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ORIGINAL ARTICLE

Evaluation of photon beam dose calculation accuracy of treatment planning systems using in vivo dosimetry

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Abstract

Objective The treatment planning system currently represents one of the basics of radiation therapy, because it is the only method to estimate patient dose delivery fast forward and accurately represent estimated tumor location of the tumor with the possibility of estimating densities in the tissue surrounding the tumor to overcome dose calculation defects but radial estimated the patient. Despite the flaws associated with the systems and calculates the dose of your programs in all programs currently existing in the world. Than necessary, to the existence of a review of the accuracy of accounts and how to confirm the radiation dose to the patient programs.

Methods A total of 35 cancer patients were considered for this study, with 245 field measurements made with low- and high-energy diode detectors for brain and prostate cases. The treatments for all patients were planned using Eclipse Treatment Planning System version 13.6.

Results Of the 105 field measurements made for the prostate cancer patients, 16 included discrepancies outside the ±5% action level. Of the 145 measurements taken of the brain cases, there were four outside the ±5% action level. The results indicated a higher degree of accuracy. The study revealed that, for the prostate measurements, the higher discrepancy in the doses for the particular fields (exceeding the action level) may have been due to the isocenter being very close to the jaws and multi-leaf collimator of the linear accelerator machine. As a result, scatter from the jaws and the multi-leaf collimator could have contributed to the high dose delivered to the diode; hence, a probable higher discrepancy of the dose in more brain cases due highest quality of VMAT technique and fixation system.

Conclusion A greater percentage of the observed discrepancies were well within the set tolerance level. However, it is recommended that the positioning of the diode on the patient's skin and the angular sensitivity of the diodes be reconsidered. It is also recommended that a more accurate calculation of expected diode values be performed, especially for fields that pass through the table. These efforts would achieve action levels of ±5%.

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Key words: diodes; *in vivo* dosimetry; radiotherapy; dose verification

The treatment planning system (TPS) currently represents one of the basics of radiation therapy because it is the only method that estimates patient dose delivery fast forward and accurately estimates tumor location with the possibility of determining estimate densities teams in the tissue surrounding the tumor to overcome dose calculation defects, but radial estimated the patient. Although the errors associated with the systems and calculates the dose of all programs currently existing in the world. For that necessary, to the existence of a review of the accuracy of accounts and how to confirm the radiation dose to the patient programs.

The rapid development of advanced treatment techniques and planning has placed higher demands on the verification of the dose delivered to the patient. *In vivo* dosimetry is an essential element in the quality assurance program used in today's radiotherapy departments. Furthermore, *in vivo* dosimetry is used to control the total

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accumulated dose in cases in which the TPS is less accurate, such as in total body irradiation (TBI), the build-up region, and at-risk organs in the head and neck region [1–2].

There is a simultaneous need to safely implement new treatment techniques in a radiotherapy department, which increases the workload and creates the potential for serious errors in radiotherapy planning and delivery. Therefore, an effective net of quality assurance procedures is highly recommended. *In vivo* dosimetry, recommended by various national and international organizations including the IAEA publication in 2013, can be performed at several levels. Two different goals can be identified: measuring doses to at-risk organs that are difficult to calculate (such as the eyes and gonads) and verifying the delivered dose to improve treatment accuracy and minimize the risk of dose misadministration. These measurements are compared to the planned doses specified by the oncologist and calculated by the TPS for the target and critical organs.

In this way, set-up calculations, motions, or transcription errors that may have gone unnoticed during pretreatment checks can be recovered prior to dose delivery. In the absence of errors, routine *in vivo* dose measurements indicate that the treatment was delivered correctly. The diodes are basically small detectors attached to a long wire that are used to measure the dose being received in real time while a patient is undergoing radiotherapy treatment. They are normally attached to the patient's body with adhesive tape at specific points where the treatment beam enters the body. Many professionals acknowledge their importance because they have the potential to detect any errors that may have slipped through the quality safety net [3]. While errors in the delivery of radiation therapy are rare and usually result in little or no patient injury, the real danger is an administration error going undetected. This may result in healthy tissues being exposed to unnecessary radiation levels or the tumor site not receiving the full therapeutic effect. According to previous studies, a severe misadministration may result in radiation necrosis to vital organs or structures and can be fatal. In recent publications, several radiotherapy reports have described erroneous patient exposure to radiation [4].

