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Assessment of dosimetric and mechanical quality assurance using KIRAMS phantom for Gamma Knife radiosurgery

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Assessment of dosimetric and mechanical quality assurance using KIRAMS phantom for Gamma Knife radiosurgery

Directed by Professor Jin Sung Kim

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ABSTRACT

Assessment of dosimetric and mechanical quality assurance using KIRAMS phantom for Gamma Knife radiosurgery

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Gamma Knife (GK) is a radiosurgery equipment with 192 or 201 Cobalt-60 (^{60}Co) sources, placed in a symmetrical hemispherical configuration, that simultaneously focus high-dose gamma rays on intracranial lesions to treat tumors. So, the quality assurance (QA) for GK is essential for ensuring that target radiation doses reach intended sites.

At domestic institutions that installed GK, Elekta GK tools are utilized for QA purposes. However, these are associated with problems, such as cost. For film dosimetry, the tool cannot conduct axial plane measurement and cannot verify the accuracy of calculated film center. Thus, a new GK QA tools are needed to address these limitations.

This study aimed to assess the performance of the new GK tools, fabricated by Korea Institute of Radiological & Medical Science (KIRAMS), in terms of QA to present it as a new QA tools. To evaluate the performance, we compared it with Elekta GK tools in terms of five QA items: output, time linearity, time error, dose profile and beam accuracy. As a results, the KIRAMS GK tools yielded similar QA results to the Elekta GK tools, so we expect that the KIRAMS GK tools to be a feasible new alternative to the Elekta GK tools.

Keywords: Radiosurgery, Gamma Knife, Quality Assurance, Acrylonitrile Butadiene Styrene

Assessment of dosimetric and mechanical quality assurance using KIRAMS phantom for Gamma Knife radiosurgery

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I. INTRODUCTION

Gamma Knife (GK) is a non-invasive stereotactic radiosurgery equipment that delivers gamma rays from 192 or 201 Cobalt-60 (^{60}Co) sources to lesions in the skull depending on the model [1,2]. It was first developed by Leksell in 1968 and has been continuously advanced (Figure 1)[3]. As GK delivers high dose to the lesion site, periodic quality assurance (QA) is essential to ensure the accurate delivery of the planned dose to the intended site.

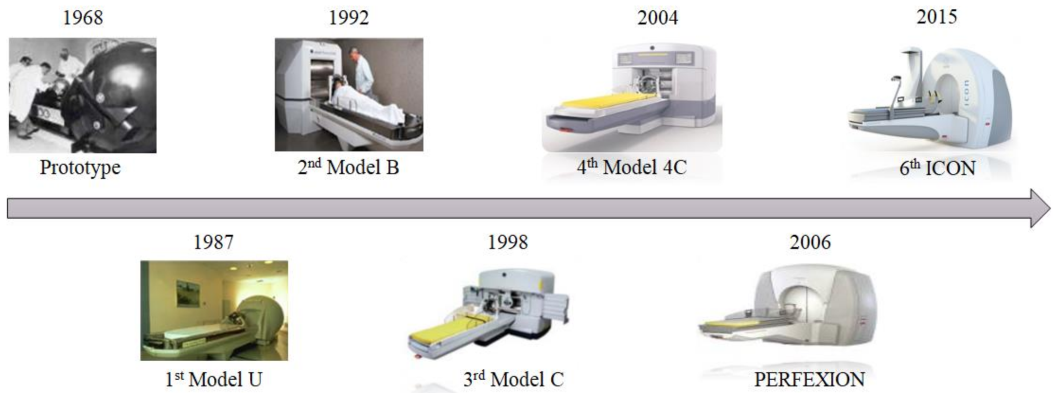


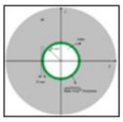
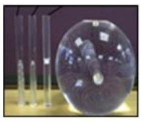
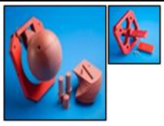
Figure 1. The history of Gamma Knife models.

In 1995, the American Association of Physicists in Medicine (AAPM) published Task Group Report 42 (TG-42) recommending inspection cycles and tolerance of QA items for GK[4]. In 2003, based on the AAPM TG-42, Seo et al. presented QA guidelines appropriate for apply in Korea[5]. In 2021, AAPM published TG-178, a second report including updated information on the latest models developed after TG-42 report [6].

Currently, in Korea, 22 GK devices are installed for radiosurgery, including three Model C, nine PERFEXION, and ten ICON. The institutions use Elekta GK QA tools, which consists of a dosimetry phantom and film holder. The dosimetry phantom is composed of solid water material and is used to measure the absorbed dose to water with ionization chamber (IC), and the film holder is used to evaluate the dose profile and beam accuracy.

However, Elekta GK QA tools have several limitations, and several studies have attempted to address these limitations (Table 1). First, the cost is expensive because the dosimetry phantom is composed of solid water material. To compensate for this limitation, the effects of several phantom materials was assessed via Monte Carlo simulation by Zhu et al.,[7] and the usefulness of the phantom composed of Polymethyl metacrylate(PMMA) and acrylic material was evaluated by JP Chung et al.[8] and Costa et al.,[9] respectively.

Table 1. Previous studies for Gamma Knife phantom material.

	Zhu et al[7]	Chung.JP et al[8]	Costa et al[9]	Elekta	KIRAMS
Phantom					
Material	PMMA[a)] Plastic water Polystyrene	PMMA	Acrylic	Solid water	ABS[b)]
Measurement tool	Exradin- A16	PTW31010 EBT3 film	PTW31010 PTW31016 Exradin- A16	PTW31010 EBT3 film	PTW31010 EBT3 film
Output	O	O	O	O	O
Profile	X	O	X	O	O
Accuracy	X	X	X	O	O

a) Polymethyl metacrylate (PMMA)
b) Acrylonitrile Butadiene Styrene (ABS)

Next, the Elekta film holder can only measures on the sagittal (y-z) and coronal (x-z) planes and cannot measure the axial (x-y) plane. Additionally, for beam accuracy evaluations, a pinhole in the film center is considered a specific point in the treatment space, called the Unit Center Point (UCP). But, there are no methods to verify the reliability of this point.

