Iranian Journal of Medical Physics

ijmp.mums.ac.ir

In Vivo Dosimetry Using a Flat Surface Sun Nuclear Corporation Diode in ^{60}co Beams for Some Radiotherapy Treatments in Ghana

Vivian Della Atuwo- Ampoh[1], Eric Naab Manson[2]*, Cyril Schandorf[2], Samuel Nii Tagoe[3], Eric K.T. Addison[1,4], Emmanuel Fiagbedzi[1]

1. Department of Oncology, Komfo Anokye Teaching Hospital, Kumasi, Ghana
2. Departments of Medical Physics, School of Nuclear and Allied Science, University of Ghana- Atomic Campus, Ghana
3. National Radiotherapy and Nuclear Medicine Centre, Korle-bu Teaching Hospital, Accra, Ghana
4. Kwame Nkrumah University of Science and Technology, Kumasi, Ghana

ARTICLE INFO

Article type:
Original Article

Article history:
Received: Mar 22, 2018
Accepted: Jun 28, 2018

Keywords:
In vivo Dosimetry
Co-60
Diode
Radiotherapy

ABSTRACT

Introduction: One of the useful standard quality assurance techniques in radiation therapy is monitoring entrance doses in in-vivo dosimetry. An overall tolerance limit of 5% of the absorbed radiation dose has been recommended by the International Commission of Radiological Units. The implementation of an in vivo dosimetry still remains as a challenge to clinical medical physicists. As a result, the practice of constant monitoring of patients undergoing radiation therapy in most of the radiotherapy departments in Africa has not been given much attention. The study aimed at the evaluation of in-vivo entrance dosimetry using diodes to verify the accuracy of the radiation delivered to patients, compared to prescribed doses.

Material and Methods: In this paper, a protocol for in vivo dosimetry using a two flat surface Sun Nuclear Corporation diode in a radiotherapy department has been implemented in equinox Cobalt 60 beams. A water phantom calibrated was performed using the International Atomic Energy Agency standards (TRS 398). Calibration coefficients were determined with diodes using a Perspex phantom to derive correction factors. A total number of 137 patients' doses were measured with the diodes during the treatment of 4 different sites.

Results: The average deviation between the measured and expected entrance dose performed by the phantom studies was 5% (0.34±1.8%) in almost all cases.

Conclusion: The developed protocol in this study indicates that in vivo dosimetry using silicon diodes is reliable, which can be adopted as a universal quality assurance tool in the radiotherapy departments. Moreover, measurements with diodes can be acquired online which produces an instant readout and is relatively cheaper as compared to the ion chamber.

► *Please cite this article as:*
Atuwo-Ampoh V, Manson Eric N, Schandorf C, Tagoe S. N, Addison Eric K.T, Fiagbedzi E. In Vivo Dosimetry Using a Flat Surface Sun Nuclear Corporation Diode in ^{60}co Beams for Some Radiotherapy Treatments in Ghana. Iran J Med Phys 2019; 16: 329-335. 10.22038/ijmp.2018.29705.1324.

Introduction

Radiation therapy accounts for 50% of treatment modalities used worldwide on people with cancer. The aim of radiation therapy is to maximize dose delivered to the tumor target whiles minimizing absorbed dose to the normal tissues as low as possible. Tumor control for patients undergoing radiation therapy depends on the accurate delivery of the radiation dose. The International Commission of Radiological Units (ICRU) has recommended that the general tolerance limit of radiation dose absorbed during radiation therapy delivery should be maintained at 5% action level [1]. Accordingly, it is very essential to provide constant monitoring for patients undergoing radiation therapy. To accurately monitor the dose delivered to a patient undergoing radiation therapy, the most commonly used method is in vivo dosimetry using detectors. This method is considered supplementary not mandatory in clinical Quality Assurance (QA) Program [2,3]; however, in other European countries in vivo dosimetry is mandatory. The performance of detectors for Quality Assurance (QA) in vivo dosimetry can be determined by establishing action levels. Action levels provides quantitative information to reject or accept in vivo data for routine QA in radiotherapy centers [4].