The errors in predicting the dose rate resulted in its underestimation by 10%–45%, which translates to the patients receiving corresponding overdoses of 10%–55%. It was eventually revealed that 426 patients received significant overdoses as a result. The IAEA also reported on an erroneous use of a TPS. In that report, the distance correction factor was erroneously applied twice for all patients treated isocentrically or at non-standard SSD. This error caused patients to receive doses lower than those prescribed [5–6]. This deficiency was 5%–35%, and in the end, it was revealed that, of 1045 patients whose calculations were affected by the incorrect procedures, 492 developed local recurrences that could be attributed to the error. The International Commission on Radiation Units and Measurements has recommended that radiation be delivered to within 5% of the prescribed dose [7–8].

Moreover, in a recent publication by the IAEA (2013), an appropriate goal is to be able to use a tolerance level of 5% for simple treatments, with a level of 7% for situations such as breast treatments and other treatments where measurement complications exist. However, it is recommended that, although in the initial stages of the introduction of in vivo dosimetry the tolerance levels may need to be higher, every effort should be made to achieve tolerance levels of about 5% by a process of progressive elimination of identified causes of dose differences [5]. This paper seeks to compare the entrance doses derived from the signal of the diode detectors placed on the skin with the theoretical values as calculated by the TPS under set tolerance values [9–11].

Materials and methods

The OmniPro-InViDos is a dosimetry management system that handles all tasks related to in vivo dosimetry. It simplifies the use of *in vivo* dosimetry by giving the user an overview of the calibration as well as the tools needed to perform the calibration efficiently by automatically selecting correction factors for each field. The OmniPro-InViDos provides instruments that improve treatment accuracy while reducing the time requirement. It may be linked to the verification and therapy system either locally on the same PC as the verification system or via the internal network. It is well known that some characteristic can be affected when the detector is exposed to high-energy radiation.

(1) The sensitivity will decrease over time; (2) For some detector types, the signal will not be proportional to the dose rate. In some cases, this non-linearity will change the cumulative dose, leading to an incorrect reading if the dose rate in the measuring position will differ from the calibration situation; (3) Sensitivity will vary with temperature; (4) Detector leakage current, which is correlated to the detector impedance. This parameter can be important if the measured dose rate is very low, and an effect voltage of the input amplifier will increase; (5) Directional and field size dependencies exist; (6) Increasing the number of parameters to handle will increase the workload for the physicist ensuring quality control of the vivo system.

When the test for several characteristics for diodes has been used in high-energy (15 MV) and low-energy (6 MV) situations for linear accelerator Varian model DMX:

(1) Diode sensitivity is one parameter that will be af-

fected (sometimes after a certain amount of use); (2) Dose linearity; (3)Dose rate linearity; (4) Temperature affects the signal per unit dose from the detector; (5) Directional and field size dependencies exist.

Dosimetry, mechanical, and safety checks are performed. These measurements ensure that the system is working as intended. The entrance dose D is defined as the maximum dose (Dmax) for the corresponding energy. The diode reading that is expected for each treatment field is given by the TPS at Dmax. The TPS uses the PBC and AAA algorithms to calculate doses and equivalent path length for homogeneity corrections. The Dmax for a 6-MV photon is 1.5 cm, while that for a 15-MV photon is 3 cm. The diodes were placed in the field based on the radiation type as well as its energy (low or high) being used to treat the patient at the time. For 6-MV photon energy, the P10 diode was used. For 15-MV photon energy, the P20 diode was used.

All measurements were performed in photon radiation beams generated by an accelerator. The *in vivo* dose measurements were taken immediately after patient set-up and before treatment was started for all radiation treatment fields. The diode should be stacked over the patient's skin for prostate tumors and over a mask for brain tumors (mask should be very stick on same patient should be measure) at the treatment site symmetrically or asymmetrically. For symmetrical fields, after set-up, the diodes were placed on the crosswire at the central beam and secured with adhesive tape. For asymmetrical fields, after set-up, the diodes were placed 2 cm from the field edge along one of the cross wires. If these were closer to the edge than 2 cm, the diodes were placed centrally into the field. However, care was taken to calculate the dose for the correct position by consideration of the inverse square correction factor when the field goes through the couch, and the diode was placed on the surface of the couch. For prostate cases, the uncertainties resulting from the angular dependence of the beam were analyzed. In these cases, a measurement point was found that could be uniquely defined and at which the expected dose could be calculated. If for some reason the diode could not be placed on the beam axis and a wedge was used, the diode was moved away from the beam axis.

