A CLINICAL IMPLEMENTATION OF *IN VIVO* DOSIMETRY WITH N-TYPE ISORAD SEMICONDUCTOR DIODES

by

Laza M. RUTONJSKI* *, Borislava S. PETROVIĆ, Milutin D. BAUCAL, Milan D. TEODOROVIĆ, Ozren N. ČUDIĆ, and Borko V. BASARIĆ

Institute of Oncology of Vojvodina, Sremska Kamenica, Serbia

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The study was aimed to check the radiotherapy treatment accuracy and definition of action levels during implementation of in vivo dosimetry as a part of quality assurance program. The calibration and correction factors for *in vivo* entrance dose measurements for six *n*-type Isorad semiconductor diodes were determined as recommended by the European Society for Radiotherapy and Oncology Booklet No. 5. The patients for *in vivo* measurements have been divided in groups, according to the treatment site/techique, in order to investigate and detect the groups where the uncertainty was larger or where a systematic error occurred. The tolerance/action levels for all groups were also defined and checked. In this study, the entrance dose measurements were performed for total of 451 treatment fields, and 338 patients over one year period. The mean value and the standard deviation for different groups were: breast +1.0% 2.89%(1 SD), brain, and head and neck – +0.74% 2.04%(1 SD), and isocentric pelvis and abdomen – +0.1% 2.86%(1 SD). All measurements – +0.72% 2.64%(1 SD). In our experience, systematic *in vivo* dosimetry proved to be a very useful tool for quality assurance of patient's plan and treatment, both in detecting systematic errors and for estimating the accuracy of radiotherapy treatment delivery.

Key words: radiotherapy, in vivo dosimetry, detector, quality assurance

INTRODUCTION

The radiotherapy treatment planning and delivery is a multi-stage process which consists of many sequential, complex steps of patient immobilization, imaging, dose prescription, treatment planning and dose calculation, patient positioning, plan verification and dose delivery. To ensure that the delivered dose agrees with the prescribed dose at the end of the entire treatment process, it has been recommended by number of international organizations that an overall check of the entire process is carried out [1-6]. One of the recommended methods is *in vivo* dosimetry.

In vivo dosimetry has proved to be a useful tool for quality assurance in radiotherapy [7-16]. The purpose of *in vivo* dosimetry is to verify that the treatment is carried out as prescribed. It is a suitable method to both monitor the treatment delivery and to detect various errors early in the course of treatment. Patient's *in vivo* measurements are subsequently compared to the values obtained from patient's teletherapy plan coming from the verified treatment planning system and dose calculation algorithm [17]. If an unacceptable difference between the measured entrance dose and the expected dose is recorded, then an immediate action must be undertaken to detect the source and cause of error and correct it. At our institution the tolerance and the action level were set at the same initial level of 5% and that tolerance/action level was applied for all groups of patients. A variety of detectors, including the thermoluminescent dosimeters (TLD), semiconductor diodes, and new detectors such as metal oxide silicon field-effect transistors (MOSFET) and optically stimulated luminescent dosimetry (OSL) are currently available for *in vivo* dosimetry. In this work, the calibration and correction factors determination of the semiconductor diodes for entrance *in vivo* dosimetry are described. Due to appropriate thickness of build up cap of diode used, the entrance dose represents dose at depth of maximum for specific energy.

The institutional experience in clinical implementation of *in vivo* dosimetry program for patients is presented, and estimation of accuracy degree is determined. The tolerance/action levels for different radiation techniques are also investigated. The work presented is the first clinical implementation of *in vivo* dosimetry for patients in Serbia, and according to the European recommendation.

* Corresponding author; e-mail: lakiruki@gmail.com

MATERIALS AND METHODS

Treatment machine and dosimetry system

All diode calibrations, corrections factors determination and patient entrance dose measurements were performed on the department's two linear accelerators: a dual energy accelerator Varian Clinac 2100C with nominal photon energies of 6 MV and 15 MV and a single energy accelerator Varian 600DBX with nominal photon energy of 6 MV (Varian Medical Systems, Palo Alto, Cal., USA). Both linear accelerators were calibrated to give 1 cGy/ MU at the depth of dose maximum for standard irradiation conditions (build up, SSD 100 cm, field size 10 cm 10 cm) and all were equipped with record and verify (RV) system (Varian Vision/Varis). All patients were planned using CMS XiO version 4.62 (Elekta CMS Software, St. Louis, Mo., USA). The number of monitor units and expected entrance doses were calculated by the treatment planning system.