On the basis of the literature, there has been a large number of studies on in vivo dosimetry using the varieties of detectors, such as thermoluminescent dosimeters, Metal oxide-silicon semiconductor field effect transistors, and diodes [5], in different radiotherapy departments all over the world. For three-dimensional conformal radiotherapy, silicon

*Corresponding Author: Email: mansonericnaab@yahoo.com

diode detectors have gained popularity as in vivo dosimeters since they provide a convenient way of measuring the entrance doses to patients at the real-time and are easy to use by the therapist [6]. Silicon diode is a semiconductor diode that offers a unique combination of radiation sensitivity and immediate readout when connected to a suitable electrometer. The response of the silicon diode signal is affected by certain physical and geometrical factors. Geometrical parameters, such as field size (FS) and source to skin distance (SSD), as well as the physical parameters of trays, blocks, and wedges have an influence on the diode. Ideally, the dependence of diode on SSD, field size, and beam modifiers should be within the range of 1-2%. Therefore, these parameters can significantly alter the diode signal. As a result of this variation in diode signal, correction coefficients are usually determined [7-9]. The correction coefficients of diode are calculated based on the responses of the diode to beam energy, dose rate, temperature, and direction of the beam [10].

Due to the lack of constant monitoring of in vivo dosimetry on patients undergoing radiation therapy in the developing countries, this research was performed to check the usefulness of silicon diodes for the in vivo verification of entrance dose in radiation therapy for pelvis, head and neck, breast and other areas (spine, abdomen, stomach, prostate) of malignancies commonly treated in West Africa. Moreover, the study moved further by comparing the obtained results of correction factors (CFs) with the values reported in the literature. This study can be considered a reference for other radiotherapy settings in the developing countries.

Materials and Methods

Two dosimetric diodes (QED detector model 1114000-3 and 1113000-3), manufactured by Sun Nuclear Corporation were calibrated on W-30010 farmer ionization chamber "PTW-Freiburg, Germany" according to International Atomic Energy Agency (IAEA) TRS-398 protocol [11]. Initially, a deep round hole was made in the solid water phantom with the dimensions of 20×20×10 cm at a depth of 5cm. Each diode was then taped to the phantom through the bore. The ion chamber was connected from the focus at a distance of 100cm in the center of an open treatment field of 10cm×10cm. using a 0^{o} gantry angle, the ionization chamber was irradiated using default treatment parameters. Also, a range of varied FS, focus surface distance, wedges and exit dose measurement were explored in order to determine CFs accounting for non-reference conditions. Using a 5cm of percentage depth dose (PDD), corrected measurements were converted to dose at maximum (Dmax) and hence the absorbed dose to water calibration factors determined.

Readings were then taken up to obtain calibration coefficients by tapping the diodes at the entrance surface of 30×30×12 cm^3 Perspex phantom (a pile of 12, 30×30×1cm^3 Perspex slabs) at a field center. They were then exposed to gamma radiation from Co-60 unit at various field sizes (4×4, 8×8, 10×10, 12×12, 16×16, 20×20, 25×25 cm^2) at standard reference depth of 5cm and depths of 3, 7, 11, 13, 15, 18, 20 cm at standard field size of 10×10 cm^2 to represent those normally used for treatment. The entrance dose of 134 patients undergoing pelvis, head and neck, breast, and spine radiation therapy on Co-60 photon beams was measured with the diodes. Entrance dose that is absorbed from the surface of the incident plane to a 5cm depth was then determined using the diode from *Equation 1*. Tissue maximum ratio (TMR) is incorporated since source to axis distance (SAD) setup is used. Moreover, decay factor (Df) accounts for the decay of Co-60 and a factor to accounts for non-isocentric teletherapy unit calibration.

$$D_{ent(Gy)} = R_{diode} * C_{cal} * \prod_i CF_i \quad (1)$$

Where, R_{diode} refers to the reading of the diode, C_{cal} is the calibration coefficient, and CF_i denotes the CFs.

