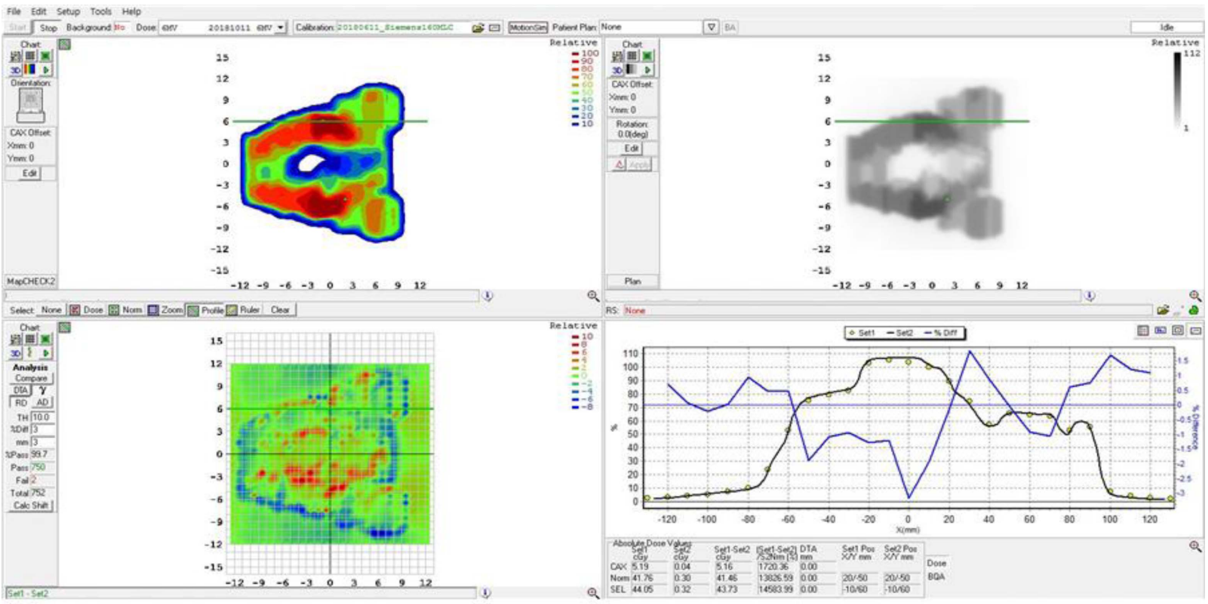

Fig. 4. (Color online) Example of gamma evaluation results for dose distribution measures using 2DAD and Sun Nuclear patient quality assurance software version 6.0.1.

scanning section because the measurement surface cannot be placed in the isocenter of tomotherapy in some cases, even if the table is raised to its maximum.

3. Results

Tables 2, 3 and 4 show the DQA results for IMRT using the linac. DQA was implemented for 15 patients in a linac using the multipurpose phantom, with 5 neck (Table 2), 5 chest (Table 3), and 5 abdomen and pelvis (Table 4) cases. The absolute dose measured using the ionization chamber and the relative dose measured using an EBT3 film were obtained. The irradiation beam for each patient was 5 or 7 fields, and the prescribed dose per treatment was 180-600 cGy. The absolute dosimetry results were measured to have an absolute dose error of ± 2.80% with an overall average of 0.36 ± 1.74% depending on the irradiation beams. The relative dose was measured with an average of 99.03 ± 0.69%, thus passing the 3 mm/3% gamma with a range from 97.3% to 100%.

Table 2. Relative and absolute doses in IMRT using linac for neck region.

