Patient Dose Verification with In Vivo Dosimetry Using Diodes in Radiotherapy

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Abstract:

This study aims to use semiconductor diodes for real-time verification of the prescribed dose to the patient in radiotherapy and the dose delivered during treatment. A quality assurance step in radiotherapy is provided by comparing the dose prescribed in patient treatment planning with the doses delivered during treatment. A well-planned in vivo dosimetry program in the clinic prevents the development of undesirable situations in patient treatments. For this purpose, patient dose verification was performed using the Scanditronix Wellhofer in vivo dosimetry system in a total of 61 patients in lung, breast, pelvic box, brain, prostate, craniospinal, esophagus, and nasopharynx patient groups. Patient entrance doses were measured with semiconductor diodes placed on the patient. Corrected doses were calculated by using measured doses with correction factors appropriate to the treatment conditions and compared with the planned doses from patient planning. According to the results of the study, it was found that there was a difference of approximately 5% between the measured doses and the corrected doses in patient treatment, and this difference decreased to less than 1% between the corrected doses and the planned doses. These results emphasize that correction factors should be determined correctly and used correctly in patient dose verification in the clinic.

1. Introduction

In vivo systems using semiconductor diodes are one of the systems developed to verify the dose delivered to the patient during patient treatment and are widely used in External Beam RadioTherapy (EBRT). In vivo dosimetry systems using semiconductor diodes allow real-time measurement of the dose delivered to the patient in radiotherapy. One of the best methods to verify dose delivery and superiority check is in vivo dosimetry, while EBRT, International Atomic Energy Agency (IAEA), is achieved to set the action level the same as the tolerance level (5%) [1]. By knowing the semiconductor diodes used by the medical physicist in the clinic and the characteristics of the in vivo dosimetry system, the plug-and-play model of dosimeters can be developed [2]. However, the dosimetric characteristics of the in vivo dosimetry system and each semiconductor diode used in the clinic for the radiation and energies used should be well determined. It is necessary to determine how much the parameters such as stability, accuracy, linearity, repeatability, angular dependence, temperature dependence, dose rate dependence, Source Skin Distance (SSD) dependence, field size dependence of these semiconductor diodes used in the clinic affect the dose results when they differ from the calibration conditions [3-4].

2. Materials and Methods

The measurements were carried out on the Elekta Synergy® (Elekta Oncology Systems) linear accelerator, providing 6 MV and 18 MV photon beams. Scanditronix Wellhöfer 12-channel DPD-12 electrometer, in-vivo dosimetry system consisting of EDP-15 (Channel 1,2,3,4), EDP-30 (Channel 5,6), EDE-5 (Channel 7,8,9,10), EDD-5 (Channel 11), EDD-2 (Channel 12) diodes were used in the study. Diode calibrations were performed using Farmer Type Chamber FC65-P 0.6cc ion chamber (Scanditronix/Wellhofer), Farmer Dosemeter 2570/1B electrometer (NE Technolgy), PMMA solid water Phantoms (IBA) with a density of 1g/cm^3 in various thicknesses of 40x40 cmxcm. EDP-15

(Channel 1,2,3,4), EDP-30 (Channel 5,6) diodes were used in the patient dose verification measurements of the study, depending on the treatment energy used in the patient treatment planning (for 6 MV or 18 MV).

2.1. Diodes Calibrations

Diodes are calibrated in 10x10 cmxcm field size, SSD=100 cm, Gantry=0º reference calibration conditions, and an ion chamber with PMMA solid phantoms placed on it at a depth of build up. Diodes are used for the first time in the clinic after production without any previous irradiation [4-5].

2.2. Accuracy Test

The diodes were irradiated with 6 MV and 18 MV photon beams, 50 MU on the phantom under reference calibration conditions using a PMMA solid phantom. Before irradiating the ion chamber and diodes, the treatment machines were calibrated as 1cGy = 1MU.