The N-type Isorad semiconductor diodes (Sun Nuclear Melbourne, Fla., USA) for two energy ranges, the 6-12 MV (yellow) and the 15-25 MV (red), were used in all measurements. The diode outputs were measured with IVD Model 1136 system (Sun Nuclear) consisting of 2 pods connected with a wireless link and interfaced to a PC computer with appropriate IVD software. A real water phantom (RW3) was used for calibration and determination of correction factors (PTW Dosimetry, Freiburg, Germany).

Calibration procedure and determination of correction factors

The diodes were calibrated individually on the equipment on which they were to be used against a SSDL calibrated Farmer type ionization chamber FC65-G (IBA Dosimetry, Schwarzenbruck, Germany). The calibration factor F_{cal} for entrance dose for each individual diode was determined as the ratio of the absorbed dose at d_{max} to the reading of the semiconductor in reference conditions (on the surface of the phantom at SSD of 100 cm and with a field size of 10 cm 10 cm). After determination of the calibration factor, a set of correction factors for field size CF_{FS}, SSD CF_{SSD}, wedge CF_{wedge}, gantry angle CF_{θ} and temperature CF_{T} has to be established to account for changes in the diode response when measurement and calibration conditions are different. The overall factor for conversion diode reading to a measured entrance dose was obtained as the product of the dose calibration factor and all the correction factors for a particular beam. So, measured entrance dose is described by

$$\text{Dose[Gy]} \quad (\text{diode\_reading}) \; F_{cal} \; CF_{FS} \; CF_{SSD} \; CF_{wedge} \; CF_{\theta} \; CF_{T}$$

The determination of calibration and correction factors was done as recommended by the ESTRO Booklet No. 5 [18].

Clinical measurement

The entrance dose was measured at one or two fields during the first or second treatment session. The patients were divided in categories according to the tumor localization and patient immobilization. Accordingly, the assessment of set up precision was done as well as the determination of tolerance/action levels for different tumor localizations. The patients were divided in next categories:

– breast patients,
– brain and head, and neck patients, and
– isocentric pelvis and abdomen patients.

The study sampled 3-D conformal breast patients with isocentric tangential half-field block technique with at least two fields. For the purpose of patient immobilization, commercially available breast positioning devices Wing-Board or Thorawedge (CIVCO Medical Solutions) were used. The entrance dose was measured at off axis distance of 3 cm to 5 cm from isocenter at medial tangential field, during the first or second treatment session. All treatment fields have had enhanced dynamic wedge, for the purpose of dose modulation. The majority of patients were treated on single energy linear accelerator Varian 600DBX.

Patients treated for head and neck and brain malignancies, were immobilized in the thermoplastic mask. The most often beam arrangement was oblique wedged field combinations with vertex field. The majority of patients were treated on single energy linear accelerator Varian 600DBX.

The majority of patients with abdominal malignancies were treated with either 4 field box technique or a 5 field combination, with or without enhanced dynamic wedges. Patients were in most cases positioned in a supine position. In most cases abdominal immobilization devices were not used. The majority of patients were treated on dual energy linear accelerator Varian 2100C.

RESULTS

Calibration procedure and determination of correction factors

Each diode was individually calibrated and corrected for the entrance dose measurement. The correction factors for every diode were in close agreement with each other and also with correction factors reported in the literature with respect to both magnitude and trend [19-21]. The results of diodes response, which vary due to the influence of external condition of measurement, are summarized in tab. 1.

The temperature correction factors were experimentally determined for every diode and their values were between 0.43-0.5%/°C. A typical literature value, for this particular type of diode, was 0.5%/deg, so that value was taken for all the diodes. The gantry angle correction factor for transversal direction was also determined, but it is not shown here, due to the fact that it was not used during the treatment planning.

Patient measurements

The entrance dose measurements were performed for total of 451 treatment fields, on 338 patients over one year period. During the measurement period, the tolerance/action level of 5% was applied for all fields. The results given in tab. 2. summarise the entrance dose measurements for different treatment sites/techniques.