Results

The external beam irradiation technique intensity-modulated radiation technique (IMRT) for tumor regions like the prostate and brain had a number of treatment fields (Fig. 1). The AAA algorithm was used to calculate dosage, with a dose grid size spacing of 0.5 × 0.5 mm. All of the patients included in this study were treated in a supine position. Computed tomography scans were acquired using a Siemens Emotion CT scanner.

Table 1 Ten IMRT brain patients for dose as total for all fields measured and calculated

Patient	Calculated dose cGY TPS	Measured dose cGY Diode	Variation %
1	212	210.5	0.75
2	214	211.0	1.5
3	203	201.0	1.0
4	200	198.2	0.9
5	211	210.1	0.45
6	200	197.5	1.25
7	215	214	0.5
8	207	201.0	3.3
9	219	216.6	1.5
10	214	209.5	2.25

Patient treatment was delivered using the linear accelerator equipped with a multi-leaf collimator (MLC) to execute the IMRT. Fig. 2 shows the data for 15 patients with prostate cancer. The standard deviation for each patient for prostate cancer by the Eclipse planning was approximately 3.5% between the calculated and measured values. In Fig. 3, data of 20 patients with brain cancer are shown. The standard deviation between the measurements and calculated values by Eclipse planning was approximately 1.2%.

As shown in Table 1, the variation between patients calculated used eclipse treatment planning and data measurement as QA for IMRT patient with max value in patient selected in this study was approximately 3.3%. (In some cases, the variation will increase due to diode displacement and not stick well in a good measurement position) (Fig. 4 and table 2).

Discussion

The *in vivo* dosimetry results for patients with brain cancer were better than those for patients with prostate cancer. Of the 105 field measurements made for the patients with prostate cancer, 16 fields had discrepancies outside the ±5% action level. Of the 145 field measurements made for the patients with brain cancer, only four field discrepancies outside the ±5% action level were recorded for each case. The results indicated a higher degree of accuracy for the brain cancer cases. In the case of the prostate measurements, the higher discrepancy in the doses for the particular fields (exceeding the action level) may have been due to the isocenter being very close to the jaws and the MLC of the linear accelerator machine and fixation system for prostate cancer and in some like example large patient dimensions. As a result, scatter from the jaws and the MLC may have contributed to the high dose delivered to the diode, hence a probable good result of the brain case due highest quality of IMRT technique and fixation system and separation of brain in comparison

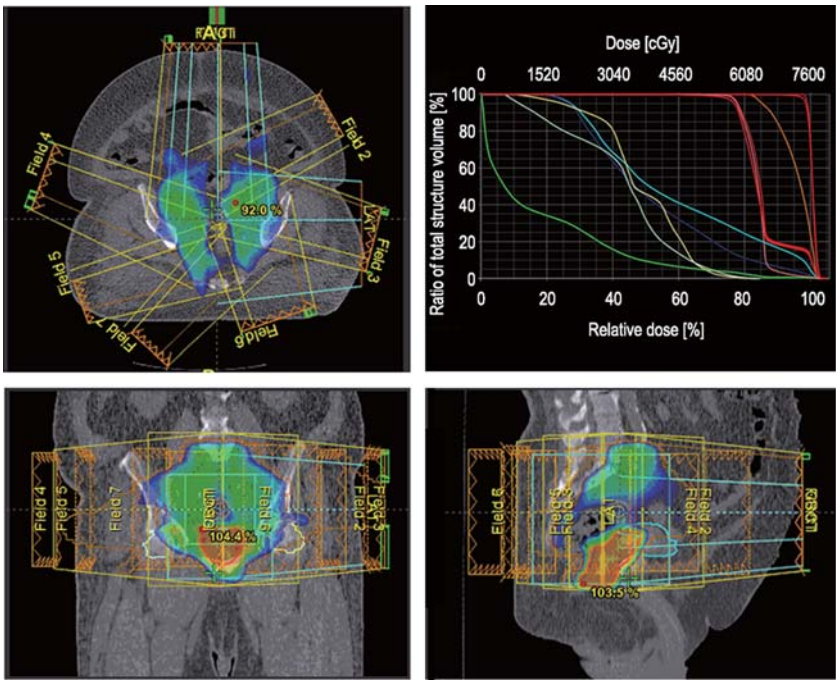

Fig. 1 Screen shot of the IMRT plan for a patient with prostate cancer difficultly plan for prostate IMRT for very large patient separation and check for dose plan. IMRT, intensity-modulated radiation technique

