

ORIGINAL ARTICLE

Patient-specific quality assurance for intracranial cases in robotic radiosurgery system

Canan Koksall, Ugur Akbas, Nazmiye Donmez Kesen, Murat Okutan, Hatice Bilge, Gonul Kemikler

Istanbul University Oncology Institute, Division of Medical Physics, Istanbul, Turkey

Summary

Purpose: The purpose of this study was to perform pre-treatment patient-specific quality assurance (QA) for intracranial irradiation using CyberKnife with an ion chamber.

Methods: Twenty-five intracranial plans created using the ray-tracing algorithm were used for this study. Computed tomography (CT) images of the water-equivalent RW3 slab phantom with PinPoint ionization chamber were acquired with 1-mm slice thickness and transferred to the MultiPlan treatment planning system (TPS). Four gold fiducial markers embedded into two different plates were used to tracking during the irradiation. Intracranial plans were transferred to CT images of the RW3 phantom. The isodose curves and sensitive volume of ion chamber were overlapped. Point dose measurements were performed three times and the mean point doses were calculated for each plan. The mean doses measured by the PinPoint ion chamber were compared with

those of the calculated by MultiPlan TPS in the sensitive volume of PinPoint.

Results: The mean percentage difference (MPD) in point dose measurements was -2.44 ± 1.97 for 25 plans. The maximum and minimum percentage differences between the measured and calculated absolute point doses were -7.14 and 0.23 , respectively. The MPD was -1.70 ± 1.90 for 12 plans using a fixed collimator and -3.11 ± 1.86 for 13 plans using an IRIS cone.

Conclusions: Point dose measurement is a reliable and functional method for pre-treatment patient-specific QA in intracranial CyberKnife plans. Point dose verification should be performed to correct any possible errors prior to patient treatment. It is recommended for use in patient-specific QA process in the CyberKnife plans.

Key words: CyberKnife, PinPoint ionization chamber, point dose measurement, quality assurance

Introduction

The stereotactic radiosurgery (SRS) is a radiotherapy technique used to deliver an extremely high radiation dose to a well-defined lesion in a single fraction. The dose to non-target tissues is significantly reduced with SRS due to the steep dose fall-off outside the target volume. Radiosurgery has become an important treatment option for brain tumors, because of their irregular shapes and the existence of many critical structures around them [1,2].

GammaKnife, a gantry-based linear accelerator and the CyberKnife device have been used for

SRS. GammaKnife, the first SRS system, was installed specifically for the treatment of intracranial targets in 1967. In this system, the patient's head is immobilized using a stereotactic frame to deliver high doses of radiation with submillimeter accuracy. CyberKnife, an image-guided robotic radiosurgery system, is used for not only intracranial but also extracranial targets without the need for the frame. A high degree of positional accuracy is required to treat lesions with the CyberKnife system. The patient's images are obtained using a pair of ceiling-mounted kilovolt X-ray tubes and

X-ray detectors to provide real-time image guidance during treatment. The narrow non-isocentric multiple beams of various size and source skin distances (SSD) are directed to the small target via circular size-fixed collimators or IRIS variable aperture collimators to obtain a highly conformal dose distribution with a steep dose gradient [3,4]. The high-dose gradient regions in the target volume occur because of the numbers of beams. For successful treatment, delivering an accurate dose within $\pm 5\%$ of the target with submillimeter accuracy is very important. Therefore, patient-specific delivery quality assurance (DQA) should be performed for CyberKnife treatment plans. Reports from AAPM Task Group 135 [5] and Task Group 142 [6] have explained the periodic QA approach for robotic radiosurgery system, but the beam-by-beam QA test has not been published yet. The accuracy of plan calculation, plan transfer and dose delivery should be considered for the verification of CyberKnife treatment plans. Pre-treatment patient-specific QA methods and procedures are well established in the intensity-modulated radiotherapy (IMRT) plans which are created using sophisticated treatment technique. Many equipments and

techniques have been developed for IMRT patient-specific QA. Point dose measurement with an ionization chamber is the most reliable and practical method to verify IMRT plans which include small radiation fields [7]. However, there is no particular procedure for pre-treatment patient-specific QA in the CyberKnife plans. The verification of CyberKnife treatment plans should be performed because the whole process of treatment delivery in CyberKnife system is very complex. In the literature, there have been very few investigations concerning pre-treatment patient-specific QA in the CyberKnife system. The purpose of the present study was to perform pre-treatment patient-specific QA for intracranial CyberKnife treatments with PinPoint ionization chamber which is recommended for measurement in small fields.