The number of measurements (N), the number of deviations greater than or equal to 4% ($N_{4\%}$) and the number of deviations greater than or equal to 5% ($N_{5\%}$), the mean value (X), and one standard deviation (SD) are shown in tab. 2. The results were plotted in histograms in figs. 1-4., and shown as the frequency distribution of the ratio of the measured dose and the expected dose (MD/ED), in percentage. A Gaussian distribution with the same parameters was plotted over the frequency distribution.

The mean value of the distribution for all measurements with errors was 0.72% and the standard deviation was 2.64%. The distribution of the mean value for all measurements after correction was 0.76%, and the standard deviation was 2.18%. Over 19 measurements which were repeated due to large errors obtained, 4 (21%) still remained larger than 4%. All of these were at the breast treatment site. The histogram plot of frequency distribution of deviations from expected dose for all measurements fitted with Gaussian

Table 1. The diodes correction factors for field size, SSD, enhanced dynamic wedge and beam incidence in axial direction

Field size			SSD		
FS [cm^2]	Yellow	Red	*SSD* [cm]	Yellow	Red
4 4	0.986-0.992	0.960-0.961	70	0.986-0.992	0.986-0.992
5 5	0.993-0.997	0.976-0.978	80	0.978-0.989	0.978-0.985
6 6	0.994-0.999	0.985-0.986	90	0.986-0.993	0.994-0.996
8 8	0.998-1.001	0.994	100	1.000	1.000
10 10	1.000	1.000	110	1.002-1.004	1.011-1.015
12 12	1.003-1.006	1.006	120	1.006-1.007	1.020-1.027
14 14	1.006-1.008	1.010-1.011	130	1.008-1.010	1.026-1.035
15 15	1.006-1.008	1.012-1.013	CF (axial angle)		
16 16	1.005-1.008	1.013-1.015	Angle [°]	Yellow	Red
18 18	1.006-1.009	1.016-1.017	–60	0.995-1.002	1.003-1.006
20 20	1.007-1.011	1.019-1.020	–50	0.999-1.008	1.003-1.006
30 30	1.008-1.013	1.022-1.027	–40	1.003-1.010	1.004-1.008
Enhanced dynamic wedge			–30	1.005-1.011	1.004-1.007
W. angle [°]	Yellow	Red	–20	1.005-1.011	1.004-1.007
0	1.000	1.000	–10	1.006-1.012	1.005-1.006
10	0.998-1.000	0.998-0.999	0	1.000	1.000
15	0.997-0.998	0.994-0.996	10	1.003-1.007	1.000-1.002
20	0.995-0.996	0.994-0.995	20	1.005-1.008	1.003-1.005
25	0.993-0.995	0.989-0.990	30	1.006-1.011	1.004-1.006
30	0.991-0.993	0.987-0.988	40	1.006-1.010	1.005-1.008
45	0.980-0.986	0.980-0.981	50	1.003-1.010	1.004-1.008

Table 2. Summary of results of entrance dose measurements

Treatment site/technique	N	X [%]	SD [%]	$N_{4\%}$ [%]	$N_{5\%}$ [%]
All fields with errors	451	0.72	2.64	10.4	4.2
All fields after correction	451	0.76	2.18	7.8	0
Breast	205	1.00	2. 89	13.6	7.8
Brain and head and neck	156	0.74	2.04	5.8	0
Isocentric pelvis and abdomen	90	0.1	2.86	11.1	3.3

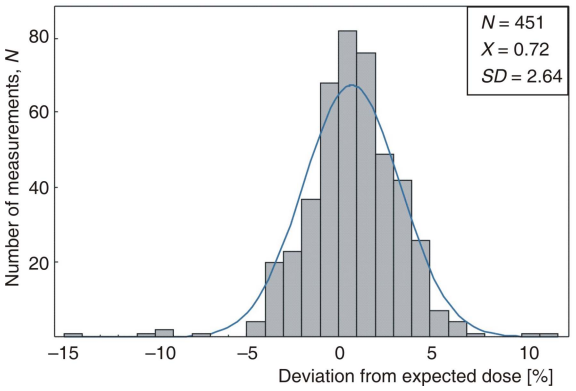

Figure 1. Frequency distribution of deviations from expected dose for measurements for all treatment sites without corrections fitted with Gaussian distribution with the same parameters