The calibration coefficient (C_{cal}) was determined through *Equation 2* at standard reference conditions (10x10cm^2 field size at iso-center, SSD=80 cm, gantry angle 0°).

$$C_{cal} = \left(\frac{D_{ic}}{R_{diode}}\right)_{\text{ref.con}} \quad (2)$$

Where, D_{ic} is the dose measured by ionization chamber placed at d_{max} in a water phantom and R_{diode} signifies the diode reading placed at the phantom surface.

The CFs accounts for the variations of diode response to the procedure described in IAEA guidelines. The CFs were determined as the ratio of the reading of the ionization chamber and the reading of the diode for a clinical irradiation situation normalized to the same ratio for the reference situation for different factors [12,13] as shown in equations 3 – 7.

$$CF(FS) = \frac{\left(\frac{Sc,p(FS)}{Sc,p(10X10)}\right)}{\left(\frac{R(FS)}{R(10X10)}\right)} \quad (3)$$

$$CF(SSD) = \frac{\left(\frac{Dw(SSD)}{Dw(100)}\right)}{\left(\frac{R(FS)}{R(10X10)}\right)} \quad (4)$$

$$CF(tray) = \frac{\left(\frac{Dw(tray)}{Dw(open0)}\right)}{\left(\frac{R(tray)}{R(open)}\right)} \quad (5)$$

$$CF(Wedge) = \frac{\left(\frac{Dw(wedge)}{Dw(open)}\right)}{\left(\frac{R(wedge)}{R(open)}\right)} \quad (6)$$

In order to accurately determine the directional response of the detector, the diode was placed in the field center, at reference conditions for different gantry angles (GA=θ). The CFs were then calculated as shown in *Equation* 7.

$$CF_{GA=\theta^0} = \frac{(R_{diode})_{(GA^0,FS=10,SSD=100cm)}}{(R_{diode})_{(GA^\theta,FS=10,SSD=100cm)}} \quad (7)$$

Results

The diode detector has been calibrated for entrance absorbed dose verification in Co-60 beam under reference conditions of temperature. Measurements have been taken on a phantom and then implemented on Patients during treatment. The phantom measurements revealed an overall mean percent deviation of ±0.34% with the SD of ±0.02 (Table 1) whilst that of overall patients entrance dose measurement (n=134) was 1.02%±4.10 (Figure 1). The measurements were grouped according to the site of treatment, including breast, head and neck (H/N), pelvis, and other areas. The head and neck, pelvis, and other areas showed positive (+ve) deviations as indicated in Table 2. The entrance calibration coefficient was estimated at 2.68. This was calculated based on the geometrical factors influencing the diode response.

Table 1. Results of phantom measurement from the in vivo dosimetry

Phantom	Equivalent square	Prescribed Dose (cGymin^{-1})	Calculated Diode Dose at treatment depth (cGymin^{-1})	Percentage Dev. (%)
1	17.9	100	103.702	3.70%
2	17.9	200	205.912	2.96%
3	17.9	400	407.600	0.02%
4	17.9	100	101.889	1.90%
5	17.9	200	202.050	1.00%
6	17.9	400	401.150	0.00%
7	17.9	200	197.394	-1.30%
8	17.9	200	197.789	-1.11%
9	17.9	200	197.048	-1.48%
10	17.9	200	197.4433	-1.28%
11	12	200	197.363	-1.32%
12	12	200	195.195	-2.40%
13	12	100	102.183	2.18%
14	12	200	202.4104	1.21%
15	12	400	404.603	1.15%
16	15	800	912.882	0.14%
Overall mean deviations and standard deviation				0.34%±0.02

