Scientific Paper

Feasibility of output quality assurance considering gantry angle using “Stealth Chamber”

Hideharu MIURA^{a,*}, Fumika TAKEICHI^b, Tsubasa ENOSAKI^a, Kiyoshi YAMADA^a, Shuichi OZAWA^a, Yasushi NAGATA^a

^aHiroshima High-Precision Radiotherapy Cancer Center, Japan

^bGifu Prefectural General Medical Center, Japan

*E-mail address: miura@hiprac.jp

Abstract

Purpose: This study was conducted to demonstrate the feasibility of X-ray output constancy quality assurance (QA) of a linear accelerator for various gantry angles using the Stealth Chamber.

Methods: The X-ray output constancy of a Varian TrueBeam STx was evaluated under various gantry angles and a 10×10 cm² field size using a Stealth Chamber. Specifically, 10X and 10X-flattening-filter-free beams with dose rates of 600 and 2400 monitor units (MU)/min, respectively, were used. The Stealth Chamber was attached to the gantry head, and irradiation was performed every 45° for gantry angles of 0–315°. To evaluate the variations in the output constancy with respect to the gantry angle, the acquired values were normalized to the value corresponding to a 0° gantry angle. The obtained results were utilized to determine the correction factors for all gantry angles. To verify the correction factors, additional measurements were performed for five days.

Results: The maximum variation in the output constancy measurement relative to the output constancy at a 0° gantry angle was found to be approximately 4.0% for both energy beams at a gantry angle of 180°. Furthermore, the measured values were dependent on the gantry angle. Upon applying the correction factor, the variation in the output constancy with respect to the gantry angle was less than 0.5%.

Conclusions: Output constancy QA using the Stealth Chamber for various gantry angles was found to be feasible with the application of a correction factor.

Key words: quality assurance; gantry angle dependence; reference chamber.

Introduction

According to the International Commission on Radiation Units and Measurements (ICRU), the dose delivered to patients must be within $\pm 5\%$ of the prescribed dose¹ and variations of less than $\pm 2\%$ in radiation dosimetry are often targeted in clinical situations. To achieve this goal, task groups (TGs) 40 and 142 of the American Association of Physicists in Medicine (AAPM) recommend general quality assurance (QA) tests for medical linear accelerators.^{2,3} Furthermore, it has been reported that accelerator beam characteristics, such as beam uniformity and dose stability, vary with the gantry position.^{4–6} Additionally, the guidelines of AAPM-TG 40 and 142 recommend checking the X-ray output constancy at all gantry angles annually using an ionization chamber. A Farmer-type ionization chamber should be carefully placed at the isocenter to measure the output dose at all gantry angles. X-rays are slightly attenuated with distance;

consequently, they are sensitive to variations in the chamber position. Currently, for an accurate setup, an ion chamber is placed at the isocenter using a room laser or cone-beam computed tomography.

The Stealth Chamber can be used as a reference chamber to perform relative measurements of the depth and transversal profiles for photon beam commissioning.^{7,8} Unlike standard reference chambers, the Stealth Chamber need not be repositioned to minimize the field perturbation. Moreover, the Stealth Chamber can be attached to the head of the linear accelerator; consequently, the set-up error for the ionization chamber is negligible. Therefore, we speculated that the Stealth Chamber can be used to evaluate the X-ray output constancy at any gantry angle.

This study was conducted to demonstrate the feasibility of output constancy evaluation under any gantry angle using the Stealth chamber.

Figure 1. Setup of (a) Stealth and (b) Farmer-type ionization chambers.