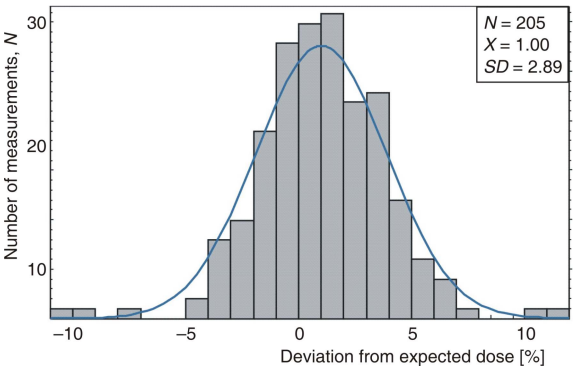

Figure 2. Frequency distribution of deviations from expected dose for measurements on breast site fitted with Gaussian distribution with the same parameters

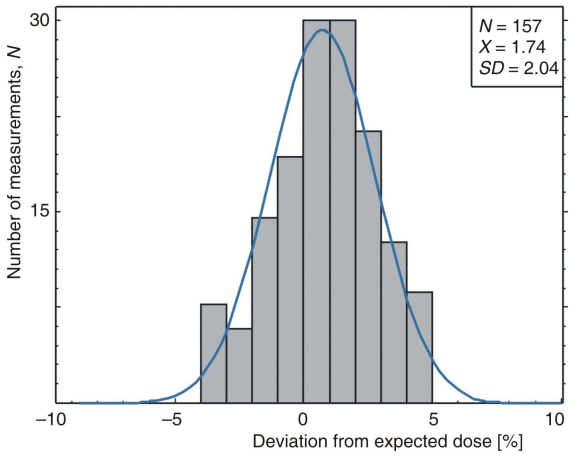

Figure 3. Frequency distribution of deviations from expected dose for measurements on head and neck site fitted with Gaussian distribution with the same parameters

function was presented in fig. 1. The histogram distribution was normal with some slight asymmetry.

The mean deviation for breast site/technique was 1.0% and standard deviation was 2.89%. The

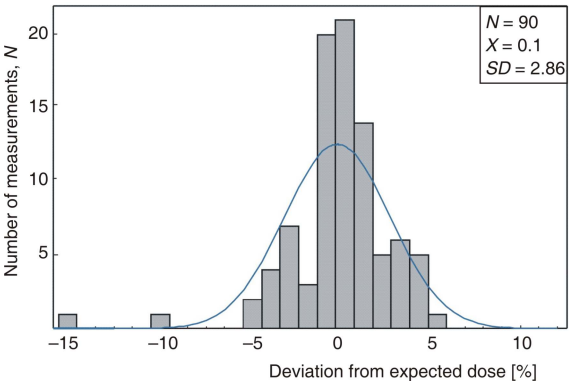

Figure 4. Frequency distribution of deviations from expected dose for measurements on isocentric pelvis and abdomen site fitted with Gaussian distribution with the same parameters

spread of deviations for this treatment site was the highest of all treatment sites. The deviations larger than 5% were detected in 19 cases (4.3%) of all measurements and most of them, 16 cases (84%), were detected for the breast treatment site. After correction in 16 measurements which exceeded 5% tolerance the mean deviation was 0.94% and standard deviation was 2.27%. The frequency distribution of deviations from expected dose, for measurements on breast site without correction, fitted with Gaussian distribution with the same parameters, is shown in fig. 2.

The mean value of the distribution for brain and head and neck treatment site was 0.74% and the standard deviation was 2.04%. This standard deviation was the lowest of all treatment sites and reflects a smaller number of random errors in treatment set up for this site. The histogram plot of frequency distribution of the deviation of expected dose for measurements on head and neck site fitted with Gaussian function were plotted in fig. 3. It was noticed that the histogram distribution for measurements on brain and head and neck site was approximately normal with a narrow spread.

