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Measurement of Beam Data for Small Radiosurgical Fields: Comparison of CyberKnife Multi-sites in Korea

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The diode detector is recommended to measure the beam from CyberKnife recently. In this study, various detectors had been used to measure the beam data and compared that for each CyberKnife of domestic and foreign departments. All measurements of the beam data were performed by several detectors: diode detector, ion chamber, Gafchromic EBT film. These measured data compared with CyberKnife sites of the Korea. Also, these measured data are compared to a set of nationwide average data.

For the collimators over than 20 mm, the beam data (TPR and OCR) from the different detectors showed a good agreement within ±3%. For the collimators less than 20 mm, the beam data have discrepancy of 10% or more for each detector. Comparing the measured output factors in this study and the average of foreign departments provided by Accuary, the agreement was less than ±0.5% except for 5 mm collimators for diode detector and ±1.5% for Gafchromic EBT film. For the collimators over than 20 mm, the beam data from the multi-sites showed a good agreement within ±1%. For the collimators less than 20 mm, it was found that the effective volume and the material of the detector affect the beam data.

KEYWORDS: CyberKnife, small field dosimetry, stereotactic radiosurgery

I. Introduction

The use of stereotactic radiosurgical systems to treat intracranial and extracranial tumors and other lesions requires a high degree of accuracy in target identification and localization. The CyberKnife radiosurgery system can deliver, with a high degree of precision, a single or several fractions of radiation dose to a well-defined small intracranial or extracranial target.[1-3]

The accuracy of the beam data directly affects the accuracy of dose delivery in CyberKnife system. This is of obvious importance for any SRS system, particularly when a single large radiation dose is delivered to a small selected target with the 5 mm collimator, as in treatment of trigeminal neuralgia. Accurate dosimetry of small-field photon beams used in stereotactic radiosurgery can be made difficult because of the presence of lateral electronic disequilibrium and steep dose gradients. In the published literature, data acquisition for radiosurgery is mainly based on diode and film dosimetry, small sensitive volume ionization chamber and thermolominescence dosimetry (TLD).[3-6]

The CyberKnife system has generally been performed using a p-type silicon diode detector with a very small active volume. The diode detector is recommended to measure the beam from CyberKnife system recently. In this study, various detectors had been used to measure the beam data and compared that for each CyberKnife of domestic and foreign departments.

II. Materials and Methods

The CyberKnife (Accuray, Sunnyvale, CA, USA) system consists of a 6 MV linear accelerator mounted on a robotic arm. For the collimation of CyberKnife, 12 circular cones are available, collimators of different sizes, including 5, 7.5, 10, 12.5, 15, 20, 25, 30, 35, 40, 50, and 60 mm.[1-3]

The tissue phantom ratio (TPR) and off center ratio (OCR) measurements were carried out using the detectors positioned in the computer controlled water phantom.

Measurements of the TPR and OCR for all 12 collimators were performed by two detectors: diode detector, 0.125 cc ion chamber. The reference depth used for normalization of the TPR data was 1.5 cm for all collimator sizes, which is the nominal depth of maximum dose. All measurements were made at a SAD of 80 cm.

The OCR at a particular depth is the ratio of the absorbed dose at a given off-axis point relative to the dose at central axis. Measurements of OCR were carried out by conducting orthogonal scans across the field at a variety of depths. OCR measurements were made for depths ranging from 1.5 cm to 30 cm and off-axis distance ranging from 0 cm to 6.0 cm.

Measurements of the output factors for all 12 collimators were performed by three detectors: diode detector, 0.015 cc ion chamber, Gafchromic EBT film. The diode detector is a p-type silicon diode for the measurement of dose

distributions of high energy photons in radiation therapy. A typical effective thickness of the measuring volume for this detector is 2.5 μm. The diode detector and ion chamber measurement were performed with water phantom. The diode detector and ion chamber were set at 1.5 cm depth with a SAD 80 cm. In the Gafchromic EBT film measurement, the water phantom was replaced with a solidwater phantom. The films were irradiated with a dose of 200 MU. The exposed films were scanned using an Epson Expression 1680 scanner and analyzed using VeriSoft software. Each collimator normalized with respects to the output factor of the largest collimator (60 mm) at 80 cm SAD and 1.5 cm depth.