In summary, the Elekta GK QA tools have three limitations, and to our knowledge, no previous studies have addressed all of these limitations. A new GK QA tool that overcomes these drawbacks is needed.

Recently, the Korea Institute of Radiological & Medical Science (KIRAMS) fabricated a multi-purpose GK phantom made of Acrylonitrile Butadiene Styrene (ABS) plastic to overcome the limitations of existing GK QA tools. Thus, this study aimed to assess the performance of the KIRAMS GK tools in terms of QA and to present it as a new GK QA tools that improved the limitations of Elekta GK QA tools.

II. BACKGROUNDS

II. 1. General formula to determine the absorbed dose to water

Since the 1980s, the AAPM and the International Atomic Energy Agency (IAEA) has continuously presented formulas used to determine the absorbed dose to water using values measured with an ionization chamber. The AAPM TG-21 (in 1983) and IAEA Technical Reports Series 277 (TRS-277) (in 1997) recommended the following formula (1) based on air kerma calibration coefficient [10,11].

$$D_w\ (Gy) = M \times N_K(1-g) \times \left(\frac{S}{\rho}\right)_{air}^{w} \times k_{others} \tag{1}$$

where, D_w is the absorbed dose to water, M is the charge value measured by ionization chamber, N_K is the calibration coefficient in terms of absorbed dose to air for an ionization chamber at the reference beam quality (Q_0), g is the fraction of energy of secondary charged particles that is lost to bremsstrahlung in a ^{60}Co beam, $\left(\frac{S}{\rho}\right)_{air}^{w}$ is the ratio of stopping powers in water and air, and k_{others} is the correction factor for environmental influences such as temperature, pressure, and the effect of polarity and ion recombination.

Subsequently, as the ionization chamber was directly calibrated in water, TG-51 (in 1999) and TRS-398 (in 2000) recommended formula (2) based on calibration coefficient for absorbed dose to water [12,13].

$$D_w\ (Gy) = M \times N_{D,w,Q_0} \times k_{Q,Q_0} \times k_{others} \tag{2}$$

where, N_{D,w,Q_0} is the calibration coefficient in terms of absorbed dose to water for an ionization chamber, k_{Q,Q_0} is the beam quality correction factor for the difference between the reference beam quality at standards laboratory and the beam quality (Q) of the conventional reference field (f_{ref}), and the others symbols are mentioned above.

In 2008, Alfonso et al. proposed the correction factor for difference in field size between calibration and experiment conditions. Based on this, TRS-483 (in 2017) and TG-178 (in 2021) recommended formula (3) [6,14,15].

$$D_w\ (Gy) = M \times N_{D,w,Q_0} \times k_{Q,Q_0} \times k_{others} \times k_{Q_{msr},Q}^{f_{msr},f_{ref}} \tag{3}$$

where, $k_{Q_{msr},Q}^{f_{msr},f_{ref}}$ is the correction factor for the differences of the field size, geometry and phantom material, and the difference between beam quality of conventional reference field and machine-specific reference beam quality (Q_{msr}) of the machine-specific reference field (f_{msr}).

In this study, k_{others} was calculated using the following formula (4):

$$k_{others} = P_{TP} \times P_{ion} \times P_{pol} \tag{4}$$

where, P_{TP} is the correction factor for temperature and pressure, P_{ion} is the correction factor for the ion recombination effect, and P_{pol} is the correction factor for polarity effect, and these correction factors were calculated through the following equations (5 to 7):

$$P_{TP} = \frac{273.2 + T}{293.2} \times \frac{101.33}{P} \tag{5}$$

where, T is the temperature and P is the pressure at the experimental environment.

$$P_{ion} = \frac{1 - \left(\frac{V_H}{V_L}\right)^2}{\frac{M_H}{M_L} - \left(\frac{V_H}{V_L}\right)^2} \tag{6}$$

where, M_H and M_L are the raw ionization chamber readings when high voltage (V_H) and low voltage (V_L) are applied, respectively.

$$P_{pol} = \left| \frac{M^+ - M^-}{2M^+} \right| \quad (7)$$

where: M^+ and M^- are the raw ionization chamber readings when positive voltage and negative voltage are applied, respectively.

II. 2. Film dosimetry

In addition to the ionization chamber, a radiochromic film is used for dosimetry[15)]. Radiochromic films have a high spatial resolution and can measure two-dimensional (2D) dose distribution. However, HD-810- and MD-55-model radiochromic films used in the early 2000s had limitations, such as low sensitivity, lack of uniformity, limited film size, and high cost[16-20)]. To overcome these issues, a new model, EBT film, was introduced in 2004[21)].

Radiochromic films darken as the irradiation dose increases. So, a dose-response calibration curve is applied to convert the film intensity to the absorbed dose. This curve is calculated based on optical density (OD) or pixel value (PV). OD is calculated using formula (8) at 16 bit:

$$\text{OD} = log_{10}\left(\frac{Max.PV \;\; at \;\; 16 \;\; bit}{PV} \right) \quad (8)$$

where, $(Max.PV$ at 16 bit$)$ $= 2^{16}$-1

II. 3. Gamma Knife characteristics

Since the delivery of gamma rays emitted from radiation source is controlled by collimator, the opening time of the collimator is a variable that directly affects the delivered dose. Therefore, the linearity and error of collimator-open time are checked when performing QA.