The smallest group of patients of the four analysed treatment site categories, was for isocentric pelvic and abdominal treatment site. The mean deviation for isocentric pelvic and abdominal site/technique was 0.1% and standard deviation was 2.86 %. After correction of three measurements which exceeded 5% tolerance the mean deviation was 0.37% and standard deviation was 2.18%. Histogram plot of frequency distribution of the deviation from expected dose for measurements on isocentric pelvic and abdominal site fitted with Gaussian function were presented in fig. 4.

DISCUSSION

The correction factors measured for the existing diodes were within the range of those reported by the manufacturer for this type of diode [19-21]. The behaviour of correction factors was quite similar for the

energy of 6 MV and 15 MV. The field size and SSD correction factors were found to be more pronounced for the higher energy. The influence of enhanced dynamic wedges is very small for lower wedge angles and it was similar for the both detectors which were used for given energy range, being directly proportional with the wedge angle. The cylindrical configuration and the build up around the diode were suitable to provide the uniform angular response around the detector axis.

The theoretical uncertainty in measuring the entrance dose with diodes, taking into consideration the uncertainties in the calibration factor and the correction factors determination and the positioning of the diode, is 1.6%. Other sources of uncertainty, which should be taken into account when choosing the tolerance/action levels, are: possible fluctuations of accelerator output, the use of asymmetric fields, the physiological movements due to breathing, possible movements of the patient during the irradiation, the use of auxiliary equipment to set-up the patient and the uncertainty in the entrance dose calculation. So, that is the reason why the majority of the radiotherapy centres have a 5% tolerance/action level for most treatments. In this work, the patients have been devided in groups, according to the treatment site/techique, in order to investigate and detect the groups for which the uncertainty was larger or for which a systematic error appeared.

Due to the half-field block technique used for breast irradiation there was no real field centre to correctly place the diode so it was decided to place the diode in the position along the beam profile, in position which is approximately 3 cm to 5 cm off axis inside the irradiation field (the off-axis correction factor was used). Due to all these facts, it was difficult to place the diode in accurate position for *in vivo* measurements. Therefore, any misplacement of the diode caused erroneous reading of the diode, and a larger spread of the results. In 16 out of 19 (85%) measurements which exceeded the 5% tolerance was for breast treatment site. The source of error identified in the most cases was incorrect position of the diode, or incorrect SSD (80%). In one case it was detected that the wrong number of MU was entered in RV system. The SD of 2.88% for breast iradiation was the largest of the four treatment site categories analysed and reflected a larger number of random errors in both treatment set up and dose measurement technique. Most publications regarding *in vivo* dosimetry in tangential irradiation of breast, reported similar standard deviations between the measured and the expected doses [11, 22-26]. Shakeshaft *et al*. [22] in reporting 2 years worth of measurements on 278 breast patient found a mean deviation equal to –2.9% and standard deviation equal to 3.5%. Data similar to ours for breast patient were found by Cozzi *et al*. [23] which found a mean deviation on 421 measurements equal to –1.33% and with standard deviation of 2.7%. Appleyard *et al*. [24, 25] reported a mean deviation on 1073 measurements on breast patients fields equal to 1.15% and standard deviation was 3.04%(1 SD). Fiorino *et al*. [26] found a mean deviation on 506 measurements equal to 0.1% and standard deviation was 3.5%. Also, it was found that the rate of second checks was significantly higher for breast patients (16/205, 7.8%) against non-breast patients (3/246, 1.2%).

The SD of 2.01% for brain, and head and neck site was lesser than the one seen for other categories and indicates a high level of reproducibility. A number of papers investigated the treatment accuracy by *in vivo* dosimetry for patients treated for brain and head and neck malignancies and they reported the results similar to ours [12, 22, 24-26]. Leunens *et al*. [12] reported the data concerning 364 measurements of 47 patients during the brain and head and neck irradiation with a mean deviation around 0% with a SD equal to 2.3%. Shakeshaft *et al*. [22] found a mean deviation equal to –0.6 % and standard deviation equal to 2.8% for *in vivo* measurements on 246 head and neck patient. Our data are congruent with the results reported by Appleyard *at al*. [24, 25], which found a mean deviation equal to 0.35% (2.20% (1 SD)) on 326 measurements for brain and head and neck patient irradiation. Fiorino *et al.* [26] found a mean deviation for head and neck patient irradiation equal to 1.0% and standard deviation was 2.8%.The largest deviations were attributed to a measurement in a highly oblique wedged fields and difficulty to place the diode into corect position for measurement, due to the patient's body contour.