2.3. Linearity Test

The PMMA solid phantom was irradiated with 6 MV and 18 MV photon beams under reference calibration conditions, with single fraction doses used in radiotherapy starting from 10 MU up to 800 MU. EDP-15, EDP-30, and EDE-5 Linearity Tests are shown in Figure 1.
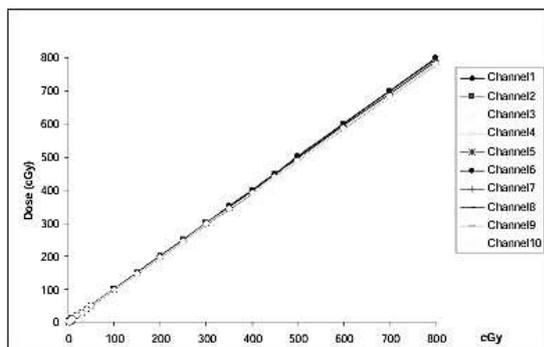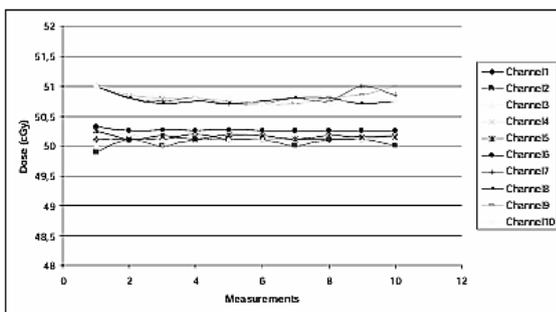

***Figure 1.** Diodes Linearity Tests*

***Figure 2.** Diodes Reproducibility Tests in a day*

2.4. Reproducibility Test

The PMMA solid phantom was irradiated with 6 MV and 18 MV photon beams at reference calibration conditions for 10 consecutive measurements of 50 MU on the same day. EDP-15, EDP-30, and EDE-5 Reproducibility Tests in a day are shown in Figure 2.

2.5. Orientation Dependence Test

At the linear accelerator's 6 MV and 18 MV energy levels with SSD=100 cm, by putting the diodes on the phantom in-plane and cross-plane in the beam center, 30 MU irradiations are done. Between the gantry angles of +/- 75 degrees, 15, 30, 45, 60 and 75 degree angle positions are irradiated to 30 MU with in-plane and cross-plane orientation to control the diode measurement dependence on angular orientation. Figures 3 and 4 show the orientation dependence of diodes.
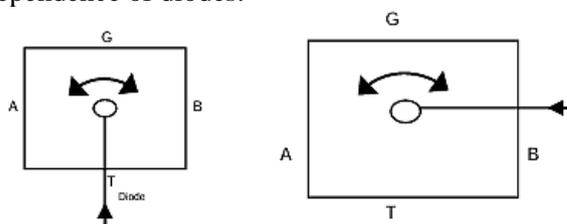

***Figure 3.** Set up of diodes in In-plane and Cross-plane orientation*
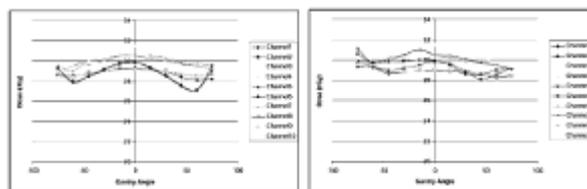
***Figure 4 .** Angular dependence of diodes in In-plane and Cross-plane orientation*

2.6. Temperature Dependence Test

The measurement set is prepared and put on water-filled phantom for a 6 MV linear accelerator. EDP-15 (Channel 1, 2, 3, 4) diode is placed on the water surface, and the ion chamber in d=5cm. In the same way, for 18 MV, EDP-30 (Channel 5, 6) diode is placed on the water surface, and the ion chamber is in d=10 cm. 50 MU irradiation was given with a linear accelerator at SSD=100 cm, and the field size was 10x10 cmxcm. The water temperature in the phantom was gradually increased from 18°C to 36°C by adding hot water. Temperature changes were measured by putting a thermometer in the water and waiting for 3 to 5 minutes to let the diodes reach the same temperature [3-5]. At the end of the measurements, ion chamber readings for every temperature level, temperature-pressure correction

was done, and compared with diode readings. The temperature dependence of the diodes is shown in Figure 5.
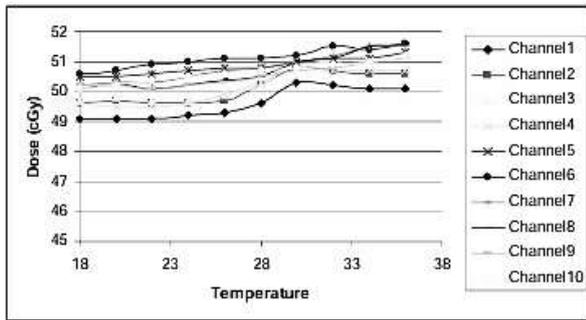