These measured data were compared to a set of standard average data, which provided by Accuray. The standard average data are an average of the measurements made by CyberKnife sites.

III. Results

1. TPR and OCR

We obtained the beam data (TPR and OCR) of 12 sizes of collimators using the two different detectors (diode detector, 0.125 cc ion chamber).

Figure 1 shows the TPR curves for 6 MV beams at a 5, 7.5, 12.5, and 20 mm field size measured with the diode detector in comparison with ion chamber. For the collimators over than 20 mm, the beam data (TPR and OCR) from the different detectors showed a good agreement within ±3%.
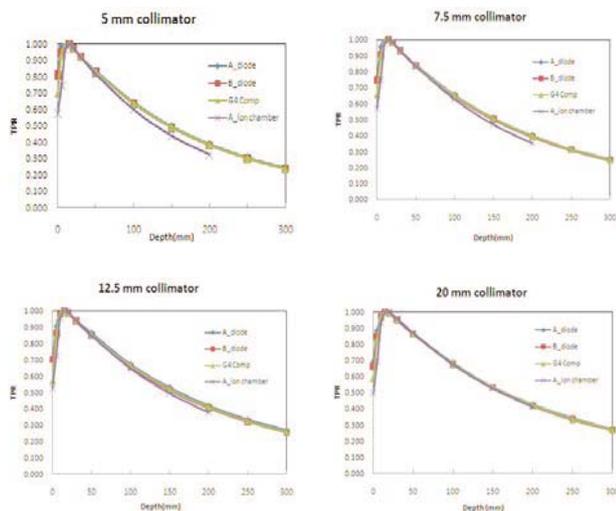
Fig. 1 TPR measured using the diode detector (A, B hospital and G4 system standard average data) and ion chamber (A hospital) for fields of 5, 7.5, 12.5, and 20 mm.

However, it is easily observed that the ion chamber was broadens the measured penumbra width in the OCR data. The broadening effect is more enhanced with decreasing beam diameter. For the collimators less than 20 mm, the beam data have discrepancy of 10% or more for each detector (**Fig. 2**).
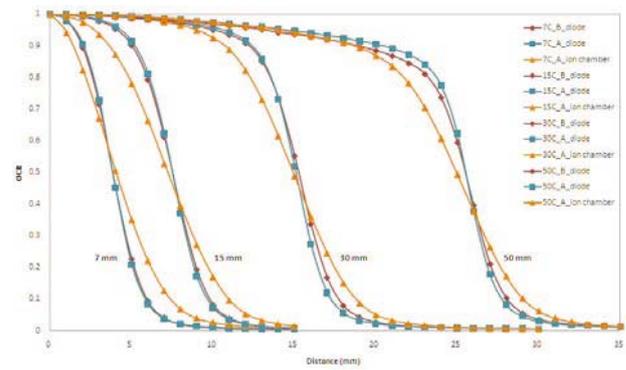
Fig. 2 The OCR measured with diode detector (A hospital) are compared to those measured with ion chamber (A hospital) and diode detector (B hospital) for collimator diameters. The profiles are for a 7 mm, 15 mm, 30 mm, and 50 mm collimator, respectively. All profiles are taken at 1.5cm depth water at 80 cm SAD.

The measured TPR and OCR using diode detector were found to be in good agreement with multi-site data which provided by Accuray. The greatest discrepancy between the measured data and the average data occurred for the surface measurement of the TPR.

2. Output Factor

We obtained the output factors of 12 sizes of collimators using the three different detectors (diode detector, 0.015 cc ion chamber, Gafchromic EBT film) (**Table 1**).