Also, it is important to check that beam accurately irradiates the intended site because GK is supposed to emit high doses to small lesions. This is evaluated by comparing UCP and Radiation Focal Point (RFP) (Figure 2). For evaluating beam accuracy, EBT3 film is recommended since it has a high spatial resolution and is suitable for measuring the dose distribution of GK's small field[22].

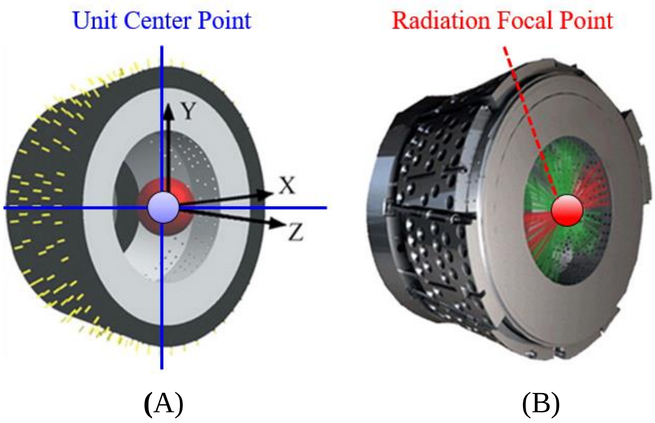


Figure 2. Pictorial description for the UCP (A) and RFP (B) of the Gamma Knife.

III. MATERIALS AND METHODS

III.1. Experiment materials

III.1.a. Gamma Knife equipment

This study used four GK: three ICON and one PERFEXION. The detailed specification of each GK are shown in Table 2. The initial dose rate means the dose rate at installation, and the decayed dose rate means the dose rate during the experiments.

Table 2. Specification of Gamma Knife used in this study.

Institution	GK[a] model	Number of ^{60}Co	CBCT[b]	Initial dose rate (Gy/min)	Decayed dose rate (Gy/min)
A	ICON	192	O	3.492	3.291
B	ICON	192	O	3.252	3.053
C	PERFEXION	192	X	3.790	1.117
D	ICON	192	O	3.279	3.149

[a] Gamma Knife (GK)
[b] Cone-beam computed tomography (CBCT)

III.1.b. Gamma Knife phantom

The KIRAMS GK phantoms consist of one outer phantom and two exchangeable inner phantoms. As recommended in IAEA TRS-483 Table 11, the outer phantom is hemispherical with a diameter of 16 cm and has an internal space for inserting an inner phantom[14)]. The inner phantom has two components: an ionization chamber holder and film holder. The ionization chamber holder is cylindrical and has an inner space to fit the size of the ionization chamber used in the experiment, and it is inserted into the outer phantom with a holder jig. The film holder is cubic with dimensions of 8×8×8 cm^3. The film holder has a central internal space for placing a film (Figure 3).

Outer phantom	Ionization chamber holder & holder jig	Film holders

Figure 3. The Gamma Knife phantoms designed by KIRAMS.

III.1.c. Measurement tool (Figure 4)

A PTW31010 (Semiflex) ionization chamber recommended in TG-178 was used to measure the absorbed dose with PTW UNIDOS^{webline} electrometer and detector extension cable. An EBT3 film was used for film dosimetry.

III.1.d. Supplementary tool (Figure 4)

① Digital thermometer and barometer

The digital thermometer and barometer were used to calculate the correction factor for temperature and pressure, respectively.

② Film punch tool and scanner

A customized film punch tool was fabricated for films that fit the film holder of KIRAMS (Figure 4). With this tool, three films (6×6 cm^2) with three holes (0.5 cm in diameter) at edge the film are made. An EPSON 10000XL scanner was used for film scanning.

Measurement tool				
	Semiflex ionization chamber		EBT3 film	
Supplementary tool				
	Digital thermometer	Digital barometer	Film punch tool	Scanner

Figure 4. Measurement and supplementary tools used in this study.

III.2. QA items

Table 3 shows the GK QA items and tolerance in Korea. Among these items, four dosimetric QA items (output, time linearity, time error, dose profile) and one mechanical QA item (accuracy) were chosen for performance evaluation of KIRAMS GK tools.

Table 3. QA items and tolerance for Gamma Knife in Korea.

	QA item	Period	Tolerance
Dosimetric QA	Output	Monthly	±3%
	Time linearity	Monthly	±1%
	Time error	Monthly	±0.6 seconds
	Leakage radiation test	Monthly	≤200 Bq
	Dose profile	Annual	FWHM[a] within 1 mm
Mechanical QA	Trunnion centricity	Monthly	±0.5 mm
	Helmet microswitches	Monthly	±0.1 mm
	Accuracy	Annual	±0.3 mm
Safety QA	Radiation monitors	Daily	Functional
	Door interlock	Daily	≤0.5 cm
	Emergency button	Monthly	Functional

[a] Full Width at Half Maximum (FWHM)

III.2.a. Dosimetric QA

① Output

The output was measured for a minute by inserting the Semiflex ionization chamber into the KIRAMS and Elekta dosimetry phantom, respectively, and measurements were conducted three times each. The collimator size and electrometer were set to 16 mm and 400 V, respectively. The dose was calculated based on formula (9) recommended by IAEA TRS-483 and AAPM TG-178:

$$D_w\ (Gy) = M \times N_{D,w,Q_0} \times k_{Q,Q_0} \times k_{others} \times \left(k_{Q_{msr},Q}^{f_{msr},f_{ref}}\right)_{ABS} \quad (9)$$

where, N_{D,w,Q_0} was 0.3016 provided at secondary standard dosimetry laboratory (SSDL), and k_{Q,Q_0} was 1.0. k_{others} was calculated for each experimental condition. To check ion-recombination effect and polarity effect, M_H, M_L were set to 400 V, 200 V and M^+, M^- were set to 400 V, -400 V, respectively.