Methods and Materials

Figure 1a shows the experimental setup for X-ray output constancy QA using the Stealth Chamber (IBA Dosimetry GmbH, Germany) with a RAMTEC SmartTM electrometer (Toyo Medic, Tokyo, Japan). The Stealth Chamber has a thickness equivalent of 0.5 mm of aluminum and a rectangular design that can be used in the data acquisition of fields ranging from $0.5 \times 0.5 \text{ cm}^2$ to $25 \times 25 \text{ cm}^2$ in size.^{7,8} The stealth detector was maintained at a negative bias voltage of -420 V. A Varian TrueBeam STx accelerator (Varian Medical Systems, Palo Alto, CA) was used to evaluate the output constancy at various gantry angles and a $10 \times 10 \text{ cm}^2$ field size. Furthermore, 10X and 10X-flattening-filter-free (FFF) beams with dose rates (DRs) of 600 and 2400 monitor units (MU)/min, respectively, were used. Irradiation was performed every 45° for gantry angles ranging from 0° to 315° under a collimator angle of 0° . Measurements for the Stealth Chamber were repeated three times at each specific gantry angle. To verify the output constancy, the point dose at the isocenter was measured using a Farmer-type ionization chamber (Model N30013; PTW, Freiburg, Germany) and a RAMTEC electrometer (Toyo Medic, Tokyo, Japan). A Farmer-type ionization chamber with a build-up cap was carefully set up at the isocenter using a laser attached to the wall (**Figure 1b**). The Farmer-type ionization detector was maintained at a positive bias voltage of 300 V. Measurements

for this ionization chamber were repeated three times for each specific gantry angle. Determining the absolute dose was not considered necessary, as this study only entailed relative measurements, and both sets of measurements were obtained under the same conditions. To create the correction factor for the Stealth Chamber, the acquired values were normalized based on the value obtained at a gantry angle of 0° , using the following

$$\text{Equation 1:} \quad \text{correction factor} = \frac{\text{Value at } 0^\circ}{\text{Value at each gantry angle}} \quad \text{Eq. 1}$$

To verify the correction factors, the measurements were repeated for five days. We calculated a correction factor to correct the gantry effect in the Stealth Chamber using the following

$$\text{Equation 2:} \quad \text{correction value} = \text{Value at each gantry angle} \times \text{correction factor} \quad \text{Eq. 2}$$

Results

Variations in the output constancy, measured using the Farmer-type ionization chamber at the isocenter, for both beam energies were confirmed to be less than 0.5% at all gantry angles (**Table 1**). A similar trend was observed for the 10X-FFF beam, that is, the dose variation effect for the linear accelerator caused by the gantry angle was stable.

Table 1. Results of measurement data for 10X beam using Farmer-type ionization chamber

Measurements	Gantry angle ($^\circ$)							
	0	45	90	135	180	225	270	315
1	17.03	17.04	17.05	17.09	17.08	17.12	17.11	17.11
2	17.03	17.04	17.06	17.09	17.09	17.12	17.11	17.11
3	17.03	17.04	17.06	17.09	17.09	17.12	17.11	17.11
Mean	17.03	17.04	17.06	17.09	17.09	17.12	17.11	17.11
Standard deviation	0.000	0.000	0.006	0.000	0.006	0.000	0.000	0.000
Relative value	1.000	1.001	1.002	1.004	1.003	1.005	1.005	1.005

*Measurement unit: nC

Figure 2 shows the values obtained at various gantry angles for the 10X beam using the Stealth Chamber, and repeated measurements at each angle show excellent reproducibility. The maximum variation in the output constancy measurement relative to the output constancy at a 0° gantry angle for the 10X beam was found to be 4.1% at a gantry angle of 180°. A similar trend was observed for the 10X-FFF beam. That is, the dose variation effect of the gantry angle using the Stealth Chamber is not negligible. We formulated a correction factor, given by the ratio of the value obtained using the Stealth Chamber to that obtained at a gantry angle of 0° (**Figure 2**). To demonstrate the accuracy of the correction factor, the measurements were performed for another five days, and the results are shown in **Figure 3a**. The variation in output constancy after compensation using the correction factor obtained based on the Stealth Chamber for various gantry angles was less than 0.5%, as shown in **Figure 3b**. A similar trend was observed for the 10X-FFF beam (**Table 2**).

Figure 2. Values obtained after three repeated measurements for 10X beam, as a function of gantry angle using the Stealth Chamber. The black dots indicate the correction factor relative to the gantry angle of 0°.

Figure 3. Values (a) without and (b) with the correction factor for 10X beam. The data were collected for an additional 5 days and normalized to the gantry angle of 0°.

Table 2. Example of mean values relative to those obtained at the gantry angle of 0° using the Stealth Chamber with or without the correction factor.