PT. No.	Treatment Site	Filed	Conventional method				Multi-purpose phantom			
			PD (cGy)	MD (cGy)	ΔD(%)	γ_{EBT} % (3mm, 3%)	PD (cGy)	MD (cGy)	ΔD(%)	γ_M % (3mm, 3%)
1	Glottic	1	20.1	20.3	1.0	97.5	18.3	18.5	1.1	98.6
		2	19.3	19.7	2.1	98.1	15.2	15.4	1.3	99.3
		3	70.8	71.2	0.6	97.8	70.2	71.2	1.4	98.6
		4	76.9	77.4	0.7	98.6	78.2	79.1	1.2	99.5
		5	37.8	38.1	0.8	99.2	43.2	42.1	-2.5	100.0
		sum	224.9	226.7	0.8		225.1	226.3	0.5	
2	Glottic	1	20.1	19.9	-1.0	98.3	19.7	19.7	-0.2	98.8
		2	14.2	14.7	3.5	98.8	14.1	13.9	-1.0	100.0
		3	85.4	86.2	0.9	99.2	86.3	85.1	-1.4	98.6
		4	81.6	82.1	0.6	99.5	82.8	84.4	1.9	100.0
		5	23.7	23.6	-0.4	99.2	22.0	21.4	-2.7	100.0
		sum	225.0	226.5	0.7		224.9	224.5	-0.2	
3	Glottic	1	10.2	10.3	1.0	97.4	11.2	10.9	-2.7	98.8
		2	47.2	47.6	0.8	98.7	46.4	47.6	2.6	100.0
		3	68.1	69.2	1.6	99.3	67.1	67.0	-0.1	99.5
		4	55.8	56.1	0.5	99.4	56.4	55.8	-1.1	98.8
		5	43.8	44.2	0.9	98.2	43.8	44.5	1.6	99.2
		sum	225.1	227.4	1.0		224.9	225.8	0.4	
4	Glottic	1	5.1	5.2	2.0	98.2	4.6	4.5	-2.2	98.5
		2	72.1	71.7	-0.6	98.5	71.5	71.8	0.4	100.0
		3	42.6	42.2	-0.9	99.1	43.7	44.9	2.8	100.0
		4	25.8	25.3	-1.9	98.5	26.4	27.1	2.7	98.5
		5	79.3	80.1	1.0	99.3	78.9	80.5	2.0	98.5
		sum	224.9	224.5	-0.2		225.1	228.6	1.6	
5	Larynx	1	20.1	19.9	-1.0	99.9	19.7	19.6	-0.5	97.8
		2	40.2	40.5	0.7	99.2	39.8	38.8	-2.5	98.6
		3	56.8	57.1	0.5	99.7	57.1	55.9	-2.1	100.0
		4	62.7	63.2	0.8	98.7	63.0	63.6	1.0	98.8
		5	45.2	45.6	0.9	98.5	45.3	46.6	2.8	100.0
		sum	225	226.3	0.6		224.9	224.5	-0.2	

PD = Plan dose in radiation therapy planning system
MD = Measurement dose using the ionization chamber
ΔD = {(MD/PD)-1} × 100
γ_{EBT} = Gamma pass using the EBT3 film
γ_M = Gamma pass using the MapCHECK2

Table 3. Relative and absolute doses in IMRT using linac for chest region.

PT. No.	Treatment Site	Filed	Conventional method				.Multi-purpose phantom			
			PD (cGy)	MD (cGy)	ΔD(%)	γ_{EBT} % (3mm, 3%)	PD (cGy)	MD (cGy)	ΔD(%)	γ_M % (3mm, 3%)
6	Esophagus	1	30.1	29.3	-2.7	97.4	29.5	30.1	2.0	99.6
		2	32.1	31.9	-0.6	96.9	31.6	32.5	2.8	99.8
		3	15.8	16.2	2.5	99.1	16.2	16.1	-0.6	98.7
		4	29.6	30.2	2.0	98.2	31.3	31.9	1.9	99.7
		5	29.3	28.6	-2.4	97.5	28.1	27.7	-1.4	98.6
		6	15.9	16.2	1.9	98.2	15.9	16.2	1.9	99.7
		7	27.6	28.1	1.8	99.5	27.2	26.5	-2.6	99.7
		Sum	180.2	180.5	0.2		179.9	181.0	0.6	
7	Breast	1	30.2	30.6	1.3	99.4	29.9	30.2	1.0	99.8
		2	37.8	38.2	1.1	98.7	38.5	39.1	1.6	97.8
		3	59.5	60.1	1.0	99.3	59.1	60.7	2.7	99.8
		4	20.6	20.3	-1.5	98.6	21.9	21.5	-1.8	99.4
		5	32.0	32.3	0.9	99.1	30.6	31.3	2.3	98.6
		sum	180.1	182.3	1.2		180.0	182.8	1.6	
8	Lung	1	136.3	135.0	-1.0	99.1	136.0	138.7	2.0	100.0
		2	70.2	68.6	-2.3	97.4	69.8	69.2	-0.9	99.0
		3	111.8	113.3	1.3	97.8	112.2	111.2	-0.9	99.5
		4	123.9	123.6	-0.2	98.3	124.7	124.9	0.2	100.0
		5	87.4	85.4	-2.3	98.3	85.3	85.0	-0.4	99.1
		6	70.6	72.0	2.0	97.8	71.9	71.8	-0.1	98.7
		Sum	600.2	597.9	-0.4		599.9	600.8	0.2	
9	Lung	1	1.4	1.37	-2.1	97.4	1.33	1.3	0.0	99.1
		2	74.1	75.1	1.3	97.3	73.8	75.0	1.6	98.8
		3	13.8	14.2	2.9	98.6	14.3	14.4	0.7	99.2
		4	56.7	57.8	1.9	98.3	56.3	57.1	1.4	99.1
		5	32.9	33.5	1.8	99.3	33.1	33.7	1.8	98.5
		6	19.1	19.4	1.6	98.5	19.4	19.8	2.1	98.2
		7	2.1	2.1	0.0	99.1	1.7	1.68	-1.2	99.5
		Sum	200.1	203.5	1.7		199.9	203.0	1.5	
10	Lung	1	3.2	3.3	3.1	98.2	3.1	3.18	2.6	97.3
		2	26.8	27.1	1.1	98.6	27.1	27.6	1.8	98.5
		3	90.3	91.3	1.1	97.4	90.9	89.7	-1.3	98.3
		4	15.2	5.4	1.3	98.5	15.4	15.2	-1.3	97.5
		5	14.6	14.8	1.4	98.6	14.1	13.7	-2.8	99.1
		Sum	150.1	151.9	1.2		150.6	149.4	-0.8	