Lastly, the correction factor $\left(k_{Q_{msr},Q}^{f_{msr},f_{ref}}\right)_{ABS}$ for ABS plastic was suggested by IAEA TRS-483 and AAPM TG-178 as 1.0146. However, in our study, we did not apply the suggested value for two reasons. First, the direction of the ionization chamber insertion was different. Herein, the ionization chamber was inserted in a parallel direction, but the value suggested by IAEA TRS-483 and AAPM TG-178 was obtained in a perpendicular direction. In studies by Sheridan et al. and Mirzakhanian et al., there was approximately 2% difference according to the insertion direction of the ionization chamber[23,24]. Second, ABS plastic may have different densities depending on the manufacturer[14,25]. For these reasons, several studies by different groups, including Johansson et al., calculated

$\left(k_{Q_{msr},Q}^{f_{msr},f_{ref}}\right)_{ABS}$ value based on Monte Carlo simulation (Table 4) . In this study, we newly calculated the correction factor based on the ratio of values measured using the Elekta dosimetry phantom and KIRAMS phantom, instead of using Monte Carlo simulation.

Table 4. Previous studies for the correction factor for ABS material.

Year	Author	Monte Carlo code	Direction of ionization chamber	$\left(k_{Q_{msr},Q}^{f_{msr},f_{ref}}\right)_{ABS}$
2012	Johansson et al[26)]	PENELOPE	Perpendicular	1.0146
2017	IAEA TRS-483[14)]	PENELOPE	Perpendicular	1.0146
2017	E Zoros et al[27)]	EGSnrc	Perpendicular	1.0220
2018	Mirzakhanian et al[24)]	EGSnrc	Parallel / Perpendicular	1.0058 / 1.0240
2018	Thomas et al[28)]	Geant4	Parallel	1.0020
2021	AAPM TG-178[6)]	PENELOPE	Perpendicular	1.0146

② Time linearity

For this evaluation, the expose time was set to 1,3 and 5 minutes, the collimator size was 16 mm, and measurements using ionization chamber were repeated three times each. The time linearity was calculated according to the following formula (10):

$$T_L = \left[\frac{\left({dD}/{dt}\right)_{max}}{\left({dD}/{dt}\right)_{min}} - 1\right] \times 100(\%) \tag{10}$$

where, T_L is the time linearity(%) and $\left({dD}/{dt}\right)$ is the dose rate for difference time.

③ Time error

Since the GK has leakage radiation from the collimator gaps, the effect of this leakage must be compensated for dosimetry. The error caused by this leakage radiation is called the time error. In this study, the time error was calculated through the measured values at 1 and 3 minutes at a collimator 16 mm, as shown in formula (11):

$$\delta t = \frac{3 \times AD_1 - AD_3}{AD_3 - AD_1} \quad (11)$$

where, δt is the time error (seconds), and AD_1 and AD_3 are the mean dose value for 1 and 3 minutes, respectively.

④ Dose profile

The dose distribution was obtained for all collimator size (4,8, and 16 mm) and 4 Gy was irradiated into the film center. The measured film was scanned by an EPSON 10000XL at 400 dots per inch (dpi). The scanned images were analyzed by a film analysis code developed in this study, and the film intensity was converted to absolute dose by dose-response calibration curve that was obtained by irradiating 0.5, 1.0, 2.0, 3.0, 4.0, 6.0 and 8.0 Gy at collimator 16 mm on the coronal (x-z) plane. The full width at half maximum (FWHM) of dose profile, based on RFP, was calculated using following formula (12):

$$\text{FWHM} = (P_2 - P_1) \times s \quad (12)$$

where, P_1 and P_2 are pixel value roughly corresponding to the FWHM, s (mm/pixel) is the length per pixel. In this study, s was 0.0635 (mm/pixel).

III.2.b. Mechanical QA

① Accuracy

This item was evaluated through the agreement between UCP and RFP. The dose distribution was acquired by irradiating 4 Gy into film center at collimator 4 mm. The UCP and RFP were calculated by the developed analysis code, and the difference between them was calculated based on formula (13):

$$\Delta\gamma = \sqrt{\Delta X^2 + \Delta Y^2 + \Delta Z^2} \quad (13)$$

where, $\Delta\gamma$ is the final difference between UCP and RFP, and ΔX, ΔY and ΔZ are the difference on each axis.

III.3. Development for film analysis code

We needed a new analysis method to fit the KIRAMS film type, so we developed the integrated code using MATLAB. In this study, the dose profile and beam accuracy were analyzed by this MATLAB code, whose flowchart is shown in Figure 5. The time obtained results varies by collimator size: within 5 seconds for collimator 4 mm, 5-10 seconds for 8 mm and 10-20 seconds for 16 mm.

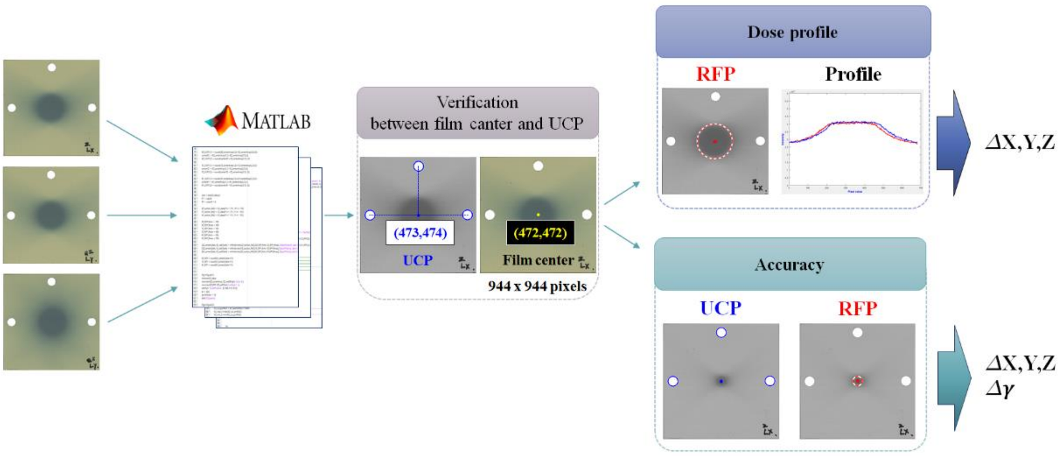


Figure 5. Flowchart of the film analysis code.