Table 1 Summary of output factors measured with different detectors

Collimator Size (mm)	0.015 cc Ion Chamber	Diode Detector	Gafchromic EBT Film
5	0.635	0.685	0.734
7.5	0.772	0.867	0.876
10	0.850	0.912	0.923
12.5	0.905	0.945	0.952
15	0.936	0.962	0.967
20	0.966	0.978	0.968
25	0.977	0.985	0.968
30	0.984	0.988	0.981
35	0.987	0.991	0.990
40	0.991	0.993	0.990
50	0.996	0.997	0.994
60	1.000	1.000	1.000

Figure 3 shows output factors measured as a function of the collimator size of 5 ~ 60 mm from the CyberKnife using three detectors. For the collimators over than 20 mm, the output factors from the different detectors showed a good agreement within ±1%. However, for the collimators less than 20 mm, the output factors have discrepancy of 10% or more for each detector.
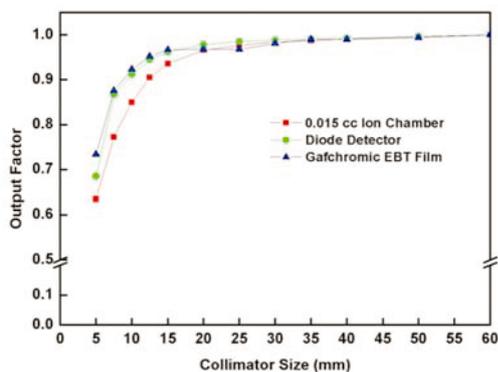
Fig. 3 Comparison of output factors measured with the diode detector, ion chamber and Gafchromic EBT film for collimator size of 5 ~ 60 mm. The measured output factors are normalized to a 60 mm collimator.

Comparing the measured output factors in this study and the average of foreign departments provided by Accuary, the agreement was less than ±0.5% except for 5 mm collimators for diode detector and ±1.5% for Gafchromic EBT film. The discrepancy of output factor for 5 mm collimators measured with both Gafchromic EBT film and diode detector were 3.5% (**Table 2**).

The output factors measured with diode detector of the domestic sites (A ~ D hospital) were found to be in good agreement with multi-site data which provided by Accuray except for 5 mm collimator (**Table 3**).

Table 2 Percentage disagreement between measured output factors and standard output factors

Collimator Size (mm)	Accuray Ave. (diode)	0.015 cc % Difference	Diode % Difference	Gaf-EBT film % Difference
5	0.710	-10.56	-3.52	3.38
7.5	0.869	-11.16	-0.23	0.81
10	0.912	-6.80	0.00	1.21
12.5	0.942	-3.93	0.32	1.06
15	0.959	-2.40	0.31	0.83
20	0.975	-0.92	0.31	-0.72
25	0.982	-0.51	0.31	-1.43
30	0.986	-0.20	0.20	-0.51
35	0.989	-0.20	0.20	0.10
40	0.992	-0.10	0.10	-0.20
50	0.994	0.20	0.30	0.00
60	1.000	0.00	0.00	0.00

Table 4 shows the output factors for the 5 ~ 60 mm collimator size as determined by previous investigators using various diode detectors, Gafchromic EBT film and Monte-Carlo calculation.[5,7-9]

For the collimators over than 20 mm, the beam data from the multi-sites showed a good agreement within ±1%. For the collimators less than 20 mm, it was found that the effective volume and the material of the detector affect the beam data (**Table 5**).