Figure 5. Temperature Dependence Test

2.7. Patient Dose Measurements

The calibration factor was found to be 1.0066 at 6 MV photon energy for EDP-15 diodes and 1.0006 at 18 MV photon energy for EDP-30 diodes. Correction factors such as SSD, field size, and wedge factors, required in clinical use, were calculated. The correction factors were multiplied by the calibration factor and diode reading doses, and the corrected measured patient doses are given in Table 3. When the diodes are placed on the patient's skin, they give input dose readings at build-up depths. At the same time, the entrance dose is measured without planning at build-up depths. The EDP-15 diode used in the measurement with 6 MV photon energy has a build-up thickness of 1,5 cm, and the EDP-30 diode used in the measurement with 18 MV photon energy has a build-up thickness of 3,0 cm. These values are suitable build-up thicknesses for these energies. During the patient treatment, online dose readings from the diodes placed in the isocenter of the treatment field on the patient's skin, corrected patient doses, and patient doses determined from the treatment plans of the patient were compared, and the differences between them were calculated.The diodes were placed on the patient in such a way that their angular dependence was neglected. In addition, the diodes were placed on the patient's skin 2-3 minutes before the treatment, allowing the diodes to reach temperature equilibrium and neglecting the temperature dependence [6-7].Patient treatment dose distributions were performed with Precise Plan TPS using 3D conformal treatment planning method. Patient treatment dose distributions were performed with Precise Plan TPS using 3D conformal treatment planning method. For treatment dose verification with diodes, measurements were performed and evaluated in the Anterior Posterior (AP) and Right Lateral (RLAT) or Left Lateral (LLAT) treatment fields of the patient treatments in 61 patients in the

lung, pelvic box, breast, prostate, craniospinal, brain, nasopharynx and oesophagus patient groups. All measured doses were compared to the TPS dose with EBRT, which was performed using an Elekta Synergy. The primary objective for each plan was to cover 95% of Planning Target Volume (PTV) covered by 95% of the prescribed dose while minimizing the dose to the Organ At Risk (OARs) was avoided as much as possible by selecting the optimal positions. All patients gave written informed consent before radiotherapeutic management with institutional tumor board approval at our tertiary cancer center, and the study has been performed in compliance with the Declaration of Helsinki principles and its later amendments.In order to verify the patient dose in the patients treated in the clinic and shown in Table 1, the differences between the reading doses (RD) from the diode during treatment and the measured doses (MD) obtained by multiplying the dose reading from this diode by the correction factors were evaluated. Furthermore, the MD values obtained were compared with the planned doses obtained from the TPS, and mean RD/MD (%) and mean MD/PD (%) values for each treatment site are given in Table 2.

3. Results and Discussions

According to Table 2, the maximum difference in mean RD/MD (%) was 4,04% in prostate treatments. The reason for this difference is considered to be the increase in the number of fields in AP, RLAT and LLAT diode RD in 7-oblique field prostate treatments, and therefore, more correction factors are taken into account when calculating MD. The minimum difference in RD/MD (%) was 0,77% in craniospinal treatments. The reason for this minimum difference is due to the simple RD in the field isocentre in the Cranium LAT fields, Cervical, Thoracal, and Lumbar fields in the craniospinal treatments, and thus the simplicity of the correction factors. In addition, the maximum difference mean MD/PD (%) was -1,68 in pelvic treatments. Furthermore, the maximum mean MD/PD (%) difference in isocentered AP and RLAT pelvic areas was -1,68%. The difference here is due to the correction factor from the field size of the pelvic box. The minimum difference in RD/MD (%) was -0,02% for craniospinal treatments, and again, the small difference was due to the single and simple field sizes in craniospinal treatments. According to the results of [8], for each field used in the treatment, there was a 5% difference between the dose measured on the patient's skin and the dose calculated from TPS. Then they showed that the maximum input dose deviation was 4,1% for all 10 cases examined. our study results show that there are

smaller differences than these results. When measuring in large, flaccid, and fatty tissues, set-up errors during patient treatment are increased, and diodes cannot always be placed at the same points. Here, differences in dose between fractions and differences between the dose read from the planning come from the patient's set-up errors. The use of the in vivo dosimetry system during patient treatment also helps to reveal set-up errors. In vivo dosimetry systems are one of the most widely used systems to verify the dose delivered in real-time during patient treatment, especially in EBRT. Although semiconductor diodes have some handling challenges due to their design, they can be reliably used in the clinic for patient dose verification when diode dose response effects are correctly determined. When we look at the literature studies, some differences were determined between the prescribed and measured doses of diodes. According to the study by Mijnheer et al, estimated dose uncertainty 1,5- 3% in lower values applies to dosimeters that are regularly calibrated and have well-known correction factors by diodes [9]. The results of a study by Kadesjö et al. for Diode dosimetry in head and neck and prostate treatments showed that 92.2%