IV. RESULTS

IV. 1. Dosimetric QA result

For accurate dose measurements, it is important to check that the reference point of the ionization chamber is precisely placed at UCP. The point of Semiflex ionization chamber was 4.5 mm from the chamber tip. After inserting the ionization chamber into KIRAMS phantom, the CT images were acquired using cone-beam computed tomography (CBCT) attached only to the ICON model, and we confirmed that the reference point was placed at UCP (Figure 6).

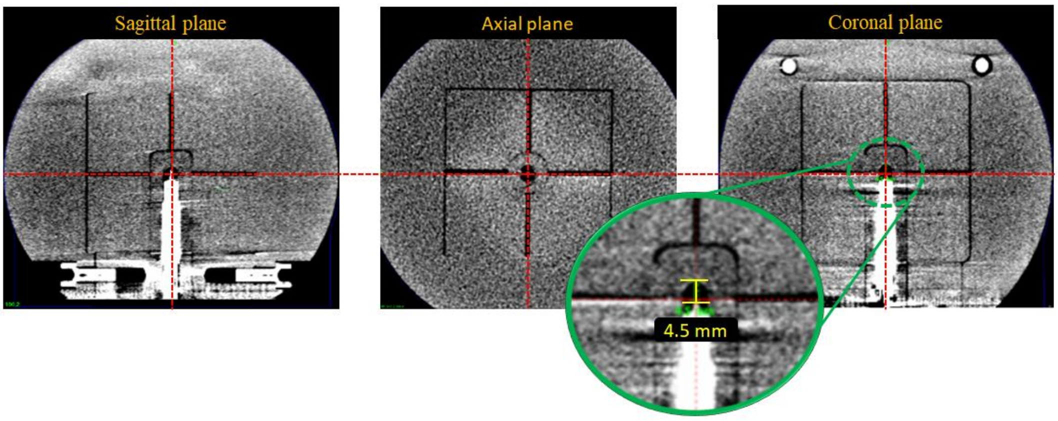


Figure 6. The CBCT images for checking the position of ionization chamber inserted in the KIRAMS GK phantom.

① Output

In this study, the calculated correction factor $\left(k^{f_{msr},f_{ref}}_{Q_{msr},Q}\right)_{ABS}$ was 1.0028, and the dose for KIRAMS GK phantom was calculated through this value. As a result, the output was 3.308 Gy (A), 3.137 Gy (B), 1.120 Gy (C), and 3.164 Gy (D) for KIRAMS phantom. The differences from the dose calculated using the treatment planning system (TPS) were less than 1% except at institution B: 0.52% (A), 2.75% (B), 0.27% (C), 0.48% (D). All results were within domestic tolerance. On the other hand, the dose for Elekta phantom was similar to the TPS dose, with error less than 0.4%.

Table 5. Output results for KIRAMS and Elekta phantoms.

Institution	Dose (Gy)			Difference		Tolerance	
	KIRAMS	Elekta	TPS	KIRAMS vs TPS	Elekta vs TPS	Korea	TG-178
A	**3.308**	3.294	3.291	**0.52%**	0.09%	± 3%	± 1.5%
B	**3.137**	3.056	3.053	**2.75%**	0.10%		
C	**1.12**	1.121	1.117	**0.27%**	0.36%		
D	**3.164**	3.144	3.149	**0.48%**	-0.16%		

② Time linearity

The time linearity results for KIRAMS and Elekta GK phantoms are shown in Table 6. Time linearity for both KIRAMS and Elekta GK phantoms were less than 0.5%, satisfying domestic and TG-178 tolerance.

Table 6. Time linearity results for KIRAMS and Elekta phantoms.

Institution	Time linearity		Tolerance	
	KIRAMS	Elekta	Korea	TG-178
A	**0.15%**	0.19%	± 1.0%	± 1.0%
B	**0.46%**	0.33%		
C	**0.26%**	0.41%		
D	**0.37%**	0.26%		

③ Time error

Table 7 shows the time error results calculated by applying KIRAMS and Elekta dosimetry phantoms. Both sets of results satisfied domestic and TG-178 tolerance. Interestingly, the units are in the negative values despite the unit being in seconds. This may be attributable to the self-correction set by the equipment manufacturer with consideration of time error. Excessive correction may result in negative values of time error.

Table 7. Time error results for KIRAMS and Elekta phantoms.

Institution	Time error (seconds)		Tolerance (seconds)	
	KIRAMS	Elekta	Korea	TG-178
A	**-0.07**	-0.15	± 0.6	± 0.6
B	**-0.41**	-0.24		
C	**-0.22**	-0.28		
D	**-0.20**	-0.18		

④ Dose profile

The dose-response calibration curve to convert film value to dose is shown in Figure 7. The FWHM calculated by MATLAB code was compared to reference FWHM provided by TMR10 which is the Elekta dose calculation algorithm. The difference and profile are shown in Table 8 and Figure 8, respectively.