PD = Plan dose in radiation therapy planning system
MD = Measurement dose using the ionization chamber
ΔD = {(MD/PD)-1} × 100
γ_{EBT} = Gamma pass using the EBT3 film
γ_M = Gamma pass using the MapCHECK2

All measurement results were obtained within ± 3%. For the conventional measurement method, the absolute dose error was 0.33 ± 1.66%, ranging from −2.7% to 3.5%. The relative dose measurement using the EBT3 film was 98.33 ± 0.79%, ranging from 95.8% to 99.9%. Fig. 6 shows box plots describing the measurement results. No significant difference was found between the values obtained from conventional measurement and

Table 4. Relative and absolute doses in IMRT using linac for abdomen and pelvic region.

PT. No.	Treatment Site	Filed	Conventional method				Multi-purpose phantom			
			P_D (cGy)	M_D (cGy)	ΔD(%)	γ_{EBT}% (3mm, 3%)	P_D (cGy)	M_D (cGy)	ΔD(%)	γ_M% (3mm, 3%)
11	Stomach	1	75.1	76.1	1.3	97.1	74.8	74.7	-0.1	99.3
		2	16.8	17.2	2.4	98.3	16.6	16.2	-2.4	99.8
		3	38.9	38.2	-1.8	97.6	39.4	39.4	0.0	98.7
		4	37.2	38.1	2.4	98.1	37.1	37.1	0.0	99.1
		5	32.2	33.1	2.8	98.6	36.1	35.6	-1.4	98.6
		Sum	200.2	202.7	1.2		204.0	203	-0.5	
12	Prostate	1	5.2	5.1	-1.3	96.7	5.1	52.0	2.0	98.1
		2	53.5	52.3	-2.2	97.3	53.8	54.7	1.7	98.7
		3	46.3	45.2	-2.4	98.3	46.3	47.2	1.9	100
		4	19.1	19.0	-0.5	97.3	18.7	19.2	2.7	98.2
		5	12.3	12.6	2.4	98.5	12.4	12.6	1.6	99.1
		6	45.7	44.9	-1.8	97.9	45.9	46.3	0.9	97.9
		7	17.8	17.6	-1.1	99.2	17.9	18.4	2.8	98.1
		sum	199.9	196.7	-1.6		200.1	203.6	1.7	
13	Prostate	1	16.1	15.8	-1.9	97.3	15.9	15.6	-1.9	99.4
		2	19.3	18.8	-2.6	97.1	19.5	19.1	-2.1	99.3
		3	60.3	59.8	-0.8	98.6	60.4	59.1	-2.2	98.9
		4	30.9	31.4	1.6	98.1	30.9	30.5	-1.3	99.1
		5	26.3	26.9	2.3	98.5	26.3	26.5	0.8	98.4
		6	27.2	27.6	1.5	97.5	26.7	27.3	2.2	99.7
		7	19.8	20.2	2.0	98.6	20.3	20.7	2.0	97.9
		sum	199.9	200.5	0.3		200.0	198.8	-0.6	
14	Cervix	1	5.4	5.5	1.9	97.5	5.5	5.4	-1.8	98.1
		2	31.9	31.1	-2.5	98.4	31.8	31.6	-0.6	98.7
		3	32.4	31.8	-1.9	98.2	32.1	32.6	1.6	98.7
		4	25.5	25.4	-0.4	97.8	24.4	23.9	-2.0	99.1
		5	26.3	25.8	-1.9	99.1	26.4	27.1	2.7	99.2
		6	30.1	30.4	1.0	97.4	31.3	31.1	-0.6	98.0
		7	28.3	29.1	2.8	98.2	28.6	28.9	1.0	99.1
		Sum	179.9	179.1	-0.4		179.9	180.6	0.4	
15	Cervix	1	5.3	5.24	-1.1	95.8	5.2	5.3	1.9	97.6
		2	31.9	31.4	-1.6	97.5	33.7	33.2	-1.5	98.8
		3	43.2	43.7	1.2	98.6	42.1	42.7	1.4	98.7
		4	20.1	19.6	-2.5	98.3	20.1	19.7	-2.0	100
		5	16.2	15.9	-1.9	99.3	17.5	17.9	2.3	99.6
		6	40.3	40.8	1.2	99.7	39.7	40.2	1.3	99.7
		7	23.1	22.8	-1.3	97.3	21.7	22.1	1.8	99.8
		Sum	180.1	179.4	-0.4	98.5	180	181.1	0.6	