Methods

All measurements were performed using the CyberKnife system. It consists of a compact 6-MV linear accelerator (LINAC) mounted on a flexible robotic manipulator, a kV image guidance system and a robotic Couch patient positioning system. The robotic manipu-

Table 1. Data from 25 intracranial treatment plans for point dose measurements

<i>Intracranial plan</i>	<i>Size of collimator (mm)</i>	<i>Collimator type</i>	<i>Number of beams</i>	<i>Number of nodes</i>
Patient 1	5, 7.5, 10	FIXED	198	103
Patient 2	7.5, 10, 12.5	FIXED	174	92
Patient 3	7.5, 15	FIXED	182	95
Patient 4	10	FIXED	104	51
Patient 5	10	FIXED	275	123
Patient 6	10	FIXED	130	59
Patient 7	10, 12.5	FIXED	104	85
Patient 8	10, 12.5	FIXED	99	74
Patient 9	10, 15	FIXED	291	121
Patient 10	10, 20	FIXED	132	89
Patient 11	10, 20	FIXED	88	61
Patient 12	12.5, 15	FIXED	151	71
Patient 13	5, 7.5, 10, 12.5	IRIS	169	93
Patient 14	7.5, 10	IRIS	130	95
Patient 15	7.5, 10	IRIS	82	50
Patient 16	7.5, 10	IRIS	73	53
Patient 17	7.5, 10, 12.5	IRIS	94	63
Patient 18	7.5, 12.5	IRIS	95	69
Patient 19	7.5, 10, 12.5, 15	IRIS	351	106
Patient 20	7.5, 10, 12.5, 15, 20, 25	IRIS	131	68
Patient 21	10, 12.5, 15	IRIS	161	89
Patient 22	10, 12.5, 15	IRIS	143	81
Patient 23	10, 15, 20	IRIS	147	76
Patient 24	10, 12.5, 15, 20	IRIS	167	90
Patient 25	10, 15, 25	IRIS	243	111

lator has six degrees of freedom, allows the LINAC to move around the patient so the radiation is delivered to tumors located anywhere in the body at many LINAC positions. Twelve fixed circular collimators (5-60 mm in diameter) or an IRIS variable aperture collimator is used to shape the beams. When the IRIS collimator, which incorporates 12 tungsten-copper alloy segments in two banks of six is used, the aperture size is varied automatically. The imaging system comprises a ceiling-mounted orthogonal kilovolt two X-ray tube and amorphous silicon X-ray detector on both sides of the couch to enable real-time image guidance treatment. The CyberKnife software provides tumor tracking methods such as bony structure tracking, fiducial tracking and soft tissue tracking. Tumor and patient movement are automatically tracked, detected and cor-

rected during treatment. Machine QA processes include LINAC output calibration. The end-to-end test was performed according to AAPM TG 135 before verification of CyberKnife treatment plans [5].