In almost all cases for isocentric pelvic, the placement of the detector on the anterior field for 4 field box technique was complicated because patient's body hair has been obstructing the positioning and taping the diode to the patient's skin and this often resulted in the detector being “sprung” slightly towards the target resulting in a higher than expected dose reading. In 2 out of 46 (4.3%) patients, *in vivo* measurements for isocentric pelvis and abdomen treatment site exceeded the tolerances. In the first of the above two patients, a closer inspection revealed that a false treatment plan had been assigned to the patient. A new therapy plan was immediately created with the correct plan parameters. In the second of the above two patients the source of error proved to be wrong treatment set up. After the corrections, *in vivo* dosimetry was repeated and the results were within the tolerance levels in both cases. The reported deviations for isocentric pelvic site were in accordance with the results reported in similar studies [24-27]. Appleyard *et al*. [24, 25] reported a mean deviation on 712 measurements on pelvic irradiation patients fields equal to 0.52% and standard deviation was 2.75%. Fiorino *et al*. [26] reported a mean deviation for pelvic irradiation patients equal to 0.8% and standard deviation was

3.0%. Strojnik [27] found a mean deviation between 0.0-1.0% and standard deviation between 2.7-3.0% for *in vivo* measurements for radiotherapy patients treated with four field box technique during the rectal cancer irradiation.

The overall results for all treatment sites showed good agreement with the results reported in number of papers [10, 22-26]. Also, it was noticed that the number of errors at the beginning of the implementation *in vivo* dosimetry decreased when process became routine practice. In the group of 338 patients and 451 measurements, *in vivo* dosimetry brought out and prevented 15 minor cases of inaccurate treatment and 3 major cases of inaccurate treatment. In all three major cases of a potentially inaccurate treatment, the cause of error was a consequence of human errors and no equipment malfunction was discovered.

The tolerance/action level of 4% was put in order to check the possibility to change the initial tolerance/action level for some treatment sites. The results for brain and head and neck treatment site showed that only 5.8% of measurements were over 4% tolerance/action level. Due to that fact the tolerance/action level for brain and head and neck site was changed to 4%.

CONCLUSION

The radiation therapy process involves multiple complex steps and also many professionals of different profile. The overall uncertainty of the whole treatment course involves different uncertainties which are human, or technology related, such as the dosimetric uncertainty, patient interfractional and intrafractional movement, accuracy and conformity of dose delivered, QA/QC uncertainty, *etc.* [28]. It is estimated to be between 4.4 and 6.6% [29]. On the other hand, the unexpected errors during the treatment, may result in minor or even major deviation in dose delivered in comparison to the prescribed and planned [16]. One of the methods for significant improvement in treatment accuracy is shown to be *in vivo* dosimetry, although it requires significant additional efforts for the physics staff. Our experience confirmed that systematic *in vivo* dosimetry was very useful quality tool for tracing and correcting random as well as systematic errors in the dose calculation and patient set up. The entrance *in vivo* dose measurements was performed on 331 patients for 437 treatment fields over a one year period. In one year since implementation of *in vivo* dosimetry 19 cases of inaccurate treatment hve been revealed and prevented. A tolerance/action level of 5% was applied for all fields during the measurement period. The patients were divided in separate groups according to the treatment site/techique in order to check the groups for which the uncertainty was larger and to check the tolerance levels for each treatment site. The tolerance level for brain and head and neck site was changed to 4%.

The calibration and correction factors for six semiconductor diodes for different energy ranges were studied and their behavior was found adequate for the measurement of the dose delivered in radiotherapy treatments. The calibration and correction factors were determined for each diode as recommended by the ESTRO Booklet No.5.

To summarize, *in vivo* dosimetry has given the full confidence that patients are being treated with the prescribed and planned dose.

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AUTHOR CONTRIBUTIONS

The theoretical analysis was carried out by L. M. Rutonjski and B. S. Petrović. All measurements were carried out by L. M. Rutonjski, O. N. Čudić and B. V. Basarić, and the results were analysed and discussed by all authors. The manuscript was written by L. M. Rutonjski and B. S. Petrović. The figures were prepared by L. M. Rutonjski.