Table 3 Percentage disagreement between output factors of the domestic sites and standard output factors

Collimator Size (mm)	A Hospital[*]	B Hospital[*]	C Hospital[*]	D Hospital[*]	E Hospital[**]
5	-3.52	-0.27	0.14	0.28	-13.38
7.5	-0.23	0.23	-0.35	0.23	-9.32
10	0.00	0.00	-0.55	-0.55	-6.47
12.5	0.32	0.00	-0.32	0.32	-4.56
15	0.31	0.00	-0.31	0.10	-3.23
20	0.31	-0.10	-0.31	0.00	-1.54
25	0.31	-0.10	-0.20	-0.10	-0.81
30	0.20	-0.10	-0.10	-0.10	-0.61
35	0.20	-0.10	0.00	0.00	-0.30
40	0.10	-0.10	-0.10	0.00	-0.30
50	0.30	0.20	0.30	0.40	0.20
60	0.00	0.00	0.00	0.00	0.00

[*] Accuray (standard data) & A ~ D hospital: diode detector
[**] E hospital: ion chamber

Table 4 Comparison of the output factors of the foreign sites

Collimator Size (mm)	Accuray Ave. (PTW diode)	Yale Univ. (MC data)	Keck School of Medicine (Scandit-ronix diode)	Parkview Compre-hensive Cancer Center (PTW diode)	Saint Francis Hosp. (PTW diode)	Saint Francis Hosp. (Gaf EBT film)
5	0.710	0.611	0.719	0.704	0.709	0.701
7.5	0.869	0.847	0.849	0.877	0.869	0.845
10	0.912	0.881	0.892	0.916	0.911	0.902
12.5	0.942	0.925	0.926	0.946	0.941	0.934
15	0.959	0.948	0.947	0.961	0.958	0.959
20	0.975	0.972	0.967	0.976	0.974	0.980
25	0.982	0.980	0.977	0.983	0.981	0.987
30	0.986	0.987	0.984	0.986	0.986	0.993
35	0.989	0.990	0.987	0.990	0.990	0.993
40	0.992	0.994	0.990	0.992	0.993	0.997
50	0.994	0.998	0.996	0.996	0.997	0.997
60	1.000	1.000	1.000	1.000	1.000	1.000

Table 5 Percentage disagreement between output factors of the foreign sites and standard output factors

Collimator Size (mm)	In This Study (PTW diode)	Yale Univ. (MC data)	Keck School of Medicine (Scandit-ronix diode)	Parkview Compre-hensive Cancer Center (PTW diode)	Saint Francis Hosp. (PTW diode)	Saint Francis Hosp. (Gaf EBT film)
5	-3.52	-13.94	1.27	-0.85	-0.14	-1.27
7.5	-0.23	-2.53	-2.30	0.92	0.00	-2.76
10	0.00	-3.40	-2.19	0.44	-0.11	-1.10
12.5	0.32	-1.80	-1.70	0.42	-0.11	-0.85
15	0.31	-1.15	-1.25	0.21	-0.10	0.00
20	0.31	-0.31	-0.82	0.10	-0.10	0.51
25	0.31	-0.20	-0.51	0.10	-0.10	0.51
30	0.20	0.10	-0.20	0.00	0.00	0.71
35	0.20	0.10	-0.20	0.10	0.10	0.40
40	0.10	0.20	-0.20	0.00	0.10	0.50
50	0.30	0.40	0.20	0.20	0.30	0.30

IV. Conclusion

We evaluated the use of the detectors for beam data measurements in the CyberKnife collimators. Accurate measurements of beam data for radiosurgical beams are an essential prerequisite for the treatment of trigeminal

neuralgia, which uses a 5 mm collimator. However, beam data measurements of stereotactic radiation fields are difficult because lateral electronic disequilibrium and steep dose gradients exist in large portions of these fields. The ideal dosimeter needs to have good spatial resolution and have linear and reproducible response.

In this study, a small sensitive volume ion chamber was found to significantly overestimate the penumbra of small fields, with the relative amount of overestimation being more severe as the field size decreases. Although the ionization chamber has a small volume of 0.015 cc, the pinpoint chamber is still too large to accurately measure the beam data of collimators less than 20 mm in diameter.

The measured TPR, OCR and output factors were found to be in good agreement with average multi-site data except for 5 mm collimator. For the collimators over than 20 mm, the beam data from the multi-sites showed a good agreement within ±1%. For the collimators less than 20 mm, it was found that the effective volume and the material of the detector affect the beam data.

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