Twenty-five intracranial plans created using the ray-tracing algorithm through the sequential optimization process were used for this study. Data related to plans are described in Table 1. The water-equivalent RW3 slab phantoms (PTW, Freiburg, Germany) sized 30x30 cm², calibrated PinPoint ionization chamber with a sensitive volume of 0.015 cm³ (model 31014; PTW, Freiburg, Germany) and PTW Unidos electrometer (PTW, Freiburg, Germany) were used for absolute point dose measurements. The schematic view of the phantom is shown in Figure 1. CT images were acquired with 1 mm-slice thickness and images were transferred to the MultiPlan version 4.6.1 (Accuray Inc., Sunnyvale, CA, USA) TPS. Four gold fiducial markers embedded into two different plates were used to tracking during the irradiation. Twenty-five intracranial plans were transferred to CT images of the RW3 phantom. The isodose curves and sensitive volume of ion chamber were overlapped (Figure 2). Then, dose distributions on phantom were recalculated with high resolution and saved. Finally, point dose measurement was performed three times for each plan and the mean value was calculated. The mean doses measured by PinPoint were compared with those of the calculated by TPS in the sensitive volume of PinPoint. The percentage difference between measured and calculated dose was assessed using the following equation:

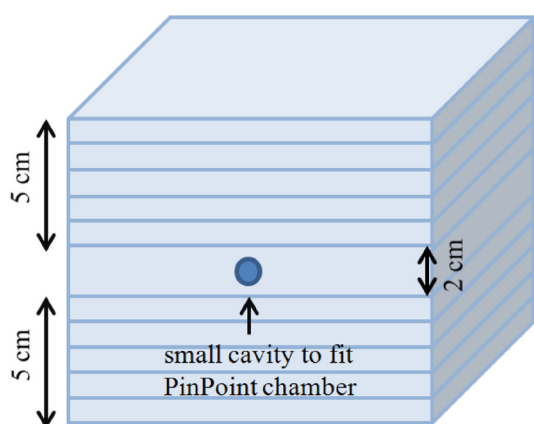


Figure 1. Schematic view of the phantom for point dose measurements.

$$\text{Percentage Dose Difference} = [(\text{Measured Dose} - \text{Calculated Dose}) / \text{Calculated dose}] \times 100.$$