of measurements were within ±5% of their expected values [10]. Parham et al. The study by Parham et al. using diodes for IMRT showed that 76% of measurements were within 10% of prescribed doses, and about 11% of the other 24% were within 15% of the calculated dose. To compare these results with phantom measurements, they said that most of the discrepancies were due to diode positioning on the patients and increased diode response at short source-surface distances (SSDs), while the rest were due to other factors such as segment size and partial irradiation of the diode [11]. This indicates that the margin of error of patient dose verification increases when the diodes are outside the treatment fields or segments. It can therefore be concluded that diodes provide more accurate patient dose verification in EBRT treatments. In another study by Barlaz US et al. using mosfet diodes and thermoluminescence dosimeters, it was shown that changes due to SSD and gantry angle can be ignored in phantom measurements, but these parameters should be taken into account in complex areas where oblique beam is used, such as breast and head and neck treatments [12].

Table 1. Reading Dose (RD), Measured Dose (MD), Planned Dose (PD), and MD/PD (%) comparisons for each patient

Patient	Treatment	Field	RD (cGy)	MD (cGy)	PD (cGy)	MD/PD (%)
1	Lung	Oblique	120	116	123	-5,69
2	Lung	Oblique	75	74	73	1,37
3	Lung	Oblique	140	134	133	0,75
4	Lung	Oblique	136	132	138	-4,35
5	Lung	Oblique	125	120	121	-0,83
6	Lung	Oblique	138	130	135	-3,7
7	Lung	Oblique	130	127	127	0
8	Lung	Oblique	151	143	141	1,42
9	Lung	Oblique	142	137	140	-2,14
10	Lung	Oblique	224	217	221	-1,81
11	Pelvic Box	AP	70	66	69	-4,35
		RLAT	93	91	91	0
12	Pelvic Box	AP	82	80	81	-1,23
		RLAT	96	93	93	-2,17
13	Pelvic Box	AP	89	83	83	0
		RLAT	87	86	87	0
14	Pelvic Box	AP	76	73	75	-1,15
		RLAT	91	86	90	-2,67
15	Pelvic Box	AP	94	91	92	-4,44
		RLAT	100	93	99	-1,09
16	Pelvic Box	AP	56	54	57	-6,06
		RLAT	88	87	90	-5,26
17	Pelvic Box	AP	80	77	77	-3,33
		RLAT	79	74	78	0
18	Pelvic Box	AP	80	77	76	-5,13
		RLAT	73	72	71	1,32
19	Pelvic Box	AP	89	85	85	0
		RLAT	92	88	90	-2,22
20	Pelvic Box	AP	72	69	70	-1,43
		RLAT	90	87	88	-1,14
21	Pelvic Box	AP	75	72	73	-1,37
		RLAT	90	88	87	1,15
22	Breast	AP-Oblique	113	111	116	0
		LAT-Oblique	132	130	139	-2,22
23	Breast	AP-Oblique	140	136	142	-1,43
		LAT-Oblique	142	138	140	-1,14
24	Breast	AP-Oblique	176	171	163	-1,37
		LAT-Oblique	197	190	164	1,15
25	Breast	AP-Oblique	141	137	146	0
		LAT-Oblique	129	128	127	-2,22
26	Breast	AP-Oblique	138	134	136	-1,43
		LAT-Oblique	129	125	147	-1,14
27	Breast	AP-Oblique	154	148	147	-1,37
		LAT-Oblique	160	153	152	1,15
28	Breast	AP-Oblique	139	132	132	0
		LAT-Oblique	155	149	148	-2,22
29	Breast	AP-Oblique	149	142	144	-1,43
		LAT-Oblique	144	137	135	-1,14
30	Breast	AP-Oblique	158	150	150	-1,37
		LAT-Oblique	159	156	155	1,15
31	Breast	AP-Oblique	152	147	148	0
		LAT-Oblique	150	145	146	-2,22
32	Prostate	AP	7	6	6	0
		LLAT	108	101	100	1
		RLAT	106	100	99	1,01
33	Prostate	AP	6	6	6	0
		LLAT	103	99	101	-1,98
		RLAT	104	100	103	-2,91
34	Prostate	AP	6	6	6	0
		LLAT	107	104	105	-0,95
		RLAT	108	105	105	0