REFERENCES

[1] ***, Diode *in vivo* Dosimetry for Patients Receiving External Beam Radiation Therapy, AAPM, Task Group 62, Report No. 87, M. P. Publishing, Madison, Wis., USA, 2005
[2] ***, Determination of Absorbed Dose in a Patient Irradiated by Beams of X of Gamma Rays in Radiotherapy Procedures, ICRU Report 24, Washington DC, USA, 1976
[3] ***, Quality Assurance in Radiotherapy, WHO, Geneva, 1988
[4] ***, Procedures in External Radiation Therapy Dosimetry with Electron and Photon Beams with Maximum Energies between 1 MeV and 50 MeV, Nordic Association of Clinical Physics (NACP), *Acta Radiol. Oncol., 19* (1980), 1, pp. 55-79
[5] ***, Comprehensive Audits of Radiotherapy Practices: a Tool for Quality Improvement: Quality Assurance Team for Radiation Oncology (QUATRO), International Atomic Energy Agency, Vienna, 2007
[6] ***, Setting Up a Radiotherapy Programme: Clinical, Medical Physics, Radiation Protection and Safety Aspects. : International Atomic Energy Agency, Vienna, 2008
[7] Frontela, D. P., *et al*., Customization of a Radiation Managment System to Support *in-vivo* Patient Dosimetry Using Diodes, *Med. Phys., 23* (1996), 8, pp. 1425-1429
[8] Frontela, D. P., *et al*., The Use of Diode Dosimetry in Quality Improvement of Patient Care in Radiation Dosimetry, *Med. Dosim., 21* (1996), 4, pp. 235-241

[9] Heukelom, S., Lanson, J. H., Mijnheer, B. J., Comparison of Entrance and Exit Dose Measurements Using Ionization Chambers and Silicon Diodes, *Phys. Med. Biol., 36* (1991), 1, pp. 47-59
[10] Heukelom, S., Lanson, J. H., Mijnheer, B. J., *In-vivo* Dosimetry During Pelvic Treatment, *Radiother. Oncol., 25* (1992), 2, pp.111-120
[11] Heukelom, S., *et al*., In-vivo Dosimetry During Tangential Breast Treatment, *Radiother. Oncol., 22* (1991), 4, pp. 269-279
[12] Leunens, G., *et al*., Quality Assurance in Radiotherapy by in-vivo Dosimetry, 1. Entrance Dose Measurements, a Reliable Procedure, *Radiother. Oncol., 17* (1990), 2, pp. 141-151
[13] Leunens, G., *et al*., Quality Assurance in Radiotherapy by in-vivo Dosimetry, 2. Determination of the Target Absorbed Dose, *Radiother. Oncol., 19* (1990), 1, pp. 73-87
[14] Li. Ch., Lamel, L.S., Tom, D., A Patient Dose Verification Program Using Diode Detectors, *Med. Dosim., 20* (1995), 3, pp. 209-214
[15] Meiler, R. J., Podgorsak, M. B., Characterization of the Response of Commercial Diode Detectors Used for in-vivo Dosimetry, *Med. Dosim., 22* (1997), 1, pp. 31-37
[16] Essers, M., Mijnheer, B. J., In vivo Dosimetry During External Photon Beam Radiotherapy, *Int. J. Radiat. Oncol. Biol. Phys., 43* (1999), 2, pp. 245-259
[17] Rutonjski, L., *et al*., Dosimetric Verification of Radiotherapy Treatment Planning Systems in Serbia: National Audit, *Radiation Oncology*, (2012), Art. No. 155
[18] Huyskens, D. P., *et al*., Practical Guidelines for the Implementation of in vivo Dosimetry with Diodes in External Radiotherapy with Photon Beams (Entrance Dose), ESTRO Booklet No. 5
[19] Islam, K., *et al*., A Study of Dosimetric Characteristics for in vivo Dosimetry with Cylindrical N-Type Isorad Diode, *Journal of Radiotherapy in Practice*, (2014), 1, pp. 1-15
[20] ***, http://www.sunnuclear.com Reference Guide, IVD Solutions™. Copyright 2002-2011 by Sun Nuclear Corporation, Melbourne, Fla., USA
[21] Wolff, T., *et al*., Characterization and Use of a Commercial N-Type Diode System, *The British Journal of Radiology, 71* (1998), 851, pp. 1168-1177
[22] Shakeshaft, J. T., Morgan, H. M., Simpson, P. D., In vivo Dosimetry Using Diodes as a Quality Control Tool-Experience of 2 Year and 2000 Patients, *The British Journal of Radiology, 72* (1999), 861, pp. 891-895
[23] Cozzi, L., Fogliata-Cozzi, A., Quality Assurance in Radiation Oncology, A Study of Feasibility and Impact on Action Levels of an *in vivo* Dosimetry Program During Breast Cancer Irradiation, *Radiotherapy and Oncology, 47* (1998), 1, pp. 29-36
[24] Appleyard, R., *et al*., Systematic *In vivo* Dosimetry for Quality Assurance Using Diodes, Part 1: Experiences and Results of the Implementation of Entrance Dose Measurements, *Journal of Radiotherapy in Practice, 3* (2003), 4, pp. 185-196
[25] Appleyard, R., *et al*., Systematic *In vivo* Dosimetry for Quality Assurance Using Diodes 2: Assessing Radiotherapy Techniques and Developing an Appropriate Action Protocol, *Journal of Radiotherapy in Practice, 4* (2005), 4, pp. 143-154
[26] Fiorino, C., *et al*., Quality Assurance by Systematic *in vivo* Dosimetry: Results on a Large Cohort of Patients, *Radiotherapy and Oncology, 56* (2000), 1, pp. 85-95
[27] Strojnik, A., *In vivo* Dosimetry with Diodes in Radiotherapy Patients Treated with four Field Box Technique, *Proceedings,* 11th Mediterranean Conference on Medical and Biological Engineering and Computing, Ljubljana, Slovenia, June 26-30, 2007, pp. 891-894
[28] ***, The Modern Technology of Radiation Oncology, Vol. 3: A Compendium for Medical Physicists and Radiation Oncologists, Van Dyk J., Battista, J. J., and Bauman, G. S., Medical Physics Publishing, Madison, Wis., USA, 2013
[29] ***, Tissue Inhomogeneity Corrections for Megavoltage Photon Beams, Report of Task Group No. 65 of the Radiation Therapy Committee of the American Association of Physicists in Medicine, 2004