P_D = Plan dose in radiation therapy planning system
M_D = Measurement dose using the ionization chamber
$\Delta D = \{(M_D/P_D)-1\} \times 100$
γ_{EBT} = Gamma pass using the EBT3 film
γ_M = Gamma pass using the MapCHECK2

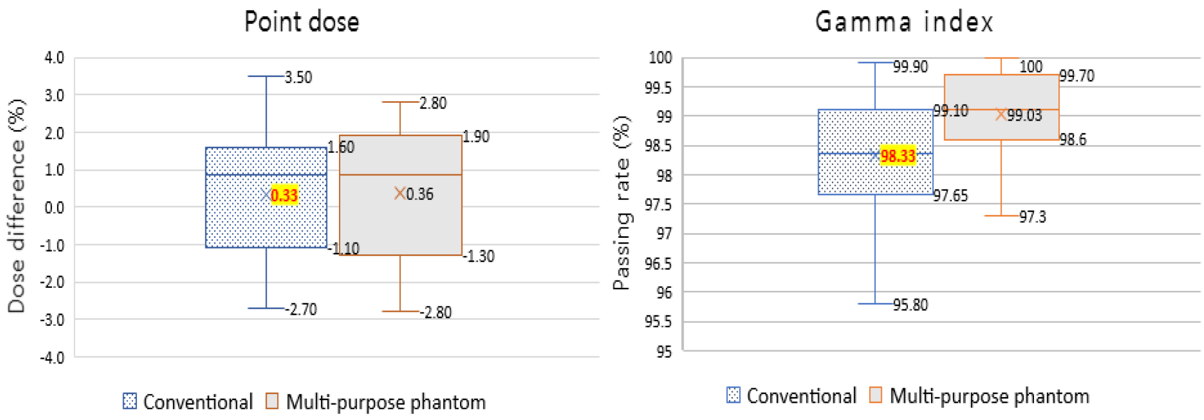

Fig. 6. (Color online) Point dose (absolute dose) and gamma analysis (relative dose) for IMRT in linac.

Table 5. Relative and absolute doses in IMRT using tomotherapy.