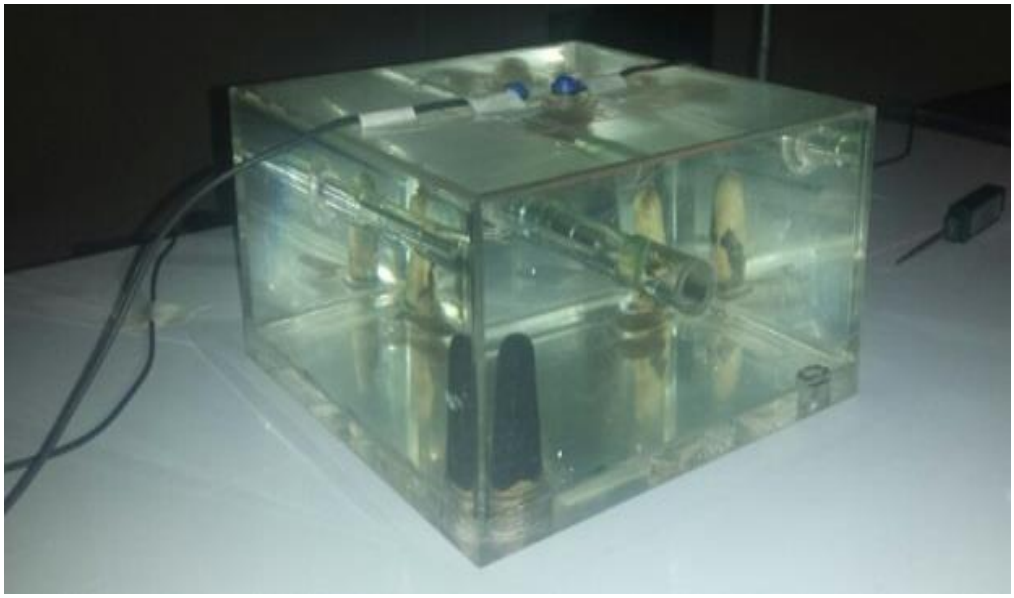

Figure 1. Schematic representation of a diode calibration set-up for with a solid water phantom

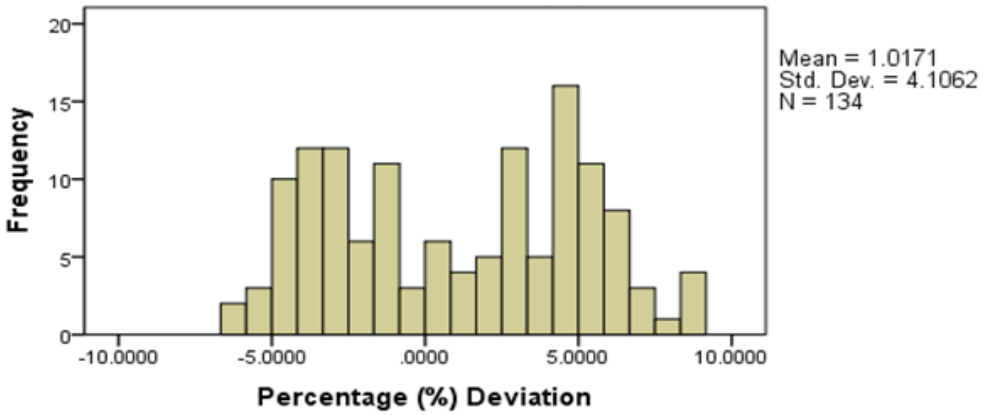

Figure 2. Histogram of deviation of all the fields (n=134)

Discussion

The current study was conducted to measure the entrance dose of in vivo dosimetry using the diode detector in the radiotherapy department. In this regard, a solid water phantom was firstly used (Figure 1) and then implemented on patients being treated between January to July, 2014. This obtained results of the present study was within ICRU recommendation. There was no significant difference between the overall prescribed dose and the measured dose. The phantom measurements revealed an overall mean percent deviation of ±0.34% with SD of ±0.02%, while that of overall entrance dose measurement (n=134) was 1.02%±4.10%.. In general, the tolerance limit for radiation dose from the study was found to be within 5% of the expected dose. Accordingly, it can be said that before the administration of in vivo for patients, the measurement process and the obtained results of the solid water phantom could serve as a guide to achieve an acceptable level of uncertainties in in vivo dosimetry.