Gantry angle (°)	10X beam		10X FFF beam	
	Without correction	With correction	Without correction	With correction
0	1.000	1.000	1.000	1.000
45	0.998	1.002	0.996	1.002
90	0.983	1.003	0.984	1.003
135	0.964	1.001	0.966	1.001
180	0.959	1.000	0.962	1.000
225	0.964	1.000	0.966	1.000
270	0.986	1.001	0.984	1.001
315	1.000	1.000	0.995	1.000

Discussion

In this study, we aimed to demonstrate that variations in output constancy with respect to the gantry angle can be determined by attaching the Stealth Chamber to the gantry head. The maximum variation in the output constancy measurement for both beams, compared with the measurement obtained at the gantry of 0°, was found to be approximately 4% when using the Stealth Chamber. Moreover, the measurements obtained using the Stealth Chamber were dependent on the gantry angle. To further investigate the cause of this phenomenon, a different Stealth Chamber was rented from another institution, and the same measurements were performed using another linear accelerator (TrueBeam; Varian Medical Systems, Palo Alto, CA). The results obtained were similar for all the conditions. During the measurements, we carefully checked the cable, the other Stealth chamber, and the X-ray table couch; however, we could not determine the underlying cause. Fortunately, the output constancy measurements exhibited high reproducibility at all gantry angles. Therefore, we created a correction factor for the output constancy QA with respect to the gantry angle.

After compensating for the correction factor, the output constancy measurements performed at various gantry angles and different days using the Stealth Chamber exhibited satisfactory reproducibility. Thus, a comparison of the output constancy at

different gantry angles can be easily performed using the Stealth Chamber and the corresponding correction factors. The Stealth Chamber can be attached to gantry heads with a high degree of accuracy and reproducibility without re-adjustment, similar to ion chamber measurements; this reduces the time required for total QA measurements. Thus, the Stealth Chamber is a transmission detector that yields reproducible results and can be used for output constancy QA at any gantry angle using the proposed correction factor.

Conclusions

We performed output constancy QA measurements at various gantry angles using the Stealth Chamber. The measurements obtained using the Stealth Chamber were dependent on the gantry angle; in particular, the values measured at a gantry angle of 0° were relatively high. Although a correction factor is necessary, performing output constancy QA measurements using the Stealth Chamber at various gantry angles was found to be feasible.

Conflict of interest

The authors declare that they have no conflict of interest to disclose.

References

1. ICRU Report 24. Determination of absorbed dose in a patient irradiated by beams of x- or gamma-rays in radiotherapy procedures. J ICRU. 1976;os13(1). <https://doi.org/10.1093/jicru/os13.1.Report24>
2. Kutcher GJ, Coia L, Gillin M, et al. Comprehensive QA for radiation oncology: Report of the AAPM Radiation Therapy Committee Task Group 40. Med Phys. 1994;21(4):581–618. <https://doi.org/10.1118/1.597316>
3. Klein EE, Hanley J, Bayouth J, et al. Task Group 142 Report: Quality assurance of medical accelerators. Med Phys. 2009;36(9):4197–242. <https://doi.org/10.1118/1.3190392>
4. Loyd MD, Lane RG, Laxton J, et al. Long term variation in beam symmetry as a function of gantry angle for a computer-controlled linear accelerator. Med Phys. 1989;16(4):614–617. <https://doi.org/10.1118/1.596363>
5. Blad B, Jacobsson L, Wendel P. The influence of the magnetron frequency, the servo settings and the gantry angle on the flatness and the dose calibration of a linear accelerator. J Med Eng Technol. 1998;22(4):185–8. <https://doi.org/10.3109/03091909809032539>
6. Huang JC, Reinstein LE. Evaluation of an innovative plastic cube phantom designed to improve the efficiency of accelerator QA. J Appl Clin Med Phys. 2000;1(4):153–7. <https://doi.org/10.1120/1.1312382>
7. Gersh J. Stereotactic beam characterization using the IBA stealth chamber reference detector. IBA Dosimetry Whitepaper 2014.
8. Vazquez Quino L, Huerta C, Calvo O, et al. Evaluation of a novel reference chamber “stealth chamber” through Monte Carlo simulations and experimental data. Int J Cancer Ther Oncol. 2015;3:4049. <https://doi.org/10.14319/ijcto.32.22>