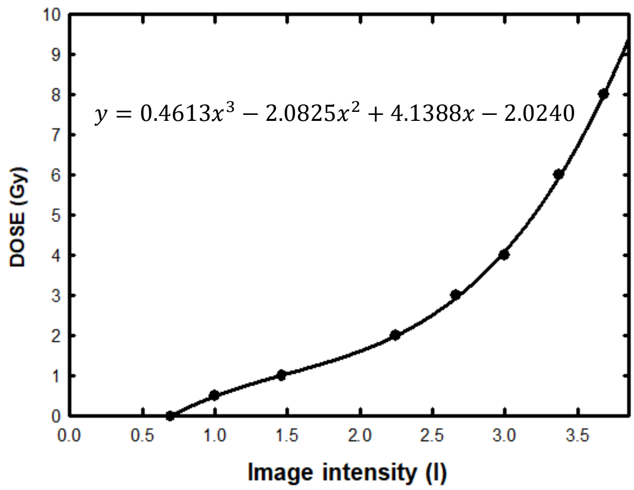


Figure 7. The dose-response calibration curve.

The differences between the MATLAB and reference FWHM were −0.13 to 0.11 mm (x-axis), −0.35 to 0.17 mm (y-axis) and −0.18 to −0.12 mm (z-axis) for collimator 4 mm. For collimator 8 mm, the differences were −0.39 to −0.10 mm (x-axis), −0.32 to 0.22 mm (y -axis), and −0.24 to −0.14 mm (z-axis), and for 16 mm, −0.24 to 0.37 mm (x-axis), −0.55 to 0.34 mm (y-axis) and −0.22 to 0.20 mm (z-axis).

In contrast, the Elekta results were as follows: −0.07 to 0.09 mm (x-axis), −0.14 to 0.16 mm (y-axis) and −0.13 to 0.10 mm (z-axis) for collimator 4 mm, and −0.95 to 0.24

mm and −0.43 to 0.39 mm (x-axis), −0.28 to 0.23 mm and −0.41 to 0.13 mm (y-axis), and −0.12 to 0.10 mm and −0.27 to 0.06 mm (z-axis), respectively, for 8 mm and 16 mm.

The Elekta results tended to have smaller difference from reference than KIRAMS results, but both results satisfied the domestic and TG-178 tolerance.

Table 8. The dose profile analysis results for each collimator size.

Institution	Difference from reference FWHM (mm)						Tolerance	
	KIRAMS			Elekta				
	X	Y	Z	X	Y	Z	Korea	TG-178
Collimator size: 4 mm							± 1mm from reference FWHM	
A	**-0.13**	**-0.35**	**-0.18**	-0.01	-0.14	-0.13		
B	**-0.09**	**-0.09**	**-0.12**	-0.07	-0.08	-0.08		
C	**0.11**	**-0.22**	**-0.12**	0.00	-0.06	-0.06		
D	**0.11**	**0.17**	**-0.15**	0.09	0.16	0.10		
Collimator size: 8 mm								
A	**-0.39**	**-0.32**	**-0.24**	-0.95	-0.28	-0.06		
B	**-0.10**	**-0.16**	**-0.14**	-0.17	-0.09	-0.12		
C	**-0.29**	**0.22**	**-0.24**	-0.03	-0.07	-0.09		
D	**-0.26**	**-0.13**	**-0.17**	0.24	0.23	0.10		
Collimator size: 16 mm								
A	**-0.24**	**-0.55**	**-0.22**	-0.43	-0.41	-0.27		
B	**0.21**	**-0.20**	**0.11**	0.02	-0.13	-0.14		
C	**0.37**	**-0.08**	**0.04**	0.08	-0.20	-0.12		
D	**0.37**	**0.34**	**0.20**	0.39	0.13	0.06		

Collimator size: 4 mm

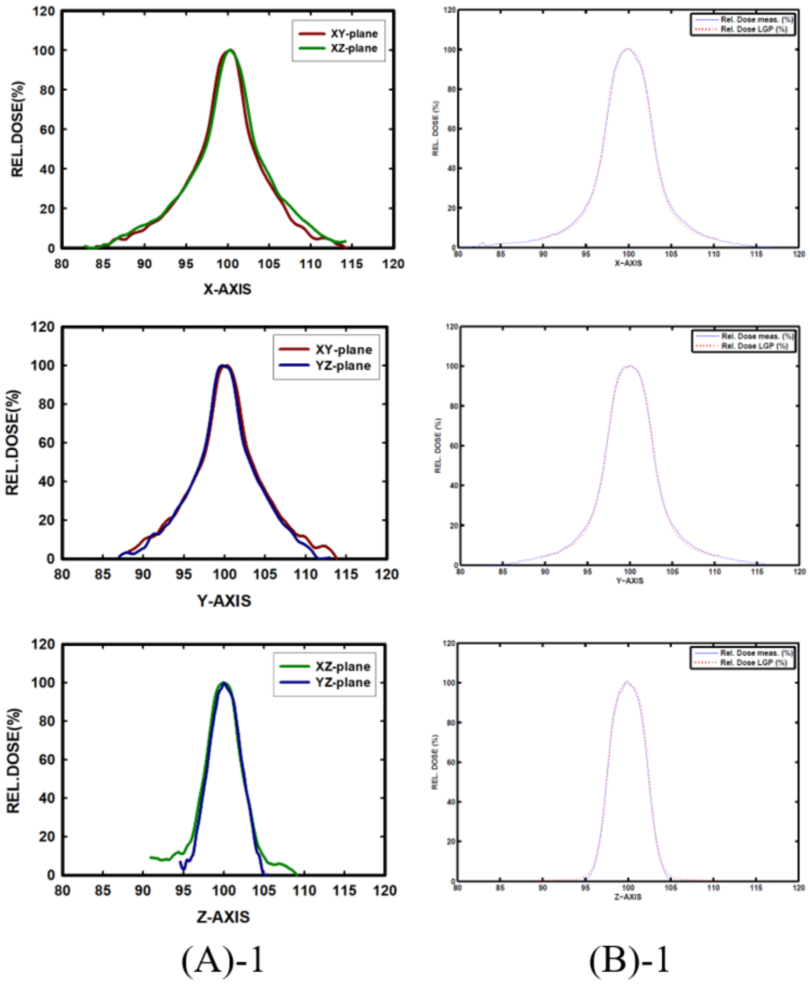


Figure 8-1. The axis dose profile for KIRAMS (A) and Elekta (B) for collimator 4 mm.