ID	Site	Field				Diff
35	Prostate	AP	8	8	7	14,29
		LLAT	113	111	111	0
		RLAT	112	109	110	-0,91
36	Prostate	AP	7	7	7	0
		LLAT	106	102	104	-1,92
		RLAT	105	101	104	-2,88
37	Prostate	AP	8	8	7	14,29
		LLAT	111	107	112	-4,46
		RLAT	109	106	107	-0,93
38	Prostate	AP	7	7	7	0
		LLAT	105	100	103	-2,91
		RLAT	101	96	98	-2,04
39	Prostate	AP	8	7	7	0
		LLAT	108	101	106	-4,72
		RLAT	109	102	107	-4,67
40	Prostate	AP	7	7	7	0
		LLAT	109	104	108	-3,7
		RLAT	109	105	108	-2,78
41	Prostate	AP	7	7	7	0
		LLAT	107	101	102	-0,98
		RLAT	106	100	104	-3,85
42	Craniospinal	Cranium RLAT	133	131	129	1,55
		Cranium LLAT	127	125	123	1,63
		Cervical	208	207	205.93	0,49
		Thoracal	207	208	206,35	0,97
		Lumbar	216	217	217,02	0
43	Craniospinal	Cranium LLAT	121	117	121	0
		Cervical	203	204	202,76	-3,31
		Thoracal	207	204	203,1	0,61
		Lumbar	196	197	202,26	0,44
44	Craniospinal	Cranium LLAT	131	126	127	0
		Cervical	207	206	206	-0,79
		Thoracal	207	208	207	0
		Lumbar	217	218	217	0,48
45	Brain	RLAT	137	133	134	-0,07
		LLAT	139	134	137	2,19
46	Brain	RLAT	145	140	144	-2,78
		LLAT	175	172	171	0,59
47	Brain	RLAT	142	137	138	-0,72
		LLAT	143	139	140	-0,71
48	Brain	RLAT	142	138	140	-1,43
		LLAT	141	137	139	-1,44
49	Brain	RLAT	130	126	127	-0,79
		LLAT	132	128	131	-2,29
50	Brain	RLAT	140	134	136	-1,47
		LLAT	142	138	139	-0,72
51	Brain	RLAT	142	138	140	-1,43
		LLAT	141	137	139	-1,44
52	Brain	RLAT	139	135	136	-0,74
		LLAT	136	132	134	-1,49
53	Brain	RLAT	142	139	138	0,73
		LLAT	144	141	140	0,71
54	Brain	RLAT	145	143	142	0,70
		LLAT	143	141	141	0
55	Nasopharynx	AP	218	220	214	2,80
		RLAT	132	129	132	-2,27
		LLAT	129	126	128	-1,56
56	Nasopharynx	AP	220	218	215	1,4
		RLAT	138	135	135	0
		LLAT	133	130	130	0
57	Nasopharynx	AP	212	213	212	0,47
		RLAT	141	138	140	-1,43
		LLAT	141	138	139	-0,72
58	Esophagus	Supra AP	209	204	211	-3,32
		Upper Mediastinum AP	153	149	154	-3,25
59	Esophagus	Supra AP	209	205	210	-2,38
		Upper Mediastinum AP	166	161	160	0,63
60	Esophagus	Supra AP	210	207	212	-2,36
		Upper Mediastinum AP	173	170	168	1,19
61	Esophagus	Supra AP	206	203	208	-2,40
		Upper Mediastinum AP	173	170	168	1,9

***Table 2.** Mean RD/MD (%) and Mean MD/PD (%) differences for each treatment group*

Treatment	RD/MD (%)	MD/PD (%)
Lung	3,75	-1,5
Pelvic Box	3,97	-1,68
Breast	3,39	-0,81
Prostate	4,04	-0,4
Craniospinal	0,77	-0,02
Brain	2,85	-0,88
Nasopharynx	1,46	-0,15
Esophagus	2,08	-1,34

4. Conclusions

According to the results of patient dose verification during 61 patient treatments, including Lung, Pelvic Box, Breast, Prostate, Craniospinal, Brain, Nasopharynx, and Esophagus EBRT treatments, correction factors such as field size, SSD, and angle dependence need to be taken into account for each diode during on-patient treatment. As the number of fields and the number of correction factors to be taken into account increases, the difference between the measured dose and the planned dose increases. Diodes can be safely used for patient dose verification in EBRT treatments. In conclusion, the Scanditronix Wellhofer in vivo dosimetry system is a very useful system for patient dose verification in radiotherapy. A well-defined in vivo dosimetry program ensures accurate reproducibility of clinical applications.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

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