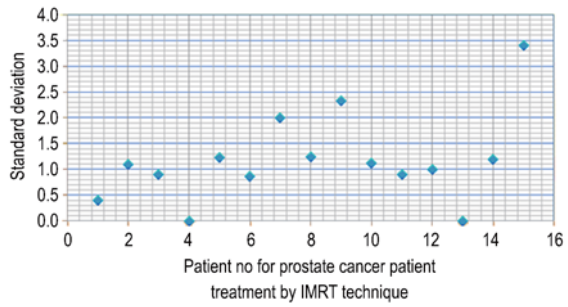

Fig. 2 Discrepancy for ten patients with prostate cancer

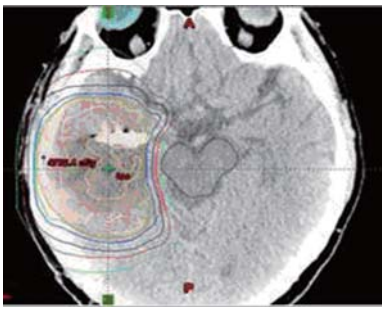

Fig. 3 Example for axilla view for IMRT for brain tumor patient

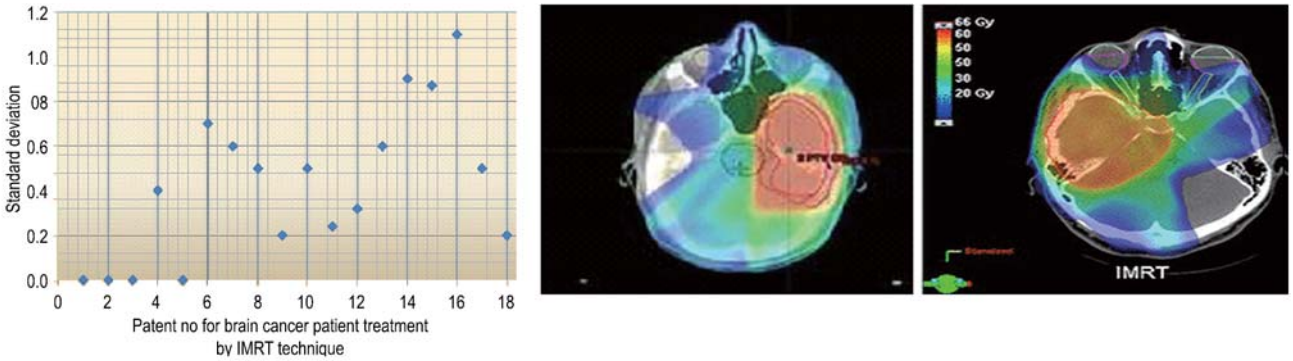

Fig. 4 Axial dose wash for intensity-modulated radiation technique for two brain cancer patients and variation between dose measured and calculated

with prostate patients.

During some of the treatment sessions, the diodes were slightly displaced as a result of adhesive tape loosening. Therefore, these diodes had recorded doses outside the isocenter, leading to some of the observed discrepancies.

Table 2 Ten IMRT prostate patients for dose as total for all fields measured and calculated

Patient	Calculated dose cGY TPS	Measured dose cGY Diode	Variation %
1	223	220.6	1.1
2	205	203.2	0.9
3	220	217.6	1.1
4	203	198.3	2.35
5	205	204.9	0.5
6	224	218	3.0
7	215	211	2
8	203	202	0.5
9	208	205.2	1.4
10	206	205.3	0.4

Illustrates the very small variation between data measurement and calculations for patients with brain cancer due to the good fixation system and lack of diode position displacement

Conclusion

In summary, *in vivo* dosimetry is an effective method for detecting radiotherapy errors, assessing clinically relevant differences between the prescribed and delivered doses, reducing potential patient harm, and fulfilling requirements set forth by national and international regulations. In this study, a much greater percentage of the observed discrepancies was well within the set tolerance level, while a greater percentage of the observed discrepancies were well within the set tolerance level. However, we recommend that the diode positioning on a patient's skin, and the angular diode sensitivity be reconsidered. We also recommended that a more accurate calculation of expected diode values be performed, especially for fields that pass through the table. These efforts would enable the achievement of action levels of ±5%.

Conflicts of interest

The authors indicated no potential conflicts of interest.

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