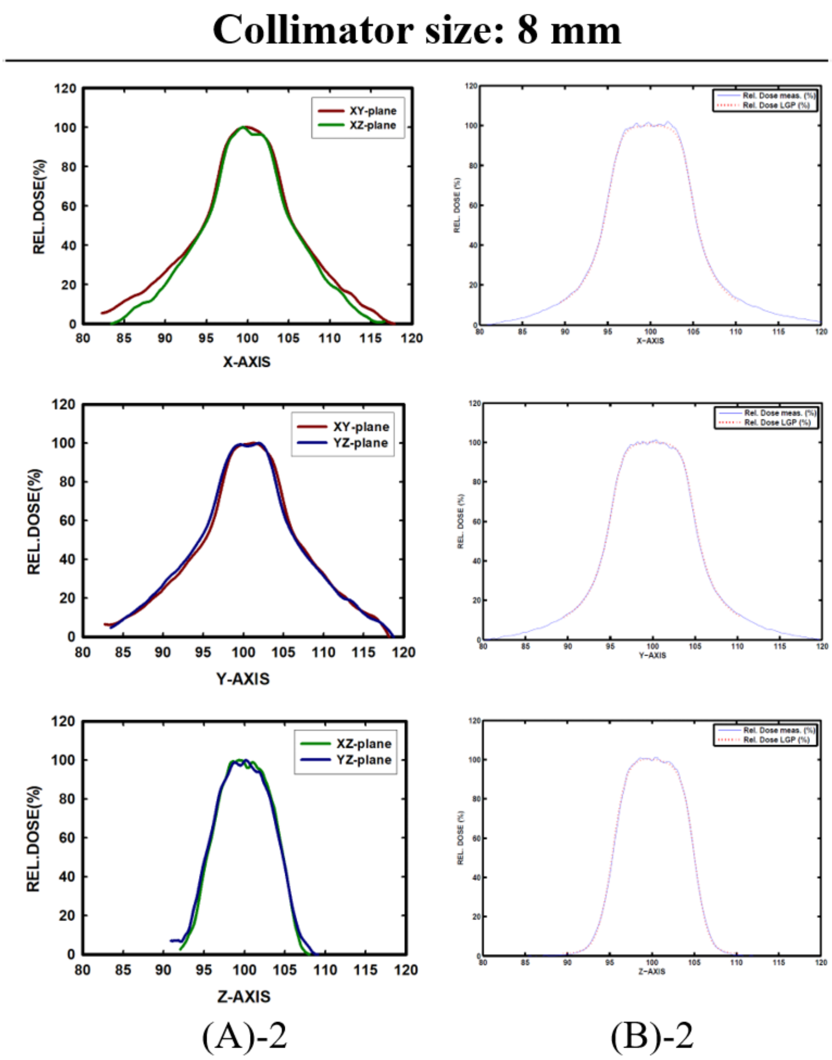
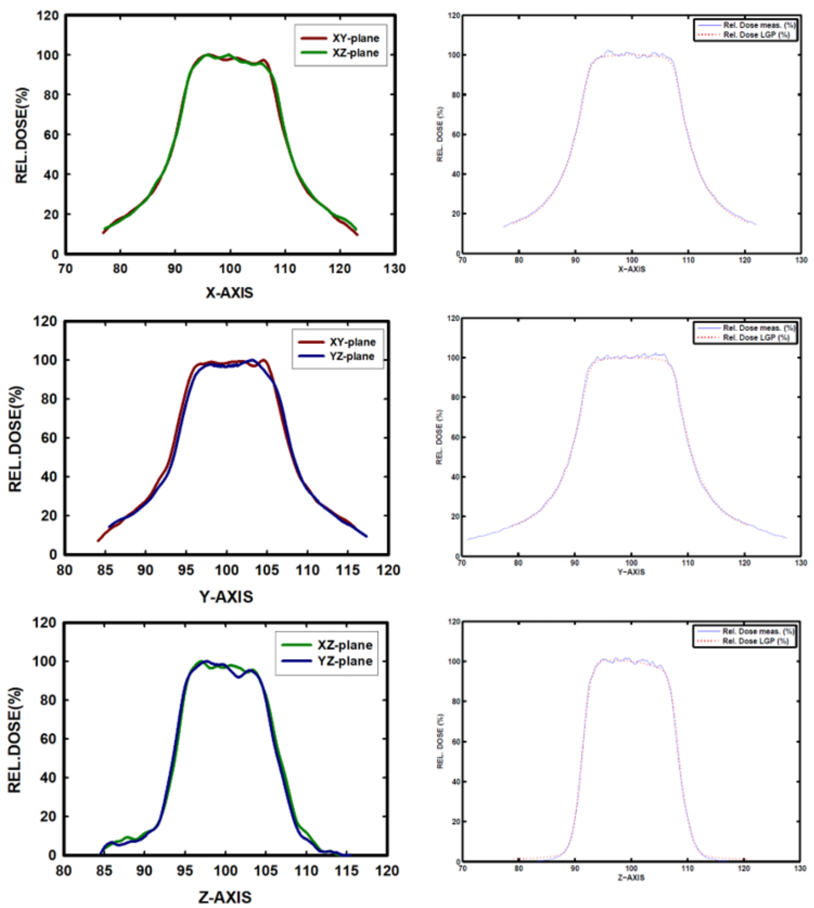


Figure 8-2. The axis dose profile for KIRAMS (A) and Elekta (B) for collimator 8 mm.