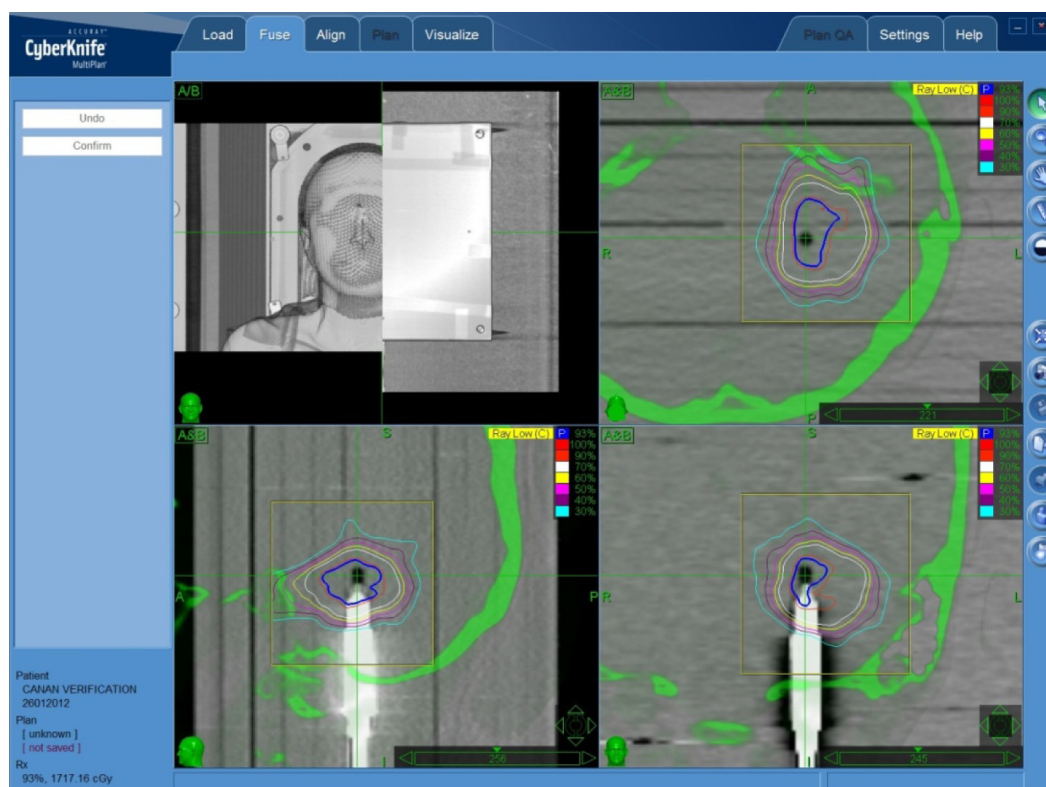


Figure 2. Overlapping the isodose curves and the sensitive volume of the ion chamber.

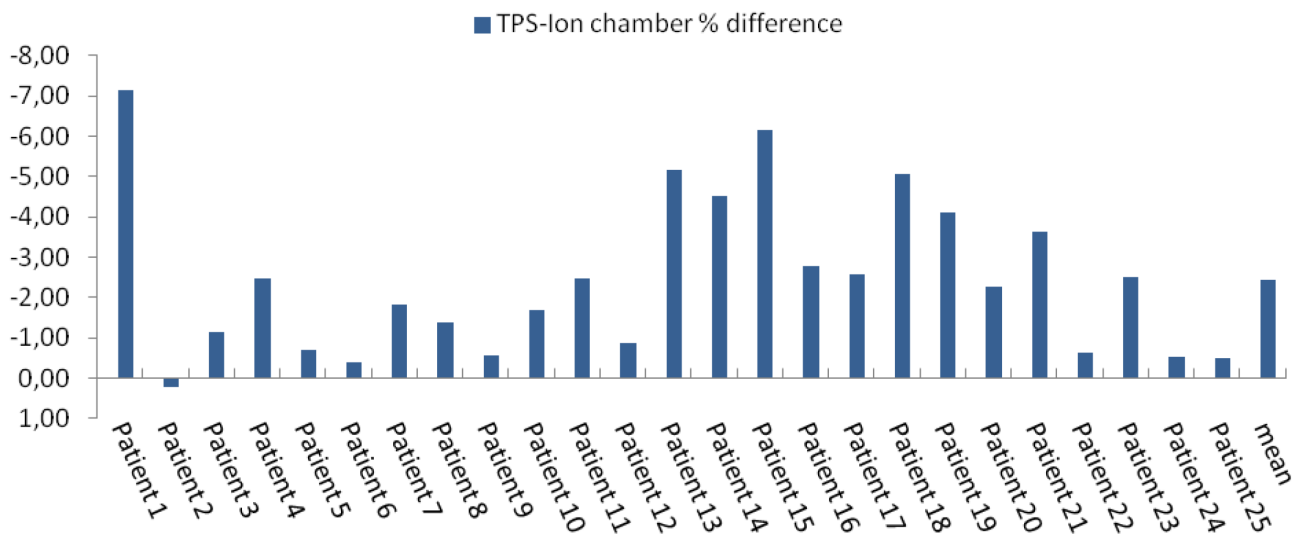


Figure 3. Percentage dose difference between measured doses and calculated doses.

Results

The maximum and minimum percentage differences between the measured and calculated absolute point doses were -7.14 and 0.23, respectively. The mean percentage difference (MPD) was -2.44 ± 1.97 for 25 plans. The percentage differences for each plan are shown in Figure 3. The measured and calculated doses were compared to plans created with a fixed collimator (12 plans) and an IRIS cone (13 plans), separately. The MPD was -1.70 ± 1.90 for 12 plans using a fixed collimator and -3.11 ± 1.86 for 13 plans using an IRIS cone.

Discussion

The CyberKnife radiosurgery system can treat targets smaller than 6 cm with high radiation dose in a single or few fractions. In this system, instead of using an invasive immobilization frame, the tumor is tracked during treatment. Non-coplanar small beams from different angles are used to achieve both a highly conformal dose distribution in the target and a sharp dose gradient outside the target [4]. The SRS offers equivalent results to surgery for brain tumors which are very close to critical structures and cannot be operated. Therefore, the SRS is an alternative treatment for brain tumors.