The overall percentage of measurement with 5% tolerance was 79.85 %, which defines acceptable results. Regarding the phantom, measurements were considered satisfactory if the measured dose did not differ from the prescribed dose by more than 5% for the pelvis, and head and neck, and by more than 7% for the breast and any other complicated measurement field. These results are comparable to a study carried out in Poland and Croatia [13], where two action levels of 5% and 7% for simple and tangential fields with diodes were adopted, respectively. In addition to the action levels, works in Poland indicated the dependence of field sizes on CFs using PTW diodes in a high energy X-ray beam. The effect of field size on CFs (Figure 3) was not apparent with the Sun Nuclear Diodes in the Co-60 beam.

Table 2. Results of deviations of all areas on the patients

SITE	N (Total No.)	No of fields	$\Delta \pm \sigma$, %	%N ($\lvert\Delta\rvert < 5\%$)
Head and Neck(H/N)	5	13	0.15 ± 4.0	92.31
Pelvis	28	60	1.92 ± 4.05	73.33
Breast	24	48	0.12 ± 4.20	83.33
Other areas	6	13	1.66 ± 3.23	83.30
Tray, Block, and Wedge fields	-	44	1.12 ± 4.14	77.27
All measurements	63	134	1.02 ± 4.10	79.85

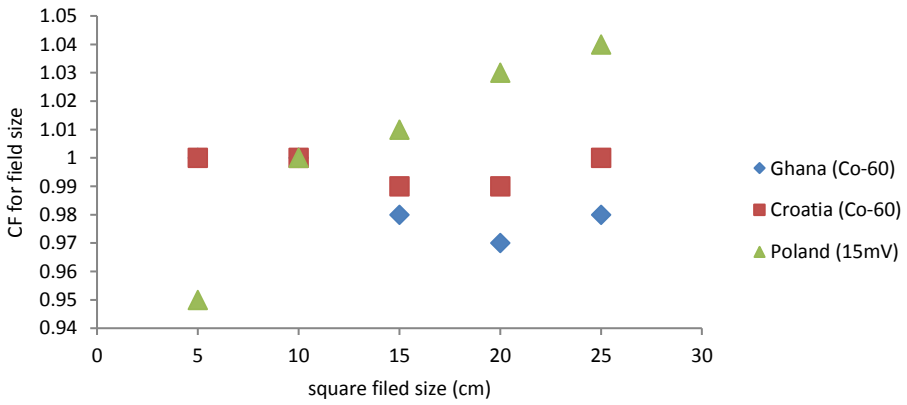

Figure 3. Inter-comparison of CF values among three countries

Table 3. Correction factors for trays with different field sizes

FS (cm)	CF for perforated tray	CF for Full tray
2	1.000	1.002
4	1.000	1.001
6	0.999	1.000
8	0.999	1.000
10	0.988	1.000
12	0.988	0.999
14	0.988	0.999
16	0.977	0.988
18	0.977	0.988

Table 4. Wedge correction factors for various field sizes

	Correction Factors			
FS (cm)	WF 15^0	WF30^0	WF45^0	WF60^0
2	0.997	1.000	1.001	1.010
4	0.999	0.999	1.003	1.002
6	0.999	1.000	1.001	1.003
8	0.998	0.999	0.999	1.001
10	0.999	1.000	1.000	1.001
12	0.998	0.998	1.000	1.000
14	0.997	0.999	0.999	1.000
16	0.999	0.999	1.000	1.001
18	0.999	1.000	1.001	1.007

It can be concluded that, the findings in this study is generally quite good and is also in perfect agreement with works done [13-14] using diodes within a Co-beam beam. This suggests that the action level of 5% established in this study was appropriate. However, about 3.73 % of the total deviations were beyond 7% of action level. These errors occurred due to the use of the wrong beam parameters as depth.

This study also addressed the effect of block trays and wedges on the diode response was also studied in. The CFs for the trays (Table 3) was within the range of 1.000±0.002, and therefore had no significant effect on the diode responds in the in vivo dosimetry program. Furthermore, wedges are commonly used to minimize the dose rate and optimize the beam quality. The response of the diode on the effect of wedge filters for different field size is shown in (Table 4). The effect of wedge filters on the diode responds for both smaller (15^0 and 30^0) and larger (45^0 and 60^0) wedges was less than 1%. Therefore, the CF_{wedge} is considered independent of field size.