Collimator size: 16 mm



(A)-3 (B)-3

Figure 8-3. The axis dose profile for KIRAMS (A) and Elekta (B) for collimator 16 mm.

IV. 2. Mechanical QA result

① Accuracy

Table 9 shows the beam accuracy results analyzed by developed MATLAB code and Elekta for a collimator size of 4 mm. The differences between UCP and RFP in each axis were as follows with MATLAB code: 0.01 to 0.19 mm (x-axis), 0.03 to 0.29 mm (y-axis), −0.22 to 0.19 mm (z-axis) and final difference was 0.15 to 0.36 mm, satisfying domestic tolerance. Compared with Elekta report, the maximum difference was 0.27 mm at institution D and the minimum was 0.02 mm at institution A.

Table 9. The beam accuracy results for collimator 4 mm.

Institution	Difference between UCP and RFP (mm)								Tolerance (mm)	
	KIRAMS				Elekta					
	ΔX	ΔY	ΔZ	Δϒ	ΔX	ΔY	ΔZ	Δϒ	Korea	TG-178
A	**0.19**	**0.03**	**-0.16**	**0.25**	-0.19	0.11	-0.15	0.27	ΔX, Y, Z	
B	**0.10**	**0.16**	**0.19**	**0.27**	-0.01	0.04	-0.04	0.06	± 0.30	± 0.25
C	**0.13**	**0.03**	**-0.06**	**0.15**	-0.02	0.07	-0.02	0.08	Δϒ	
D	**0.01**	**0.29**	**-0.22**	**0.36**	0.01	0.09	0.01	0.09	-	± 0.40

V. DISCUSSION

In this study, we evaluated the performance of GK phantom, developed by KIRAMS, for five QA items. Output, time linearity and time error were evaluated by comparing the measured value of the same ionization chamber inserted into the KIRAMS and Elekta dosimetry phantoms. For others items-dose profile and accuracy- the evaluation consisted of comparing the results analyzed by in-house code of the Elekta and KIRAMS, respectively. In this study process, the correction factor for ABS material was newly calculated, and an analysis code for the KIRAMS film type was developed.

The QA results yielded by the KIRAMS GK tools satisfied the recommended tolerances and were similar to those of the Elekta report. Additionally, KIRAMS tools have the advantage of overcoming the problems associated with Elekta tools. Since the KIRAMS phantom were composed of ABS plastic, the cost was lower than those of Elekta dosimetry phantom, which is made of solid water. For film dosimetry, the KIRAMS tools allow for measurements on the axial plane, which could not be conducted using the Elekta film holder, and the calculated UCP can be verified. Additionally, the results can be obtained 1 minute through developed film analysis code.

However, there are several points that still need to be supplemented. First, the reliability of the newly calculated correction factor $\left(k_{Q_{msr},Q}^{f_{msr},f_{ref}}\right)_{ABS}$ should be confirmed. In our study, the gamma rays from GK installed the general institution were used to calculate the factor. To increase the reliability, the calculated factor must be compared to those obtained based on Monte Carlo simulation or experimentally using the reference ^{60}Co beam at standards laboratory. Second, the versatility of the KIRAMS GK tools should be expanded.

Only two model of GK (PERFEXION and ICON) and one type ionization chamber (Semiflex ionization chamber) were used in this study. In future research, it will be necessary to evaluate the performance of KIRAMS GK tools with other models of GK (such as Model C) and ionization chambers.

VI. CONCLUSION

The objective of this study is to evaluate the performance of KIRAMS GK tools and to present a new GK QA tool that improved the limitations of Elekta GK QA tools. The performance was assessed for five QA items. As a result, the KIRAMS GK tools yielded similar QA results to those of the Elekta GK QA tools, which satisfied recommended tolerances. Based on our findings, we expect that the KIRAMS GK tools are utilized as an additional QA tool along with Elekta GK QA tools.

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ABSTRACT (IN KOREAN)

KIRAMS 팬텀을 이용한 감마나이프 선량학적 및 기계적 품질관리 평가

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백 승 협

감마나이프는 장비에 따라 192개 또는 201개의 코발트-60(^{60}Co)을 반구형 대칭 형태로 배치하여, 두개 내 병변 부위에 고선량 감마선을 한 번에 집속시켜 종양을 치료하는 방사선 수술 장비 중 하나이다. 그래서, 정확한 위치에 계획된 방사선량이 조사될 수 있도록 주기적으로 품질관리를 수행하는 것이 중요하다.

국내 감마나이프 기관은 품질관리 시, Elekta의 품질관리 툴을 이용하고 있다. 하지만 이 툴은 비싼 제작비용, axial plane 에 대한 측정 불가능, 그리고 장치 중심점에 대한 검증이 어렵다는 단점이 있다.

이와 같은 단점을 해결하는 새로운 감마나이프 품질관리 툴이 필요한 상황이다.

본 연구는 품질관리 측면으로 한국원자력의학원에서 제작된 감마나이프 툴의 성능평가를 하고 나아가 새로운 품질관리 툴로 제안하는 것이 목적이다. 다섯 가지 품질관리 항목에 대해 제작된 툴의 유용성이 평가되었고, 그 결과 Elekta 툴의 결과와 유사한 결과를 얻었다. 따라서, 본 연구진은 새롭게 제작된 감마나이프 툴이 새로운 감마나이프 품질관리 툴로 활용될 수 있을 것이라 기대한다.

키워드: 방사선수술, 감마나이프, 품질관리, ABS 합성 수지