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Лаза М. РУТОЊСКИ, Борислава С. ПЕТРОВИЋ, Милутин Д. БАУЦАЛ, Милан Д. ТЕОДОРОВИЋ, Озрен Н. ЧУДИЋ, Борко В. БАСАРИЋ

КЛИНИЧКА ИМПЛЕМЕНТАЦИЈА *IN VIVO* ДОЗИМЕТРИЈЕ ПОМОЋУ ISORAD ПОЛУПРОВОДНИЧКИХ ДИОДА Н-ТИПА

Овај рад има за циљ да провери тачност радиотерапијског третмана и постављене нивое акције при имплементацији *in vivo* дозиметрије као дела програма осигурања квалитета. На основу препорука из Приручника бр. 5. издатог од стране Европског друштва за радиотерапију и онкологију одређени су калибрациони и корекциони фактори за мерење улазне дозе помоћу *in vivo* дозиметрије за шест Isorad полупроводничких диода н-типа. Пацијенти на којима су вршена *in vivo* мерења подељени су у групе, на основу локализације и технике зрачења, у циљу лакшег одређивања група код којих је несигурност већа или где се појављује систематска грешка. Такође, за све групе су дефинисани и проверени нивои толеранције и акције. У току једне године урађено је мерење улазне дозе на 451 третманском пољу, односно на 338 пацијената. Средња вредност и стандардна девијација за дојку је +1.0% 2.89% (1 SD), а за мозак, главу и врат +0.74% 2.64% (1 SD). На основу нашег искуства показало се да *in vivo* дозиметрија представља врло користан алат за осигурање квалитета плана пацијената и третмана, истовремено вршећи детекцију систематских грешака и процењујући тачност радиотерапијског третмана.

Кључне речи: радиотерапија, in vivo дозиметрија, детектор, осигурање квалитета