The increased level of SSD from 75 to 120 cm increases the CFs (Figure 4) by about 1%. Due to scattered photons and electron contamination in the head of the treatment machine, there was a larger number of electrons that reach the diode for smaller SSD. The magnitude of correction was associated with not only the capacity of the buildup cap but also the energy dependence of the diode. The correction coefficients were very close to 1.0. Diodes that have build up caps in a form of a hemisphere and ground plate usually have larger directional CFs than cylindrical ones. In this study, for angles of 80^0, the largest CF 3% (Figure 5) was found to be smaller than works conducted and reported in other studies [15].

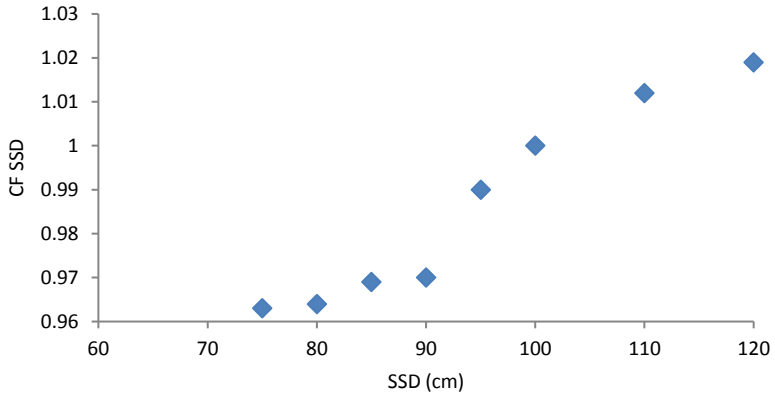

Figure 4. Computed Tomography (CT) source to skin distance increasing with source to skin distance for the investigated diode

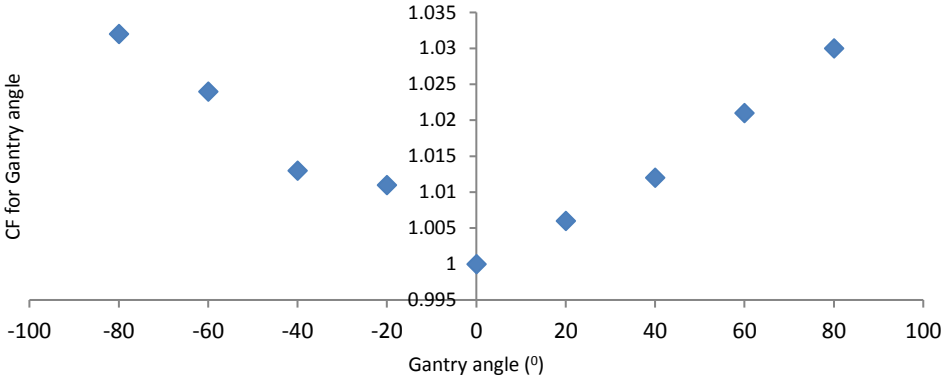

Figure 5. Correction factors as a function of gantry angle

Conclusion

In vivo dosimetry is an appropriate tool that offers several benefits in radiotherapy. It is a commonly used method to improve treatment accuracy. Clinically, it is also successfully used to assess and differentiate the prescribe dose, delivered dose and absorbed dose received by patients undergoing radiotherapy. In this paper, diodes were calibrated, CFs were determined and tested on a solid water phantom and then utilized for patients. . The value of CFs was generally 1.0 and did not vary much from the value suggested by IAEA report 2011 for similar diodes of the same type. The phantom measurements revealed satisfactory outcomes when compared to the doses measured on the patients' sites. The overall percentage of measurement with 5% tolerance was 79.85 %, which defines acceptable results.