PT. No.	Treatment Site	F. W	Pitch	M.F	TD (cGy)	Conventional method PD (cGy)	Conventional method MD (cGy)	Conventional method ΔD(%)	Conventional method γ_{EDR} % (3 mm, 3%)	Multi-purpose phantom PD (cGy)	Multi-purpose phantom MD (cGy)	Multi-purpose phantom ΔD(%)	Multi-purpose phantom γ_M % (3 mm, 3%)
1	Brain	2.50	0.287	2.5	225	139.7	140.5	0.6	98.2	164.3	166.7	1.5	99.5
2	Brain	2.50	0.287	2.3	200	143.8	140.3	-2.4	97.9	159.4	162.3	1.8	99.3
3	Brain	1.05	0.300	2.3	200	136.1	135.5	-0.6	99.1	151.6	154.8	2.1	98.3
4	Brain	1.05	0.300	2.3	200	135.8	139.5	2.7	97.6	151.6	154.8	2.1	98.3
5	Glottic	2.50	0.287	2.3	225	120.3	119.5	-0.7	98.6	138.1	137.4	-0.5	99.3
6	Glottic	1.05	0.287	2.5	225	145.7	147.2	1.0	98.2	156.8	159.5	1.8	99.2
7	Mandible	1.05	0.287	2.5	200	156.7	154.8	-1.2	97.2	134.3	134.7	0.3	99.3
8	Neck	2.50	0.287	2.5	225	173.5	175.6	1.2	98.5	182.5	185	1.4	98.8
9	Lung	2.50	0.287	2.5	200	156.8	153.5	-2.1	98.5	163.5	160.9	-1.6	97.9
10	Lung	2.50	0.287	2.3	300	240.6	246.2	2.3	97.3	243.1	247.5	1.8	99.1
11	Breast	5.02	0.287	2.5	250	191.2	195.3	2.1	99.1	215.1	219.6	2.1	97.1
12	Breast	5.02	0.287	2.5	250	180.3	183.2	1.6	98.5	215.1	219.6	2.1	97.1
13	Adrenal	2.50	0.287	2.0	200	161.5	160.5	-0.6	97.5	174.9	179.6	2.7	97.9
14	Pelvis	5.02	0.287	2.5	400	364.8	370.5	1.6	98.7	398.0	406.1	2.0	99.1
15	Rectum	2.50	0.287	2.5	230	213.2	210.8	-1.1	97.6	240.1	239.6	-0.2	98.4
16	Prostate	2.50	0.287	2.5	220	198.5	196.5	-1.0	97.3	216.2	219.2	1.4	99.7
17	Prostate	2.50	0.287	2.5	235	212.4	210.3	-1.0	98.2	234.6	236.7	0.9	98.7
18	Prostate	2.50	0.287	2.5	235	213.2	210.4	-1.3	98.7	234.2	238.2	1.7	99.8
19	Rectum	2.50	0.287	2.5	200	195.2	193.2	-1.0	98.3	220.5	225.4	2.2	97.8
20	EM	2.50	0.287	2.5	200	182.6	180.2	-1.3	97.3	214.6	218.5	1.8	99.0

F.W = Field width (cm)
M.F = Modulation factor, longest leaf opening time in a plan divided by the average opening time of all nonzero leaf opening times.
TD = Treatment dose
PD = Plan dose in radiation therapy planning system
MD = Measurement dose using the ion chamber
$\Delta D = \{(MD/PD)-1\} \times 100$
γ_{EDR} = Gamma pass using the EDR2 film
γ_M = Gamma pass using the MapCHECK2

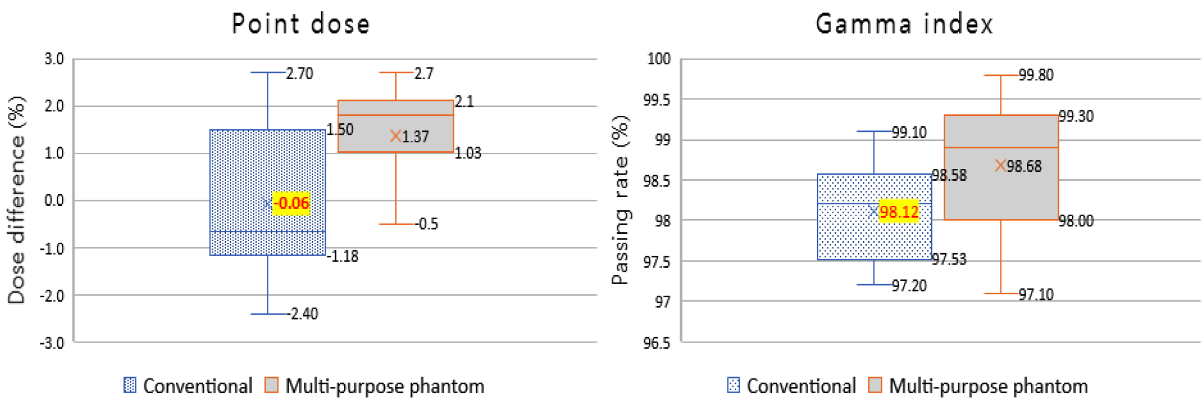

Fig. 7. (Color online) Point dose (absolute dose) and gamma analysis (relative dose) for IMRT in tomotherapy.

measurement using the proposed multipurpose phantom. Table 5 lists the DQA results for tomotherapy. The absolute dose measured using the multipurpose phantom was 1.37 ± 1.05%, ranging from −1.6% to 2.7%.