In SRS treatments, dosimetric accuracy is very important because of the sophisticated treatment technique. Therefore, it is necessary to verify that the desired treatment plan can be implemented in the patient. In this study, dose verification was performed for intracranial irradiation. Patient-specific point dose measurements were made using PinPoint ionization chamber for 25 patient

treatment plans. Also, the feasibility of point dose measurement for pre-treatment patient-specific QA was investigated for intracranial cases.

Unlike conventional conformal radiotherapy, small radiation fields are used in the SRS technique. Mostly field sizes of less than $3 \times 3 \text{ cm}^2$ are assessed, different from the traditional radiotherapy field size. Special attention is required when dose measurements and calculations are made in small fields. There have been many studies about the adequacy of ion chambers for quality assurance of radiotherapy plans consisting of small fields. The choice of appropriate detector is very important for point dose measurements in IMRT QA, because of the steep dose gradient and lateral electronic disequilibrium [8]. Escudé et al. [9] measured the point doses in prostate IMRT plans using three cylindrical ionization chambers with volumes of 0.6 cc, 0.125 cc, and 0.015 cc. They reported that the doses measured by the small volume chambers were in a good agreement with the calculated doses by TPS. The sensitive volume of the detector must be very small to measure the absolute dose in small fields with high accuracy [10].

In the present study, a 0.015 cc PinPoint ionization chamber was used to carry out the absolute point dose measurements. The mean percentage difference between measured and calculated doses for 25 plans was found to be -2.44 ± 1.97 . The range of percentage variation was -7.14-0.23. The MPD was -1.70 ± 1.90 for 12 plans using a fixed collimator and -3.11 ± 1.86 for 13 plans using an IRIS cone. The dose deviations were below 5% in 84% of all cases. Rondi et al. [11] performed absolute point dose measurements using a PinPoint ionization chamber and an Easy cube phantom for 137 patient treatment plans in the CyberKnife

system. The measured dose was compared to the calculated dose; the mean percentage difference was found to be 4.8 ± 4.1 . The range of percentage variation was -7.2 to 9.1. The dose deviations were below 5% in 73.9% of all cases in their study. In the literature, there have not been many investigations concerning absolute point dose measurements for patient-specific QA in the CyberKnife system. However, there have been some studies about point dose validation on IMRT plans which were generated by using inverse treatment planning. Agazaryan et al. [12] verified the absolute point doses of 160 clinical IMRT and intensity-modulated radiosurgery (IMRS) by using a 0.015 cc PinPoint ionization chamber (PTW 31006) and the MED-TEC IMRT phantom on the Novalis LINAC. The maximum percentage dose disagreement was -4.79. The mean percentage difference with standard deviation was 0.26 ± 1.75 . Chung et al. [13] performed point dose measurement for 206 patients treated with IMRT plans (42 patients with brain tumor, 89 patients with head-and-neck tumor and 75 patients with abdominal or prostate cancer). Used were 0.125 cc Semiflex ion chamber and cylindrical phantom. The range of percentage dose differences was -4.1 to 3.9 (mean and standard deviation: 0.55 ± 1.51) for the brain case, -4.6 to 2.7 (-1.62 ± 1.23) for the head-and-neck case, and -4.6 to 2.5 (-0.41 ± 1.21) for the abdominal or prostate case. All the beams may not have passed through the effective point of measurement of the ion chamber, because the CyberKnife treatments are non-isocentric and the beams are directed from different angles. Therefore, the measured point dose values were found to be less than calculated and the dose difference between measured and calculated was found to be greater in this study.