This suggests that the considered 5% action level in this study was appropriate. However, about 3.73 % of the total deviations were beyond 7% of action level. The head and neck, pelvic and other fields showed positive deviations. Therefore, it is necessary to commence the in vivo dosimetry program as a major QA, and it is recommended that personnel are well trained in the radiotherapy department for accuracy and quality. The procedure described in this paper for in vivo dosimetry in radiotherapy departments can serve as a guide in calibration, determination of the effectiveness of treatment plan, and patient setup. Moreover, The findings of the current study can pave the way for the evaluation of the output performance of cobalt-60 teletherapy machine.

Acknowledgment

We thank the entire staff at the National Center for Radiotherapy Department at Kole-Bu Teaching Hospital and Komfo Anokye Teaching Hospital, Ghana, for the preparation of the radiation treatment plans for this research.

References

1. Huang, K., Bice Jr, W. S., & Hidalgo-Salvatierra, O. Characterization of an in vivo diode dosimetry system for clinical use. Journal of applied clinical medical physics, 2003; 4(2), 132-142.
2. Feldman A, Edwards FM. The routine use of personal patient dosimeters is of little value in detecting therapeutic misadministrations; Point/Counterpoint. Med Phys. 2001;28:295-7.
3. Kutcher GJ, Coia L, Gillin M, Hanson WF, Leibel S, Morton RJ, et al. Comprehensive QA for radiation oncology: Report of AAPM Radiation Therapy Committee Task Group 40. Med Phys.1994; 21:581-618.

4. Vinall, A. J., A. J. Williams, V. E. Currie, A. Van Esch, and D. Huyskens. "Practical guidelines for routine intensity-modulated radiotherapy verification: pre-treatment verification with portal dosimetry and treatment verification with in vivo dosimetry." The British journal of radiology 83, no. 995 (2010): 949-957.
5. Meiler RJ , Podgorsak MB. Characterization of the response of commercial diode detectors used for in vivo dosimetry. Med Dosim. 1997; 22(6): 31‑7.
6. Gager LD, Wright AE, Almond PR. Silicon diode detectors used in radiological physics measurements, Part I: Development of an energy compensating shield. Med Phys. 1997; 4: 494‑8.
7. Huyskens D, Bogaerts R, Verstraete J, Lööf M, Nyström H, Fiorino C, et al. Practical guidelines for the implementation of in vivo dosimetry with diodes in external radiotherapy with photon beams (entrance dose). ESTRO booklet. 2001; 5: 13-28.
8. Essers M, Mijnheer BJ. In vivo dosimetry during external photon beam radiotherapy. Int J Radiat Oncol Biol Phys. 1999; 43:245-59.
9. Jornet N, Ribas M, Eudaldo T. In vivo dosimetry: Intercomparison between p-type and n-type based diodes for the 16-25 MV range. Med Phys. 2000; 27:1287-93.
10. Mrčela I, Bokulić T, Budanec M, Kusić Z. Calibration of p-type silicon diodes for dosimety in 60Co beams. Zbornikradova Šestogasimpozija Hrvatskogadru štvazazaštituodzra čenja. 2005;300-5.
11. International Atomic Energy Agency. Absorbed dose determination in external beam radiotherapy: An international code of practice for dosimetry based on standards of absorbed dose to water; technical reports series, Vienna, Austria. 2000; 398.
12. Huyskens D, Bogaerts R., Verstraete J, Lööf M, Nyström H, Fiorino C, et al. Practical Guidelines for the Implementation of in vivo Dosimetry with Diodes in External radiotherapy with Photon Beams (entrance dose). ESTRO Physics for Clinical Radiotherapy, Booklet No. 5. 2001.
13. International Atomic Energy Agency. Development of Procedures for in Vivo Dosimetry in Radiotherapy. Human Health Reports, No. 8. 2013. Available from: http://www-pub.iaea.org/MTCD/publications/PDF/Pub1606_web.pdf.
14. Voordeckers M, Goossens H, Rutten J, Van den Bogaert W. The implementation of in vivo dosimetry in a small radiotherapy department. Radiotherapy and oncology. 1998;47(1): 45-8.
15. Van Dam J, Marinello G. Methods for in vivo dosimetry in external radiotherapy. Physics for clinical radiotherapy. ESTRO Booklet No.l. 1994.
16.