For the gamma evaluation, the relative dose measurement was 98.68 ± 0.78%, ranging from 97.1% to 99.8%. All the measurements had error below 3%. The absolute dose measurement error using the existing cheese phantom was −0.06 ± 1.5%, ranging from −2.4 to 2.7%. The gamma evaluation result was 98.1 ± 0.60%, ranging from 97.2% to 99.1%. Fig. 7 shows box plots describing the measurement results. No significant difference was found between the values obtained from conventional measurement and measurement using the multipurpose phantom.

4. Discussion

Conventional measurements for IMRT DQA involve relative dosimetry using a film and absolute dosimetry using an ionization chamber [8, 9, 17]. They are time consuming and require skilled operators to obtain high accuracy. Therefore, a simpler DQA method was required. The simultaneous evaluation of relative and absolute doses using films has been reported [18]. Despite the high resolution of radiation measurement films, they require a separate development process. The Gafchromic film does not require such development, but real-time measurement is difficult because the film should be scanned after a period [19]. In addition, pixel calibration is required, and accurate measurement of the absolute dose is difficult owing to large variations depending on the development conditions [11].

Film measurements are influenced by the scan mode, being necessary to correct for distortions that occur along and perpendicular to the scanning direction owing to the non-uniformity and scattering of the scan light source. In addition, films are sensitive to temperature and humidity, hindering their handling and management [20, 21]. Compared with films, 2DADs are easier to handle and enable real-time measurement while avoiding development and waiting times. However, an array of diode detectors is 7-14 mm, providing a lower resolution than films, and the absolute dose is difficult to evaluate using 2DADs.

In a previous study, DQA of IMRT was performed using a Gafchromic film and a 2DAD, but it the analysis was limited to demonstrating its usefulness feasibility through relative dose comparisons [22, 23]. It remained necessary to measure doses using an ionization chamber to evaluate the absolute dose. The proposed multipurpose phantom can simultaneously measure relative and absolute doses. Using the phantom, IMRT DQA using linac and tomotherapy was performed. For the relative dose, gamma evaluation (γ index) was performed to quantitatively determine whether the dose distribution calculated during treatment planning agrees with the measured dose distribution. Gamma evaluation is usually 3 mm/3% [8, 9, 17]. Gamma evaluation results using the multipurpose phantom were measured considering 3 mm/3%, obtaining 99.03 ± 0.69% in linac and 98.68 ± 0.78% in tomotherapy. Film measurement using a conventional method provided results of 98.33 ± 0.79% in the linac and 98.1 ± 0.6% in tomotherapy. The absolute dose was 0.35 ± 1.74% in the linac and 1.37 ± 1.05% in tomotherapy. Thus, linac and tomotherapy were within 3% of measurement error. IMRT DQA for linac and tomotherapy using the proposed multipurpose phantom is accurate for the relative and absolute doses that are simultaneously acquired. The multipurpose phantom may support DQA and can be fabricated and used considering different shapes or functions. If the phantom production is combined with next-generation technologies such as 3D printing, its applicability may be expanded.

In this study, an ionization chamber was used for absolute dosimetry, but various methods are available to measure the absorbed dose, such as glass dosimeters. These methods should be explored with the multipurpose phantom, and DQA standardization may be eventually achieved for radiation therapy. The standard measurement methods for DQA of IMRT are relative dosimetry using a film and absolute dosimetry using an ionization chamber

5. Conclusion

A multipurpose phantom is introduced to measure relative and absolute doses accurately and simultaneously for DQA before IMRT. The multipurpose phantom provides fast and simple measurements, reducing the execution time of DQA to less than half. Moreover, it can be applied to a linac and tomotherapy. The planned treatment dose and measured absolute dosimetry error were less than 3%. The two-dimensional dose distribution, which is a relative dose, and the gamma index passing through the permissible standard of 3 mm/3% were above 97%, satisfying the required standard. Overall, multi-purpose phantoms made of PMMA-based resin seem suitable for IMRT DQA and may support radiation therapy.

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