The deviations for plans based on IRIS cone were found greater than those for plans based on fixed collimator. Physical characteristics of dodecagon-shaped IRIS collimator may be lead the results. The disagreement between measured and

calculated doses for plans created by using collimators with small diameters was found the greatest. The ionization chamber may have been positioned in high dose gradient regions due to very small fields and it may have caused the large dose differences. The percentage dose difference was found to be -5.53 for Patient 3. It has been noticed that the reason of the dose difference between measured and calculated doses is that the ion chamber has been placed in high dose gradient region. Then a new QA plan was created and the ion chamber was placed in the more homogeneous dose region. The percentage dose difference was found to be -1.15. The ionization chamber should be placed in regions of minimum dose variation to obtain good agreement between measured and calculated doses. In this work, all absolute dose measurements were repeated three times with consistent results. It has been found that the system has successfully provided the reproducibility of the measurements.

Currently, there is no particular method for pre-treatment patient-specific QA for CyberKnife. The treatment is delivered with submillimeter accuracy in the CyberKnife system. For this reason, a strict patient-specific QA procedure is required. In this study, patient-specific QA for intracranial cases in CyberKnife was successfully implemented using an ion chamber. For point dose verification, the ion chamber should be placed in a homogeneous region to obtain excellent agreement between calculations and measurements. Point dose measurement is a reliable and functional method for pre-treatment patient specific QA in intracranial CyberKnife plans. Point dose verification should be performed to correct any possible errors prior to patient treatment and it is recommended for use in patient-specific QA process in the CyberKnife plans.

Conflict of interests

The authors declare no conflict of interests.

References

1. Kavanagh BD, Timmerman RD. Stereotactic radiosurgery and stereotactic body radiation therapy: an overview of technical considerations and clinical applications. *Hematol Oncol Clin North Am* 2006;20: 87-95.
2. Collins SP, Coppa ND, Zhang Y, Collins BT, McRae DA, Jean WC. CyberKnife® radiosurgery in the treatment of complex skull base tumors: analysis of treatment planning parameters. *Radiat Oncol* 2006;1:1-10.
3. Niranjan A, Bowden G, Flickinger JC, Lunsford LD. Gamma Knife Radiosurgery. In: Chin LS, Regine WF (Eds): Principles and practice of stereotactic radiosurgery (2nd Edn) Springer, 2015, pp 111-119.
4. Kilby W, Dooley JR, Kuduvali G, Sayeh S, Maurer Jr.

- CR. The CyberKnife® Robotic Radiosurgery System in 2010. Radiosurgery in the treatment of complex skull base tumors: analysis of treatment planning parameters. *Technol Cancer Res Treat* 2010;9:433-52.
5. Report of AAPM Task Group 135. Quality assurance for robotic radiosurgery. AAPM report no.135. *Med Phys* 2011;38:2914-36.
 6. Report of AAPM Task Group 142. Quality assurance of medical accelerators. AAPM report no.142. *Med Phys* 2009;36:4197-4212.
 7. Dong L, Antolak J, Salehpour M et al. Patient-specific point dose measurement for IMRT monitor unit verification. *Int J Radiat Oncol Biol Phys* 2003;56:867-77.
 8. Das IJ, Ding GX, Ahnesjö A. Small fields: nonequilibrium radiation dosimetry. *Med Phys* 2008;35:206-15.
 9. Escudé L, Linero D, Mollà M, Miralbell R. Quality assurance for radiotherapy in prostate cancer: point dose measurements in intensity modulated fields with large dose gradients. *Int J Radiat Oncol Biol Phys* 2006;66:136-40.
 10. Laub WU, Wong T. The volume effect of detectors in the dosimetry of small fields in IMRT. *Med Phys* 2003;30:341-7.
 11. Rondi E, Vigorito S, Bazani A, Mastella E, Russo S, Piperno G. Validation of a pretreatment specific patient QA method for CyberKnife. *Radiother Oncol* 2013;106 (Suppl 2): 439.
 12. Agazaryan N, Ullrich W, Lee SP, Solberg TD. A methodology for verification of radiotherapy dose calculation. *J Neurosurg* 2004;101:356-61.
 13. Chung JB, Kim JS, Ha SW, Ye S. Statistical analysis of IMRT dosimetry quality assurance measurements for local delivery guideline. *Radiat Oncol* 2011;6:1-8.